Biomass and Bioenergy 102 (2017) 44–51

Contents lists available at ScienceDirect

Biomass and Bioenergy

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

Research paper

Biomass yield components for 12 switchgrass cultivars grown in Northern China

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ARTICLE INFO

Article history:
Received 13 July 2016
Received in revised form
19 November 2016
Accepted 1 May 2017

Keywords:
Switchgrass
Cultivars
Biomass yield
Plant height
Tiller
Phytomer

ABSTRACT

Switchgrass (*Panicum virgatum* L.) has been developed into a major herbaceous bioenergy crop for the production of cellulosic biofuels in North America and many counties in European. As cultivar selection has a major impact on the ultimate biomass productivity, we evaluated the adaptability and yield potential of 12 switchgrass cultivars including both upland and lowland ecotypes from 2010 to 2013 in the Beijing region, Northern China. Plant height was measured after anthesis, but phytomer number and tiller density were investigated at harvest. One single autumn harvest was carried out each year and biomass yields were determined. It was found that the lowland cultivars 'Alamo', 'Kanlow' and 'NewYork' produced the most biomass for their better performances in number of phytomers per tiller and mass per phytomer, though upland cultivars had higher tiller density. 'Cave-in-rock' and 'Trailblazer' had better biomass production among the upland cultivars and they were also recommended for planting together with lowland ones for their excellent cold tolerance in this region.

1. Introduction

Switchgrass (*Panicum virgatum* L.), a warm-season C4 perennial bunchgrass, is native to North American grasslands [1]. Being one of the predominant species in tallgrass prairies, switchgrass has traditionally been used as an unmanaged rangeland forage crop [2,3]. Recently, switchgrass has been developed into a major herbaceous bioenergy crop for the production of cellulosic biofuels in North America due to its broad adaptability to diverse growing conditions, high biomass productivity, low nutrient requirement, high water use efficiency, and potential environmental benefits [4–7]. In addition, it is a candidate for cellulosic bioenergy feedstock development in many parts of Europe [8,9].

As a kind of good herbage for soil and water conservation, switchgrass was firstly introduced to the Loess Plateau of China in the 1990s [10]. However, recently it has received increasing attention as a candidate for cellulosic bioenergy feedstock in northern China. Switchgrass adaptability and yield production have been evaluated in marginal land in the arid and semi-arid regions of China, such as Guyuan in Ningxia Province, Dingbian and Yangling in Shaanxi Province, and Ganqika in northeastern Inner Mongolia [10,11]. Switchgrass not only provides a large quantity of lignocellulosic biomass materials but also improves the ecological environment of marginal lands [11]. Use of marginal land for lignocellulose bioenergy production is the most likely option in China, and it is estimated that about 45 million hm^2 of marginal land could be brought into high potential biomass energy production [12]. Therefore, switchgrass has good development potential in China.

Switchgrass has been classified into two main ecotypes based on its morphology and habitat, i.e., upland and lowland [6,13,14]. The upland ecotypes have longer rhizomes and are able to grow in drier and colder zones, such as northern USA or southern Canada, whereas the lowland ecotypes are more adapted for growth in warm, wet conditions; they are taller and more productive than upland ecotypes [1,2,6,15,16]. Lowland ecotypes are primarily tetraploid ($2n = 4x = 36$), whereas upland ecotypes can be hexaploid ($2n = 6x = 54$) or tetraploid but predominantly octoploid ($2n = 8x = 72$) [17–19]. However, there have been no reports of switchgrass cultivars derived from crossing lowland and upland germplasm with different ploidy levels due to their cross incompatibility, and artificial hybridization between tetraploid and octoploid switchgrass cultivars has largely been unsuccessful [20,21]. Previous studies reported that lowland varieties, such as Alamo and Kanlow, generally yield more dry matter than upland ones even under drought stress [8,22], which shows that lowland

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http://dx.doi.org/10.1016/j.biombioe.2017.05.001
0961-9534/© 2017 Published by Elsevier Ltd.

cultivars may have more potential for biomass production.

In this study, we evaluated the adaptability and biomass productivity of 12 upland and lowland switchgrass cultivars in the Beijing region, Northern China, from 2010 to 2013, by analyzing their agronomic traits including plant height, tiller density, number of phytomers per tiller and mass per phytomer, and cultivars with good potential were recommended for this region or regions with similar climates.

2. Materials and methods

2.1. Experimental site

The experiments were conducted from 2010 to 2013 at the National Experimental Station for Precision Agriculture in Xiaotangshan (116°26′E, 40°10′N), a suburb of Beijing, Northern China. This region has a typically warm, temperate and monsoon climate. It has a mean temperature of 12–17 °C, average rainfall of 640 mm (80% occurring between June and August), active accumulated temperature (≥10 °C) of 4200 °C per year, and a frost-free period of 190 days from mid-April to mid-October. The soil in this area contained 44% sand, 31.2% silt and 24.8% clay (Fluvisols, according to FAO soil classification) [23]. The pH was 7.6, and the soil had 1.5% organic matter, 84.0 mg·kg^{-1}alk-hydro N, 16.5 mg kg^{-1} available P and 129.0 mg kg^{-1} available K. Before planting, the top soil (0–20 cm) of each plot was sampled for analysis.

