Biomass composition in cool-season pastures harvested for energy in southern Iowa

by

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A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Crop Production and Physiology

Program of Study Committee:
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Iowa State University

Ames, Iowa

2004

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CHAPTER 1. GENERAL INTRODUCTION

Introduction

Southern Iowa is known for its sloping hills, high erosion rate, and low row crop productivity, due to the formation of its land thousands of years ago. Because of low productivity soils, much of the land in southern Iowa is seeded into pasture, grassland, or is in the Conservation Reserve Program (CRP). Warm-season (C4) grasses are grown in this area, but the majority of land is seeded into perennial cool-season (C3) grasses. Iowa is located in the upper Midwest and Plains region where the winters are considerably cool and the summers tend to be fairly hot. Iowa generally receives regular amounts of rain throughout the summer to help against drought. This climate allows the cool-season grasses to thrive and grow well in the early spring and fall.

Recently, different organizations, cooperatives, and agencies are looking at the potential of co-firing agricultural biomass with coal to produce electricity and heat. Some of the area in southern Iowa has been influential in this process, since a majority of the land is capable of producing or already produces grasses. Initially, switchgrass (*Panicum virgatum* L.) was the model herbaceous crop that researchers had thought would be capable of producing high yields, 11-13 mtons/ha, in the poorly productive soil. It was soon discovered that extensive soil limitations prevented the anticipated yield of switchgrass. Cool-season grasses could be a potential biomass to supplement for the low switchgrass yield.

In this study, areas of southern Iowa were surveyed to determine the species present and relative frequencies in different areas. Diversity, species richness, species evenness and biomass yield were also calculated for each location. Chemical analysis was performed on the grasses to determine the fuel burning qualities they had in comparison to that of switchgrass and other biomass co-fired with coal. Near infrared reflectance spectroscopy (NIRS) was also assessed as a tool to determine if it was capable of predicting the chemical values and burning properties of the grasses.

Thesis Organization

This thesis is organized into four distinct chapters. The first chapter includes a general introduction to the study performed. The second chapter is a literature review on previous research performed on the topic and other critical aspects that pertain to the study. The third chapter is a paper to be submitted to the Biomass and Bioenergy Journal. The fourth and final chapter is an overall conclusion on the importance of the topic and where future research is headed.

CHAPTER 2. LITERATURE REVIEW

Southern Iowa Land Characteristics

There are four counties in southern Iowa, near the Ottumwa Generating Station, which are involved in the Chariton Valley Biomass Program. They are Appanoose, Lucas, Monroe, and Wayne Counties. These counties belong to the region known as the Southern Iowa Drift Plain landform. This region was formed by glacial deposits left by ice sheets that extended south into Missouri thousands of years ago (Prior, 1991). The deposits were carved by deepening episodes of stream erosion so that only a horizon line of hill summits marks the once-continuous glacial plain (Prior, 1991). Numerous hills, creeks, and rivers branch out across the landscape shaping the old glacial deposits into steeply rolling hills and valleys. Because of this landform, the area is known for its variable row crop productivity due to the high sloping land and severe erosion.

The corn suitability rating (CSR) is an index procedure developed in Iowa to rate different kinds of soils for its potential row crop productivity. The average Iowa CSR is 62.9. The weighted corn suitability rating for the four counties ranged from 39.7 to 43.1 (Miller et al., 2004). This is an extremely low number, considering the highest rating for the best crop producing land is 100. Soil profile properties and weather conditions are the most dominant factors that affect productivity and contribute most highly to the CSR (Miller, 1988). Slope characteristics are major factors that determine how land should be used, whether it is suitable for row-crops or needs permanent vegetation to reduce soil erosion. Slope landscape and slope length are also factors in determining the rating. They affect potential erosion rates, water infiltration, and ease and efficiency of machinery operation

(Miller, 1988). Because of the high sloping land, erosion is a major concern. Miller et al. (1988) identified southern Iowa as one of the major cropland areas having severe erosion potential. Most of the upland soils in the area have subsoils unfavorable for plant root penetration because of marginal soil and high erosion rates (Miller et al., 1988). Most of the pasture and grassland in the area is either grazed or has been seeded into native grass prairies. A high portion of the land has also been enrolled in the Conservation Reserve Program.

Cool-Season Grasslands and Pastures

Permanent vegetation is one of the most effective commonly used practices to control soil erosion (Miller et al., 1988). Cool-season grasslands and pastures make up a high percentage of the farmland in the area. Because of the low CSR values, there is a large amount of land seeded as pasture or idle cropland, rangeland or grassland in the four-county area to help control erosion. The four counties range from 41-46% of land in farms that are used for this very purpose (Census of Ag, 2002). Grassland is the only effective, long-term management strategy on much of the landscape in the area (Sellers, 1999). Perennial cool-season grasses are ideal for biomass production in temperate regions, since they help to prevent soil erosion and can be productive on marginal lands generally not suited to grain crop production (Cherney et al., 1986). Once established, perennial thin-stemmed grasses provide erosion control equal to that of undistributed grassland (Wright, 1994). With a significant amount of the land in established cool-season grassland and pastures, this could serve as a potential biomass source.

Conservation Reserve Program

The Conservation Reserve Program (CRP) was initiated under the Food Security Act in 1985, largely to stabilize and improve soils degraded by overcropping (Downing et al., 1995). The CRP has become the principal U.S. Department of Agriculture (USDA) conservation program with enrollment of over 13.7 million ha (34 million acres) as of 2003 and is the largest conservation program in the United States (Allen and Vandever, 2003). The program was designed to help in reducing soil erosion and the amount of sedimentation in lakes and streams, improving water quality, establishing wildlife habitat, and enhancing forest and wetland resources.

The CRP has already removed millions of acres of highly erodible land from row crop production into permanent ground cover (Mayer et al., 2002). Producers enrolled in the CRP program plant long-term, resource-conserving vegetative covers to improve the quality of water, control soil erosion, and enhance wildlife habitat (CRP Fact Sheet, 2003). Much of the land has been replanted to perennial grasses that were native to the original prairie. Perennial grasses grown under the CRP conserve and improve soil quality and also provide an excellent protective cover and food for wildlife (Downing et al., 1995). This land cannot be harvested, grazed, or planted with row crops until the contract has expired or granted special permission by the local conservation office. Contracts in the program usually run 10-15 years. When the duration of the contract has ended, the land can be kept as cover crops, cycled back into row crop rotation, grazed, hayed, etc. One negative aspect of using land in the CRP is that it would not be readily accessible, unless granted special permission to harvest the biomass for energy production.

A national survey was conduction by Allen and Vandever (2003) to get feedback from CRP participants regarding the environmental effects, wildlife issues, and vegetation management of program lands. One benefit was that eighty-five percent (85%) of the respondents believed that the CRP contributed to the diminished soil erosion problem. Seventy-three percent (73%) reported increased populations in wildlife with land enrolled in the program. Thirty-nine percent (39%) believed there was an improvement in water quality. Other positive aspects described included enhancement of soil organic matter and fertility improving potential future productivity of CRP land. Lower use of agricultural chemicals was also cited as a positive effect. Some of the economic benefits included increased grain prices and an increase in overall farm property value. Some negative aspects were participants viewed the CRP land as a collection of weeds, making their land appear untidy or poorly managed. The CRP ground was also viewed as a potential fire hazard in some drier climates and in some cases attracted unwanted wildlife. The survey results revealed that the majority of the respondents were satisfied with the CRP program and the many environmental, social, and economic benefits gained from having land in the program.

As of August 2004, the total CRP enrollment for the state of Iowa was 768,304 ha (1,898,521 acres) (USDA, 2004a). The Conservation Reserve Program land can consist of trees, grass waterways, living snow fences, and many other cover crop vegetation methods that help control soil erosion. Approximately 238,547 ha (589,442 acres) or 30% of the land in the Iowa CRP is of vegetative-cover grass or legumes species already established (USDA, 2004b). Enrollment of CRP acreage in the four counties surrounding the Ottumwa Generating Station as of October 2003 was 11,663 ha (28,820 acres) for Appanoose County, 14,390 ha (35,558 acres) in Lucas County, 11,130 ha (27,501 acres) in Monroe County, and

24,724 ha (61,092 acres) in Wayne County (CRP Acres, 2003). The approximate amount of land in the four-county area is 488,440 ha (1,206,918 acres); therefore about 12% of this is in the CRP. With a significant amount of the CRP planted in perennial grass and legumes, there is a potential to use biomass produced from this land to co-fire with coal to produce electricity.

Biomass/Energy Crops

With such a large portion of the land near the Ottumwa Generating Station managed as cool-season pastures, grassland, or in the CRP, there is a great potential to harvest this biomass for energy production. An alternative to returning the land to the very practices that made CRP necessary would be to use it to produce energy crops that could both enhance land quality and provide an economic return to landowners (Downing et al., 1995). One opportunity for energy crop development is to use land that is currently idle or poorly suited for food crops, such as that in the CRP (Clean Energy, 2004). While corn is currently the most widely used energy crop, native trees and grasses are likely to become the most popular in the future (Clean Energy, 2004).

Biomass can be derived from the cultivation of dedicated energy crops, such as perennial grasses (McKendry, 2002b). Perennial grasses display many beneficial attributes as energy crops, and there has been increasing interest in their use in the US and Europe since the mid-1980s (Lewandowski et al., 2003). Perennial, herbaceous energy crops offer a significant opportunity to improve agricultural sustainability through crop diversification, decreased erosion, and improved water quality compared with a traditional annual row crop system (Tolbert and Wright, 1998). The perennial nature of these crops make their cultivation desirable on highly erosive land, particularly if they can produce acceptable yields on poor quality soils (Lemus et al., 2002). Perennial energy crops need considerably less fertilizer, pesticide, herbicide, and fungicide than annual row crops (Clean Energy, 2004).

