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Biomass and Bioenergy 30 (2006) 522–528

BIOMASS & BIOENERGY

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# Yield and composition of herbaceous biomass harvested from naturalized grassland in southern Iowa

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Received 6 December 2004; received in revised form 31 October 2005; accepted 2 December 2005
Available online 27 January 2006

**Abstract**

Much of the land area in southern Iowa is used for perennial pastures that are dominated by cool-season grass species. These species are well adapted to the soils and climate and have become naturalized within the region. Biomass produced from these pastures might potentially be used as a feedstock for cofiring with coal to supplement supplies of dedicated energy crops such as switchgrass (*Panicum virgatum* L.). While much is known about the use of these pasture species for forage production, relatively little information is available on their use as a bioenergy feedstock. This research was conducted to assess the potential of harvesting cool-season pastures for cofiring with coal. Ten representative sites located in south central Iowa were evaluated. Across all sites, 26 plant species were identified, with individual sites having between 5 and 14 species. Biomass yield was determined at several sampling locations within each site. Yields ranged from 0.75 to 8.24 t ha$^{-1}$ over all sites. Mean yield across all sites was 4.20 t ha$^{-1}$. 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 ranged from 58.5–118.1 g kg$^{-1}$ DM across all sites. Chlorine ranged from 0.8–7.6 g kg$^{-1}$ DM and sulfur content ranged from 0.7–3.4 g kg$^{-1}$ DM. Highest heating value (HHV) ranged from 17.69–19.46 MJ kg$^{-1}$. These results indicate that cool-season grassland in southern Iowa can produce biomass of sufficient yield and quality to supplement other sources for cofiring with coal to generate electricity.


*Keywords:* Ash; Biofuel quality; Cofiring; Energy; Productivity

## 1. Introduction

The use of biomass for cofiring with coal to produce energy has recently gained prominent attention [1,2]. 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-1980s [3]. Warm-season ($C_4$) grasses possess a number of characteristics that make them well suited as potential bioenergy crops. Switchgrass (*Panicum virgatum* L.) 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 [4,5]. 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 [6]. However, switchgrass yields in southern Iowa have been highly variable and generally less than anticipated [7]. Other perennial plant species commonly grown in the area may be a viable alternative for supplying biomass when switchgrass production does not meet the demand for herbaceous biomass.

Approximately one hundred fifty thousand hectares of grasslands and pastures are located within a 112-km radius of the Alliant Power Ottumwa Generating Station near Chillicothe, Iowa. This coal-fired plant has been modified for cofiring with switchgrass to determine the long-term feasibility of producing electricity by burning herbaceous biomass with coal [8]. Chariton Valley Resource and Conservation Development is a non-profit corporation that is working with growers in Appanoose, Lucas, Monroe, and Wayne counties to develop a stable biomass

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doi:10.1016/j.biombioe.2005.12.007

supply for the power plant. Most of the grassland in the four-county area consists mainly of cool-season grass species and a significant amount of this acreage is enrolled in the conservation reserve program (CRP). The CRP was initiated under the Food Security Act of 1985, largely to stabilize and improve soils degraded by overcropping. 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. 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 [4]. As of October 2003 about 11,663 ha (28,820 acres) were actively enrolled in the CRP 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 [9].

The abundance of 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 yield of this biomass is critical to determining its potential value for cofiring with coal to produce electricity.

The main goal of this project was to survey and evaluate existing cool-season grassland to evaluate its potential for use as an energy crop for cofiring with coal to produce electricity. Specific objectives of the research were: (1) to determine variability in the species composition of cool-season grassland within and among sites in the Chariton Valley Biomass Project area, (2) to determine biomass availability and yield at each survey sample site, and (3) to determine variability in chemical composition in terms of biofuel characteristics of harvested samples.

## 2. Materials and methods

Ten fields in pasture, hay, or CRP of less than 8 ha in the Chariton Valley Biomass Project area were selected as 'random' survey locations. The ten sites were designated as 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10. 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

Within each site, 6 or 10 sampling areas were selected along transects, depending on the area of the site. Sites 3, 6, and 9 each had 6 sampling areas, whereas sites 1, 2, 4, 5, 7, 8, and 10 each had 10. There were 88 total sampling areas. Within each of these areas, botanical composition of the plant community was determined in late June using a sampling frame. A 1 $m^2$ 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 and sampling areas within each site. 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). The Shannon–Weaver diversity index was calculated for each site using the formula [10]

$$H' = -\sum_{i-1}^{k} p_i \log p_i \quad (1)$$

where $k$ 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 $i$. Evenness ($J'$) of the distribution of species within a site was calculated as the ratio of H′ over the theoretical maximum diversity which is equal to $\log k$. Evenness reflects the homogeneity of the species distribution within a sample and has a maximum value of 1 when all species are equally distributed.

