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Seasonal changes in chemical composition and leaf proportion of elephantgrass and energycane biomass

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ABSTRACT

Changes in chemical composition of warm-season perennial grasses during the growing season affect conversion of biomass to biofuels, thus influencing choice of harvest date. The objective was to quantify these changes for three candidate bioenergy grasses in the USA Gulf Coast region during two growing seasons and relate them to optimal harvest management. Grasses included two elephantgrass [*Pennisetum purpureum* Schum.; synonym *Cenchrus purpureus* (Schumach.) Morrone] entries, 'Merkeron' and breeding line UF1, and the energycane (*Saccharum* spp. hybrid) cultivar 'L79-1002'. Quantification of cell wall constituents and mineral composition of above-ground biomass occurred monthly throughout the growing season. With the exception of hemicellulose, elephantgrass cell wall constituents (cellulose, lignin, neutral detergent fiber and acid detergent fiber) increased from early in the growing season until late summer and either remained relatively constant (UF1) or increased slightly (Merkeron) during the remainder of the season. In contrast, concentrations of energycane cell wall constituents peaked in late summer and decreased during the remainder of the growing season. Nitrogen, P, and ash concentrations decreased with increasing maturity for all grass entries, and they were much greater in leaf than in stem. Elephantgrass leaf, particularly of UF1, contributed less to total biomass harvested than energycane leaf. Likewise, the proportion of total ash harvested that was in the leaf fraction was greater for energycane than for elephantgrass when harvest occurred late in the growing season. Thus, delayed harvest until late in the season was generally a superior management strategy for elephantgass because it resulted in biomass with greater cell wall constituent concentrations, lesser leaf percentage, and lesser concentrations of N and ash, all of which may provide advantages in some conversion processes. In contrast, greater accumulation of extractives by energycane and greater lignin concentration in elephantgrasses late in the growing season may reduce efficiency of some conversion methods.

1. Introduction

Dependence on imported fossil fuels has created political and economic challenges for many countries, and combustion of fossil fuels is associated with climate change (Kim and Day, 2011; Parrish and Fike, 2005). Lignocellulose represents an alternative energy production system; a potential cellulose-to-liquid fuel bioenergy (Anderson and Akin, 2008; Carroll and Somerville, 2009). Perennial C4 grasses are a promising source of lignocellulose for conversion to biofuel in the Southeast USA (Knoll et al., 2012; Na et al., 2015a). Elephantgrass [or napiergrass; *Pennisetum purpureum* Schum.; synonym *Cenchrus purpureus* (Schumach.) Morrone], and energycane (*Saccharum* spp. hybrid) have documented high biomass production (Morais et al., 2012; Na et al., 2015b; Woodard and Prine, 1993) and are considered two of the most promising dedicated energy crops in tropical and subtropical environments (Fedenko et al., 2013).

While high levels of lignocellulose are desirable for biofuel production, high N and/or ash concentrations in biomass may reduce the efficiency of thermochemical conversion to fuel (Shahandeh et al., 2011). Thus, characterizing the chemical properties of biomass is important. The detergent fiber analyses, which were originally proposed for forages (Van Soest et al., 1991), provide estimates of cell wall constituents including cellulose, hemicellu-

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lose, and lignin. They can be useful indicators of cellulosic biomass quality because the plant cell wall is the primary energy source for ruminant microorganisms (Guretzky et al., 2011; Jung and Lamb, 2004), and in the ruminant animal these microbes face barriers limiting access to structural carbohydrates that are similar to those that occur in bioconversion to ethanol (Lorenz et al., 2009a). Further, it has been shown that cellulose and hemicellulose concentrations, estimated from detergent fiber analysis, are correlated with theoretical ethanol yield potential (r = 0.91 and 0.51, respectively; Lorenz et al., 2009b).

For a relatively low value crop such as perennial grasses for biofuel, it is essential to minimize N input and increase efficiency of N cycling (Erickson et al., 2012; Erisman et al., 2010). Previous research has shown that concentrations of N, P, and K in harvested plant material are dependent on harvest date (Adler et al., 2006; Heaton et al., 2009; Kering et al., 2012), and nutrient removal in harvested biomass is strongly affected by harvest date and frequency (Na et al., 2014). Changes in plant-part proportion as the season progresses, specifically decreasing amount of leaf (Woodard et al., 1993), affect biomass nutrient concentration and inform harvest timing decisions.

Most biomass plant-part and nutrient composition data for perennial grasses are from experiments harvested once at the end of the growing season (Adler et al., 2006; Fedenko et al., 2013; Guretzky et al., 2011). Thus, there are limited data available that describe compositional changes of perennial grasses throughout the growing season. This information, along with seasonal patterns of biomass accumulation (Na et al., 2015a), is valuable for identifying optimum harvest dates and frequencies. The objectives of this experiment were to quantify seasonal changes in i) fiber and nutrient composition of elephantgrass and energycane biomass and ii) leaf proportion and the effect of inclusion of leaf on composition of harvested biomass.