2.2. Plant materials and experimental design

12 cultivars of switchgrass were included in the study and they were ‘Alamo’, ‘Kanlow’, ‘NewYork’, ‘Ranlow’, ‘Rise’, ‘Ansai’, ‘Japan’, ‘Forestburg’, ‘Pathfinder’, ‘Blackwell’, ‘Trailblazer’ and ‘Cave-in-Rock’, as shown in Table 1.

Seedlings of the 12 cultivars were first cultured in a greenhouse in the early spring of 2010, and they were transplanted into field plots in mid-May. The plots were arranged in a complete randomized block design with four replicates. Each plot was 8 m in length and 5 m in width, consisting of 7 rows with a planting space of 0.8 m.

The plots were irrigated as necessary during the first year to ensure establishment, but they were not irrigated in the following years. A basal fertilizer with the equivalent of 150 kg ha^{-1} of N, P, K fertilizer (15-15-15) was applied, followed by a urea application (150 kg ha^{-1}) in mid-June for plant establishment. Thereafter, only 150 kg ha^{-1} urea was applied once a year during the booting period.

2.3. Sampling and data collection

At the end of each November from 2010 to 2013, the stems of the switchgrass cultivars had fully senesced, though the stems of the lowland varieties, Alamo, Kanlow and NewYork, had been killed by frost. Two rows from the center of each plot were harvested for biomass yield at 10-cm stubble height. Fresh weight was measured and recorded, a representative subsample (about 3000 g) was collected from each plot, the subsamples were weighed and dried in an oven at 50 °C for 72 h to determine the dry weight and moisture contents, and then the dry matter yield for each plot was calculated. Plant height was measured in situ after anthesis, but phytomer number and tiller density were determined at harvest. 12 plants were selected randomly from each plot for the determination of plant height. Subsamples of twenty tillers with uniform size were selected for the estimation of mean number of phytomers per tiller and mean dry matter per phytomer.

Table 1
Sources and origins of twelve switchgrass cultivars used in this study.

Cultivars	Ecotype	Ploidy	Origin
Alamo	Lowland	Tetraploid (4n)	South Texas 28°
Kanlow	Lowland	Tetraploid (4n)	Central Oklahoma 35°
NewYork	Lowland	Tetraploid (4n)	–
Ranlow	Upland	Tetraploid (4n)	–
Rise	Upland	Tetraploid (4n)	–
Ansai	Upland	Tetraploid (4n)	–
Japan	Upland	Tetraploid (4n)	–
Forestburg	Upland	Tetraploid (8n)	South Dakota 44°
Pathfinder	Upland	Tetraploid (8n)	Nebraska/Kansas 40°
Blackwell	Upland	Octoploid (8n)	Northern Oklahoma 37°
Trailblazer	Upland	Octoploid (8n)	Nebraska 40°
Cave-in-Rock	Upland	Octoploid (8n)	South Illinois 38°

2.4. Data analysis

Data (mean biomass per square meter, mean number of tillers per square meter, mean number of phytomers per tiller, and mean dry matter per phytomer) were log transformed to create an additive relationship for the multiplicative yield component model, yield (g m^{-2}) = tillers plot^{-1} × phytomers tiller^{-1} × g phytomer^{-1}, which was employed for analysis with stepwise multiple linear regression [24]. Linear correlation between agronomic traits, path coefficients, and linear correlation coefficients between biomass and each yield component were calculated and analyzed according to Boe and Beck [24]. All statistical analyses were performed and box plots were generated using JMP software (SAS Institute, Cary, NC, USA).

3. Results

3.1. Biomass yields

All of the 12 switchgrass cultivars had a low biomass yield, with an average dry matter yield of 3.70 t/ha, in the first year. The dry matter yield rapidly reached 11.09 t/ha and 23.50 t/ha rapidly in 2011 and 2012, respectively. However, the biomass yield began to decline from the fourth year (Fig. 1A). The switchgrass cultivars differed significantly with respect to dry matter yield (Fig. 1B), and the differences were obvious in the planting year. The lowland cultivar ‘Alamo’ had the highest biomass production with an average dry matter yield of 27.23 t/ha (2010–2013), followed by ‘Kanlow’, with an average dry matter yield of 17.54 t/ha. Among the upland cultivars, ‘Cave-in-rock’ and ‘Trailblazer’ had the most biomass production with an average dry matter yield of 15.14 t/ha and 15.04 t/ha, respectively. The upland cultivar ‘Ranlow’ had an average dry matter yield of only 8.96 t/ha, which was the lowest among the cultivars (Fig. 1B). The biomass yield of the lowland cultivars was significantly higher than that of the upland cultivars, and the trend was consistent from 2010 to 2013 (Fig. 1C).

Varieties that originated from low latitude areas showed higher mean biomass yield from 2010 to 2013 compared with the cultivars that originated from high latitude areas (Fig. 2A). There was a significantly negative correlation between the biomass yield and the latitude of origin for the tested cultivars in the Beijing region (Fig. 2B).

3.2. Plant height

In the Beijing region, changes in switchgrass plant height were quite evident among the four years, with the average plant height ranging from 140.1 cm to 213.1 cm (Fig. 3A). The tallest plants were developed in the third growing season. A similar plant height was recorded in the fourth growing season. There were large variations