Variation in Biomass Yield of Switchgrass Grown for Biofuel

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Abstract

Switchgrass (*Panicum virgatum* L.) is a native warm-season perennial grass that is being developed as a bioenergy crop in the USA. The objective of this research was to assess variation in yield of commercial switchgrass fields managed for biomass production. Six fields were intensively sampled to determine variation in potential biomass productivity within and among diverse landscapes representative of southern Iowa. Yield data were collected August 8-9 and on December 3-5. Biomass yield for the summer harvest ranged from 2.2 to 8.8 Mg ha^{-1} among the six locations and averaged 5.7 Mg/ha^{-1} over all locations. Location (site) variance accounted for 65.2% of the total variation in biomass yield among all samples. There was, however significant variation in biomass yield within fields. Standard deviations ranged from 0.98 to 3.01 across the locations. For the autumn harvest, mean biomass yield ranged from 1.2 to 8.3 Mg ha^{-1} among the six locations and averaged 4.2 Mg ha^{-1} overall. Location variance accounted for 71.2% of the total variation in biomass yield among all samples. However, as with the summer harvest, there was significant variation in biomass yield within fields. Standard deviations for yield ranged 0.92 to 2.46 across the locations. The biomass yields observed in this study were less than those typically obtained in yield performance trials. However, they are more reflective of the variation in biomass yields that are likely to be obtained from commercial production fields.

Media Summary: Switchgrass has received attention as a potential biomass feedstock under assumptions of high yield capacity. Most data, however, have been developed under experimental conditions of relatively intensive management. Our results show that actual yields in commercial production switchgrass fields are considerably lower and more variable than commonly reported in the literature.

Introduction

Warm-season (C4) grasses possess a number of attributes making them well-suited as bioenergy crops. Switchgrass (*Panicum virgatum* L.), a warm-season grass native to North America, has been identified as a ideal biomass energy crop because of its ability to yield well on marginal soils with moderate inputs and its favorable fuel characteristics in terms of energy content, ash content, and chemistry. Switchgrass and other C4 grasses also contain low amounts of silica, the major component of ash. In addition to the benefits of growing switchgrass as an alternative fuel, the plant also possesses beneficial environmental attributes. The dense, fibrous root system also traps nitrogen, nutrients, and pesticides that escape other plant root systems, thus protecting groundwater; and it also offers the potential for sequestering large amounts of atmospheric carbon. A comprehensive review of literature pertaining to switchgrass as a biofuel feedstock is presented by Parrish and Fike (2005).

Annual yield per hectare is one of the most important qualities of a biomass crop, not only from the perspective of the producer, but also from the perspective of the processor, who needs to be assured of a reliable supply of feedstock within a reasonable distance from the plant. Significant genetic variation exists in switchgrass yield capacity of different strains (Vogel and Masters, 1998) underscoring the potential to increase yields through breeding. Considerable phenotypic variation has been documented at regional and landscape levels due to daylength and climatic variables (Casler et al., 2004), and the considerable variability within populations (Casler, 2005) could cause natural selection according to local environmental conditions such as slope, aspect, or soil characteristics. Much of the existing data for switchgrass has been obtained on small plots under relatively intensive management. The objective of this study was to document variation in switchgrass yield on commercial production fields across and within six different locations southern Iowa, a region well suited to switchgrass production, but with extremely diverse landscapes in terms of elevation, slope, and soil characteristics (Prior, 1991).

Materials and Methods

Six switchgrass swards from two counties in southern Iowa were selected as 'random' fields. These swards were production fields managed by different participants in the Chariton Valley Biomass Project (CVRCD, 2000.) The six sites, located within a 25 km radius, were designated as A, B, C, D, E, and F. Establishment methods, liming additions, and fertilizer inputs varied among sites and represented the diversity of management practices encountered in the project area.

Yield data were collected on August 8-9, 2002, and again from December 3-5, 2002. For the summer harvest, samples were collected from a sampling grid that consisted of 23-m centers with occasional random subsampling at shorter distances. During the summer harvest, yield was measured using a 1- m^2 sampling frame. All biomass within the quadrat was clipped to one-inch above the ground and put into cloth bags for drying to estimate biomass yield at each plot. Samples were dried for 48 hr or until dry in a forced-air dryer at 60° C to determine biomass yield. The autumn harvest was made after a killing frost had occurred and the standing crop was completely senesced. Each fields was mowed with a self-propelled mower conditioner cutting a 4.1-m effective swath. To calculate yield, one-meter sections of the windrow were weighed in the field and then subsampled. Subsamples were put into cloth bags and later were dried for 48 hr or until dry in a forced-air dryer at 60° C to determine percent dry matter. The yield of each plot was derived from the percent dry matter of the subsamples.umn harvest,

Samples from both harvests were initially ground to pass through a 6-mm mesh screen using a Model 4 Wiley Laboratory Mill then ground again using a 1-mm screen in a UDY cyclone mill (UDY Manufacturing, Fort Collins, CO) in preparation for fuel characteristics assessment. Fuel characteristics evaluated were ash and gross energy concentration. Percent ash was determined by igniting 2-gram samples at 600° C in a muffle furnace over night. Gross energy was determined by Hazen Analytical Laboratories (Golden, CO).

