Chariton Valley Biomass Project
Task 5.9.0

Assessment of the Biomass Potential of Cool-Season Grasslands in Southern Iowa

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August 2004

Table of Contents

List of Tables

List of Figures

BACKGROUND

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. Efficient production of bioenergy from perennial grasses requires the choice of the most appropriate grass species for the given ecological/climatic conditions (Lewandowski et al., 2003). Warm-season (C4) grasses possess a number of characteristics that make them well suited as potential bioenergy crops. Switchgrass (*Panicum virgatum* L.) has been identified as a preferred herbaceous energy crop for the US based primarily on its ability to yield well on marginal soil with moderate inputs and favorable fuel characteristics in terms of net energy, ash content, and chemistry. Ideally, herbaceous biomass used for co-firing would contain a high concentration of lignin and cellulose while minimizing total ash, chloride, and other undesirable elements (Lemus et al., 2002). One major benefit of switchgrass and other C4 grasses is that they contain a low silica concentration, which is the major component of ash.

Much of the two million acres of grassland located around the Ottumwa Generating Station are enrolled in the Conservation Reserve Program. The Conservation Reserve Program (CRP) was initiated under the Food Security Act of 1985, largely to stabilize and improve soils degraded by overcropping. Much of this land was replanted to perennial grasses that were the principal species of the original prairie. An alternative to returning these 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 (Downing et al., 1995). As of August 2003 about 29,000 acres are actively enrolled in the program in Appanoose County; 38,000 in Lucas County; 28,000 in Monroe County; and 60,000 in Wayne County (FSA, 2003).

The long-term goal of the Chariton Valley Biomass Project is to develop commercially viable sources of renewable fuel to co-fire with coal to generate electricity (Braster, 2000). The project's focus has been on the development of switchgrass and other grasses common in southern Iowa. The relative abundance of cool-season grasses such as reed canarygrass (*Phalaris arundinacea* L.), smooth bromegrass (*Bromus inermis* Leyss.), orchardgrass (*Dactylis glomerata* L.), and tall fescue (*Festuca arundinacea* Shreb.) in southern Iowa has generated interest in their use as biomass. The Office of Technology Assessment has estimated that grass could supply up to 29% of the potential bioenergy resources needed for a significant biomass conversion program in the USA (Cherney et al., 1986).

RATIONALE

Biomass has excellent potential as a source of renewable energy through the conversion of plant material into suitable forms of energy. The use of biomass for co-firing with coal to produce energy has recently gained prominent attention. Many organizations have been cooperating on the Chariton Valley Biomass Project in an effort to increase switchgrass production. The focus has been to harvest switchgrass, a native warm-season grass, as an energy crop to be co-fired with coal to produce energy. 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 low ash content. Switchgrass, however, is not in abundant supply within the area surrounding Ottumwa Generating Station and does not yield as well in the area as previous estimates had suggested.

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 two million acres of grassland are located within the 70-mile potential biomass production area around the Ottumwa Generating Station. 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 abundance of these cool-season grass species reflects their ability to successfully adapt to the region. Many characteristics about these grass species are known for their common uses such as 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.

OBJECTIVES

The main goal of this project was to survey and analyze existing cool-season grasslands 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. Determine variability in the species composition of cool-season grass swards within and among sites in the Chariton Valley Biomass Project area.
2. Determine biomass availability and yield at each survey sample site at maximum harvest biomass date.
3. Determine variability in chemical composition in terms of biofuel characteristics of harvested samples.

4. Evaluate the feasibility of using near-infrared reflectance spectroscopy (NIRS) for determining chemical composition and biofuel characteristics of cool-season grasses used for biomass.

APPROACH

Ten fields in pasture, hay, or CRP of less than twenty acres 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. The selected locations received management activities and inputs, such as fertilizer and weed control, representative of those applied to biomass production fields.

Sampling

Objective 1. 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 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. The Shannon-Weaver diversity index was used to calculate species diversity and evenness. Diversity reflects the number of species, whereas evenness relates to how the species are distributed (i.e. 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 (Zar 1996):

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

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

$$H'_{\mathrm{max}} = \log k$$

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.

$$J' = H'/H'_{\mathrm{max}}$$

Objective 2. Forage within the frames used in Objective 1 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.

Chemical Analyses

Objective 3. 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 evaluated were ash, gross energy (BTU), ultimate, proximate, chlorine and sulfur analyses (Hazen Analytical Laboratories, Golden, CO).

Objective 4. 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 determined for Objective 3. Groups of twenty and forty samples were first centered and then randomly chosen as calibration samples. NIRS 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, fixed C, sulfur, carbon, hydrogen, nitrogen, oxygen, chlorine, ashMM, sulfurMM, HHV, MMF, and MAF. AshMM and sulfurMM are the pounds of ash or sulfur that would be generated per one million BTU's. HHV is defined as the high heating value of a burn. MMF is defined as "mineral matter free" per BTU per pound. This value is mathematically calculated removing sulfur and ash for the ranking of coal. MAF is defined as "moisture and ash free". This value is calculated on a dry basis with ash subtracted out.

Statistical Analysis

Variation in yield and composition was assessed by ANOVA using a nested model (SAS, 1991) with 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 (See Appendix for complete listing of data and statistical analyses).

RESULTS

Objective 1 – Botanical Composition

Table 1 shows the frequency data, species richness, *H'* and *J'* (Shannon-Weaver index for diversity and evenness) 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, Kentucky bluegrass (*Poa pratensis* L.), tall fescue, 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 site 9 having the lowest species richness and site 8 having the highest. The Shannon-Weaver diversity index was used to calculate species diversity, H', and evenness, J'. Grass species diversity at each site reflects the relative abundance of plant species supported at each site. Site 9 had the lowest diversity with H'=0.46 and site 8 had the highest diversity with H'=1.82. Diversity over all the 88 sampling areas was H'=1.90. The quantity J' reflects the evenness with which species are distributed within a site. The lower value of J' indicates a higher level of homogeneity, meaning that there is not much difference in the distribution of species within a location. Site 9 had the lowest value of J'=0.65 and site 8 had the highest value of J'=1.59. The overall evenness value across all sampling areas was J'=1.34, indicating that only a few species accounted for most of the plant community over all sites.

Objective 2 – Biomass Yield

Biomass yield varied within and among locations (Fig. 2). Data is shown in box-plot form. The 'tails' point out the extremes of the highest and lowest yields found at each site. The upper and lower lines that make up the ends of the boxes show the 75th and 25th percentiles of the data collected. The 'x' shows the mean or average of the biomass yield found and the diamond represents the median or the middle value of all of the yields found at each location. A 'shrunken' box plot represents less variability within the location, whereas a 'stretched-out' box plot indicates there was greater variability in the yield found at a site. Average yields across locations ranged from approximately 1.34 T/A at site 3 to 2.75 T/A at site 9. Average biomass yield across all locations was 1.88 T/A. 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 sites (Table 2). Yield varied dramatically among the sampling areas within each site. 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.

There was a good correlation (R^2=0.72) between species richness at each site and biomass yield (Fig. 3). Sites with the lowest species richness had the highest yield and the sites with the highest species richness had the lowest yield. Species diversity 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.

Objective 3 – Chemical Composition

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 (Cuiping, 2004). The majority of variation in elemental composition occurred within locations, not among them. There was not a good correlation between species richness and elemental variation. 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 canonical correspondence analysis indicated certain species were more associated with specific chemical components (Fig. 4). 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 5 and 6. The concentration and chemical composition of ash are closely related to operational problems such as slagging, fouling, sintering, and corrosion **(**Cuiping, 2004**)**. Alkali is the water-soluble component of ash. 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). Ash values ranged from 5-12 %, sulfur values ranged from 0.07-0.34%, chlorine ranged from 0.08-0.76%, and HHV ranged from7610-8372 BTU/lb. These values are comparable to the values found from the interim test burn of switchgrass in December 2003 (Comer, 2004); ash ranged from 4.08-5.27%, sulfur ranged from 0.07-0.12%, chlorine from 0.03-0.08%, and HHV ranged from 7410-7579 BTU/lb. The greatest difference in composition was between ash content 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 (Samson, 1998). Silica levels are lowest in the stem fraction of grasses, and highest in inflorescences, leaves, and leaf sheaths (Miles et al, 1995).

Objective 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 determined for Objective 3. The R^2, standard error of calibration, standard error of validation, validation coefficient of determination, 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. A study done by (Kelly et al., 2004) tested the effectiveness of NIRS for measuring chemical composition of biomass. They found that the performance of NIRS was promising given the tremendous diversity of the biomass samples and that a good correlation between the measured and predicted concentrations of the three major components could be obtained with the NIRS technique. The 1-VR 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, ashMM, HHV, MMF, and MAF had moderate prediction values. NIRS would not be a good method for predicting concentrations of the other constituents. Modified partial step regression and stepwise (MPLS) regression are both shown to compare prediction values of both calibration methods. MPLS predicted better than stepwise when using 40 samples. It did not matter which calibration approach was used with the 20 sample set.

DISCUSSION

The surveyed grassland showed that there was a great amount of variability in biomass yield and composition among selected sites surrounding the Ottumwa Generating Station. Species richness varied among sites from just a handful of different species to a much more diverse collection of plant species. Species diversity was related to the amount of biomass yield found at each site. Low species richness and diversity sites produced higher yields than those sites with high species richness and diversity. Smooth bromegrass was found at all sites and was present in high frequency across all sampling locations. Yields were quite variable across locations, but were surprisingly high for areas that have had received relatively little fertilizer and other management inputs.

Because of the diversity of herbaceous plant species in the sampled grasslands, chemical composition was quite variable. Some locations would be better suited for biomass harvest for burning with coal because of lower ash, sulfur, and chlorine content found in their biomass than other locations. Many factors, such as species and variety, choice of soil type and location, fertilization practices, and time of harvest can affect the ash concentration of grasses. Elemental composition and the concentration of alkali, sulfur, chlorine, and silica found, appear to be the best indicators of the tendency of fuels to slag (Miles et al., 1995). 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 should be useful information allowing power plants to predict and develop means to prevent fouling and slagging when burning biomass origninating from cool-season grasslands.

The ash component of plants varies greatly among families of plants as well as among individual species (Miles et al., 1995). This was very evident in this study. Ash ranged from about 6 to 12%. Ash content was quite high, higher than most power plants would prefer, even if only burning at 5% biomass. The main concern is that the ash percentage can be known or predicted before burning so necessary adjustments can be made for the co-firing process. Near Infrared Reflectance Spectroscopy proved to be a possible way of predicting ash and other constituents.

CONCLUSIONS

The results of this study indicate that cool-season pastures could 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 grassland have become naturalized and are very well adapted to the soils and climate of Southern Iowa. The growth pattern of these pastures is different from and complementary to that of switchgrass. 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. However, this constraint might be effectively managed by use of herbicides and other cultural practices.

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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.