Many studies have researched different grasses and legumes to determine the most productive and efficient crop that could be used for biomass. Of the perennial grasses and legumes investigated in a study done by Cherney et al. (1990), switchgrass (*Panicum virgatum* L.) showed the most potential as a biomass candidate. Switchgrass is a perennial, warm-season grass native to Iowa suitable for marginal land primarily because it grows well with relatively moderate inputs and can effectively protect against erosion (Duffy and Nanhou, 2001). Switchgrass is a vigorous grass which will produce better growth on droughty, infertile, eroded soils than most grasses, and has been used extensively for erosion control (Heath et al., 1985). The US DOE (Department of Energy) and Oak Ridge National Laboratory's Biofuels Feedstock Development Program have also identified switchgrass as a model herbaceous energy crop. However, switchgrass has not produced the tonnage in southern Iowa predicted using yield trial results. The soil in this area is highly eroded and not fertile enough to produce high yielding crops. The lower than expected switchgrass yields have prompted researchers to evaluate other potential sources of biomass already established and grown in large quantities in southern Iowa.

Cool-Season Biomass

Pastures, grasslands, and CRP lands in any area are usually comprised of a wide variety of different plant species. Some of the cool-season species will be more favorable for biomass production than others. In general, characteristics of an ideal energy crop would include high yield, low energy input to produce, low cost, composition with the least contaminants, and low nutrient requirements (McKendry, 2002a). A study done by Saterson and Luppold (1979) found that the Central US, including Iowa, offered potential for growing many productive cool-season grasses such as orchardgrass (*Dactylis glomerata* L.), tall fescue (*Festuca arundinacea* L.) and reed canarygrass (*Phalaris arundinacea* L.).

A study done by Tracy and Sanderson (2000) identified a total of 161 different plant species across the northeast USA region. Perennial forbs were the most common functional group followed by perennial grasses. They found that the pastures typically supported one or two dominant and subordinate species with the remainder of the richness accounted for by transient, weedy species. Plant species diversity refers to the number of species (richness) and their relative abundance (evenness) within a defined area (Sanderson et al., 2004). Tracy and Sanderson (2000) also compared grazed vs. ungrazed lands in the eastern US, and found that ungrazed old fields showed a distinct trend towards increased diversity after abandonment. In the grazed pastures, diversity remained constant through time since the pastures had been converted from cropland.

Biomass has the potential of being harvested from pastures, grassland, rangeland, and CRP land in southern Iowa. It has been shown that this land will vary in plant diversity because of the type of land it is seeded in. Little is known about the ecology and diversity of pastures, grassland, and CRP land in southern Iowa. More information regarding species richness and evenness will be helpful in evaluating potential land to harvest for biomass.

Co-Firing Biomass

About 56% of the electricity generated in the US comes from coal (Battista Jr. et al., 2000). Currently, about nine hundred thousand metric tons of coal is consumed annually in the US for energy generation (Tillman, 2000a). In a world with ever expanding economies, coal has a substantial energy role that it must play. There is no ready substitute for this fuel in the quantities required at this time and for the foreseeable future (Tillman, 2000a). Co-firing biomass with coal has been studied as a means of mitigating environmental impacts associated with burning coal to produce heat and electricity.

Biomass is a general term for all organic material that comes from plants. Biomass production occurs from green plants that convert sunlight into plant material through photosynthesis (McKendry, 2002a). The energy stored in biomass (organic matter) is called bioenergy. Bioenergy can be used to provide heat, make fuels, and generate electricity (Bioenergy, 2001). In the past 10 years, there has been renewed interest worldwide in biomass as an attractive alternative to fossil fuels (Cuiping et al., 2004).

Co-firing is the simultaneous combustion of different fuels in the same boiler. In this case, co-firing would be defined as the combustion of coal and biomass at the same time. Co-firing is a low-cost and low-risk approach for utilities to use biomass in electricity generating applications (Tillman, 2000b). Co-firing can be used to generate clean, renewable electricity meeting the objectives and standards of most renewable energy portfolio standards (Tillman, 2000a).

Biomass Burning Problems

Not only does an ideal energy crop need to have high yield and low nutrient requirements, but also more importantly it needs to meet certain chemical and elemental characteristics. Biomass fuels have significantly different elemental characteristics compared to coal, particularly concerning the elements important for ash and deposit formation (Cuiping et al., 2004; Nordin, 1994), resulting in engineering problems within power plants. Problems with deposits were not originally expected with biomass fuels. When new biomass power plants originally contracted to burn substantial quantities of crop residues with other fuels, they experienced fouling of convection passes and severe deposits on grates (Miles et al., 1996). It was found that certain chemical elements caused these problems in the power plants. The slagging fuels (problem fuels) characteristically contained high levels of potassium and other alkalis which vaporize or react with other elements as they pass through the boiler, partially condensing to form sticky deposits on metal and other surfaces (Miles et al., 1996).

Knowledge of the composition and speciation of inorganic elements in fuels is of vital importance for studies of combustion-related topics, such as ash and deposit formation as well as sulfur and chlorine retention in ash (Nordin, 1994). Ash content and chemistry is important in the combustion process because it can contribute to slagging of internal boiler surfaces leading to formation of deposits that reduce boiler efficiency and increase maintenance costs (Miles et al., 1993). Understanding the chemical composition of biomass is a key in determining potential uses for, and the value of, a specific biomass resource (Kelley et al., 2004a).

Modeling and analysis of energy conversion processes require adequate knowledge of fuel characteristics, especially average and variations in elemental composition (Nordin, 1994). Certain material properties of biomass such as moisture content, calorific value, ratio of fixed carbon and volatiles, ash/residue content, and alkali metal content become important during energy production (McKendry, 2002a). Calorific value, such as higher heating value (HHV) is the total energy content released when the fuel is burnt in air, including the latent heat contained in the water vapor and therefore represents the maximum amount of energy potentially recoverable from a given biomass source (McKendry, 2002a). Volatile matter (VM) of a solid fuel is that portion driven-off as a gas (including moisture) by heating. The fixed carbon (FC) content is the mass remaining after the releases of volatiles, excluding the ash and moisture contents (McKendry, 2002a).

A definitive means of overcoming these obstacles is to work on improving combustion systems designed to handle higher ash fuels, as well as to develop feedstocks with improved biomass quality (Samson and Mehdi, 1998). Biomass power plants usually sample fuels to assure compliance with contract specifications for moisture, ash and heating values (Miles et al., 1996). Plant operation has improved and slagging and fouling have been reduced where owners systematically sampled and analyzed the alkali contents of fuels (Miles et al., 1996).

A method that the coal industry developed to classify the slagging behavior of various coals involves calculating the weight of alkali oxides per unit heat in the fuel. Annual growth from energy crops contains sufficient amounts of volatile alkali to sufficiently lower the fusion temperature of the ash so that it melts in combustion, causing slagging (Miles et al., 1995). Plant experience and field tests have shown that a slagging risk increases above

0.17-0.34 kg/GJ alkalis. Above 0.34 kg/GJ, the fuel is virtually certain to slag and foul to an unmanageable degree (Miles et al., 1996). Other power plant specifications have not yet been determined for other chemical elements. However, it is known that sulfur, chlorine, and alkalis are the most destructive to biomass power plant operations.

Chemical and Fuel Characteristics of Biomass

Mineral composition in biomass differs from coal, especially in amounts of potassium, calcium and chlorine. Furnace operating temperatures and combustion conditions also differ, resulting in deposits that have different characteristics and occurrences (Miles et al., 1995). The major obstacle in using herbaceous biomass material for heat and electricity generation is its unsuitability as a combustion material compared to wood. High silica, potassium, and chlorine content in herbaceous feedstocks can combine to cause fouling and slagging of combustion systems when temperatures exceed the melting point of ash (Samson and Mehdi, 1998).

The chemical breakdown of a biomass fuel, either by thermo-chemical or bio-chemical processes, produces a solid residue. When produced by combustion in air, this solid residue is called "ash" and forms a standard measurement parameter for solid and liquid fuels. The alkali metal content of biomass, i.e. sodium, potassium, magnesium, phosphorus, and calcium, is especially important for any thermo-chemical conversion processes. The reaction of alkali metals with silica present in the ash produces a sticky, mobile liquid phase, which can lead to blockages of airways in the furnace and boiler plant (McKendry, 2000a). Proximate analysis of fuels includes content of volatile matter, fixed carbon, and ash.

Ultimate analysis includes amounts of carbon, hydrogen, oxygen, nitrogen, sulfur, chlorine, and ash (Miles et al., 1995).

The major component of ash is silica. Warm season (C4) grasses are found to have lower silica levels than cool-season (C3) grasses, primarily because they utilize water 50% more efficiently (Samson and Mehdi, 1998). The main difference in silica levels between perennial grass species is often related to the photosynthetic mechanism of the grass, and to the amount of water being transpired by the plant. The decreased water usage reduces the uptake of silicic acid and decreases the ash content of the plant. Silica levels are lowest in the stem fraction of grasses and highest in inflorescences, leaves, and leaf sheaths (Samson and Mehdi, 1998). The term "alkali" is used to describe the sum of potassium and sodium compounds, generally expressed as the oxides K_2O and Na_2O (Miles et al., 1995).

Chlorine may be an important element in vaporization of alkali species, leading to the formation of more severe deposits (Miles et al., 1995). Experience indicated that chlorine, rather than alkali, can be the limiting reactant in determining the total amount of alkali vapor produced. Deposit formation and tenacity tend to increase with increasing degrees of vaporization. Therefore, both chlorine and alkali content are important in predicting deposit properties (Miles et al., 1996).

Herbaceous Chemical and Elemental Values

There has been limited documentation of cool-season herbaceous chemical elemental biomass values. Most of the research so far has been concentrated on different woods, warm season (C4) grasses, straw, peat, etc. Fuel elemental composition and the concentration of alkali, sulfur, chlorine and silica in the fuels appear to be the best indicators of the tendency of fuels to slag (Miles et al, 1995).

A study by Cuiping et al. (2004) compared different herbaceous and woody biomass samples. Ash ranged from 8.90-152.5 g/kg depending on biomass type. Woody species had much lower ash contents than agricultural species. Ash and volatile matter content of the bituminous coal in this study was 200.8 and 283.3 g/kg respectively and the sulfur content was 9.7 g/kg. Wheat straw in this study had 124.5 g/kg ash and 3.2 g/kg sulfur. Out of all of the biomass samples analyzed, none had higher ash contents than the bituminous coal and they all had lower sulfur values compared to coal.

