Biomass and Bioenergy 80 (2015) 330–337

Contents lists available at ScienceDirect

Biomass and Bioenergy

journal homepage: http://www.elsevier.com/locate/biombioe

Research paper

Effects of delayed winter harvest on biomass yield and quality of napiergrass and energycane

Joseph E. Knoll [a, *], Jennifer M. Johnson [b, 1], Ping Huang [b, 2], R. Dewey Lee [b], William F. Anderson [a]

[a] USDA-ARS, Crop Genetics and Breeding Research Unit, P.O. Box 748, Tifton, GA 31793, USA
[b] University of Georgia-Tifton Campus, Department of Crop and Soil Sciences, 2360 Rainwater Road, Tifton, GA 31793, USA

ARTICLE INFO

Article history:
Received 3 November 2014
Received in revised form
18 June 2015
Accepted 23 June 2015
Available online 1 July 2015

Keywords:
Simultaneous saccharification and fermentation
Cellulosic ethanol
Nitrogen
Cenchrus purpureus (Schumach.) Morrone
Saccharum hyb

ABSTRACT

Napiergrass (*Cenchrus purpureus* (Schumach.) Morrone) and energycane (*Saccharum* hyb.) are perennial grasses that are well-suited for biomass production in the southeastern USA. The purpose of this study was to determine the effects of delayed winter harvest on biomass yield and quality of these grasses. The study was conducted on two adjacent sites near Midville, GA. Each site used a split-plot design with four replications, with species as the main plot, and harvest times (December, January, or February) as subplots. Dry matter (DM) yields were measured by mechanical harvesting, and a sample of biomass was taken from each harvest for determination of ethanol production by simultaneous saccharification and fermentation (SSF). Biomass moisture, N, P, K, and ash mass fractions were also measured. Energycane DM yields were stable from December (46.8 Mg ha^{-1}) to January (42.9 Mg ha^{-1}), but then declined (36.8 Mg ha^{-1}), while napiergrass yields declined sharply from December (47.0 Mg ha^{-1}) to January (35.0 Mg ha^{-1}). Napiergrass moisture mass fraction was reduced by an average of 18% in February harvests compared to December. Mass fractions of N, K, and ash tended to decrease with later harvesting, but sometimes increased due to changes in biomass composition. Delaying harvest of napiergrass from December to January reduced N removal by an average of 144 kg ha^{-1}, while delaying harvest of energycane to February reduced N removal by an average of 54 kg ha^{-1}. In SSF, later-harvested energycane produced less ethanol per unit of DM while napiergrass was less affected by harvest date.

Published by Elsevier Ltd.

1. Introduction

Napiergrass (*Cenchrus purpureus* (Schumach.) Morrone; formerly *Pennisetum purpureum* Schumach.) is a highly productive perennial bunch grass with excellent potential as an energy-producing biomass crop for the southeastern USA [1]. Though it is of tropical origin, several selections have been identified which are able to overwinter successfully in warmer temperate regions where frost kills the above-ground portion of the plant but does not kill the underground rhizomes and roots. The cultivar Merkeron, for example, which was developed at Tifton, GA, has withstood temperatures as low as −18 °C [2]. Energycanes are also highly productive bunch grasses with good biomass potential in this region. As hybrids of sugarcane (*Saccharum* spp.) and related species, they were developed specifically for bioenergy purposes. They tend to have greater cold tolerance, a higher proportion of fiber, and a lower proportion of free sugars in the stems than commercial sugarcanes [3]. Both napiergrass and energycane should be suitable for cellulosic ethanol production or for thermal energy applications, but production systems for these crops are still being developed. Relatively little information is available on how different production practices will affect yields and biomass quality of these grasses for specific applications.

To maximize yield and stand persistence, Calhoun and Prine [4] suggest that a biomass production system utilizing napiergrass should involve a single harvest at the end of the growing season. A

Abbreviations: DM, dry matter; SSF, simultaneous saccharification and fermentation.

* Corresponding author.
E-mail addresses: Joe.Knoll@ars.usda.gov (J.E. Knoll), jmj0027@auburn.edu (J.M. Johnson), pzh0001@auburn.edu (P. Huang), deweylee@uga.edu (R.D. Lee), Bill.Anderson@ars.usda.gov (W.F. Anderson).
[1] Present address: Auburn University, Department of Crop, Soil, and Environmental Sciences, 238 Funchess Hall, Auburn University, AL 36849, USA.
[2] Present address: Auburn University, Department of Entomology and Plant Pathology, 209 Rouse Life Science Building, Auburn University, AL 36849, USA.

http://dx.doi.org/10.1016/j.biombioe.2015.06.018
0961-9534/Published by Elsevier Ltd.

recent study by Na et al. [5] showed that an additional midsummer harvest of energycane or napiergrass is possible, but that the two-harvest system resulted in higher nutrient removal and greater biomass moisture content. The midsummer harvest also caused decreased stand persistence, with energycane showing greater stand reduction than napiergrass. Thus, for both of these grasses, harvest would most often occur in the late fall or winter after active growth has stopped, or after dormancy has been induced by cold temperatures. Over the winter months the standing biomass can be stored in the field, allowing flexibility in harvest timing and utilization of the biomass. Delaying the harvest may offer additional benefits in biomass quality. Late winter or spring harvest has been shown to greatly reduce biomass moisture mass fraction in several perennial species including reed canarygrass (*Phalaris arundinacea* L.) [6,7], switchgrass (*Panicum virgatum* L.) [8], and *Miscanthus* × *giganteus* [9] in colder climates. Knoll et al. [10] however reported only a modest reduction in moisture mass fraction of energycane with late winter harvest in Georgia, USA.