Scientific name	**Common name**	**Location**										
		1	2	3	4	5	6	7	8	9	10	Freq Overall
*Agropyron repens (*L.) Nevkski	Quackgrass	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.17	0.00	0.02
Apocynum cannabinum L.	Hemp dogbane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.01
Bromus inermis Leyss.	Smooth bromegrass	0.80	0.90	0.83	0.80	0.50	1.00	1.00	0.80	1.00	0.70	0.82
Chamaecrista nictitans (L.) Moench	Partridge pea	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.00	0.00	0.08
Convolvulus L.	Bindweed	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.03
Conyza canadensis (L.) Cronq.	Marestail	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Erigeron nanus Nutt.	Dwarf fleabane	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Abildgaardia Vahl	Sedge	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Dactylis glomerata L.	Orchardgrass	0.00	0.00	0.00	0.10	0.00	0.00	0.30	0.00	0.17	0.00	0.06
Daucus carota L.	Wild carrot	0.20	0.10	0.00	0.20	0.00	0.00	0.00	0.20	0.00	0.00	0.08
Festuca arundinacea Shreb.	Tall fescue	0.70	0.00	0.17	0.50	1.00	0.17	0.20	0.60	0.00	0.10	0.38
Helianthus annuus L.	Sunflower	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.01
Helianthus tuberosus L.	Jerusalem artichoke	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.03
Lotus corniculatus L.	Birdsfoot trefoil	0.20	0.60	0.33	0.00	0.60	0.33	0.20	0.50	0.83	0.00	0.34
Medicago sativa L.	Alfalfa	0.00	0.10	0.17	0.00	0.00	0.33	0.00	0.00	0.17	0.00	0.06
Melilotus officinalis (L.) Lam	Yellow sweetclover	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Panicum virgatum L.	Switchgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.02
Pastinaca sativa L.	Wild parsnip	0.80	0.10	0.00	0.50	0.20	0.00	0.20	0.00	0.00	0.00	0.20
Phalaris arundinacea L.	Reed canarygrass	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.30	0.00	0.40	0.09
Phleum pratense L.	Timothy	0.00	0.00	0.50	0.00	0.10	0.00	0.00	0.10	0.00	0.00	0.06
Poa pratensis L.	Kentucky bluegrass	0.40	0.80	0.83	0.50	0.40	0.17	0.30	0.50	0.00	0.00	0.40
Salidago L.	Goldenrod	0.30	0.30	0.50	0.20	0.10	0.17	0.00	0.40	0.00	0.00	0.19
Taraxacum officinale (Weber)	Common dandelion	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Trifolium pratense L.	Red clover	0.00	0.50	0.50	0.50	0.20	0.00	0.00	0.10	0.00	0.00	0.18
Trifolium repens L.	White clover	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	Other Weed	0.20	0.00	0.17	0.10	0.00	0.17	0.00	0.20	0.00	0.00	0.08
	Species richness	10	12	11	10	9	7	6	14	5	5	26
	diversity-H'	1.30	1.30	1.39	1.26	1.02	0.84	0.73	1.82	0.46	0.61	1.90
	evenness-J'	1.30	1.20	1.34	1.26	1.07	0.99	0.94	1.59	0.65	0.87	1.34

Table 2. Variation in biomass yield and chemical composition within and among cool-season grassland sampling sites.

Component	σ^2_{total}	σ^2_{among}	**% Total**	σ^2_{within}	**% Total**
Biomass (ton/acre)	0.535	0.136	25.4	0.399	74.6
Ash (% DM)	1.475	0.304	20.6	1.171	79.4
Sulfur (% DM)	0.0023	0.0005	22.0	0.0018	78.0
Carbon (% DM)	1.171	0.559	47.7	0.612	52.3
Hydrogen (% DM)	0.056	0.036	64.6	0.020	35.4
Nitrogen (% DM)	0.104	0.036	34.9	0.068	65.1
Oxygen (% DM)	1.941	0.647	33.3	1.294	66.7
Chlorine (% DM)	0.022	0.011	48.5	0.011	51.5
Fixed C (% DM)	3.328	0.335	10.1	2.993	89.9
Volatiles (% DM)	3.161	0.542	17.1	2.619	82.9
Ash (lb/BTU)	3.165	0.411	13.0	2.754	87.0
SO_2 (lb/BTU)	0.016	0.004	22.4	0.013	77.6
HHV (BTU/lb)	25896	2987	11.5	22909	88.5
MMF (BTU/lb)	26070	5639	21.6	20431	78.4
MAF (BTU/lb)	24718	5201	21.0	19518	79.0

Table 3. Near Infrared Reflectance Spectroscopy calibration and validation population statistics.

Constituent	40 calibration samples			20 calibration samples			48 validation samples		
	mean	range	std dev	mean	range	std dev	mean	range	std dev
Ash (%DM)	7.681	5.85-11.81	1.318	7.742	5.85-10.66	1.280	8.000	5.86-10.69	1.100
Volatiles (%DM)	75.732	72.32-81.75	1.963	75.908	72.32-81.75	2.351	75.285	71.95-79.58	1.582
Fixed C (%DM)	16.510	11.86-19.70	1.924	16.172	11.86-19.70	2.186	16.584	11.57-18.95	1.740
Sulfur (%DM)	0.155	0.08-0.26	0.035	0.173	0.10-0.30	0.044	0.159	0.07-0.34	0.057
Carbon (%DM)	51.298	48.46-53.61	1.106	51.497	49.88-53.61	1.100	50.500	48.83-52.42	0.870
Hydrogen (%DM)	5.323	4.89-5.88	0.243	5.309	4.89-5.91	0.283	5.338	5.03-5.91	0.209
Nitrogen (%DM)	1.282	0.68-2.29	0.380	1.418	0.75-2.29	0.449	1.128	0.81-2.07	0.246
Oxygen (%DM)	34.184	29.39-37.31	1.417	33.684	30.75-36.01	1.414	34.744	30.75-37.36	1.253
Chlorine (%DM)	0.231	0.09-0.68	0.126	0.238	0.12-0.68	0.133	0.280	0.08-0.76	0.153
Ash (lb/BTU)	9.728	5.28-15.52	2.016	9.903	7.08-13.96	1.952	10.295	6.79-13.85	1.518
sulfur (lb/BTU)	0.390	0.19-0.67	0.091	0.433	0.25-0.76	0.110	0.402	0.19-0.90	0.150
HHV (BTU/lb)	7995.625	7610.00-8372.00	176.674	8023.950	7636.00-8372.00	204.448	7907.833	7660.00-8212.00	134.284
MMF (BTU/lb)	8727.400	8378.00-9406.00	174.171	8784.400	8499.00-9212.00	180.424	8673.479	8446.00-9212.00	145.696
MAF (BTU/lb)	8668.875	8349.00-9319.00	169.428	8714.250	8448.00-9127.00	179.171	8608.167	8389.00-9127.00	138.650

Table 4. Near Infrared Reflectance Spectroscopy calibration statistics.

Constituent	SEC	RSQ	SEV	1-VR	bias	math trt	SEC	RSQ	SEV	1-VR	bias	math trt
	Modified Partial Least Square Regression											
	40 samples						**20 samples**					
Ash (%DM)	0.424	0.897	0.644	0.768	0.189	2 10 10 1	0.297	0.946	1.012	0.775	0.594	1 5 5 1
Volatiles (%DM)	1.241	0.495	1.644	0.037	0.087	4 10 10 1	1.971	0.334	2.139	0.171	-1.503	4 10 10 1
Fixed C (%DM)	1.673	0.225	1.820	-0.402	-0.247	1 5 5 1	0.679	0.869	2.678	0.252	1.455	1 5 5 1
Sulfur (%DM)	0.026	0.306	0.058	0.201	0.016	4 10 10 1	0.017	0.738	0.052	0.333	0.012	1 5 5 1
Carbon (%DM)	0.334	0.902	0.654	0.796	-0.340	3 10 10 1	0.418	0.828	0.655	0.448	-0.282	3 10 10 1
Hydrogen (%DM)	0.131	0.707	0.204	0.260	0.007	2 10 10 1	0.229	0.444	0.357	0.352	-0.230	1 5 5 1
Nitrogen (%DM)	0.037	0.991	0.071	0.974	0.004	1 5 5 1	0.062	0.981	0.104	0.955	0.068	2 10 10 1
Oxygen (%DM)	0.655	0.565	1.075	0.518	0.049	3 10 10 1	0.788	0.486	1.090	0.397	0.236	2 10 10 1
Chlorine (%DM)	0.069	0.333	0.156	0.074	0.075	1 5 5 1	0.036	0.661	0.154	0.086	0.058	4 10 10 1
Ash (lb/BTU)	0.828	0.785	1.086	0.646	0.275	3 10 10 1	0.222	0.984	1.900	0.836	-0.287	3 10 10 1
Sulfur (lb/BTU)	0.066	0.126	0.155	0.111	0.044	1 5 5 1	0.042	0.771	0.140	0.376	0.040	1 5 5 1
HHV (lBTU/lb)	91.970	0.729	103.874	0.559	-12.444	1 5 5 1	55.429	0.926	143.171	0.673	-81.174	1 5 5 1
MMF (lBTU/lb)	115.382	0.306	125.609	0.234	-5.501	2 10 10 1	69.988	0.793	116.910	0.499	-31.171	1 5 5 1
MAF (lBTU/lb)	113.574	0.309	119.352	0.236	-13.022	2 10 10 1	45.091	0.915	106.929	0.732	2.796	1 5 5 1
	Stepwise Regression											
	40 samples						**20 samples**					
Ash (%DM)	0.468	0.874	0.707	0.611	0.179	2 10 10 1	0.394	0.905	0.819	0.529	0.157	3 10 10 1
Volatiles (%DM)	1.371	0.369	1.549	0.054	-0.237	1 5 5 1	1.895	0.351	1.488	0.177	-0.521	3 10 10 1
Fixed C (%DM)	1.666	0.250	2.087	-0.466	-0.273	1 5 5 1	1.291	0.651	3.142	-2.218	2.089	3 10 10 1
Sulfur (%DM)	0.024	0.333	0.057	-0.033	0.010	1 5 5 1	0.012	0.856	0.055	-0.174	0.019	1 5 5 1
Carbon (%DM)	0.403	0.840	0.629	0.706	-0.269	3 10 10 1	0.306	0.922	0.715	0.683	-0.153	4 10 10 1
Hydrogen (%DM)	0.126	0.704	0.220	-0.111	0.008	2 10 10 1	0.186	0.470	0.263	-0.531	-0.117	1 5 5 1
Nitrogen (%DM)	0.047	0.985	0.066	0.948	0.003	1 5 5 1	0.055	0.985	0.077	0.957	0.011	1 5 5 1
Oxygen (%DM)	0.425	0.853	1.020	0.422	0.029	3 10 10 1	0.652	0.788	1.370	0.283	0.003	1 5 5 1
Chlorine (%DM)	0.084	0.495	0.154	0.096	0.068	1 5 5 1	0.036	0.928	0.165	-0.262	0.076	2 10 10 1
Ash (lb/BTU)	0.707	0.865	1.210	0.412	0.407	2 10 10 1	0.595	0.907	1.896	-0.204	0.507	1 5 5 1
Sulfur (lb/BTU)	0.063	0.295	0.152	-0.033	0.028	1 5 5 1	0.042	0.725	0.142	-0.125	0.037	1 5 5 1
HHV (lBTU/lb)	110.986	0.605	119.326	0.439	-26.275	3 10 10 1	41.927	0.958	152.985	0.184	-57.340	1 5 5 1
MMF (lBTU/lb)	108.276	0.359	120.073	0.359	-9.655	1 5 5 1	79.756	0.805	230.405	-0.581	-136.062	3 10 10 1
MAF (lBTU/lb)	105.475	0.373	112.902	0.398	-16.798	1 5 5 1	51.550	0.889	108.579	0.546	2.284	1 5 5 1

SEC=standard error of calibration, RSQ=coefficient of determination, SEV=standard error of validation, 1-VR=validation coefficient of determination, bias, and math treatment.