Nordin (1994) looked at 280 samples of biomass fuels to determine if there were any similarities in chemical elemental composition between the samples. Two of the few herbaceous samples examined were timothy (*Phelum pratense* L.) and lucerne (*Medicago sativa* L.). It was discovered that timothy and lucerne had high content of P (phosphorus) and K (potassium). The sulfur levels of timothy and lucerne were 1.6 g/kg and 2.5 g/kg and chlorine was 0.3 and 6.0 g/kg respectively. The two coals in this study had sulfur average contents of 5.0 g/kg and chlorine average contents of 0.36 g/kg. Timothy had lower ash and chlorine values and lucerne had a lower sulfur content compared to the coal.

McKendry, (2002a) found most commercial activity directed toward lower moisture-content biomass for burning. He decided to investigate woody plants and herbaceous species of lower moisture-content types. Three of the samples he looked at were miscanthus (*Misanthus sinensis* Anderss.), switchgrass, and bituminous coal. They had ash levels of 28.0, 45.0 and 80.0 g/kg respectively. The HHV of miscanthus was 18.5 MJ/kg and for switchgrass was 17.4 MJ/kg. The FC content was 150.9 g/kg for miscanthus and 570.0 g/kg for coal. Miscanthus had a VM content of 668.0 g/kg and coal had a VM content of 350.0 g/kg. This study showed that most of the other biomass sources had lower critical elemental values compared to coal that would indicate a potential to slag.

The Chariton Valley Biomass interim test burn compared fuel properties of coal and debaled switchgrass. The study looked at comparing the proximate and ultimate analysis of the two different fuels. Comer (2004) presented the results in a report presented at the Chariton Valley Biomass Project research review. Average coal and switchgrass ash contents were 54.5 and 46.3 g/kg, sulfur values were 3.1 and 0.9 g/kg, and chlorine content was 0.0 and 0.6 g/kg respectively. These numbers show that when switchgrass was co-fired, less amounts of ash and sulfur was produced compared to coal. These results were promising and could be a breakthrough to examine other herbaceous biomass because of the lower ash and sulfur contents.

Near Infrared Reflectance Spectroscopy (NIRS)

Understanding the chemical composition of biomass is a key feature in determining potential uses for, and the value of, a specific biomass (Kelly et al., 2004a). The botanical composition of pastures, grasslands, and CRP land can be very heterogeneous. Chemical composition varies among herbaceous biomass species (Cherney et al., 1988). Since it would be hard to separate out plant species within areas harvested for biomass or unfeasible to do, it would be ideal to have some method to determine chemical, elemental, and burning values of biomass material before co-firing. Spectroscopy-based compositional analysis methods are applicable to a wide variety of biomass and biomass-derived materials (Hames et al., 2003).

Determining the chemical composition of plant tissues has traditionally been a slow and complex matter involving sample preparation and wet chemical analysis. Recently, however, new spectroscopic methods have been developed which largely eliminate sample preparation and wet chemistry (McNicol and Cowe, 1990). Near infrared reflectance spectroscopy has been used for the characterization of different forms of biomass for more than 15 years (Marten et al., 1985). An NIRS spectrophotometer measures diffused reflectance from an irradiated sample in the spectral region of 1100-2500nm. Sample preparation is simple and analysis is rapid in that each sample spectrum is derived in seconds and several different constituents can be estimated from the same spectral measurements (McNicol and Cowe, 1990). Chemical composition can be determined much more accurately by using light beyond the visible range of wavelengths and into the near infrared (NIR).

A study by Kelley et al. (2004b) analyzed the use of NIRS to measure chemical properties of wood. They found two promising results that would be useful to the wood industry. First, there was little reduction in the correlation coefficient when the spectral range was reduced. Secondly, they found that the NIRS was able to predict the chemical composition of an unknown sample. It was also determined that the accuracy of the NIR calibration models was comparable to that of the wet chemical methods. The NIRS predicted some constituent values better than others, but most of the correlations were very strong, with correlation coefficients generally above 0.80.

Another study by Kelley et al. (2004a) focused on ways to demonstrate that spectroscopy tools could be used to measure the chemical composition of a wide variety of agricultural residues. Their results suggested that NIR could be used to rapidly rank and compare samples based on composition of their major components. Good correlations between measured and predicted concentrations were obtained with spectroscopy techniques.

Halgerson et al. (2004) researched the effectiveness of using NIRS for determining the total ash and minerals in alfalfa leaves and stems. They found that NIRS accurately predicted leaf and stem concentration, total ash, and macrominerals calcium, potassium, and phosphorus. The speed of NIRS allowed analysis of massive amounts of biomass required daily in a power plant to be adjusted for burner efficiency in real time.

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CHAPTER 3. BIOMASS COMPOSITION IN COOL-SEASON PASTURES HARVESTED FOR ENERGY IN SOUTHERN IOWA

A paper to be submitted to *Biomass and Bioenergy*

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Abstract

Approximately one hundred fifty thousand hectares of pasture and grassland exist in the four-county area near the Ottumwa Generating Station in Chillicothe, Iowa. Most of this land is dominated by cool-season grass species that are well adapted to the area and are managed with little fertilizer and chemical inputs. If yield and composition of these cool-season species are acceptable they could be potentially used as the biofuel portion in co-firing with coal. Ten sites in the surrounding area were evaluated. Across these sites, 26 different plant species were identified, with a single site having between 5 and 14 species. Biomass yield was determined at several sampling locations within each site. Biomass yield varied significantly among sites, but there was more variation in yield within sites than among them. Yields at each site ranged from as low as 0.75 mtons/ha to as high as 8.24 mtons/ha. Mean yield across all locations was 4.20 mtons/ha. Fuel characteristics of the cool-season species were evaluated for burning qualities. Concentrations of ash, chlorine and sulfur are important for determining suitability in a biofuel. Ash content of the sites ranged from 58.5-118.1 g/kg DM. Chlorine content of the sites ranged from 0.8-7.6 g/kg DM and sulfur content ranged from 0.7-3.4 g/kg DM. Near infrared reflectance spectroscopy (NIRS) was evaluated as a means to determine burning quality traits. Acceptable NIRS calibrations were achieved for ash, carbon and nitrogen, but not for volatile, sulfur and chlorine. These results indicate that cool-season pastures can produce biomass of sufficient yield and quality to supplement other sources for co-firing with coal to generate electricity.

Keywords: Biomass, Cool-season grasses, Chemical elemental characteristics, Co-firing

1. Introduction

The use of biomass for co-firing with coal to produce energy has recently gained prominent attention. Perennial grasses possess many beneficial attributes as energy crops, and there has been increasing interest in their use for this purpose in the US and Europe since the mid-1980's [1]. Efficient production of bioenergy from perennial grasses requires the choice of the most appropriate grass species for the given ecological/climatic conditions [1]. Many organizations have been cooperating on the Chariton Valley Biomass Project in an effort to increase switchgrass (*Panicum virgatum* L.) production. Warm-season (C4) grasses possess a number of characteristics that make them well suited as potential bioenergy crops. The focus has been to harvest switchgrass an energy crop to be co-fired with coal to produce energy. Switchgrass is a vigorous grass that will produce better growth on droughty, infertile, eroded soils than most grasses, and has been used extensively for erosion control [2]. Switchgrass has been identified as a model herbaceous energy crop based on its ability to yield relatively well despite moderate to low inputs, marginal soils, and favorable fuel characteristics in terms of high net energy, ash content, and chemistry [3,4]. Unfortunately, switchgrass yield in southern Iowa has not produced the tonnage that was previously forecasted by yield models. Other grass species commonly grown in the area may be a viable alternative to help alleviate the problem of a possible shortage with switchgrass production.

Approximately one hundred fifty thousand hectares of grassland and pasture are located within the 112-km potential of the Chariton Valley Biomass Project production area near the Ottumwa Generating Station in Chillicothe, Iowa. The four counties surrounding the generating station are Appanoose, Lucas, Monroe, and Wayne. Most of the grassland in this four-county area consists mainly of cool-season grass species and a significant amount of this acreage is in the CRP (Conservation Reserve Program). The Conservation Reserve Program was initiated under the Food Security Act of 1985, largely to stabilize and improve soils degraded by overcropping. An alternative to returning the lands to the very practices that made CRP necessary would be to use them for energy crops that can both enhance land quality and provide an economic return to landowners [3]. As of October 2003 about 11,663 ha (28,820 acres) are actively enrolled in the program in Appanoose County, 14,390 ha (35,558 acres) in Lucas County, 11,130 ha (27,501 acres) in Monroe County, and 24,724 ha (61,092 acres) in Wayne County [5].

The abundance of these cool-season grass species reflects their successful adaptation to the region. These grass species are commonly used for pasture, hay, and ground cover; but little is known of their qualities as a potential biofuel. Understanding the botanical composition and variation in chemical composition and yield of this biomass is critical to determining its potential value for co-firing with coal to produce electricity.

Near infrared reflectance spectroscopy (NIRS) has been used as an indicator of forage quality. Kelly et al. [6] tested the effectiveness of NIRS for measuring chemical composition of biomass. Performance of NIRS was promising given the tremendous diversity of biomass samples and a good correlation between the measured and predicted concentrations of the three major components were obtained with the NIRS technique.

The main goal of this project was to survey and analyze existing cool-season pastures in terms of the potential that they may have as energy crops for the purpose of co-firing with coal to produce electricity. Specific objectives of the research were: 1) to determine variability in the species composition of cool-season grass swards within and among sites in the Chariton Valley Biomass Project area, 2) to determine biomass availability and yield at each survey sample site, 3) to determine variability in chemical composition in terms of biofuel characteristics of harvested samples, and 4) to evaluate the feasibility of using near infrared reflectance spectroscopy (NIRS) for determining chemical composition and biofuel characteristics of cool-season grasses used for biomass.

