Field Crops Research 227 (2018) 144–154

Contents lists available at ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

Establishing sustainable sweet sorghum-based cropping systems for forage and bioenergy feedstock in North China Plain

Chao-Chen Tang[a,b], Xiao-Lin Yang[a,b,*], Guang-Hui Xie[a,b,*]

[a] College of Agronomy and Biotechnology, China Agricultural University, Beijing 100193, China
[b] National Energy R&D Center for Non-food Biomass, China Agricultural University, Beijing 100193, China

ARTICLE INFO

Keywords:
Monoculture
Double cropping system
Dry biomass yield
Theoretical ethanol yield
Chemical composition

ABSTRACT

Sweet sorghum [*Sorghum bicolor* (L.) Moench] offers a sustainable and renewable bioenergy resource for feed and biomass production. Two separate field experiments were conducted on arable land at Shangzhuang Station and on saline-alkali land at Quzhou Station in the North China Plain. Three cultivars of sweet sorghum including early- (ZS1) (114 days), medium- (CT2) (138 days), and late-maturity (LN3) (160 days), were sole cropped on arable land in 2006–2007. Using the same cultivars, sweet sorghum based - double cropping systems with winter wheat rotation were analyzed on saline-alkali land in 2009–2011. This study aims to determine the planting potential of three sweet sorghum cultivars and develop an optimized sweet sorghum - based double cropping system on saline-alkali land to maximize the production outputs. The aboveground biomass yield, energy output, theoretical ethanol yield (TEY), and chemical composition of three sweet sorghum cultivars - based cropping systems were assessed. Results indicate that: (1) the annual average dry biomass yield and dry matter content of the three sweet sorghum cultivars showed an overall uptrend with the increasing crop growth length. The average dry biomass yield of three sorghum maturity groups on arable land were 48.9% higher than that on saline-alkali land. (2) Sweet sorghum cultivars of late- (LN3) and medium- maturity (CT2) displayed better chemical composition for both bioenergy utilization (higher starch, soluble sugar, cellulose and hemicellulose and lower ash) and forage quality (better relative feed value (RFV) and lower acid detergent fiber (ADF) and neutral detergent fiber (NDF)). (3) The double cropping system of medium-maturity sweet sorghum (CT2) and winter wheat presented the best total dry biomass yield (24.9 t ha^{-1}), energy output (394.6 GJ ha^{-1}), and theoretical ethanol yield (6857 L ha^{-1}). Therefore, this double cropping system can be recommended for extensive planting in the North China Plain for bioenergy or forage production.

1. Introduction

Sweet sorghum (*Sorghum bicolor* (L.) Moench) is suggested to be an ideal non-food crop for the production of feedstock and bioethanol (Rooney et al., 2007; Fertitta-Roberts et al., 2017). Compared with other competing crops (Yu et al., 2008), sweet sorghum offers a better energy balance and exhibits great bioenergy potential (Zhou and Thomson, 2009) due to its advantageous properties. Such advantages include low input requirements (Teetor et al., 2011), wide adaptability (Vasilakoglou et al., 2011), remarkable biological productivity with adequate soluble (glucose and sucrose) and insoluble (cellulose and hemicellulose) carbohydrates (Zhao et al., 2009; Cifuentes et al., 2014), and short lifecycle (3–5 months). In addition, sweet sorghum bagasse with leaf residues after juice extraction for bioethanol production can be used as a major complete feed component, which could mitigate feed shortage (Anandan et al., 2012). Sweet sorghum as a diverse feedstock supply is crucial to address the increasing concerns of forage scarcity and energy shortages in China.