### 2.2. Biomass yield

Forage within the frames was hand harvested in late June to a stubble height of 2.5 cm, weighed, and put into cloth bags for drying to determine biomass yield. Samples were dried for 48 h 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. Fuel characteristics measured were ash, gross energy (J), and ultimate and proximate analysis (Hazen Analytical Laboratories, Golden, CO). Proximate analysis of fuels includes content of volatile matter (VM), fixed carbon (FC), and ash. Ultimate analysis includes amounts of carbon, hydrogen, oxygen, nitrogen, sulfur, chlorine, and ash [11]. High heating value (HHV) was also determined. Ash and sulfur were also reported in kilograms that would be generated per one gigajoule of energy produced (kg $GJ^{-1}$).

### 2.4. Statistical analysis

Variation in yield and composition was assessed by analysis of variance (ANOVA) using a linear model where sample areas were nested within location. The statistical analysis was performed using the VARCOMP procedure of SAS [12]. Variances associated with yield and chemical constituents were determined for comparison among and within locations. The relationship between biomass composition and species abundance was evaluated using canonical correspondence analysis (CCA) [13].

## 3. Results and discussion

### 3.1. Botanical composition

Table 1 shows the frequency data, species richness, diversity, $H'$ (1) and evenness, $J'$ values for the sampling sites and locations. Twenty-six 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 10 sites with sites 9 and 10 having the lowest species richness and site 8 having the highest. Species richness within sites is also shown in box plot form (Fig. 1). Sampling areas within sites 1 and 3 had the largest range of species, therefore having a great amount of variability. The other sites had relatively little variation in species richness among sampling areas. Species richness varied among and within sites from just a few different species to a much more diverse collection of plant species.

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 number of different plant 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 and were found in bulk in some areas. Site 1 had the highest value of $J' = 0.93$ and

Table 1
Botanical composition of cool-season grassland sampled at ten sites in Lucas and Wayne counties

| Scientific name | Common name | Location | | | | | | | | | | Freq overall |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| *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 |

Values represent the frequency of occurrence for a species at each location.
[a]Species richness at each location.
[b]Average species richness for each sampling area within a site.

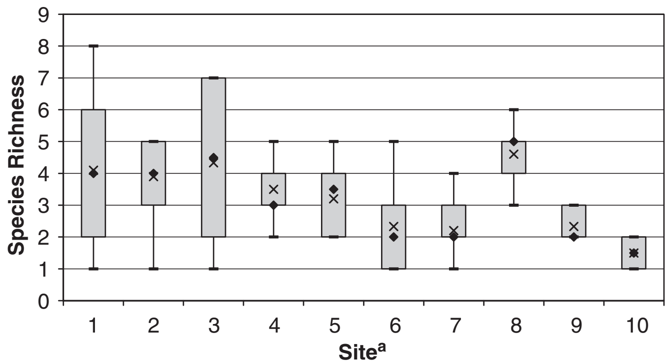


Fig. 1. Box plots of species richness within each of 10 sampling sites: [a], sites 3, 6, and 9 had six sampling areas. Sites 1,2,4,5,7, and 8 had ten sampling areas; ×, mean; ◆, median; tails represent the highest and lowest extremes found at each site; upper and lower ends of the shaded box makeup the 25th and 75th percentiles.

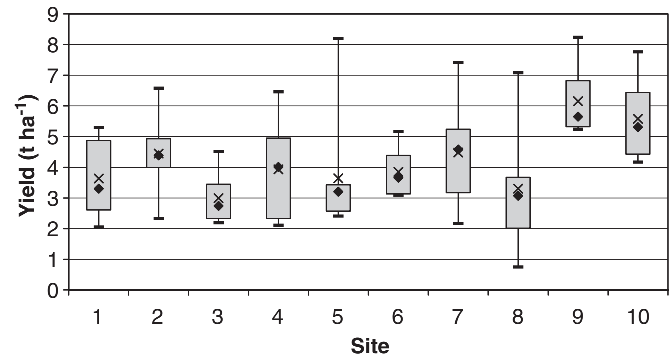


Fig. 2. Box plots of biomass yield within each of 10 sampling sites: ×, mean; ◆, median; tails represent the highest and lowest extremes found at each site; upper and lower ends of the shaded box makeup the 25th and 75th percentiles.

site 9 had the lowest value of $J' = 0.81$. 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. 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. 2). Yields across locations ranged from approximately $0.75\,t\,ha^{-1}$ at site 8 to $8.24\,t\,ha^{-1}$ at site 9. Average biomass yield across all locations was $4.20\,t\,ha^{-1}$. 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. 2). Yields were variable across locations, but were surprisingly high for areas that may have received relatively little fertilizer and other management inputs.