2. Approach

Ten fields in pasture, hay, or CRP of less than eight hectares in the Chariton Valley Biomass Project area were selected as 'random' survey locations. The ten sites included were designated as 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10. Their locations are indicated in the map presented in Fig. 1. Management practices and inputs varied across locations, such as fertilizer and weed control, and were representative of those applied to grassland in the region.

2.1. Sampling variability

Within each site, six or ten sampling areas were selected along transects, depending on the area of the site. Sites 3, 6, and 9 each had six sampling areas, whereas sites 1, 2, 4, 5, 7, 8, and 10 each had ten. In total, there were eighty-eight total sampling areas. Within each of these areas, botanical composition of the sward was determined in late June using a sampling frame. A one square-meter frame was placed over the plant canopy at two locations within each sampling area. Every species in the frame was determined and ranked in order from most to least predominant and a percentage cover was estimated for the respective sampling areas. Species richness was calculated by determining the number of different species at each site, which gave a raw estimate number, and sampling area, which gave a more precise count of the different species in the area. The Shannon-Weaver diversity index was used to calculate species diversity and evenness [7]. Diversity reflects the number of species, whereas evenness relates to how the species are distributed (e.g. 1 major, 2 minor species or 3 species equally distributed). An appropriate calculation used to measure diversity can be calculated by the Shannon-Weaver index [7]:

$$H' = -\sum_{i-1}^{k} p_i \log p_i \tag{1}$$

Here, k is the number of different grass species found at a site (species richness) and p_i is the proportion of the species found in category i. Denoting n to be sample size, and f_i to be the number of observations in category i, then $p_i = f_i/n$.

The magnitude of H' is affected not only by the distribution of the data but also by the number of categories, for theoretically, the maximum possible diversity for a set of data consisting of k species richness is

$$H'_{\max} = \log k \tag{2}$$

The quantity J' has been termed evenness and may also be referred to as homogeneity, thus expressing the observed diversity as a proportion of the maximum possible diversity.

$$J' = H'/H'_{\max} \tag{3}$$

2.2. Biomass yield

Forage within the frames was hand-harvested in late June to a height of 2.5cm, weighed, and put into cloth bags for drying to assess potential maximum biomass yield at each site. Samples were dried for 48 hr or until dry in a forced-air dryer at 60° C to determine biomass yield.

2.3. Chemical composition

Dried samples were then ground to pass through a 1-mm mesh screen using a UDY cyclone mill (UDY Manufacturing, Fort Collins, CO) and processed to assess fuel quality and combustion characteristics of the cool-season grasses. Fuel characteristics measured evaluated were ash, gross energy (Joules), ultimate, proximate, chlorine and sulfur (Hazen Analytical Laboratories, Golden, CO).

2.4. Near infrared reflectance spectroscopy

Near infrared reflectance data was collected from all the samples using a scanning monochromator (NIRS systems, Silver Springs, MD). Multivariate calibration procedures were used to develop mathematical relationships between reflectance and fuel quality traits.

Groups of twenty and forty samples were selected on the basis of spectral properties [8]. Near infrared reflectance spectroscopy prediction equations were evaluated using 5 sample subsets in a cross validation scheme developed using modified partial least squares and stepwise regression to predict the values of ash, volatile (VM), fixed C (FC), sulfur, carbon, hydrogen, nitrogen, oxygen, chlorine, ash (kg/GJ), sulfur (kg/GJ), high heating value (HHV), mineral-matter free (MMF), and moisture and ash free (MAF). Volatile or volatile matter (VM) is that portion driven-off as a gas by heating. Fixed carbon content (FC) is the mass remaining after the releases of volatiles, excluding the ash and moisture contents. Ash (kg/GJ) and sulfur (kg/GJ) are the amounts of ash or sulfur that would be generated per one gigajoule of energy produced. The HHV is defined as the high heating value of a burn of the total energy content released when the fuel is burnt in air. The MMF is defined as "mineral matter free". This value is mathematically calculated removing sulfur and ash for the ranking of coal. The MAF is defined as "moisture and ash free". This value is calculated on a dry basis with ash subtracted out.

2.5. Statistical analysis

Variation in yield and composition was assessed by analysis of variance (ANOVA) using a linear model (SAS, 1991) where sample areas were nested within location. The statistical analysis was performed using the VARCOMP procedure (SAS, 1991). Variances associated with yield and chemical constituents were determined for comparison among and within locations.

3. Results

3.1. Botanical composition

Table 1 shows the frequency data, species richness, diversity, *H′* (1) and evenness, *J′* (3) values for the sampling sites and locations. Twenty-six different grass species were identified across all sites and the frequency of each species was determined within each site. Smooth bromegrass (*Bromus inermis* Leyss.), Kentucky bluegrass (*Poa pratensis* L.), tall fescue (*Festuca arundinacea* Shreb.) and birdsfoot trefoil (*Lotus corniculatus* L.) were the most dominant species found in the surveyed grassland. Their overall frequencies, or occurrences in all sampling frames, were 82, 40, 38 and 34%, respectively. Species richness ranged from 5 to 14 species among the ten sites with sites 9 and 10 having the lowest species richness and site 8 having the highest. Species richness was also determined for the sampling areas within each site (Fig. 2). Species richness is shown in box plot form. A 'shrunken' box plot represents less variability within a site, whereas a 'stretched-out' box plot indicates there was greater variability at a site. Sampling areas within sites 1 and 3 had the largest range of species and had a great amount of variability. The other sites had relatively little variation in species richness among sampling areas.

Grass species diversity at each site reflects the relative abundance of plant species supported at each site. Diversity ranged from *H′*=0.57 at site 9 to *H′*=1.06 at site 8. Site 9 had a small amount of place species, whereas site 8 had a large abundance of plant species. The maximum possible diversity that could occur in this study would be *H′*=1.41. Diversity over all the 88 sampling areas was *H′*=1.09. The quantity *J′* reflects the evenness with which species are distributed within a site. The higher value of *J′* indicates the grass species were distributed evenly among the locations, whereas a low *J′* indicates the species were not evenly spread out. Site 9 had the lowest value of J'=0.81 and site 1 had the highest value of J'=0.93. The overall evenness value across all sampling areas was J'=0.77, indicating that only a few species accounted for most of the plant community over all sites.

The grassland surveyed demonstrated that there was a great amount of variability in biomass composition among selected sites near the Ottumwa Generating Station. Species richness varied among and within sites from just a few of different species to a much more diverse collection of plant species. Even though site 1 had a total species richness of 10, the sampling areas within that site ranged from a species richness of 1 to 8. Smooth bromegrass was found at all sites and was present at a high frequency across all sampling locations.

3.2. Biomass yield

Biomass yield varied within and among locations (Fig. 3). Data is shown in box-plot form. Average yields across locations ranged from approximately 0.75 mtons/ha at site 8 to 8.24 mtons/ha at site 9. Average biomass yield across all locations was 4.20 mtons/ha. The majority of the variation in biomass yield, however, occurred within locations and not among them. About 25% of the variability was due to differences among locations, while 75% was due to the variation within locations (Table 2). Sites 3, 6, and 9 had the least amount of variation within each site, whereas sites 4, 7, and 8 had the most yield variation within each site (Fig. 3). Yields were quite variable across locations, but were surprisingly high for areas that may have received relatively little fertilizer and other management inputs.

There was a good coefficient of determination correlation (R^2=0.72) between species richness at each site and biomass yield (Fig. 4). Sites with the lowest species richness tended to have higher yields and sites with the highest species richness tended to have lower yields.

Species richness within a location may be a good indicator of the biomass yield potential at each site. No such relationship was found between species richness and any fuel characteristics.

3.3. Proximate and ultimate analysis results

Chemical composition varied within and among locations (Table 2). Wide ranges in elemental composition were observed. It is believed that alkali metals are the main cause of slagging, fouling, and sintering in power plants. These metals are virtually non-avoidable in an herbaceous crop, but can be selected for a lower chemical concentration in some grasses [9]. The majority of variation in elemental composition occurred within locations, not among them. The variation within locations is probably due to individual plant species found at each site, not the total number found at each site (Fig. 5). Evaluation of species composition and chemical composition data over the sites using canonical correspondence analysis indicated certain species were more associated with specific chemical components (Fig. 5). Alfalfa (*Medicago sativa* L.), tall fescue and birdsfoot trefoil were more positively related to ash content than other species. Red clover (*Trifolium pratense* L.) and wild carrot (*Daucus carota* L.) appeared to be more positively related to sulfur and nitrogen concentration.

The range, mean, median and upper and lower quartiles for each of the chemical constituents for samples collected at each site are shown in figures 6 and 7. Fuel elemental composition and the concentration of alkali, sulfur, chlorine and silica in the fuels appear to be the best indicators of the tendency of fuels to slag [10]. Alkali is the water-soluble component of ash. The reaction of alkali metals with silica present in the ash produces a sticky, mobile liquid phase, which can lead to blockages of airways in the furnace and boiler plant [11]. Ash values ranged from 58.5-118.1 g/kg, sulfur values ranged from 0.7-3.4 g/kg, chlorine ranged from 0.8-7.6 g/kg, and HHV ranged from 17.69-19.46 MJ/kg. These values are comparable to the values found from the interim test burn of switchgrass and coal in December 2003 [12]. Ash ranged from 43.3-56.0 g/kg, sulfur ranged from 0.7-1.3 g/kg, chlorine from 0.4-0.8 g/kg, and HHV ranged from 18.2-18.6 MJ/kg in switchgrass [12]. Coal values were ash ranged from 54.9-103.4 g/kg, sulfur values ranged from 3.9-4.5 g/kg, chlorine content was not present, and HHV ranged from 26.2-28.1 MJ/kg [12].

The greatest difference in composition was between ash contents found in the cool-season grasses and switchgrass. The major component of ash is silica. Warm season (C4) grasses typically have lower silica levels than cool season (C3) grasses primarily due to the fact that they utilize water 50% more efficiently [13]. Silica levels are lowest in the stem fraction of grasses, and highest in inflorescences, leaves, and leaf sheaths [13].