Variation in yield was evaluated with the Nested procedure (SAS, Cary, NC) using a nested model with plots nested within location. The mean, standard deviation, and range were determined for yield, ash concentration, and gross energy using the Univiariate procedure in SAS. Variances associated with yield were determined for comparison among and within locations.

Results and Discussion

Biomass yield, ash content, and energy content varied within and among sites (Fig. 1). The data from each site is displayed in boxplot form. The shaded box represents the 25th percentile (at the bottom) through the 75th percentile (at the top) of the data while the 'tails' represent the extreme high and low yield, ash content, and energy content that was measured. The 'X' within the box represents the mean or average value, and the '–' represents the median or middle value that was measured. A 'stretched' box plot represents more variability within a site while a 'shrunken' box plot represents more uniformity.

Component	$^{2}_{total}$	$^{2}_{site}$	% Total	$^{2}_{plot}$	% Total
Summer					
Yield (Mg DM ha^{-1})	12.282	8.002	65.2	4.280	34.8
Ash (g kg^{-1} DM)	278.92	140.23	50.3	138.69	49.7
Energy (MJ kg^{-1})	0.092	0.017	18.4	0.075	81.6
Fall					
Yield (Mg DM ha^{-1})	7.693	5.479	71.2	2.214	28.8
Ash (g kg^{-1} DM)	140.93	41.12	29.2	99.81	70.8

Table 1. Variation in biomass yield and fuel characteristics among and within warm-season switchgrass sampling sites.