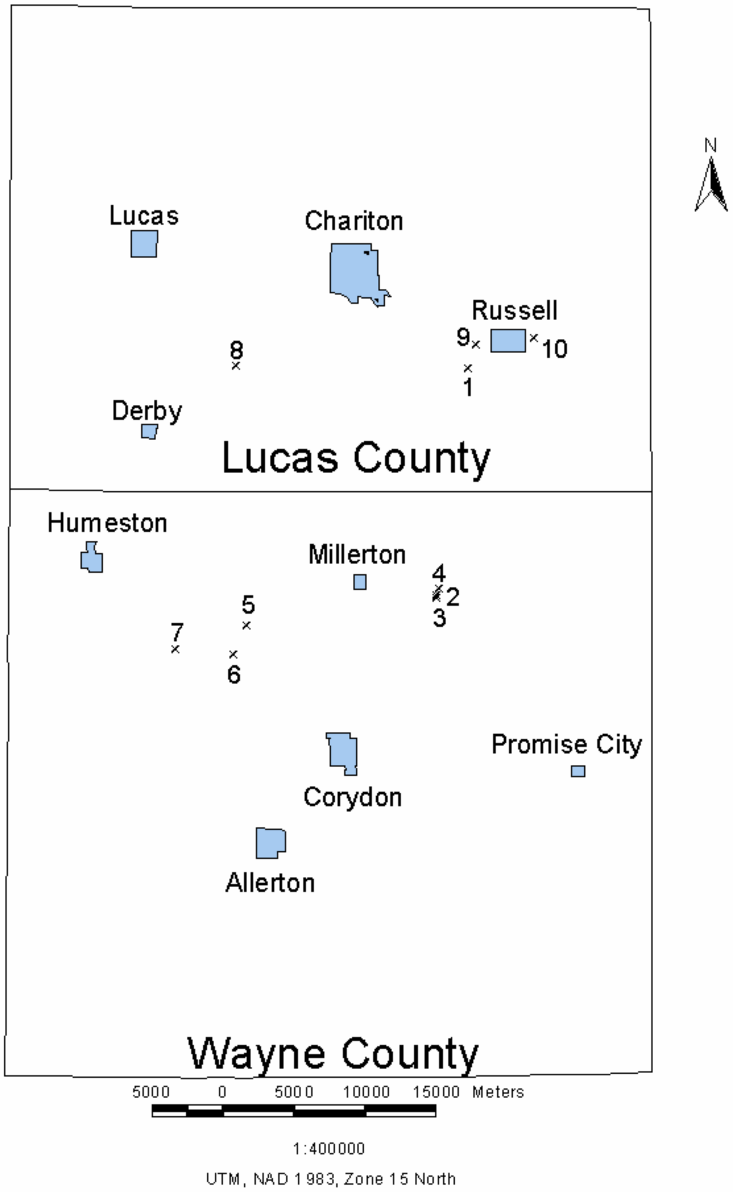

Figure 1. Map locations of ten field sites sampled in study.

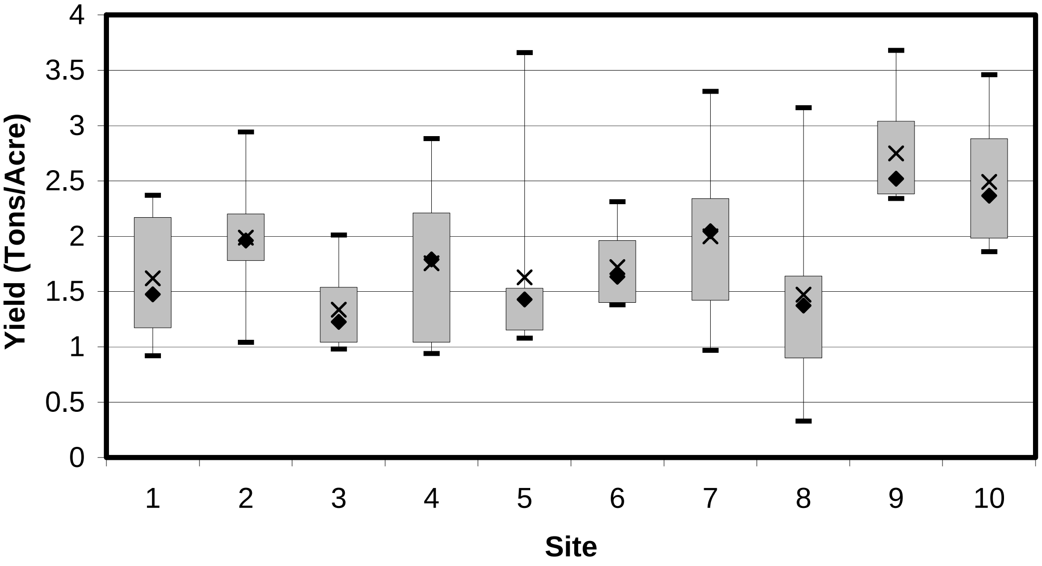

Figure 2. Box plots of biomass yield for each location.

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.

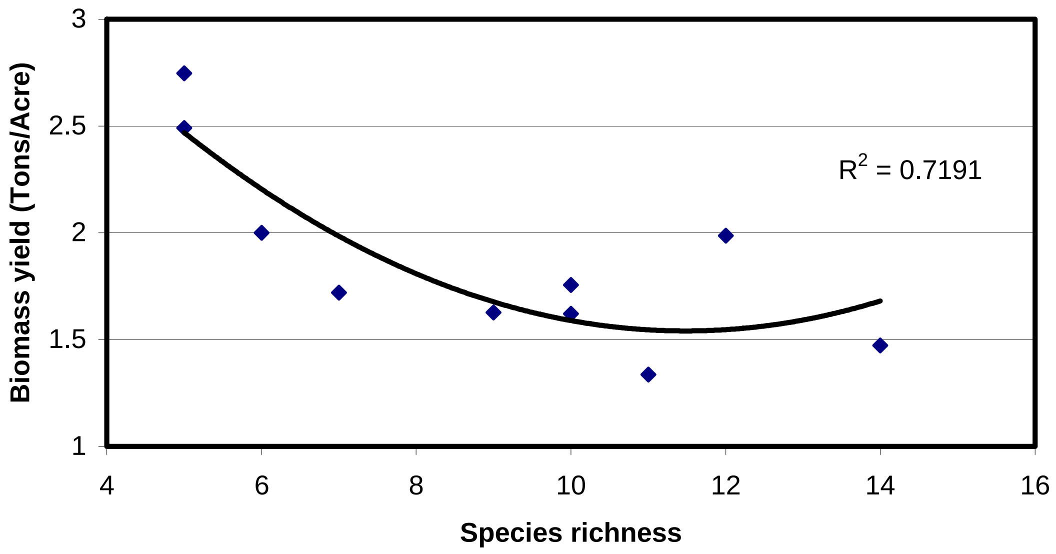

Figure 3. Relationship between species richness and biomass yield.

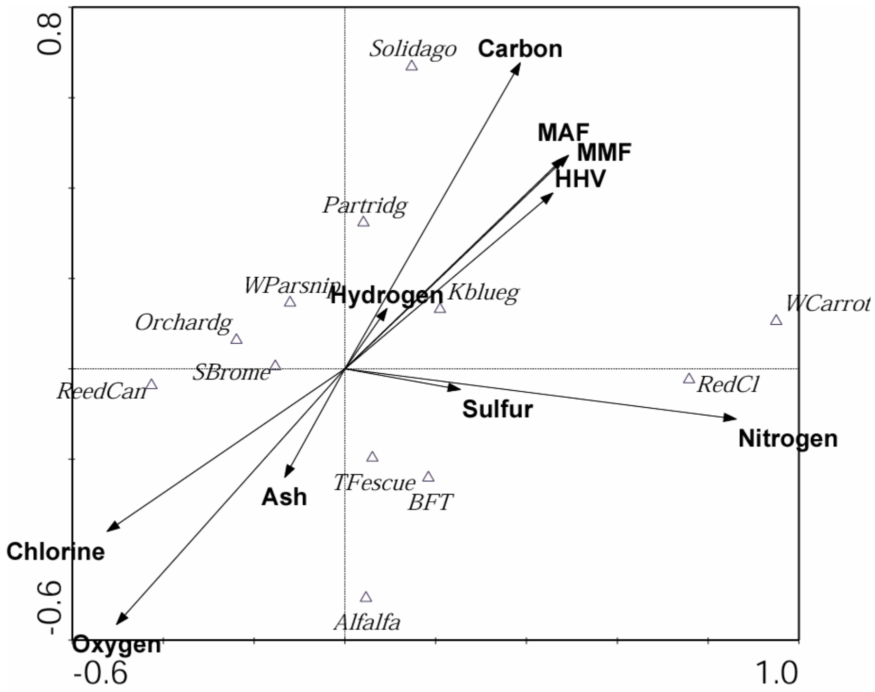

Figure 4. Biplot showing the relationships among cool-season species and chemical composition of biomass samples. Arrows represent the direction of maximum change in chemical constituents. Species nearest an arrow are more positively related to the constituent it represents than those farther away. Species located more closely together on the plot are more likely to be found in the same sample than those farther apart.

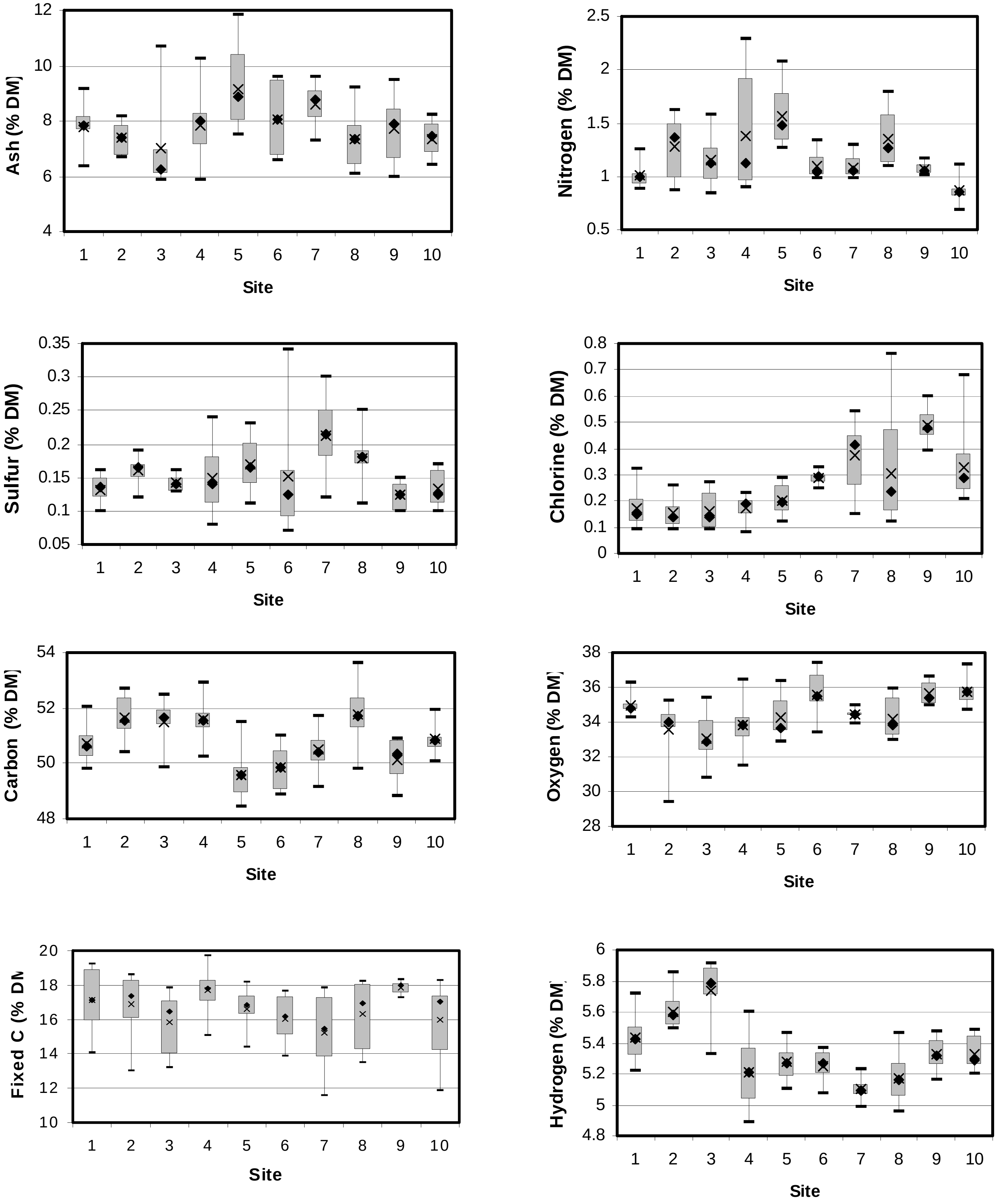

Figure 5. Box plots of biomass chemical constituents at each site.