3.4. Near infrared reflectance analysis

Population statistics for NIRS calibration and validation sample sets are presented in Table 3. Mean, range, and standard deviations of each constituent are shown for 20- and 40-sample calibration sets and for the validation sample set. Multivariate calibration procedures were used to develop mathematical relationships between reflectance and fuel quality traits. The majority of the 20 sample calibration set had wider constituent ranges and larger standard deviations compared to the 40 sample set, thus it would be better for predicting the validation sample set.

The standard error of calibration, RSQ, standard error of validation, validation coefficient of determination, bias, and math treatment for prediction equations are shown in Table 4. Math treatments listed are those that provided the best (1-VR), validation coefficient of determination values. Some constituents can more easily be predicted than others using NIRS. The (1-VR) value is a percentage of the expected explained variation, which indicates how well a NIRS calibration performs in predicting the composition of a sample not used to develop the calibration. The higher the (1-VR) value, the better the predictive performance of the calibration. Ash, carbon, and nitrogen had the highest (1-VR) values. Oxygen, ash (kg/GJ), HHV, MMF, and MAF had moderate prediction values. Near infrared reflectance spectroscopy would not be a good method for predicting concentrations of the other constituents. Halgerson et al. [14] determined that NIRS was a rapid and accurate method for determining leaf, total ash, and calcium, potassium, and phosphorus concentrations in sun-cured hay and oven-dried research samples.

Modified partial least squares (MPLS) and stepwise regressions were evaluated as calibration methods. Equations deviated with MPLS regression resulted in better predictions when using 20 samples and equations deviated with stepwise regression resulted in better predictions when using 40 samples.

4. Discussion

Because of the diversity of herbaceous plant species in the sampled grasslands, chemical composition is quite variable. Some locations are better suited than others for biomass harvest for burning with coal because of lower ash, sulfur, and chlorine content. Many factors, such as species and variety, choice of soil type and location, fertilization practices, and time of harvest affect the ash concentration of grasses [13]. Elemental composition and the concentration of alkali, sulfur, chlorine, and silica, appear to be the best indicators of the tendency of fuels to slag [10]. These data provide engineers basic data on the amount or variation of ash that will be present while burning biomass harvested from cool-season grasslands. This will be useful information allowing power plants to predict and develop means to prevent fouling and slagging when burning biomass originating from cool-season grasslands. Knowledge of mineral concentration in herbage is necessary to improve efficiency of the gasifier operation and reduce costs associated with excess slag production [14].

The ash component of plants varies greatly among families of plants as well as among individual species [10]. This was very evident in this study. Ash ranged from 58.5 to 118.1 g/kg. Ash content in cool-season species was higher than switchgrass and coal , but still comparable. The main concern is that the ash percentage can be known or predicted before burning so necessary adjustments, such as biomass proportion and mixture, can be made for the co-firing process. Near infrared reflectance spectroscopy proved to be a possible way of predicting ash and other constituents.

5. Conclusion

The results of this study indicate that cool-season pastures can serve as an alternative source of herbaceous biomass in addition to switchgrass. Cool-season pastures are the predominant form of grassland vegetation within the four-county area and represent an abundant supply of biomass. The species comprising most of this pasture have become naturalized and are very well adapted to the soils and climate of southern Iowa. Biomass accumulation in cool-season pastures is greatest in spring and early summer while that of switchgrass and other warm-season species is greatest in late spring and summer. Therefore, cool-season grasses could be harvested as a source of biomass earlier in the season if stored supplies of switchgrass become limiting. One negative aspect of using cool-season species is potentially higher ash concentration. Future research could examine if ash concentration would be decreased by herbicide use to eliminate high ash grass species.

Acknowledgement

The authors are grateful to the Chariton Valley Biomass Program for their collaboration and financial support in the development of this research study.

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Table 1
Botanical composition of cool-season grassland sampled at ten sites in Lucas and Wayne counties.
(Values represent the frequency of occurrence for a species at each location.)

		Location										
Scientific Name	**Common Name**	1	2	3	4	5	6	7	8	9	10	Freq Overall
Agropyron repens (L.) Nevkski	Quackgrass	0	0	0	0	0.1	0	0	0	0.17	0	0.02
Apocynum cannabinum L.	Hemp dogbane	0	0	0	0	0	0	0	0.1	0	0	0.01
Bromus inermis Leyss.	Smooth bromegrass	0.8	0.9	0.83	0.8	0.5	1.0	1.0	0.8	1.0	0.7	0.82
Chamaecrista fasciculata L.	Partridge pea	0.3	0	0	0	0	0	0	0.4	0	0	0.08
Convolvulus L.	Bindweed	0.2	0	0	0	0	0	0	0	0	0.1	0.03
Conyza canadensis (L.) Cronq.	Marestail	0	0.1	0	0	0	0	0	0	0	0	0.01
Erigeron nanus Nutt.	Dwarf fleabane	0	0.2	0	0	0	0	0	0	0	0	0.02
Abildgaardia Vahl	Sedge	0	0.1	0	0	0	0	0	0	0	0	0.01
Dactylis glomerata L.	Orchardgrass	0	0	0	0.1	0	0	0.3	0	0.17	0	0.06
Daucus carota L.	Wild carrot	0.2	0.1	0	0.2	0	0	0	0.2	0	0	0.08
Festuca arundinacea Shreb.	Tall fescue	0.7	0	0.17	0.5	1.0	0.17	0.2	0.6	0	0.1	0.38
Helianthus annuus L.	Sunflower	0	0	0	0	0	0	0	0.1	0	0	0.01
Helianthus tuberosus L.	Jerusalem artichoke	0	0	0	0	0	0	0	0.3	0	0	0.03
Lotus corniculatus L.	Birdsfoot trefoil	0.2	0.6	0.33	0	0.6	0.33	0.2	0.5	0.83	0	0.34
Medicago sativa L.	Alfalfa	0	0.1	0.17	0	0	0.33	0	0	0.17	0	0.06
Melilotus officinalis (L.) Lam	Yellow sweetclover	0	0.1	0	0	0	0	0	0	0	0	0.01
Panicum virgatum L.	Switchgrass	0	0	0	0	0	0	0	0	0	0.2	0.02
Pastinaca sativa L.	Wild parsnip	0.8	0.1	0	0.5	0.2	0	0.2	0	0	0	0.20
Phalaris arundinacea L.	Reed canarygrass	0	0	0.17	0	0	0	0	0.3	0	0.4	0.09
Phleum pratense L.	Timothy	0	0	0.5	0	0.1	0	0	0.1	0	0	0.06
Poa pratensis L.	Kentucky bluegrass	0.4	0.8	0.83	0.5	0.4	0.17	0.3	0.5	0	0	0.40
Salidago L.	Goldenrod	0.3	0.3	0.5	0.2	0.1	0.17	0	0.4	0	0	0.19
Taraxacum officinale (Weber)	Common dandelion	0	0	0	0.1	0	0	0	0	0	0	0.01
Trifolium pratense L.	Red clover	0	0.5	0.5	0.5	0.2	0	0	0.1	0	0	0.18
Trifolium repens L.	White clover	0	0	0.17	0	0	0	0	0	0	0	0.01
	Other Weed	0.2	0	0.17	0.1	0	0.17	0	0.2	0	0	0.08
	Species richness[a]	10	12	11	10	9	7	6	14	5	5	26
	Avg. species richness[b]	4.1	3.9	4.3	3.5	3.2	2.3	2.2	4.6	2.3	1.5	
	H'-diversity	0.93	0.92	0.96	0.90	0.82	0.73	0.68	1.06	0.57	0.58	1.09
	J'-evenness	0.93	0.86	0.92	0.90	0.86	0.86	0.87	0.92	0.81	0.83	0.77

[a]species richness at each location
[b]average species richness for each sampling area within a site

Table 2
Variances associated with biomass yield and chemical composition within and among cool-season grassland sampling sites.

Component	σ^2_{total}	σ^2_{among}	% Total $_{among}$	σ^2_{within}	% Total $_{within}$
Biomass (mton/ha)	2.6860	0.6830	25.4	2.0030	74.6
Ash (g/kg)	147.5366	30.4224	20.6	117.1142	79.4
Carbon (g/kg)	194.1358	64.7299	33.3	129.4060	66.7
Chlorine (g/kg)	0.1340	0.0283	21.1	0.1057	78.9
Fixed C (g/kg)	332.8150	33.5149	10.1	299.3002	89.9
Hydrogen (g/kg)	2.2273	1.0804	48.5	1.1470	51.5
Nitrogen (g/kg)	0.1397	0.0161	11.5	0.1237	88.5
Oxygen (g/kg)	0.1408	0.0304	21.6	0.1104	78.4
Sulfur (g/kg)	0.2323	0.0510	22.0	0.1813	78.0
Volatile (g/kg)	316.0786	54.1852	17.1	261.8934	82.9
Ash (kg/GJ)	0.5869	0.0761	13.0	0.5109	87.0
SO_2 (kg/GJ)	0.0030	0.0007	22.2	0.0024	77.8
HHV (MJ/kg)	117.0594	55.8599	47.7	61.1995	52.3
MAF (MJ/kg)	10.3923	3.6268	34.9	6.7655	65.1
MMF (MJ/kg)	5.5742	3.6029	64.6	1.9713	35.4

Table 3
Near infrared reflectance spectroscopy calibration and validation population statistics.