Delayed harvest may also reduce the mass fractions of ash and nutrients such as N and K, which improves the quality of the biomass for combustion [11]. For example, Burvall [12] observed that in spring-harvested reed canarygrass, ash mass fraction tended to decrease and ash fusion temperature tended to increase, indicating an improvement in combustion properties. In the fall during senescence, grasses such as switchgrass [13] and *Miscanthus* [14] actively translocate N into the rhizomes. After senescence, various minerals including K are lost from the standing biomass through leaching and leaf drop [6,8,9,14], which also improves the nutrient efficiency of biomass production.

Despite the potential improvements in biomass quality for combustion, one important disadvantage of delayed harvest of perennial grasses is the high potential for loss of total dry matter yield, primarily in the leaf fraction, during the winter. Winter yield reductions have been reported in reed canarygrass [7,15] and *Miscanthus* [14]. Significant losses were also reported in delayed harvests of switchgrass, primarily due to lodging which hindered mechanical harvesting [8]. However, in that study lodging was primarily due to snowfall over the winter, which is rarely a concern in regions where napiergrass and energycane can be grown. Information is needed for napiergrass and energycane to determine the extent of the tradeoff between improved biomass quality for combustion or fermentation and total dry matter yield losses due to delayed harvest. A recent study by Knoll et al. [10] reported changes in energycane biomass quality with delayed harvest, but yield losses were not quantified due to small plot size. Na et al. [16] recently reported that delayed winter harvest of energycane did not result in significant yield loss, but an average of 30% yield loss was observed for delayed harvest of napiergrass.

The purpose of this study was to determine the effects of delayed winter harvest on the quantity and quality of harvestable biomass of napiergrass and energycane. Cellulosic ethanol production from these grasses harvested at different times was measured directly in the laboratory using a simultaneous saccharification and fermentation (SSF) procedure. The effects of delayed harvest on nutrient removal by these crops were also investigated.

2. Materials and methods

2.1. Experimental design and study site

This study was conducted at the Southeast Georgia Research and Education Center near Midville, GA (32°52′36″N, 82°12′33″W). The soil at this site is a Dothan loamy sand (Fine-loamy, siliceous, thermic Plinthic Kandiudults). On 30 Oct 2008 stem cuttings of napiergrass cultivar Merkeron [2] and energycane L79-1002 [17] were planted horizontally at a depth of 10 cm [18]. The entire field was irrigated during plot establishment, and then the field was divided into two adjacent locations (Site 1 and Site 2). Site 1 was maintained as dryland, while Site 2 received irrigation. Irrigation at Site 2 began in April, around the time the grasses began to show substantial growth, and ended in October. Irrigation was applied at a rate of approximately 19–25 mm per week unless sufficient rainfall was received. From April through November Site 1 received 594, 420, and 722 mm of rainfall in 2010, 2011, and 2012 respectively. Average rainfall for this period is 737 mm at this location [19]. Adding rainfall and irrigation, Site 2 received a total of 945, 958, and 855 mm rainfall equivalent in the 2010, 2011, and 2012 growing seasons, respectively. Nitrogen fertilizer in the form of granular NH_4NO_3 was surface-applied each year in early spring, around the time the grasses began to show new growth, at a rate of 112 kg ha^{-1} of N. In order to simulate a low-input production system, no P or K was applied during the study period.

Each location was laid out in a split plot design with four replications. Species was the main plot, and harvest time was the subplot. Each main plot consisted of eight rows, 9 m long and 1.8 m apart, with the outermost rows serving as borders. Beginning in December 2010 subplots of two rows each were harvested in December, January, or February (Year 1). This was repeated in the winters of 2011–2012 (Year 2) and 2012–2013 (Year 3). All harvests took place after the first killing freeze. Exact harvest dates are shown in Table 1. The biomass was harvested mechanically with a Champion C1200 tractor-mounted forage harvester (Kemper, Stadtlohn, Germany). The fresh yields were recorded using a Cibus TRM tractor-mounted weighing system (Wintersteiger USA, Salt Lake City, UT). A sample (approx. 1 kg) from each subplot was weighed fresh, dried to constant weight in an oven at 60 °C, and weighed again to determine dry matter (DM) and moisture mass fractions. The dried samples were then ground in a Wiley mill to pass a 2-mm screen for further analyses.

2.2. Nutrient analysis of biomass

Mass fractions of nutrients in dried, ground biomass samples were determined at the University of Georgia Agricultural and Environmental Services Laboratories (AESL). Nitrogen mass fraction was determined by dry combustion, and P and K mass fractions by inductively-coupled plasma (ICP) spectrometry. Total nutrient removal was calculated by multiplying nutrient mass fraction by DM yield. Ash mass fraction was determined by weighing a sample of dry biomass, combusting the sample in a Muffle furnace for six hours at 450 °C, and then weighing the remaining ash.

2.3. Biomass pretreatment and simultaneous saccharification and fermentation (SSF)

Conversion of biomass to ethanol was conducted by using a benchtop dilute acid pretreatment and SSF procedure as described by Doran-Peterson et al. [20] with minor modifications. Samples of biomass were dried overnight in an oven at 70 °C to determine exact moisture content to correct for moisture absorbed during storage (usually around 50 g kg^{-1}). Two grams DM were then

Table 1
Dates of first freeze and biomass harvests at Midville, GA over the three-year study.

	Year 1	Year 2	Year 3
First freeze	Nov. 7, 2010	Nov. 11, 2011	Nov. 25, 2012
Harvest 1	Dec. 8, 2010	Dec. 8, 2011	Dec. 19, 2012
Harvest 2	Jan. 14, 2011	Jan. 12, 2012	Jan. 16, 2013
Harvest 3	Feb. 24, 2011	Feb. 8, 2012	Feb. 20, 2013