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.

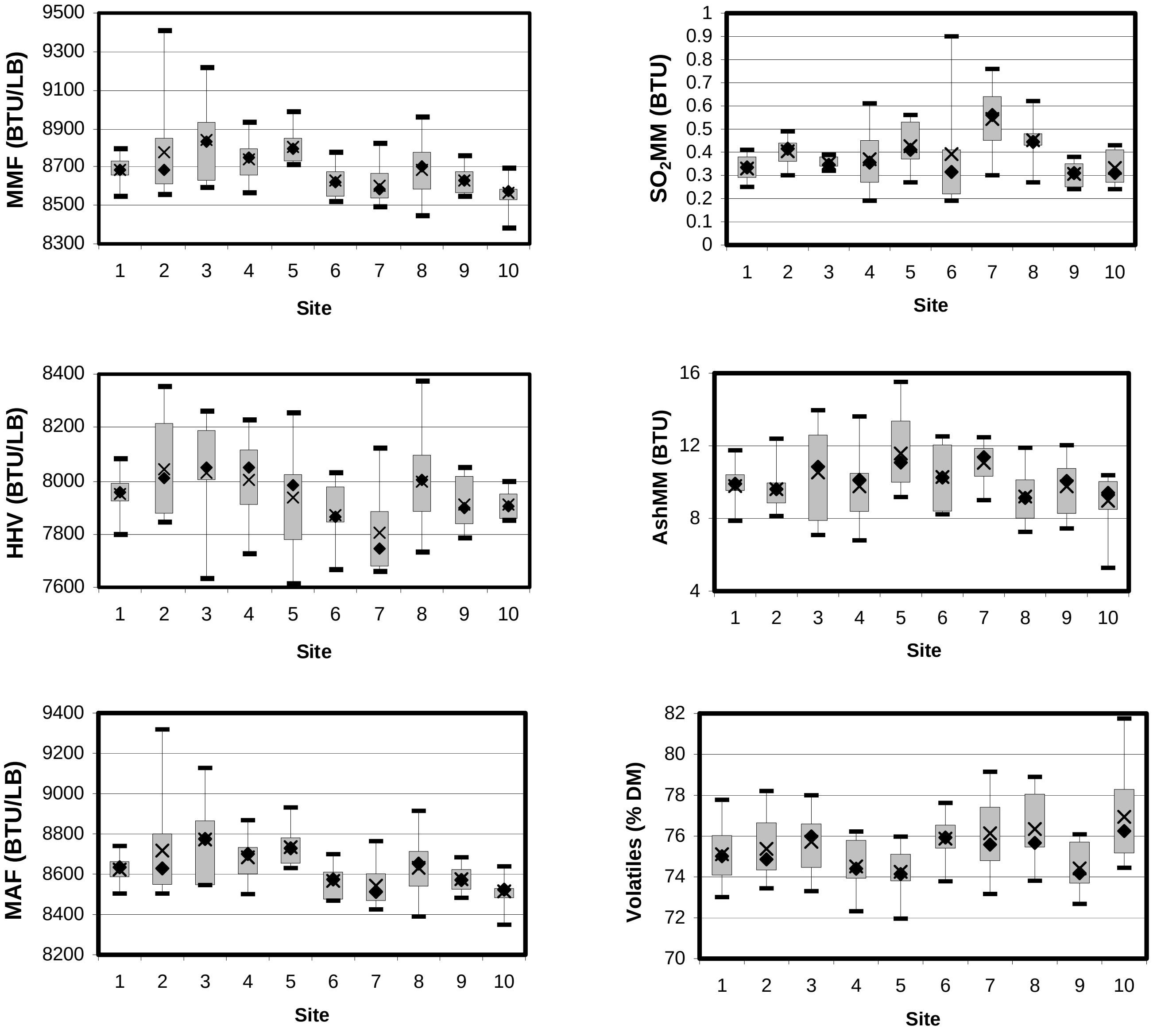

Figure 6. Box plots of biomass burning characteristics at each site.

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.

APPENDIX

Data and Statistical Analyses

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                                                           Fixed
Obs Location   Plot      LbA     TonA    Ash  Volatile       C  Sulfur    HHV   MMF   MAF  Carbon  Hydrogen  Nitrogen  Oxygen  Chlorine  AshMM  SO2MM

  1        1      1  3988.54  1.99427   9.16     74.09   16.75    0.15   7800  8655  8586   49.79      5.30      0.89   34.71      0.16  11.74   0.38
  2        1      2  2546.26  1.27313   6.37     75.43   18.20    0.15   7962  8550  8504   50.99      5.32      0.93   36.24      0.21   8.00   0.38
  3        1      3  1834.02  0.91701   7.67     76.03   16.30    0.14   7990  8711  8653   51.53      5.38      1.02   34.26      0.14   9.60   0.35
  4        1      4  2101.11  1.05055   7.85     76.85   15.30    0.14   7928  8663  8604   50.23      5.22      1.03   35.53      0.12   9.91   0.35
  5        1      5  4344.66  2.17233   7.87     74.59   17.54    0.12   7955  8694  8635   50.57      5.63      1.02   34.79      0.32   9.89   0.30
  6        1      6  4736.40  2.36820   8.17     77.77   14.06    0.10   7849  8609  8548   50.34      5.50      0.97   34.92      0.28  10.41   0.25
  7        1      7  2332.59  1.16629   8.49     75.59   15.92    0.11   7927  8727  8662   50.77      5.47      0.91   34.25      0.09  10.71   0.27
  8        1      8  4647.37  2.32368   7.69     73.36   18.95    0.12   8068  8798  8740   50.68      5.72      0.94   34.85      0.09   9.53   0.29
  9        1      9  2759.93  1.37997   6.36     74.39   19.25    0.13   8084  8680  8633   52.01      5.48      1.25   34.77      0.17   7.86   0.32
 10        1     10  3133.86  1.56693   8.11     73.01   18.88    0.16   7962  8726  8665   50.25      5.35      1.10   35.03      0.12  10.18   0.41
 11        2      1  5056.90  2.52845   6.73     74.79   18.48    0.13   8002  8629  8580   52.10      5.59      1.62   33.83      0.10   8.41   0.32
 12        2      2  5875.98  2.93799   7.74     74.95   17.31    0.16   7847  8562  8505   50.39      5.49      0.97   35.25      0.15   9.86   0.41
 13        2      3  2083.30  1.04165   7.98     73.43   18.59    0.19   8020  8776  8715   51.23      5.57      1.35   33.68      0.09   9.95   0.49
 14        2      4  3881.71  1.94085   7.84     74.73   17.43    0.18   7879  8607  8549   51.06      5.67      0.98   34.27      0.11   9.95   0.47
 15        2      5  4398.08  2.19904   7.38     75.57   17.05    0.17   7876  8557  8503   51.51      5.50      0.87   34.57      0.17   9.37   0.44
 16        2      6  3952.93  1.97647   7.42     74.29   18.29    0.17   7982  8677  8622   51.60      5.70      1.50   33.61      0.11   9.30   0.43
 17        2      7  2884.57  1.44229   7.09     76.84   16.07    0.12   8021  8686  8634   51.38      5.62      1.39   34.40      0.18   8.84   0.30
 18        2      8  4380.28  2.19014   8.19     74.34   17.47    0.17   8212  9008  8944   52.42      5.51      1.42   32.29      0.13   9.97   0.42
 19        2      9  3561.20  1.78060   6.68     78.21   15.11    0.16   8212  8851  8800   52.37      5.54      1.14   34.11      0.24   8.13   0.40
 20        2     10  3632.42  1.81621   6.66     76.65   13.01    0.15   8355  9406  9319   52.70      5.85      1.57   29.39      0.26  12.38   0.36
 21        3      1  3080.44  1.54022   6.07     78.00   13.22    0.13   8003  8841  8773   51.39      5.78      0.84   33.08      0.09  10.97   0.32
 22        3      2  1958.66  0.97933   6.16     75.67   14.02    0.14   8187  9212  9127   51.91      5.91      0.98   30.75      0.14  12.59   0.34
 23        3      3  2261.36  1.13068   6.94     74.46   16.87    0.14   8095  8931  8864   51.77      5.80      1.27   32.35      0.10  10.71   0.35
 24        3      4  4024.16  2.01208  10.66     73.30   16.04    0.13   7636  8629  8547   49.88      5.33      1.26   32.74      0.23  13.96   0.34
 25        3      5  2635.29  1.31764   5.85     76.29   17.86    0.16   8262  8819  8776   52.47      5.88      1.58   34.06      0.27   7.08   0.39
 26        3      6  2083.30  1.04165   6.31     76.59   17.10    0.15   8006  8591  8545   51.50      5.71      0.97   35.36      0.14   7.88   0.38
 27        4      1  5110.32  2.55516   6.80     75.79   17.41    0.14   8112  8754  8704   51.30      5.60      0.90   35.26      0.10   8.38   0.35
 28        4      2  4415.89  2.20794   8.29     75.84   15.07    0.14   7728  8569  8501   50.22      5.44      0.96   34.15      0.20  11.76   0.36
 29        4      3  5769.14  2.88457   8.15     74.25   17.60    0.16   8021  8795  8733   51.58      5.37      1.08   33.66      0.19  10.16   0.40
 30        4      4  2083.30  1.04165   7.15     74.12   19.70    0.21   8160  8744  8698   52.92      4.99      2.29   33.41      0.20   7.58   0.51
 31        4      5  3525.59  1.76279   8.00     75.06   16.94    0.08   7912  8660  8600   51.57      5.19      1.18   33.98      0.19  10.11   0.19
 32        4      6  2902.38  1.45119   8.05     73.94   18.01    0.11   7931  8686  8625   51.43      5.11      1.02   34.28      0.17  10.15   0.27
 33        4      7  3774.87  1.88744   5.86     76.22   18.30    0.10   8076  8584  8544   51.80      5.23      0.95   36.44      0.08   6.79   0.24
 34        4      8  2012.08  1.00604  10.22     72.32   17.09    0.24   7780  8785  8702   50.84      4.89      1.92   31.52      0.15  13.62   0.61
 35        4      9  1887.44  0.94372   8.50     73.03   18.47    0.18   8113  8933  8867   51.56      5.23      1.43   33.10      0.23  10.48   0.45
 36        4     10  3632.42  1.81621   7.16     74.57   18.27    0.13   8227  8916  8862   52.81      5.03      2.11   32.76      0.19   8.70   0.32
 37        5      1  7318.27  3.65913   7.98     75.69   16.33    0.22   8000  8754  8694   51.47      5.41      2.07   32.85      0.16   9.98   0.54
 38        5      2  2884.57  1.44229  11.81     73.80   14.39    0.14   7610  8723  8630   48.46      5.27      1.45   32.87      0.29  15.52   0.37
 39        5      3  3062.63  1.53132   9.21     75.97   14.82    0.15   7972  8853  8781   49.84      5.46      1.79   33.55      0.21  11.55   0.38
 40        5      4  2296.97  1.14849  10.69     71.95   17.36    0.20   7720  8728  8645   48.91      5.26      1.36   33.58      0.28  13.85   0.53
 41        5      5  2243.56  1.12178   9.44     73.87   16.80    0.17   7946  8836  8764   49.65      5.34      1.77   33.74      0.22  11.74   0.43
 42        5      6  3062.63  1.53132  10.39     73.08   16.53    0.18   7778  8761  8680   49.47      5.10      1.34   33.52      0.26  13.36   0.47
 43        5      7  2831.15  1.41558   8.52     73.98   17.50    0.13   8045  8861  8795   49.84      5.18      1.50   34.83      0.16  10.60   0.32
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                                                          Fixed
Obs  Location  Plot     LbA       TonA     Ash  Volatile    C     Sulfur   HHV   MMF   MAF  Carbon  Hydrogen  Nitrogen  Oxygen  Chlorine  AshMM  SO2MM