	40 calibration samples			20 calibration samples			48 validation samples		
Constituent	mean	range	std dev[a]	mean	range	std dev[a]	mean	range	std dev[a]
Ash (g/kg)	76.81	58.50-118.10	13.18	77.42	58.50-106.60	12.80	80.00	58.60-106.90	11.00
Carbon (g/kg)	512.98	484.60-536.10	11.06	514.97	498.80-536.10	11.00	505.00	488.30-524.20	8.70
Chlorine (g/kg)	2.31	0.90-6.80	1.26	2.38	1.20-6.80	1.33	2.80	0.80-7.60	1.53
Fixed C (g/kg)	165.10	118.60-197.00	19.24	161.72	118.60-197.00	21.86	165.84	115.70-189.50	17.40
Hydrogen (g/kg)	53.23	48.90-58.80	2.43	53.09	48.90-59.10	2.83	53.38	50.30-59.10	2.09
Nitrogen (g/kg)	12.82	6.80-22.90	3.80	14.18	7.50-22.90	4.49	11.28	8.10-20.70	2.46
Oxygen (g/kg)	341.84	293.90-373.10	14.17	336.84	307.50-360.10	14.14	347.44	307.50-373.60	12.53
Sulfur (g/kg)	1.55	0.80-2.60	0.35	1.73	1.00-3.00	0.44	1.59	0.70-3.40	0.57
Volatile (g/kg)	757.32	723.20-817.50	19.63	759.08	723.20-817.50	23.51	752.85	719.50-795.80	15.82
Ash (kg/GJ)	4.19	2.27-6.68	0.87	4.26	3.05-6.01	0.84	4.43	2.92-5.96	0.65
SO_2 (kg/GJ)	0.17	0.08-0.29	0.04	0.19	0.11-0.33	0.05	0.17	0.08-0.39	0.06
HHV (MJ/kg)	18.58	17.69-19.46	0.41	18.65	17.75-19.46	0.48	18.38	17.80-19.08	0.31
MAF (MJ/kg)	20.15	19.40-21.66	0.39	20.25	19.63-21.21	0.42	20.01	19.50-21.21	0.32
MMF (MJ/kg)	20.28	19.47-21.86	0.40	20.41	19.75-21.41	0.42	20.16	19.63-21.41	0.34

[a]standard deviation

Table 4
Near infrared reflectance spectroscopy calibration statistics.

Constituent	SEC[a]	RSQ[b]	SEV[c]	(1-VR)[d]	bias[e]	math trt[f]	SEC[a]	RSQ[b]	SEV[c]	(1-VR)[d]	bias[e]	math trt[f]
	Modified Partial Least Square Regression											
	40 samples						20 samples					
Ash (g/kg)	4.240	0.897	6.440	0.768	1.890	2 10 10 1	2.970	0.946	10.120	0.775	5.940	1 5 5 1
Carbon (g/kg)	3.340	0.902	6.540	0.796	-3.400	3 10 10 1	4.180	0.828	6.550	0.448	-2.820	3 10 10 1
Chlorine (g/kg)	0.690	0.333	1.560	0.074	0.750	1 5 5 1	0.360	0.661	1.540	0.086	0.580	4 10 10 1
Fixed C (g/kg)	16.730	0.225	18.200	-0.402	-2.470	1 5 5 1	6.790	0.869	26.780	0.252	14.550	1 5 5 1
Hydrogen (g/kg)	1.310	0.707	2.040	0.260	0.070	2 10 10 1	2.290	0.444	3.570	0.352	-2.300	1 5 5 1
Nitrogen (g/kg)	0.370	0.991	0.710	0.974	0.040	1 5 5 1	0.620	0.981	1.040	0.955	0.680	2 10 10 1
Oxygen (g/kg)	6.550	0.565	10.750	0.518	0.490	3 10 10 1	7.880	0.486	10.900	0.397	2.360	2 10 10 1
Sulfur (g/kg)	0.260	0.306	0.580	0.201	0.160	4 10 10 1	0.170	0.738	0.520	0.333	0.120	1 5 5 1
Volatile (g/kg)	12.410	0.495	16.440	0.037	0.870	4 10 10 1	19.710	0.334	21.390	0.171	-15.030	4 10 10 1
Ash (kg/GJ)	0.356	0.785	0.467	0.646	0.118	3 10 10 1	0.096	0.984	0.818	0.836	-0.123	3 10 10 1
SO_2 (kg/GJ)	0.028	0.126	0.067	0.111	0.019	1 5 5 1	0.018	0.771	0.060	0.376	0.017	1 5 5 1
HHV (MJ/kg)	0.214	0.729	0.241	0.559	-0.029	1 5 5 1	0.129	0.926	0.333	0.673	-0.189	1 5 5 1
MAF (MJ/kg)	0.264	0.309	0.277	0.236	-0.030	2 10 10 1	0.105	0.915	0.249	0.732	0.006	1 5 5 1
MMF (MJ/kg)	0.268	0.306	0.292	0.234	-0.013	2 10 10 1	0.163	0.793	0.272	0.499	-0.072	1 5 5 1
	Stepwise Regression											
	40 samples						20 samples					
Ash (g/kg)	4.680	0.874	7.070	0.611	1.790	2 10 10 1	3.940	0.905	8.190	0.529	1.570	3 10 10 1
Carbon (g/kg)	4.030	0.840	6.290	0.706	-2.690	3 10 10 1	3.060	0.922	7.150	0.683	-1.530	4 10 10 1
Chlorine (g/kg)	0.840	0.495	1.540	0.096	0.680	1 5 5 1	0.360	0.928	1.650	-0.262	0.760	2 10 10 1
Fixed C (g/kg)	16.660	0.250	20.870	-0.466	-2.730	1 5 5 1	12.910	0.651	31.420	-2.218	20.890	3 10 10 1
Hydrogen (g/kg)	1.260	0.704	2.200	-0.111	0.080	2 10 10 1	1.860	0.470	2.630	-0.531	-1.170	1 5 5 1
Nitrogen (g/kg)	0.470	0.985	0.660	0.948	0.030	1 5 5 1	0.550	0.985	0.770	0.957	0.110	1 5 5 1
Oxygen (g/kg)	4.250	0.853	10.200	0.422	0.290	3 10 10 1	6.520	0.788	13.700	0.283	0.030	1 5 5 1
Sulfur (g/kg)	0.240	0.333	0.570	-0.033	0.100	1 5 5 1	0.120	0.856	0.550	-0.174	0.190	1 5 5 1
Volatile (g/kg)	13.710	0.369	15.490	0.054	-2.370	1 5 5 1	18.950	0.351	14.880	0.177	-5.210	3 10 10 1
Ash (kg/GJ)	0.304	0.865	0.521	0.412	0.175	2 10 10 1	0.256	0.907	0.816	-0.204	0.218	1 5 5 1
SO_2 (kg/GJ)	0.027	0.295	0.065	-0.033	0.012	1 5 5 1	0.018	0.725	0.061	-0.125	0.016	1 5 5 1
HHV (MJ/kg)	0.258	0.605	0.277	0.439	-0.061	3 10 10 1	0.097	0.958	0.356	0.184	-0.133	1 5 5 1
MAF (MJ/kg)	0.245	0.373	0.262	0.398	-0.039	1 5 5 1	0.120	0.889	0.252	0.546	0.005	1 5 5 1
MMF (MJ/kg)	0.252	0.359	0.279	0.359	-0.022	1 5 5 1	0.185	0.805	0.535	-0.581	-0.316	3 10 10 1

[a]standard error of calibration (variation within the reference population not explained by the calibration)
[b]explained variation for calibration
[c]standard error of validation
[d]validation coefficient of determination (measure of the expected explained variation)
[e]systematic difference between true and predicted values
[f]math treatment that gave the best-fit equation

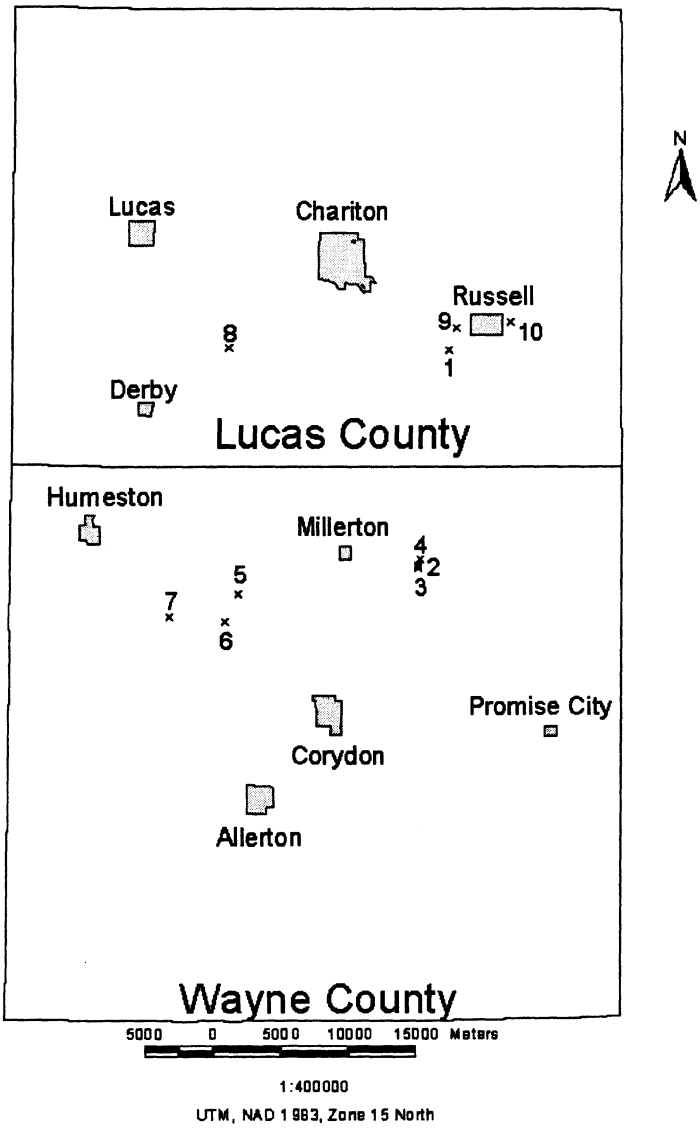

Figure 1. Map locations of ten field sites sampled in study.