### 3.3. Proximate and ultimate analysis results

Chemical composition varied within and among locations (Table 2). Wide ranges in elemental composition were observed. 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 [14]. It is believed that alkali metals are the main cause of slagging, fouling, and sintering in power plants [15]. These metals are virtually non-avoidable in an herbaceous crop, but can be selected for a lower chemical concentration in some grasses [15]. 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. Evaluation of species-composition and chemical-composition data over the sites using CCA indicated certain species were more associated with specific chemical components (Fig. 3). 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.

Biomass fuels have significantly different elemental characteristics compared to coal, particularly concerning the elements important for ash and deposit formation [14,15], resulting in engineering problems within power plants. The range, mean, median and upper and lower quartiles for each of the chemical constituents for samples collected at each site are shown in Figs. 4 and 5. 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 [11]. 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 [16]. Ash values ranged from $58.5–118.1\,g\,kg^{-1}$, sulfur ranged from $0.7–3.4\,g\,kg^{-1}$, chlorine ranged from $0.8–7.6\,g\,kg^{-1}$, and HHV ranged from $17.69–19.46\,MJ\,kg^{-1}$ across all sampling sites. These values are comparable to the values found from the interim test burn of switchgrass and coal in December 2003 [17]. Switchgrass had ash values ranging from $43.3–56.0\,g\,kg^{-1}$, sulfur values from $0.7–1.3\,g\,kg^{-1}$, chlorine values from $0.4–0.8\,g\,kg^{-1}$, and HHV values ranged from $18.2–18.6\,MJ\,kg^{-1}$. Coal had ash values ranging from $54.9–103.4\,g\,kg^{-1}$, sulfur values from were $3.9–4.5\,g\,kg^{-1}$, chlorine was not present, and HHV ranged from $26.2–28.1\,MJ\,kg^{-1}$ [17].

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

| Component | $\sigma^2_{total}$ | $\sigma^2_{among}$ | % $total_{among}$ | $\sigma^2_{within}$ | % total $_{within}$ |
|---|---|---|---|---|---|
| Biomass ($t\,ha^{-1}$) | 2.6860 | 0.6830 | 25.4 | 2.0030 | 74.6 |
| Ash ($g\,kg^{-1}$) | 147.5366 | 30.4224 | 20.6 | 117.1142 | 79.4 |
| Carbon ($g\,kg^{-1}$) | 194.1358 | 64.7299 | 33.3 | 129.4060 | 66.7 |
| Chlorine ($g\,kg^{-1}$) | 0.1340 | 0.0283 | 21.1 | 0.1057 | 78.9 |
| Fixed C ($g\,kg^{-1}$) | 332.8150 | 33.5149 | 10.1 | 299.3002 | 89.9 |
| Hydrogen ($g\,kg^{-1}$) | 2.2273 | 1.0804 | 48.5 | 1.1470 | 51.5 |
| Nitrogen ($g\,kg^{-1}$) | 0.1397 | 0.0161 | 11.5 | 0.1237 | 88.5 |
| Oxygen ($g\,kg^{-1}$) | 0.1408 | 0.0304 | 21.6 | 0.1104 | 78.4 |
| Sulfur ($g\,kg^{-1}$) | 0.2323 | 0.0510 | 22.0 | 0.1813 | 78.0 |
| Volatile ($g\,kg^{-1}$) | 316.0786 | 54.1852 | 17.1 | 261.8934 | 82.9 |
| Ash ($kg\,GJ^{-1}$) | 0.5869 | 0.0761 | 13.0 | 0.5109 | 87.0 |
| $SO_2$ ($kg\,GJ^{-1}$) | 0.0030 | 0.0007 | 22.2 | 0.0024 | 77.8 |
| HHV ($MJ\,kg^{-1}$) | 117.0594 | 55.8599 | 47.7 | 61.1995 | 52.3 |