 44      5       8   2154.53  1.07726  8.44    74.72    16.84    0.11   8026  8831  8766   48.89     5.27       1.27     36.02     0.18    10.51   0.27
 45      5       9   2653.09  1.32655  7.58    75.11    17.31    0.16   8254  8990  8931   49.97     5.29       1.75     35.25     0.13     9.18   0.39
 46      5      10   4024.16  2.01208  7.51    74.31    18.18    0.23   8004  8710  8654   49.41     5.18       1.32     36.35     0.12     9.39   0.56
 47      6       1   3917.32  1.95866  6.74    75.62    17.64    0.10   8030  8660  8610   50.01     5.37       1.05     36.73     0.33     8.40   0.24
 48      6       2   4611.75  2.30588  6.57    76.25    17.18    0.07   7977  8586  8537   49.65     5.34       1.01     37.36     0.30     8.23   0.19
 49      6       3   2759.93  1.37997  8.89    73.78    17.33    0.15   7844  8677  8610   49.02     5.26       1.03     35.65     0.29    11.33   0.39
 50      6       4   3098.24  1.54912  9.48    75.41    15.11    0.16   7874  8772  8699   48.90     5.20       0.98     35.28     0.25    12.04   0.41
 51      6       5   3436.56  1.71828  7.20    77.62    15.18    0.09   7858  8520  8468   51.00     5.27       1.34     35.10     0.27     9.17   0.22
 52      6       6   2795.54  1.39777  9.59    76.54    13.87    0.34   7663  8547  8476   50.46     5.07       1.18     33.36     0.30    12.51   0.90
 53      7       1   3169.47  1.58473  9.57    73.16    17.27    0.18   7678  8562  8490   50.06     5.07       1.17     33.95     0.43    12.46   0.47
 54      7       2   6623.83  3.31192  9.08    74.80    16.12    0.25   7660  8492  8425   50.07     5.13       1.00     34.47     0.44    11.85   0.64
 55      7       3   1940.85  0.97043  9.01    76.23    14.76    0.22   7765  8601  8534   50.36     5.11       1.01     34.29     0.24    11.60   0.56
 56      7       4   5181.55  2.59077  8.38    79.15    12.47    0.30   7881  8664  8602   50.69     5.13       1.11     34.39     0.26    10.64   0.76
 57      7       5   2813.35  1.40667  7.74    74.94    17.32    0.12   7977  8704  8646   51.54     5.20       0.98     34.42     0.40     9.70   0.30
 58      7       6   4362.47  2.18124  9.48    78.95    11.57    0.25   7665  8538  8468   49.17     5.06       1.06     34.98     0.46    12.36   0.64
 59      7       7   4576.14  2.28807  8.13    74.79    17.08    0.15   7880  8638  8577   50.81     5.07       1.02     34.82     0.39    10.31   0.38
 60      7       8   4682.98  2.34149  7.31    74.84    17.85    0.18   8122  8818  8763   51.71     5.23       1.17     34.40     0.15     9.00   0.45
 61      7       9   3810.48  1.90524  8.76    77.41    13.83    0.21   7706  8510  8445   50.45     5.03       1.06     34.49     0.45    11.36   0.56
 62      7      10   2831.15  1.41558  8.79    77.17    14.04    0.26   7727  8537  8472   50.19     4.99       1.29     34.48     0.54    11.38   0.67
 63      8       1   6321.13  3.16057  6.28    75.66    18.06    0.14   7885  8457  8413   51.84     5.11       1.26     35.37     0.27     7.96   0.35
 64      8       2   1798.41  0.89920  6.99    77.02    15.99    0.19   8102  8764  8712   52.37     5.27       1.79     33.39     0.16     8.63   0.48
 65      8       3   3276.30  1.63815  7.35    78.89    13.76    0.11   8028  8720  8665   51.61     5.22       1.13     34.58     0.12     9.15   0.27
 66      8       4   2386.00  1.19300  8.33    78.19    13.48    0.17   7987  8777  8713   51.50     4.96       1.75     33.29     0.17    10.43   0.43
 67      8       5    667.73  0.33386  7.30    75.46    17.24    0.17   8010  8694  8640   51.97     5.09       1.13     34.34     0.12     9.11   0.43
 68      8       6   3267.40  1.63370  7.68    78.05    14.27    0.18   8094  8826  8768   52.64     5.05       1.44     33.01     0.21     9.49   0.45
 69      8       7   5056.90  2.52845  9.23    73.81    16.96    0.18   7768  8628  8558   51.28     5.03       1.28     33.00     0.47    11.89   0.47
 70      8       8   1201.91  0.60095  6.08    75.68    18.24    0.18   8372  8960  8914   53.61     5.30       1.58     33.25     0.26     7.26   0.44
 71      8       9   2394.91  1.19745  7.83    75.26    16.91    0.22   7733  8446  8389   49.81     5.24       1.10     35.80     0.76    10.12   0.58
 72      8      10   3098.24  1.54912  6.40    75.48    18.12    0.25   7993  8586  8540   50.89     5.46       1.10     35.90     0.50     8.01   0.62
 73      9       1   4967.87  2.48394  9.46    72.67    17.87    0.15   7862  8756  8683   48.83     5.16       1.11     35.29     0.53    12.03   0.38
 74      9       2   7353.88  3.67694  6.65    76.08    17.27    0.10   8049  8672  8623   50.69     5.26       1.05     36.25     0.45     8.27   0.24
 75      9       3   5128.13  2.56406  8.42    74.01    17.57    0.11   7836  8620  8557   50.05     5.33       1.06     35.03     0.39    10.75   0.27
 76      9       4   4682.98  2.34149  5.97    75.71    18.32    0.14   8016  8568  8525   50.81     5.41       1.02     36.65     0.60     7.45   0.35
 77      9       5   6089.65  3.04483  7.55    74.37    18.08    0.14   7937  8640  8584   50.89     5.31       1.17     34.94     0.46     9.51   0.35
 78      9       6   4754.20  2.37710  8.25    73.68    18.07    0.10   7782  8544  8482   49.60     5.47       1.01     35.57     0.49    10.61   0.25
 79     10       1   5751.34  2.87567  7.45    75.41    17.14    0.11   7866  8554  8499   50.54     5.35       0.85     35.70     0.27     9.47   0.27
 80     10       2   6926.53  3.46327  6.39    81.75    11.86    0.16   7941  8529  8483   51.40     5.29       0.75     36.01     0.32     8.05   0.41
 81     10       3   6356.74  3.17837  7.51    78.28    14.21    0.12   7990  8695  8638   50.81     5.26       1.11     35.19     0.40     9.40   0.29
 82     10       4   4825.43  2.41271  8.22    79.58    12.20    0.16   7921  8693  8631   50.86     5.27       0.81     34.68     0.38    10.38   0.41
 83     10       5   3952.93  1.97647  7.10    76.18    16.72    0.15   7848  8499  8448   50.77     5.29       0.89     35.80     0.68     9.05   0.38
 84     10       6   3721.45  1.86073  7.88    74.79    17.33    0.11   7856  8587  8528   50.86     5.45       0.86     34.84     0.31    10.03   0.27
 85     10       7   4647.37  2.32368  6.75    76.32    16.93    0.13   7949  8573  8524   50.92     5.44       0.82     35.94     0.25     8.49   0.32
 86     10       8   3917.32  1.95866  6.83    77.52    18.26    0.17   7996  8378  8349   51.95     5.48       0.87     37.31     0.21     5.28   0.43
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                                                          Fixed
Obs  Location  Plot    LbA       TonA    Ash  Volatile    C    Sulfur   HHV   MMF   MAF  Carbon  Hydrogen  Nitrogen  Oxygen  Chlorine  AshMM  SO2MM

 87     10       9   3988.54  1.99427  7.96    74.45    17.59   0.10   7851  8588  8529   50.06     5.20      1.10     35.58    0.24    10.13   0.24
 88     10      10   5733.53  2.86677  7.44    75.17    17.39   0.12   7887  8575  8521   50.52     5.26      0.68     35.98    0.22     9.43   0.30
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The MEANS Procedure

                 N                                                                   Lower                         Upper
    Location   Obs  Variable   Label                                   Mean       Quartile         Median       Quartile        Maximum        Minimum
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           1    10  LbA        Biomass Yield (lbs/acre)             3242.47        2332.59        2946.89        4344.66        4736.40        1834.02
                    TonA       Biomass Yield (ton/acre)           1.6212363      1.1662930      1.4734465      2.1723320      2.3681980      0.9170090
                    Ash        Proximate Ash (%DM)                7.7740000      7.6700000      7.8600000      8.1700000      9.1600000      6.3600000
                    Volatile   Proximate Volatiles (%DM)         75.1110000     74.0900000     75.0100000     76.0300000     77.7700000     73.0100000
                    FixedC     Proximate Fixed Carbon (%DM)      17.1150000     15.9200000     17.1450000     18.8800000     19.2500000     14.0600000
                    Sulfur     Proximate Sulfur (%DM)             0.1320000      0.1200000      0.1350000      0.1500000      0.1600000      0.1000000
                    HHV        Proximate HHV (BTU/LB)               7952.50        7927.00        7958.50        7990.00        8084.00        7800.00
                    MMF        Proximate MMF (BTU/LB)               8681.30        8655.00        8687.00        8726.00        8798.00        8550.00
                    MAF        Proximate MAF (BTU/LB)               8623.00        8586.00        8634.00        8662.00        8740.00        8504.00
                    Carbon     Ultimate Carbon (%DM)             50.7160000     50.2500000     50.6250000     50.9900000     52.0100000     49.7900000
                    Hydrogen   Ultimate Hydrogen (%DM)            5.4370000      5.3200000      5.4250000      5.5000000      5.7200000      5.2200000
                    Nitrogen   Ultimate Nitrogen (%DM)            1.0060000      0.9300000      0.9950000      1.0300000      1.2500000      0.8900000
                    Oxygen     Ultimate Oxygen (%DM)             34.9350000     34.7100000     34.8200000     35.0300000     36.2400000     34.2500000
                    Chlorine   Ultimate Chlorine (%DM)            0.1700000      0.1200000      0.1500000      0.2100000      0.3200000      0.0900000
                    AshMM      Ultimate LB Ash/MM BTU             9.7830000      9.5300000      9.9000000     10.4100000     11.7400000      7.8600000
                    SO2MM      Ultimate LB SO2/MM BTU             0.3300000      0.2900000      0.3350000      0.3800000      0.4100000      0.2500000