41.0°N latitude x 93.3°W longitude

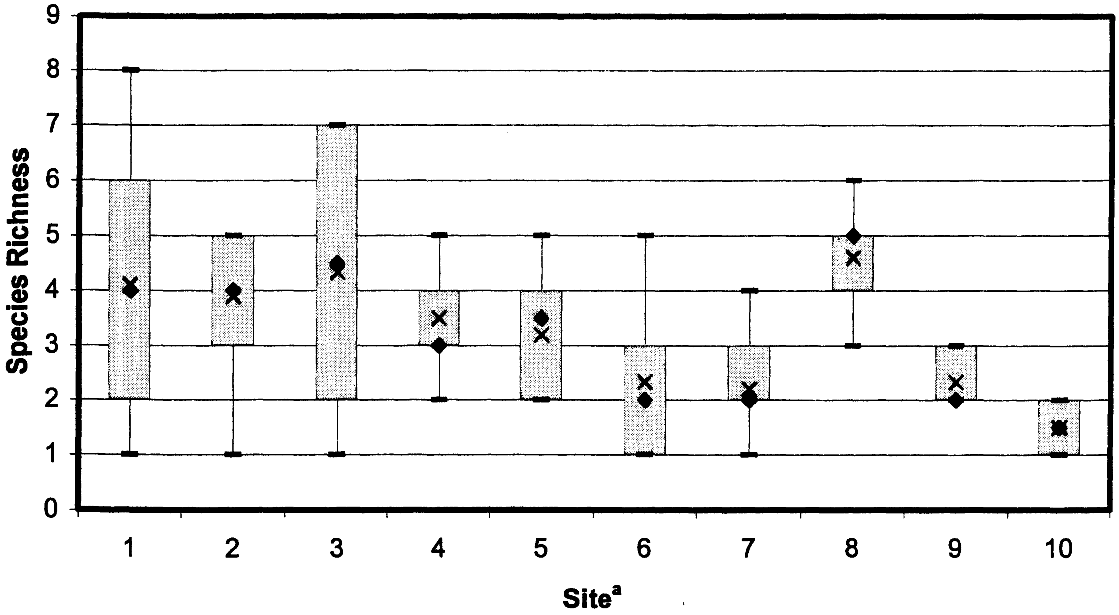

Figure 2. Box plots of species richness within each of ten locations.

[a]Sites 3, 6, and 9 has six sampling areas. Sites 1,2,4,5,7, and 8 had ten sampling areas.
[x]mean or average
[♦]median or middle value
Tails represent the highest and lowest extremes found at each site.
Upper and lower ends of the shaded box makeup the 25th and 75th percentiles.

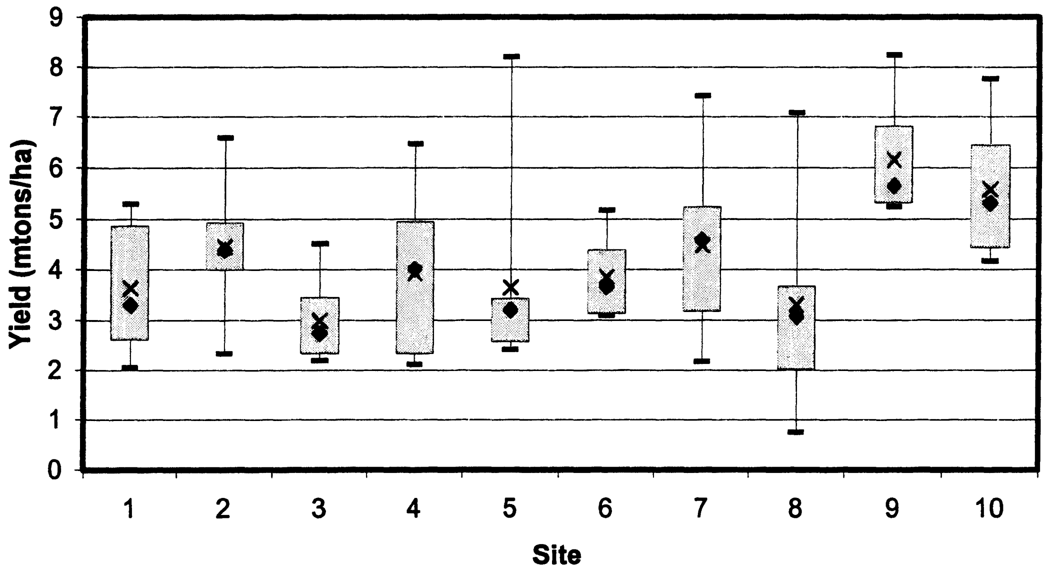

Figure 3. Box plots of biomass yield for each location.

ˣmean or average
♦median or middle value
Tails represent the highest and lowest extremes found at each site.
Upper and lower ends of the shaded box makeup the 25th and 75th percentiles.

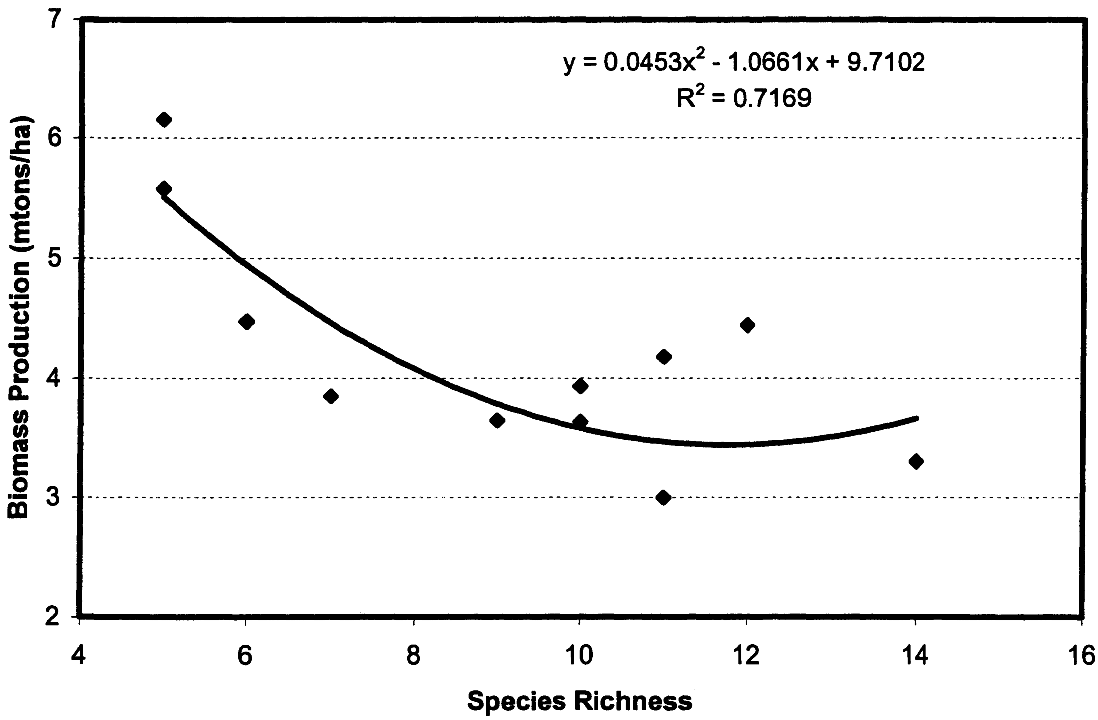

Figure 4. Relationship between species richness and biomass yield.

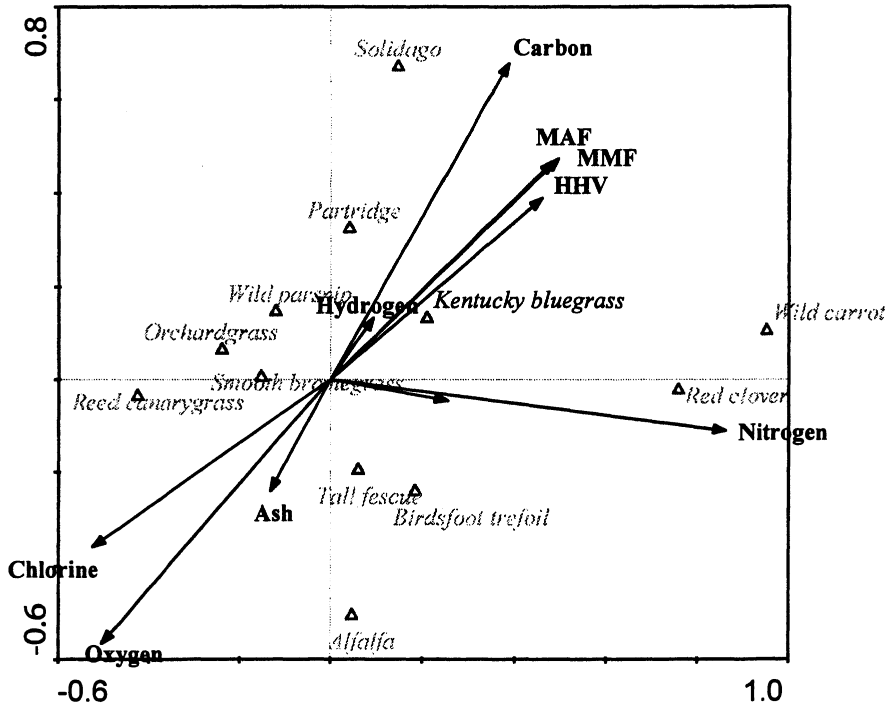

Figure 5. Biplot showing the relationships among cool-season species and chemical composition of biomass samples.

Arrows represent the direction of maximum change in chemical constituents. Species nearest an arrow are more positively related to the constituent it represents than those farther away. Species located more closely together on the plot are more likely to be found in the same sample than those farther apart.