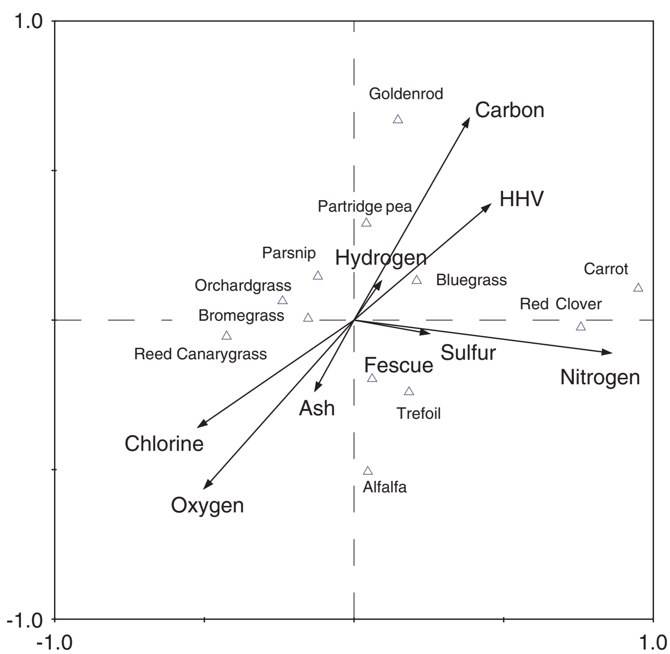


Fig. 3. Ordination biplot showing the relationships among plant species and chemical composition of biomass samples. Arrows represent the direction of maximum change in chemical constituents. Species nearest an arrow are more positively related to the constituent it represents than those farther away. Species located more closely together on the plot are more likely to be found in the same sample than those farther apart.

Because of the diversity of herbaceous plant species in the sampled grasslands, chemical composition was variable. Some locations are better suited than others for biomass harvest for burning with coal because of lower ash, sulfur, and chlorine content. The majority of the cool-season pastures had higher ash levels compared to that of switchgrass, but had values close to the levels found in coal. Sulfur levels in the cool-season pastures were comparable to that of switchgrass and were lower than the values found in coal. The greatest difference in chemical composition was the ash contents found in the cool-season grasses and switchgrass. The major component of ash is silica. Warm season ($C_4$) grasses typically have lower silica levels than cool-season ($C_3$) grasses primarily due to the fact that they utilize water 50% more efficiently [18]. Silica levels are lowest in the stem fraction of grasses, and highest in inflorescences, leaves, and leaf sheaths [18]. 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 [18].

## 4. Conclusion

The results of this study indicate that cool-season pastures can serve as an alternative source of herbaceous biomass in addition to switchgrass in southern Iowa. The species comprising most of this pastureland are capable of producing high yields, especially those native or naturalized to 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.

The ash component of plants varies greatly among families of plants as well as among individual species [11]. This was very evident in this study. Ash ranged from 58.5–118.1 $g\,kg^{-1}$. Ash content in cool-season species was higher than switchgrass and comparable with coal. 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 cofiring process.

This study provides basic data on the amount or variation of biomass and chemical values of grassland available for biomass harvest in southern Iowa. 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