           2    10  LbA        Biomass Yield (lbs/acre)             3970.74        3561.20        3917.32        4398.08        5875.98        2083.30
                    TonA       Biomass Yield (ton/acre)           1.9853690      1.7806000      1.9586600      2.1990410      2.9379900      1.0416510
                    Ash        Proximate Ash (%DM)                7.3710000      6.7300000      7.4000000      7.8400000      8.1900000      6.6600000
                    Volatile   Proximate Volatiles (%DM)         75.3800000     74.3400000     74.8700000     76.6500000     78.2100000     73.4300000
                    FixedC     Proximate Fixed Carbon (%DM)      16.8810000     16.0700000     17.3700000     18.2900000     18.5900000     13.0100000
                    Sulfur     Proximate Sulfur (%DM)             0.1600000      0.1500000      0.1650000      0.1700000      0.1900000      0.1200000
                    HHV        Proximate HHV (BTU/LB)               8040.60        7879.00        8011.00        8212.00        8355.00        7847.00
                    MMF        Proximate MMF (BTU/LB)               8775.90        8607.00        8681.50        8851.00        9406.00        8557.00
                    MAF        Proximate MAF (BTU/LB)               8717.10        8549.00        8628.00        8800.00        9319.00        8503.00
                    Carbon     Ultimate Carbon (%DM)             51.6760000     51.2300000     51.5550000     52.3700000     52.7000000     50.3900000
                    Hydrogen   Ultimate Hydrogen (%DM)            5.6040000      5.5100000      5.5800000      5.6700000      5.8500000      5.4900000
                    Nitrogen   Ultimate Nitrogen (%DM)            1.2810000      0.9800000      1.3700000      1.5000000      1.6200000      0.8700000
                    Oxygen     Ultimate Oxygen (%DM)             33.5400000     33.6100000     33.9700000     34.4000000     35.2500000     29.3900000
                    Chlorine   Ultimate Chlorine (%DM)            0.1540000      0.1100000      0.1400000      0.1800000      0.2600000      0.0900000
                    AshMM      Ultimate LB Ash/MM BTU             9.6160000      8.8400000      9.6150000      9.9500000     12.3800000      8.1300000
                    SO2MM      Ultimate LB SO2/MM BTU             0.4040000      0.3600000      0.4150000      0.4400000      0.4900000      0.3000000

           3     6  LbA        Biomass Yield (lbs/acre)             2673.87        2083.30        2448.33        3080.44        4024.16        1958.66
                    TonA       Biomass Yield (ton/acre)           1.3369338      1.0416510      1.2241625      1.5402190      2.0120780      0.9793300
                    Ash        Proximate Ash (%DM)                6.9983333      6.0700000      6.2350000      6.9400000     10.6600000      5.8500000
                    Volatile   Proximate Volatiles (%DM)         75.7183333     74.4600000     75.9800000     76.5900000     78.0000000     73.3000000
                    FixedC     Proximate Fixed Carbon (%DM)      15.8516667     14.0200000     16.4550000     17.1000000     17.8600000     13.2200000
                    Sulfur     Proximate Sulfur (%DM)             0.1416667      0.1300000      0.1400000      0.1500000      0.1600000      0.1300000
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The MEANS Procedure

                 N                                                                   Lower                          Upper
    Location   Obs   Variable   Label                                  Mean       Quartile         Median       Quartile        Maximum        Minimum
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           3     6   HHV        Proximate HHV (BTU/LB)              8031.50        8003.00        8050.50        8187.00        8262.00        7636.00
                     MMF        Proximate MMF (BTU/LB)              8837.17        8629.00        8830.00        8931.00        9212.00        8591.00
                     MAF        Proximate MAF (BTU/LB)              8772.00        8547.00        8774.50        8864.00        9127.00        8545.00
                     Carbon     Ultimate Carbon (%DM)            51.4866667     51.3900000     51.6350000     51.9100000     52.4700000     49.8800000
                     Hydrogen   Ultimate Hydrogen (%DM)           5.7350000      5.7100000      5.7900000      5.8800000      5.9100000      5.3300000
                     Nitrogen   Ultimate Nitrogen (%DM)           1.1500000      0.9700000      1.1200000      1.2700000      1.5800000      0.8400000
                     Oxygen     Ultimate Oxygen (%DM)            33.0566667     32.3500000     32.9100000     34.0600000     35.3600000     30.7500000
                     Chlorine   Ultimate Chlorine (%DM)           0.1616667      0.1000000      0.1400000      0.2300000      0.2700000      0.0900000
                     AshMM      Ultimate LB Ash/MM BTU           10.5316667      7.8800000     10.8400000     12.5900000     13.9600000      7.0800000
                     SO2MM      Ultimate LB SO2/MM BTU            0.3533333      0.3400000      0.3450000      0.3800000      0.3900000      0.3200000

           4    10   LbA        Biomass Yield (lbs/acre)            3511.34        2083.30        3579.01        4415.89        5769.14        1887.44
                     TonA       Biomass Yield (ton/acre)          1.7556716      1.0416510      1.7895030      2.2079440      2.8845720      0.9437180
                     Ash        Proximate Ash (%DM)               7.8180000      7.1500000      8.0250000      8.2900000     10.2200000      5.8600000
                     Volatile   Proximate Volatiles (%DM)        74.5140000     73.9400000     74.4100000     75.7900000     76.2200000     72.3200000
                     FixedC     Proximate Fixed Carbon (%DM)     17.6860000     17.0900000     17.8050000     18.3000000     19.7000000     15.0700000
                     Sulfur     Proximate Sulfur (%DM)            0.1490000      0.1100000      0.1400000      0.1800000      0.2400000      0.0800000
                     HHV        Proximate HHV (BTU/LB)              8006.00        7912.00        8048.50        8113.00        8227.00        7728.00
                     MMF        Proximate MMF (BTU/LB)              8742.60        8660.00        8749.00        8795.00        8933.00        8569.00
                     MAF        Proximate MAF (BTU/LB)              8683.60        8600.00        8700.00        8733.00        8867.00        8501.00
                     Carbon     Ultimate Carbon (%DM)            51.6030000     51.3000000     51.5650000     51.8000000     52.9200000     50.2200000
                     Hydrogen   Ultimate Hydrogen (%DM)           5.2080000      5.0300000      5.2100000      5.3700000      5.6000000      4.8900000
                     Nitrogen   Ultimate Nitrogen (%DM)           1.3840000      0.9600000      1.1300000      1.9200000      2.2900000      0.9000000
                     Oxygen     Ultimate Oxygen (%DM)            33.8560000     33.1000000     33.8200000     34.2800000     36.4400000     31.5200000
                     Chlorine   Ultimate Chlorine (%DM)           0.1700000      0.1500000      0.1900000      0.2000000      0.2300000      0.0800000
                     AshMM      Ultimate LB Ash/MM BTU            9.7730000      8.3800000     10.1300000     10.4800000     13.6200000      6.7900000
                     SO2MM      Ultimate LB SO2/MM BTU            0.3700000      0.2700000      0.3550000      0.4500000      0.6100000      0.1900000

           5    10   LbA        Biomass Yield (lbs/acre)            3253.16        2296.97        2857.86        3062.63        7318.27        2154.53
                     TonA       Biomass Yield (ton/acre)          1.6265781      1.1484870      1.4289315      1.5313160      3.6591330      1.0772630
                     Ash        Proximate Ash (%DM)               9.1570000      7.9800000      8.8650000     10.3900000     11.8100000      7.5100000
                     Volatile   Proximate Volatiles (%DM)        74.2480000     73.8000000     74.1450000     75.1100000     75.9700000     71.9500000
                     FixedC     Proximate Fixed Carbon (%DM)     16.6060000     16.3300000     16.8200000     17.3600000     18.1800000     14.3900000
                     Sulfur     Proximate Sulfur (%DM)            0.1690000      0.1400000      0.1650000      0.2000000      0.2300000      0.1100000
                     HHV        Proximate HHV (BTU/LB)              7935.50        7778.00        7986.00        8026.00        8254.00        7610.00
                     MMF        Proximate MMF (BTU/LB)              8804.70        8728.00        8796.00        8853.00        8990.00        8710.00
                     MAF        Proximate MAF (BTU/LB)              8734.00        8654.00        8729.00        8781.00        8931.00        8630.00
                     Carbon     Ultimate Carbon (%DM)            49.5910000     48.9100000     49.5600000     49.8400000     51.4700000     48.4600000
                     Hydrogen   Ultimate Hydrogen (%DM)           5.2760000      5.1800000      5.2700000      5.3400000      5.4600000      5.1000000
                     Nitrogen   Ultimate Nitrogen (%DM)           1.5620000      1.3400000      1.4750000      1.7700000      2.0700000      1.2700000
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The MEANS Procedure

                 N                                                                 Lower                     Upper
    Location   Obs   Variable   Label                                  Mean     Quartile       Median     Quartile      Maximum      Minimum
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           5    10   Oxygen     Ultimate Oxygen (%DM)            34.2560000   33.5200000   33.6600000   35.2500000   36.3500000   32.8500000
                     Chlorine   Ultimate Chlorine (%DM)           0.2010000    0.1600000    0.1950000    0.2600000    0.2900000    0.1200000
                     AshMM      Ultimate LB Ash/MM BTU           11.5680000    9.9800000   11.0750000   13.3600000   15.5200000    9.1800000
                     SO2MM      Ultimate LB SO2/MM BTU            0.4260000    0.3700000    0.4100000    0.5300000    0.5600000    0.2700000