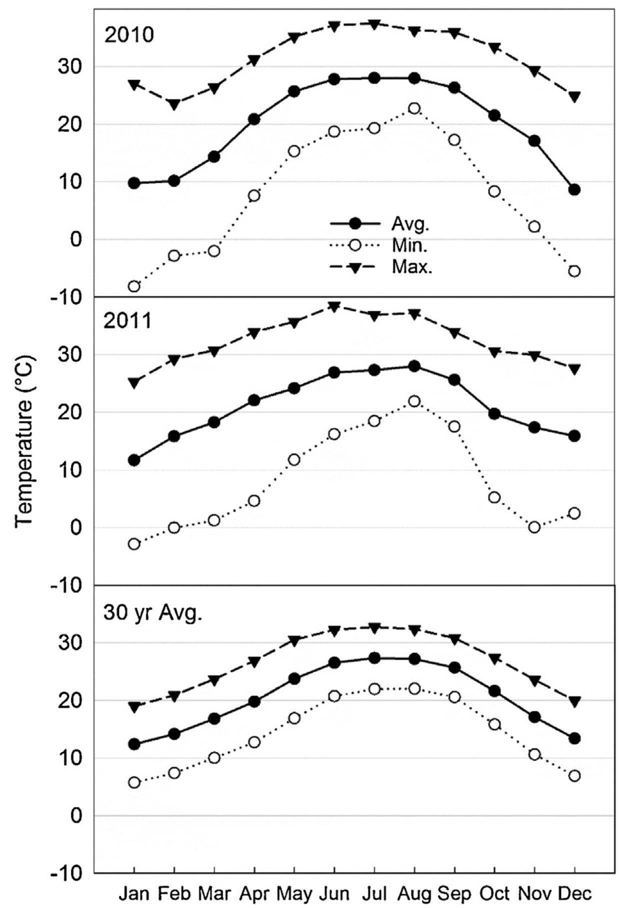

Fig. 1. Monthly mean, maximum, and minimum air temperatures for 2010 and 2011 at the experimental location (Florida Automated Weather Network, http://fawn.ifas.ufl.edu), and the 30-year average for Gainesville, Florida (Florida Climate Center, http://climatecenter.fsu.edu).

2. Material and methods

2.1. Experimental site, treatments, and design

A field experiment was conducted during 2010 and 2011 at the University of Florida Plant Science Research and Education Unit at Citra, Florida (29°24′20″N, 82°08′41″W and 22 m altitude). The soil series was a well-drained Candler sand (hyperthermic, uncoated Lamellic Quartzipsamments) (Soil Survey Staff, 2013). Initial soil characterization of topsoil (0–20 cm) showed an average soil pH of 7.0, and Mehlich-1 extractable P, K, and Mg of 54, 20, and 123 mg kg^{-1}, respectively. These concentrations are considered to be high for P, very low for K, and very high for Mg. Average high, low, and mean temperature (Fig. 1) and monthly rainfall data (Fig. 2) at the experimental location are shown. In 2010, the last freeze event in spring was 7 March (−1.4 °C) and the first freeze event in fall was 2 December (−2 °C). In 2011, the last freeze event in spring was 14 February (-0.9 °C), and the first freeze of the following winter season did not occur until 3 Jan 2012 (−3.0 °C).

Treatments were three grass entries replicated four times in a randomized complete block design (RCBD). The grass entries included two elephantgrasses, 'Merkeron' (Burton, 1989) and a breeding line referred to as UF1, and 'L79-1002' energycane (Bischoff et al., 2008). Merkeron and L79-1002 were chosen because they were the most available and widely used cultivars of these species. In addition, breeding line UF1 elephantgrass was included because in preliminary research it demonstrated outstanding potential as a bioenergy feedstock (Na et al., 2016, 2015a, 2015b; Sollenberger et al., 2014) and may be released as a cultivar.

Propagation materials were collected from an on-site nursery, maintained by Dr. Lynn Sollenberger. Plots contained six rows of 6-m length, with rows spaced 1 m apart. The seedbed was prepared using a moldboard plow and leveling disk. Plots were established using above-ground stem pieces planted on 15 Dec. 2009, 2 wk prior to first freeze (29 December). Mature stems of each grass were cut in 30-cm long pieces that were planted in 8- to 10-cm deep furrows, with stems overlapping 100% (i.e., two stems side by side along the entire length of the furrow). The 2010 data are from the establishment year of the grasses, and 2011 data are from fully established stands. In both years, N was applied as ammonium sulfate at a rate of 150 kg N ha^{-1} yr^{-1}, and K was applied as muriate of potash (KCl) at a rate of 90 kg K ha^{-1} yr^{-1}. Nutrients were side-dressed two times, with applications of 50 kg N and 45 kg K ha^{-1} in mid-April and 100 kg N and 45 kg K ha^{-1} in mid-May. No P was needed based on soil testing. Limited irrigation was applied to the experiment when significant visual drought stress was observed (leaf rolling) associated with rain-free periods of to 2–3 weeks. Water was applied using a traveling gun system; there were five irrigation events (20 May, 29 June, 27 July, 17 September, and 12 October) in 2010 totaling 60 mm and three irrigation events (13 May, 1 and 13 June) in 2011 totaling 50 mm.

2.2. Response variables

Sampling occurred at approximately 8-wk intervals with the exception of the final date. Dates were 9 June, 28 July, 22 September, 8 November, and 8 December 2010, and 1 June, 17 July, 16 September, 10 November, and 13 December 2011. Last sample collection was set to occur within 1 wk of the first freeze event in