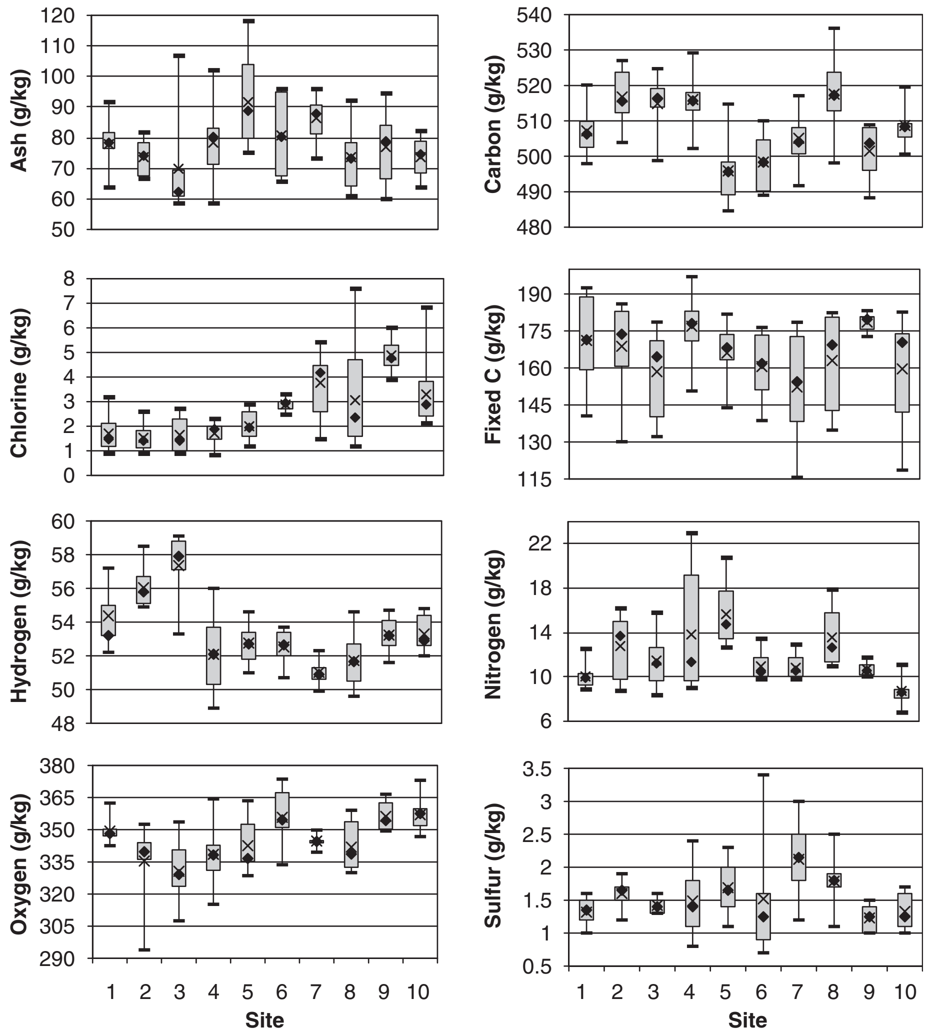


Fig. 4. Box plots of biomass chemical constituents within each of 10 sampling sites: ×, mean; ◆, median; tails represent the highest and lowest extremes found at each site; upper and lower ends of the shaded box makeup the 25th and 75th percentiles.

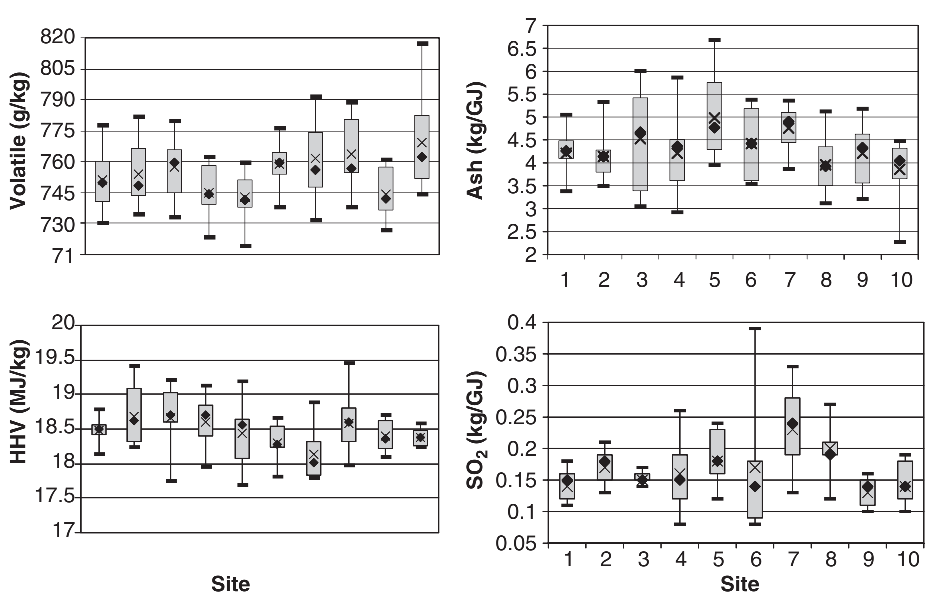


Fig. 5. Box plots of biomass burning characteristics within each of 10 sampling sites: ×, mean; ◆, median; tails represent the highest and lowest extremes found at each site; upper and lower ends of the shaded box makeup the 25th and 75th percentiles.

necessary to improve efficiency of the gasifier operation and reduce costs associated with excess slag production.

## Acknowledgement

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

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