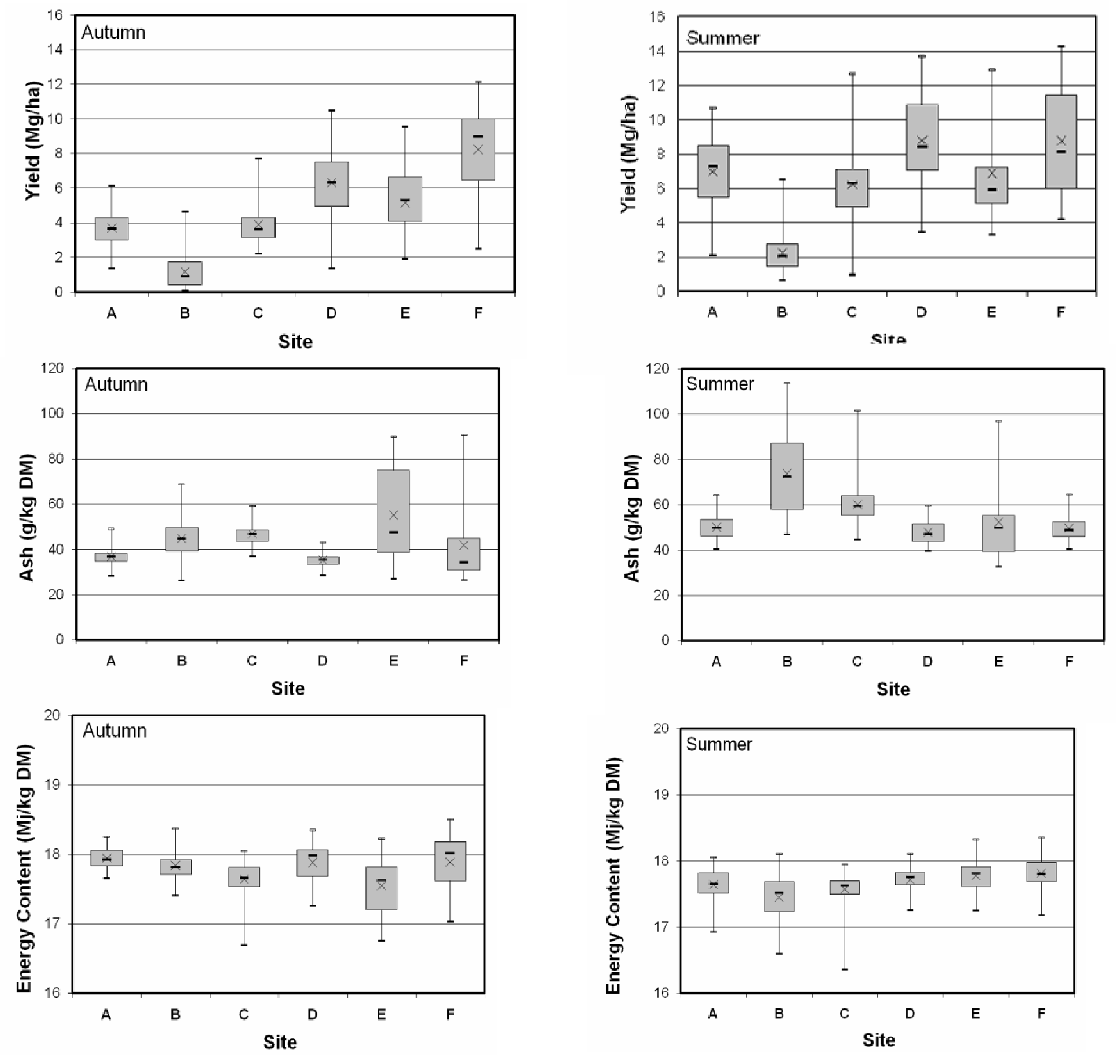

Figure 1. Box plots of biomass yield, ash content, and energy content for summer and autumn harvests at each site

Average biomass yield across all sites was 5.7 Mg ha^{-1} in the summer and 4.2 Mg ha^{-1} in the autumn. Mean yields across sites ranged from 2.2 Mg ha^{-1} at site B to 8.8 Mg ha^{-1} at sites D and F in the summer and from 1.2 Mg ha^{-1} at site B to 8.3 Mg ha^{-1} at site F in the autumn. In both the summer and autumn harvests, a majority of the variation in yield was described by differences between sites (Table 1). During the summer harvest, 65.2% of the total variation in yield was measured by differences among sites, and site variation increased to 71.2% during the autumn harvest. In general, the yields on these commercial fields were considerably lower than the 10 to 15 Mg ha-1 yields commonly reported for research plots (Parrish and Fike, 2005).

The average ash content over all locations was 60 g kg^{-1} during the summer harvest to 43 g kg^{-} in the autumn. The range of averages between fields in the summer was from 48 g kg^{-1} at site D to 74 g kg^{-1} at site B. In the autumn, the average ash content between all fields ranged from 48 g kg^{-1} at site D to 74 g kg^{-1} at site E. As shown in the boxplots (Fig. 1), there was either very little variation in ash content within fields or much variation. During the summer, at sites A, D, and F, the range varied from 20 g kg^{-1} to 24 g kg^{-1}. At sites B, C, and E, the range was greater and varied from 57 g kg^{-1} to 67 g kg^{-1}. The trend was similar in the autumn; however, it was sites A, C, and D that showed little variation (15 g kg^{-1} to 22 g kg^{-1}). The variation in sites B, E, and F was greater and ranged from43 g kg^{-1} to 64 g kg^{-1}. Unlike biomass yield, less than half of the total variation in ash content was described among sites. During the summer harvest, 50.3% of the variation was accounted for among sites then decreased to 29.2% during the autumn harvest. The majority of the autumn variation (70.8 $kg^{-1)}$ was accounted for within sites.

The energy content of the biomass did not vary considerably among and within sites. In the summer, energy content ranged from 17.5 KJ kg^{-1} at site B to 17.8 KJ kg^{-1} at site F with an overall mean of 17.6 KJ kg^{-1}. In the autumn, the mean energy content was 17.8 KJ kg^{-1} with a range in means from 17.6 KJ kg^{-1} at site E to 17.9 KJ kg^{-1} at site A. The variation in energy content was much greater within fields than between fields. Between field variation only described 18.4% of the total variation in the summer and 23.6% of the total variation in the autumn.

The six sites exhibited considerable variability in biomass yield, ash content, and energy content. A possible reason for the variability may have been due in part to the variation in edaphic characteristics such as soil fertility, elevation, and slope. Another possibility is that part of the variation was due to genotypic differences among the switchgrass populations at the different sites, as suggested by Casler (2005).

Conclusion

The biomass yields observed in this study were less than those typically obtained in yield performance trials. However, the yields are more reflective of the variation in biomass yields that are likely to be obtained from commercial production fields. If switchgrass is to be an economically viable source of biomass, research is needed to improve the level and uniformity of yield over the variety of environmental and edaphic conditions that are to be encountered in a given production region.

References

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