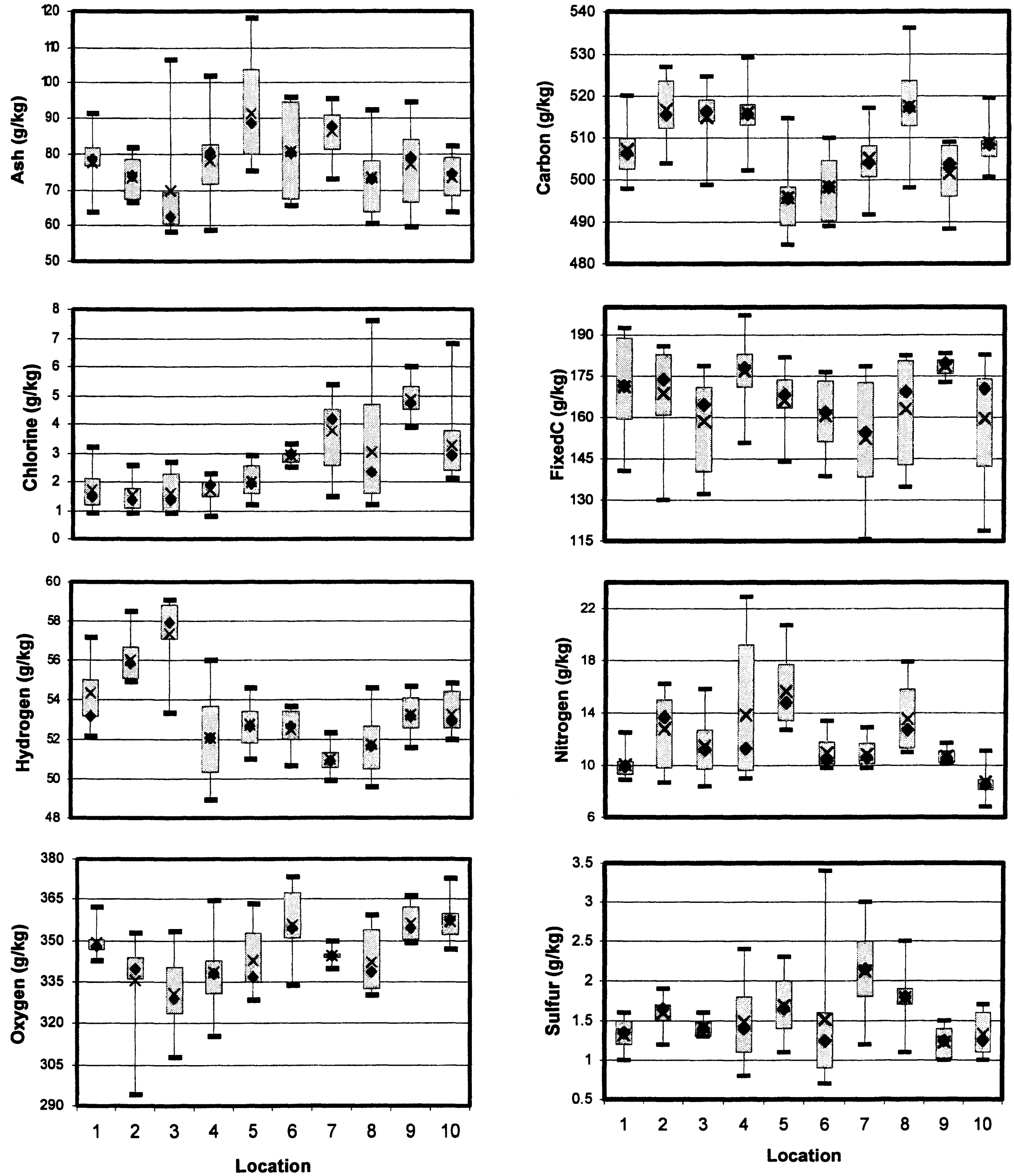

Figure 6. Box plots of biomass chemical constituents at each location.

ˣmean or average

♦median or middle value

Tails represent the highest and lowest extremes found at each site.

Upper and lower ends of the shaded box makeup the 25th and 75th percentiles.

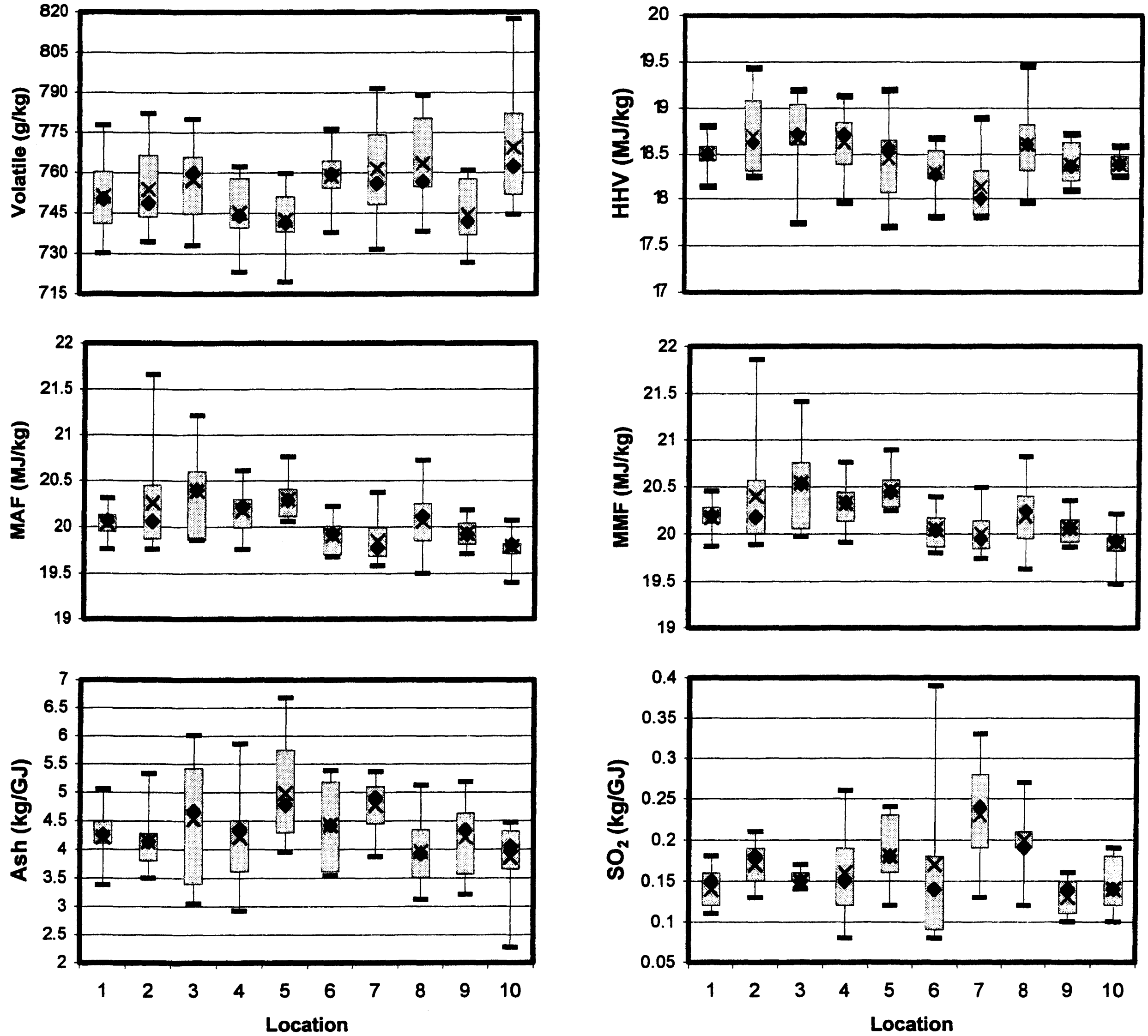

Figure 7. Box plots of biomass burning characteristics at each location.

[x]mean or average
[♦]median or middle value
Tails represent the highest and lowest extremes found at each site.
Upper and lower ends of the shaded box makeup the 25th and 75th percentiles.

MAF=moisture and ash free
HHV=high heating value
MMF=mineral matter free

CHAPTER 4. GENERAL CONCLUSION

Southern Iowa is known for its poor soil and therefore is predominately seeded in cool-season pastures and grassland. Cool-season grasses could serve as a potential alternative biomass source to switchgrass. Cool-season grasses are capable of producing high yields, especially those native or naturalized to Iowa. If switchgrass tonnage is low, due to poor yield, insect, or disease damage, cool-season grasses could serve as an alternative source of biomass, because its growth patterns complements that of switchgrass (a warm-season grass). It would be in the best interest of farmers and energy producers to have a "back-up" crop if extra biomass is needed to co-fire with coal to produce electricity or heat.

Total plant species diversity ranged greatly between sites. Yield was highest in the sites with the smallest species richness. The majority of the cool-season grasses had higher ash levels compared to that of switchgrass, but the levels are still lower than that of coal. Other chemical values, such as chlorine and alkali, were also lower than the coal they would be co-fired with. Near infrared reflectance spectroscopy proved to be an effective tool in predicting certain burning characteristics of cool-season grasses. If energy producers are capable of predicting the concentrations of certain chemicals in the biomass before burning, they can modify the burn and heat rate to deal with certain problems, such as fouling and slagging in power plants.

ACKNOWLEDGEMENTS

I would like to thank my family, friends, peers, co-workers, and those who encouraged me to pursue this challenging endeavor. I am ever thankful for your countless prayers, advice, and thoughts throughout this process.

To my parents, David and Sharon, thank you for you wisdom and guidance. Thanks for letting me "fly away" and supporting my decision to try new opportunities far away from home. You were instrumental in all of my decisions and have helped mold me into the person I am now.

Katie and Jacob, thanks for being great sibling throughout all of this. Jacob, sorry I wasn't able to make it to more of your football games and be a bigger part of your high school years. You have done very well and I am very proud of you. Katie, thank you for all of your countless advice on the phone. It's great to see that you are pursing a career that you love. Good luck with teaching.

Corey, I don't think I can ever say "thank you" enough for all that you have done. Thank you for allowing me to continue my education and putting our future plans on hold until I was through with school. You compassion and understanding made this process possible. Also thank you so much for making the countless treks from Indiana and Illinois. I look forward to our future together.

To Dr. Moore and the members of my committee. Thank you so much for all of your help throughout this process. This was truly a fun experience. Dr. Moore, thank you for all your edits, thoughts, and suggestions as I put together this final product.

Thank you to everyone in forages who was there to help me with the research, especially Trish Patrick, Roger Hintz, Dan Kilborn, and Bryan Terrell. It was not easy

moving far away from home, but your group was truly amazing at how well you all made me feel right at home. I will always remember you guys and the countless lunches and road trips we had together.

I will never forget the time spent here at Iowa State University. It was an amazing experience, one I will never forget. Good luck to all of you in the future and God bless.