           6     6   LbA        Biomass Yield (lbs/acre)            3436.56      2795.54      3267.40      3917.32      4611.75      2759.93
                     TonA       Biomass Yield (ton/acre)          1.7182790    1.3977710    1.6337005    1.9586600    2.3058770    1.3799650
                     Ash        Proximate Ash (%DM)               8.0783333    6.7400000    8.0450000    9.4800000    9.5900000    6.5700000
                     Volatile   Proximate Volatiles (%DM)        75.8700000   75.4100000   75.9350000   76.5400000   77.6200000   73.7800000
                     FixedC     Proximate Fixed Carbon (%DM)     16.0516667   15.1100000   16.1800000   17.3300000   17.6400000   13.8700000
                     Sulfur     Proximate Sulfur (%DM)            0.1516667    0.0900000    0.1250000    0.1600000    0.3400000    0.0700000
                     HHV        Proximate HHV (BTU/LB)              7874.33      7844.00      7866.00      7977.00      8030.00      7663.00
                     MMF        Proximate MMF (BTU/LB)              8627.00      8547.00      8623.00      8677.00      8772.00      8520.00
                     MAF        Proximate MAF (BTU/LB)              8566.67      8476.00      8573.50      8610.00      8699.00      8468.00
                     Carbon     Ultimate Carbon (%DM)            49.8400000   49.0200000   49.8300000   50.4600000   51.0000000   48.9000000
                     Hydrogen   Ultimate Hydrogen (%DM)           5.2516667    5.2000000    5.2650000    5.3400000    5.3700000    5.0700000
                     Nitrogen   Ultimate Nitrogen (%DM)           1.0983333    1.0100000    1.0400000    1.1800000    1.3400000    0.9800000
                     Oxygen     Ultimate Oxygen (%DM)            35.5800000   35.1000000   35.4650000   36.7300000   37.3600000   33.3600000
                     Chlorine   Ultimate Chlorine (%DM)           0.2900000    0.2700000    0.2950000    0.3000000    0.3300000    0.2500000
                     AshMM      Ultimate LB Ash/MM BTU           10.2800000    8.4000000   10.2500000   12.0400000   12.5100000    8.2300000
                     SO2MM      Ultimate LB SO2/MM BTU            0.3916667    0.2200000    0.3150000    0.4100000    0.9000000    0.1900000

           7    10   LbA        Biomass Yield (lbs/acre)            3999.23      2831.15      4086.48      4682.98      6623.83      1940.85
                     TonA       Biomass Yield (ton/acre)          1.9996138    1.4155770    2.0432385    2.3414890    3.3119160    0.9704270
                     Ash        Proximate Ash (%DM)               8.6250000    8.1300000    8.7750000    9.0800000    9.5700000    7.3100000
                     Volatile   Proximate Volatiles (%DM)        76.1440000   74.8000000   75.5850000   77.4100000   79.1500000   73.1600000
                     FixedC     Proximate Fixed Carbon (%DM)     15.2310000   13.8300000   15.4400000   17.2700000   17.8500000   11.5700000
                     Sulfur     Proximate Sulfur (%DM)            0.2120000    0.1800000    0.2150000    0.2500000    0.3000000    0.1200000
                     HHV        Proximate HHV (BTU/LB)              7806.10      7678.00      7746.00      7881.00      8122.00      7660.00
                     MMF        Proximate MMF (BTU/LB)              8606.40      8537.00      8581.50      8664.00      8818.00      8492.00
                     MAF        Proximate MAF (BTU/LB)              8542.20      8468.00      8512.00      8602.00      8763.00      8425.00
                     Carbon     Ultimate Carbon (%DM)            50.5050000   50.0700000   50.4050000   50.8100000   51.7100000   49.1700000
                     Hydrogen   Ultimate Hydrogen (%DM)           5.1020000    5.0600000    5.0900000    5.1300000    5.2300000    4.9900000
                     Nitrogen   Ultimate Nitrogen (%DM)           1.0870000    1.0100000    1.0600000    1.1700000    1.2900000    0.9800000
                     Oxygen     Ultimate Oxygen (%DM)            34.4690000   34.3900000   34.4450000   34.4900000   34.9800000   33.9500000
                     Chlorine   Ultimate Chlorine (%DM)           0.3760000    0.2600000    0.4150000    0.4500000    0.5400000    0.1500000
                     AshMM      Ultimate LB Ash/MM BTU           11.0660000   10.3100000   11.3700000   11.8500000   12.4600000    9.0000000
                     SO2MM      Ultimate LB SO2/MM BTU            0.5430000    0.4500000    0.5600000    0.6400000    0.7600000    0.3000000

           8    10   LbA        Biomass Yield (lbs/acre)            2946.89      1798.41      2746.58      3276.30      6321.13  667.7250000
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The MEANS Procedure

                 N                                                                      Lower                          Upper
    Location   Obs   Variable   Label                                  Mean       Quartile         Median       Quartile        Maximum        Minimum
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           8    10   TonA       Biomass Yield (ton/acre)          1.4734465      0.8992030      1.3732878      1.6381520      3.1605650      0.3338625
                     Ash        Proximate Ash (%DM)               7.3470000      6.4000000      7.3250000      7.8300000      9.2300000      6.0800000
                     Volatile   Proximate Volatiles (%DM)        76.3500000     75.4600000     75.6700000     78.0500000     78.8900000     73.8100000
                     FixedC     Proximate Fixed Carbon (%DM)     16.3030000     14.2700000     16.9350000     18.0600000     18.2400000     13.4800000
                     Sulfur     Proximate Sulfur (%DM)            0.1790000      0.1700000      0.1800000      0.1900000      0.2500000      0.1100000
                     HHV        Proximate HHV (BTU/LB)              7997.20        7885.00        8001.50        8094.00        8372.00        7733.00
                     MMF        Proximate MMF (BTU/LB)              8685.80        8586.00        8707.00        8777.00        8960.00        8446.00
                     MAF        Proximate MAF (BTU/LB)              8631.20        8540.00        8652.50        8713.00        8914.00        8389.00
                     Carbon     Ultimate Carbon (%DM)            51.7520000     51.2800000     51.7250000     52.3700000     53.6100000     49.8100000
                     Hydrogen   Ultimate Hydrogen (%DM)           5.1730000      5.0500000      5.1650000      5.2700000      5.4600000      4.9600000
                     Nitrogen   Ultimate Nitrogen (%DM)           1.3560000      1.1300000      1.2700000      1.5800000      1.7900000      1.1000000
                     Oxygen     Ultimate Oxygen (%DM)            34.1930000     33.2500000     33.8650000     35.3700000     35.9000000     33.0000000
                     Chlorine   Ultimate Chlorine (%DM)           0.3040000      0.1600000      0.2350000      0.4700000      0.7600000      0.1200000
                     AshMM      Ultimate LB Ash/MM BTU            9.2050000      8.0100000      9.1300000     10.1200000     11.8900000      7.2600000
                     SO2MM      Ultimate LB SO2/MM BTU            0.4520000      0.4300000      0.4450000      0.4800000      0.6200000      0.2700000

           9     6   LbA        Biomass Yield (lbs/acre)            5496.12        4754.20        5048.00        6089.65        7353.88        4682.98
                     TonA       Biomass Yield (ton/acre)          2.7480593      2.3771010      2.5240005      3.0448260      3.6769390      2.3414890
                     Ash        Proximate Ash (%DM)               7.7166667      6.6500000      7.9000000      8.4200000      9.4600000      5.9700000
                     Volatile   Proximate Volatiles (%DM)        74.4200000     73.6800000     74.1900000     75.7100000     76.0800000     72.6700000
                     FixedC     Proximate Fixed Carbon (%DM)     17.8633333     17.5700000     17.9700000     18.0800000     18.3200000     17.2700000
                     Sulfur     Proximate Sulfur (%DM)            0.1233333      0.1000000      0.1250000      0.1400000      0.1500000      0.1000000
                     HHV        Proximate HHV (BTU/LB)              7913.67        7836.00        7899.50        8016.00        8049.00        7782.00
                     MMF        Proximate MMF (BTU/LB)              8633.33        8568.00        8630.00        8672.00        8756.00        8544.00
                     MAF        Proximate MAF (BTU/LB)              8575.67        8525.00        8570.50        8623.00        8683.00        8482.00
                     Carbon     Ultimate Carbon (%DM)            50.1450000     49.6000000     50.3700000     50.8100000     50.8900000     48.8300000
                     Hydrogen   Ultimate Hydrogen (%DM)           5.3233333      5.2600000      5.3200000      5.4100000      5.4700000      5.1600000
                     Nitrogen   Ultimate Nitrogen (%DM)           1.0700000      1.0200000      1.0550000      1.1100000      1.1700000      1.0100000
                     Oxygen     Ultimate Oxygen (%DM)            35.6216667     35.0300000     35.4300000     36.2500000     36.6500000     34.9400000
                     Chlorine   Ultimate Chlorine (%DM)           0.4866667      0.4500000      0.4750000      0.5300000      0.6000000      0.3900000
                     AshMM      Ultimate LB Ash/MM BTU            9.7700000      8.2700000     10.0600000     10.7500000     12.0300000      7.4500000
                     SO2MM      Ultimate LB SO2/MM BTU            0.3066667      0.2500000      0.3100000      0.3500000      0.3800000      0.2400000

          10    10   LbA        Biomass Yield (lbs/acre)            4982.12        3952.93        4736.40        5751.34        6926.53        3721.45
                     TonA       Biomass Yield (ton/acre)          2.4910594      1.9764660      2.3681980      2.8756690      3.4632670      1.8607270
                     Ash        Proximate Ash (%DM)               7.3530000      6.8300000      7.4450000      7.8800000      8.2200000      6.3900000
                     Volatile   Proximate Volatiles (%DM)        76.9450000     75.1700000     76.2500000     78.2800000     81.7500000     74.4500000
                     FixedC     Proximate Fixed Carbon (%DM)     15.9630000     14.2100000     17.0350000     17.3900000     18.2600000     11.8600000
                     Sulfur     Proximate Sulfur (%DM)            0.1330000      0.1100000      0.1250000      0.1600000      0.1700000      0.1000000
                     HHV        Proximate HHV (BTU/LB)              7910.50        7856.00        7904.00        7949.00        7996.00        7848.00
------------------------------------------------------------------------------------------------------------------------------------------------------
```

```
The MEANS Procedure

                 N                                                                    Lower                          Upper
    Location   Obs   Variable   Label                                  Mean        Quartile         Median        Quartile         Maximum         Minimum
──────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────
          10    10   MMF        Proximate MMF (BTU/LB)              8567.10         8529.00        8574.00         8588.00         8695.00         8378.00
                     MAF        Proximate MAF (BTU/LB)              8515.00         8483.00        8522.50         8529.00         8638.00         8349.00
                     Carbon     Ultimate Carbon (%DM)            50.8690000      50.5400000     50.8350000      50.9200000      51.9500000      50.0600000
                     Hydrogen   Ultimate Hydrogen (%DM)           5.3290000       5.2600000      5.2900000       5.4400000       5.4800000       5.2000000
                     Nitrogen   Ultimate Nitrogen (%DM)           0.8740000       0.8100000      0.8550000       0.8900000       1.1100000       0.6800000
                     Oxygen     Ultimate Oxygen (%DM)            35.7030000      35.1900000     35.7500000      35.9800000      37.3100000      34.6800000
                     Chlorine   Ultimate Chlorine (%DM)           0.3280000       0.2400000      0.2900000       0.3800000       0.6800000       0.2100000
                     AshMM      Ultimate LB Ash/MM BTU            8.9710000       8.4900000      9.4150000      10.0300000      10.3800000       5.2800000
                     SO2MM      Ultimate LB SO2/MM BTU            0.3320000       0.2700000      0.3100000       0.4100000       0.4300000       0.2400000
──────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────
```

```
Variance Components Estimation Procedure

           Class Level Information

Class         Levels    Values

Location          10    1 2 3 4 5 6 7 8 9 10


Number of observations    88


Dependent Variable:    LbA


                          REML Iterations

Iteration          Objective      Var(Location)         Var(Error)

        0         1255.05398       420663.25000      1631182.11123
        1         1254.89726       535825.43125      1596929.53463
        2         1254.89662       543914.29232      1594931.99212
        3         1254.89662       544596.16186      1594765.64803
        4         1254.89662       544596.16186      1594765.64803


Convergence criteria met.


      REML Estimates

Variance
Component          Estimate

Var(Location)      544596.2
Var(Error)        1594765.6


     Asymptotic Covariance Matrix of Estimates

                  Var(Location)         Var(Error)

Var(Location)         1.29527E11         -9.94134E9
Var(Error)            -9.94134E9         6.57551E10
```

```
Variance Components Estimation Procedure

Dependent Variable:    TonA


                          REML Iterations

Iteration          Objective      Var(Location)         Var(Error)

        0     -67.5030488727       0.1051658125       0.4077955278
        1     -67.6597728651       0.1339563578       0.3992323837
        2     -67.6604057061       0.1359785731       0.3987329980
        3     -67.6604095137       0.1361490405       0.3986914120
        4     -67.6604095137       0.1361490405       0.3986914120


Convergence criteria met.


      REML Estimates

Variance
Component          Estimate

Var(Location)       0.13615
Var(Error)          0.39869


     Asymptotic Covariance Matrix of Estimates

                   Var(Location)         Var(Error)

Var(Location)          0.0080954         -0.0006213
Var(Error)            -0.0006213          0.0041097


Dependent Variable:    Ash


                          REML Iterations

Iteration          Objective      Var(Location)         Var(Error)

        0      24.3527213583       0.3398121075       1.1614801073
        1      24.3241232003       0.3030933993       1.1714761458
        2      24.3240911105       0.3042731752       1.1711273634
```

```
Variance Components Estimation Procedure

                          REML Iterations

Iteration          Objective      Var(Location)         Var(Error)

        3      24.3240910496       0.3042238468       1.1711419068
        4      24.3240910496       0.3042238468       1.1711419068


Convergence criteria met.


      REML Estimates

Variance
Component          Estimate

Var(Location)       0.30422
Var(Error)          1.17114


     Asymptotic Covariance Matrix of Estimates

                   Var(Location)         Var(Error)

Var(Location)           0.04201         -0.0035697
Var(Error)            -0.0035697           0.03500


Dependent Variable:    Volatile


                          REML Iterations

Iteration          Objective      Var(Location)         Var(Error)

        0      93.0157414318       0.6151703517       2.5960229925
        1      92.9829876269       0.5386385488       2.6200348468
        2      92.9829170884       0.5420381006       2.6188702509
        3      92.9829168526       0.5418520302       2.6189337370
        4      92.9829168526       0.5418520302       2.6189337370
```

```
Variance Components Estimation Procedure

Convergence criteria met.


      REML Estimates

Variance
Component          Estimate

Var(Location)       0.54185
Var(Error)          2.61893


     Asymptotic Covariance Matrix of Estimates

                   Var(Location)         Var(Error)

Var(Location)            0.15340           -0.01742
Var(Error)              -0.01742            0.17475


Dependent Variable:    FixedC


                          REML Iterations

Iteration          Objective      Var(Location)         Var(Error)

        0     101.4791451300       0.3331291269       2.9939665807
        1     101.4791057430       0.3351351865       2.9930080044
        2     101.4791057411       0.3351488843       2.9930014784


Convergence criteria met.


      REML Estimates

Variance
Component          Estimate

Var(Location)       0.33515
Var(Error)          2.99300
```

```
Variance Components Estimation Procedure

     Asymptotic Covariance Matrix of Estimates

                   Var(Location)         Var(Error)

Var(Location)            0.10654           -0.02647
Var(Error)              -0.02647            0.22953


Dependent Variable:    Sulfur


                          REML Iterations

Iteration          Objective      Var(Location)         Var(Error)

        0    -538.1225815695     0.000563173489       0.0017989069
        1    -538.1464713875     0.000508606033       0.0018130720
        2    -538.1464938802     0.000510217498       0.0018126209
        3    -538.1464939156     0.000510155907       0.0018126381
        4    -538.1464939156     0.000510155907       0.0018126381


Convergence criteria met.


      REML Estimates

Variance
Component          Estimate

Var(Location)     0.0005102
Var(Error)        0.0018126


     Asymptotic Covariance Matrix of Estimates

                   Var(Location)         Var(Error)

Var(Location)         1.12916E-7         -8.6091E-9
Var(Error)            -8.6091E-9         8.38745E-8
```

```
Variance Components Estimation Procedure

Dependent Variable:    HHV


                          REML Iterations

Iteration          Objective      Var(Location)         Var(Error)

        0     880.2233549360         3211.87345        22813.20117
        1     880.2162736726         2979.74976        22911.95849
        2     880.2162649805         2987.72135        22908.42782
        3     880.2162649665         2987.41375        22908.56387
        4     880.2162649665         2987.41375        22908.56387


Convergence criteria met.


      REML Estimates

Variance
Component          Estimate

Var(Location)        2987.4
Var(Error)          22908.6


     Asymptotic Covariance Matrix of Estimates

                   Var(Location)         Var(Error)

Var(Location)          6963662.1         -1416085.3
Var(Error)            -1416085.3           13386646


Dependent Variable:    MMF


                          REML Iterations

Iteration          Objective      Var(Location)         Var(Error)

        0     874.4198574234         5484.23138        20475.98490
        1     874.4180853055         5637.61824        20431.67151
        2     874.4180850659         5639.42069        20431.16122
```

```
Variance Components Estimation Procedure

                          REML Iterations

Iteration          Objective      Var(Location)         Var(Error)

        3     874.4180850659         5639.42069        20431.16122


Convergence criteria met.


      REML Estimates

Variance
Component          Estimate

Var(Location)        5639.4
Var(Error)          20431.2


     Asymptotic Covariance Matrix of Estimates

                   Var(Location)         Var(Error)

Var(Location)           14670984         -1296850.6
Var(Error)            -1296850.6           10712916


Dependent Variable:    MAF


                          REML Iterations

Iteration          Objective      Var(Location)         Var(Error)

        0     870.2200531416         5047.94164        19563.03014
        1     870.2180689513         5199.15225        19518.23948
        2     870.2180686389         5201.07069        19517.68325
        3     870.2180686389         5201.07069        19517.68325


Convergence criteria met.
```

```
Variance Components Estimation Procedure

      REML Estimates

Variance
Component          Estimate

Var(Location)        5201.1
Var(Error)          19517.7


     Asymptotic Covariance Matrix of Estimates

                   Var(Location)         Var(Error)

Var(Location)           12761205         -1185123.5
Var(Error)            -1185123.5          9777198.4


Dependent Variable:    Carbon


                          REML Iterations

Iteration          Objective      Var(Location)         Var(Error)

        0     -23.1142056570       0.5537157327       0.6125384126
        1     -23.1145012067       0.5585988766       0.6119950407
        2     -23.1145012069       0.5586027962       0.6119946082


Convergence criteria met.


      REML Estimates

Variance
Component          Estimate

Var(Location)       0.55860
Var(Error)          0.61199
```

```
Variance Components Estimation Procedure

     Asymptotic Covariance Matrix of Estimates

                   Var(Location)         Var(Error)

Var(Location)            0.08884         -0.0011526
Var(Error)            -0.0011526          0.0096044


Dependent Variable:    Hydrogen


                          REML Iterations

Iteration          Objective      Var(Location)         Var(Error)

        0    -316.0753573455       0.0290791294       0.0202226602
        1    -316.2860008242       0.0361461784       0.0197061451
        2    -316.2860461794       0.0360304458       0.0197129316
        3    -316.2860461859       0.0360290483       0.0197130138


Convergence criteria met.


      REML Estimates

Variance
Component          Estimate

Var(Location)       0.03603
Var(Error)          0.01971


     Asymptotic Covariance Matrix of Estimates

                   Var(Location)         Var(Error)

Var(Location)          0.0003310         -1.3935E-6
Var(Error)            -1.3935E-6         9.97606E-6


Dependent Variable:    Nitrogen
```

```
Variance Components Estimation Procedure

                          REML Iterations

Iteration          Objective      Var(Location)         Var(Error)

        0    -218.6417480470       0.0452635882       0.0663864458
        1    -218.8031754959       0.0360482972       0.0676931010
        2    -218.8033010807       0.0362796134       0.0676529711
        3    -218.8033014053       0.0362683904       0.0676549075
        4    -218.8033014053       0.0362683904       0.0676549075


Convergence criteria met.


      REML Estimates

Variance
Component          Estimate

Var(Location)       0.03627
Var(Error)          0.06765


     Asymptotic Covariance Matrix of Estimates

                   Var(Location)         Var(Error)

Var(Location)          0.0004176         -0.0000105
Var(Error)            -0.0000105          0.0001168


Dependent Variable:    Oxygen


                          REML Iterations

Iteration          Objective      Var(Location)         Var(Error)

        0      37.6438848273       0.4973648288       1.3279656578
        1      37.4373761546       0.6407070321       1.2952722294
        2      37.4370667087       0.6469172597       1.2941291962
        3      37.4370656778       0.6472986524       1.2940595985
        4      37.4370656778       0.6472986524       1.2940595985
```

```
Variance Components Estimation Procedure

Convergence criteria met.


      REML Estimates

Variance
Component          Estimate

Var(Location)       0.64730
Var(Error)          1.29406


     Asymptotic Covariance Matrix of Estimates

                   Var(Location)         Var(Error)

Var(Location)            0.15110         -0.0065459
Var(Error)            -0.0065459            0.04320


Dependent Variable:    Chlorine


                          REML Iterations

Iteration          Objective      Var(Location)         Var(Error)

        0    -368.6076013737       0.0083603074       0.0118033350
        1    -368.8651013633       0.0107936333       0.0114706011
        2    -368.8651046677       0.0108034806       0.0114695432
        3    -368.8651046707       0.0108037863       0.0114695103


Convergence criteria met.


      REML Estimates

Variance
Component          Estimate

Var(Location)       0.01080
Var(Error)          0.01147
```

```
Variance Components Estimation Procedure

     Asymptotic Covariance Matrix of Estimates

                   Var(Location)         Var(Error)

Var(Location)         0.00003389         -5.0071E-7
Var(Error)            -5.0071E-7         3.38364E-6


Dependent Variable:    AshMM


                          REML Iterations

Iteration          Objective      Var(Location)         Var(Error)

        0      95.6520886055       0.4981221677       2.7219886876
        1      95.5902997482       0.4030622941       2.7571016421
        2      95.5897470492       0.4115522427       2.7535654509
        3      95.5897399878       0.4106868096       2.7539218796
        4      95.5897399878       0.4106868096       2.7539218796


Convergence criteria met.


      REML Estimates

Variance
Component          Estimate

Var(Location)       0.41069
Var(Error)          2.75392


     Asymptotic Covariance Matrix of Estimates

                   Var(Location)         Var(Error)

Var(Location)            0.10924           -0.01745
Var(Error)              -0.01745            0.19226
```

```
Variance Components Estimation Procedure

Dependent Variable:    SO2MM


                          REML Iterations

Iteration          Objective      Var(Location)         Var(Error)

        0    -369.6486130134       0.0040160389       0.0124457550
        1    -369.6741131203       0.0036179520       0.0125468965
        2    -369.6741360867       0.0036294346       0.0125437425
        3    -369.6741361222       0.0036289998       0.0125438617
        4    -369.6741361222       0.0036289998       0.0125438617


Convergence criteria met.


      REML Estimates

Variance
Component          Estimate

Var(Location)     0.0036290
Var(Error)          0.01254


     Asymptotic Covariance Matrix of Estimates

                   Var(Location)         Var(Error)

Var(Location)         5.62443E-6         -4.1201E-7
Var(Error)            -4.1201E-7         4.01693E-6
```