Extensive researches have been done on the potential of sweet sorghum for forage or bioenergy production and have recognized the crop as one of the most promising feedstock (Cutz et al., 2013; Dar et al., 2018; Tang et al., 2018a). For instance, Tew et al. (2008) suggested that sweet sorghum grown for ethanol production could serve as a complementary crop by generating additional revenue for food crop producers. Zhao et al. (2009) reported that sweet sorghum exhibited a high aboveground dry biomass yield of 35.2 t ha^{-1} on cropland. Linton et al. (2011) reported that sweet sorghum production costs were consistently lower compared with competing crops, such as maize (*Zea*

* Corresponding authors at: College of Agronomy and Biotechnology, China Agricultural University, No. 2, Yuanmingyuan West Road, Haidian District, Beijing 100193, China.
E-mail addresses: yangxiaolin429@163.com (X.-L. Yang), xiegh@cau.edu.cn (G.-H. Xie).

https://doi.org/10.1016/j.fcr.2018.08.011
Received 18 April 2018; Received in revised form 11 August 2018; Accepted 16 August 2018
0378-4290/

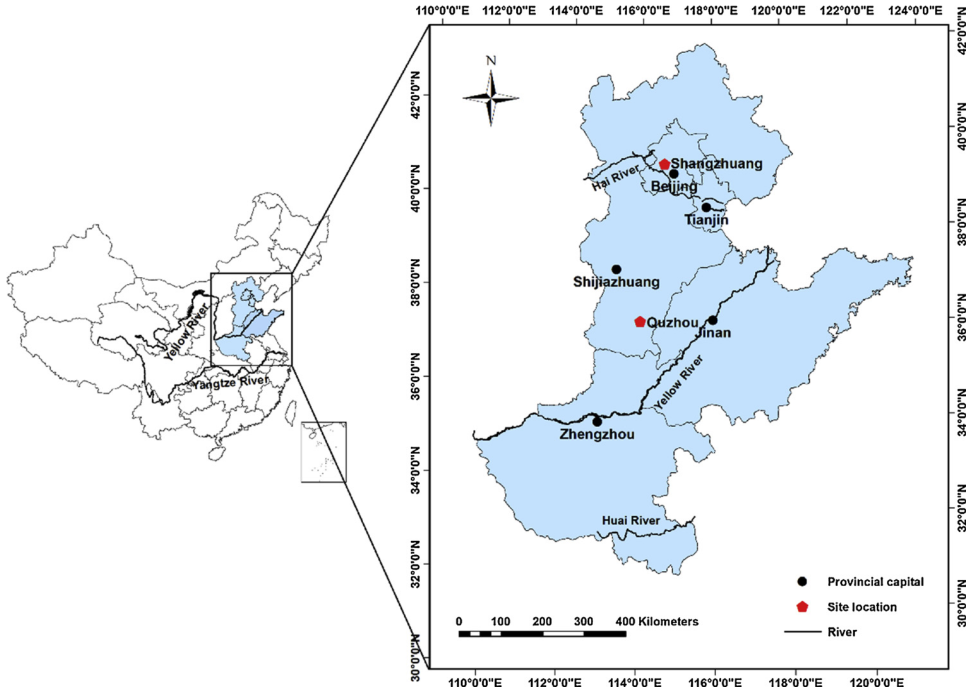

Fig. 1. The locations of Shangzhuang Experimental Station (SES) and Quzhou Experimental Station (QES).

mays L.), cotton (*Gossypium hirsutum* L.), and soybean (*Glycine max* (L.) Merr.), based on the economic feasibility analysis of producing sweet sorghum as an ethanol feedstock in the southeastern United States. Qu et al. (2014) demonstrated that sweet sorghum, which has stable nutritive value and allows multiple harvests, appears promising as an alternative silage crop compared with maize in the relatively humid climates of eastern China. Liu et al. (2015) suggested that sweet sorghum exhibited a better energy crop return to scale on investment than cotton and sunflower (*Helianthus annuus* L.) in northern China. However, due to China's limited arable land resources, bioenergy feedstock production has been restricted to marginal land such as saline-alkali land and/or low-quality land to avoid land use competition with food crops (Zhuang et al., 2011).

Previous studies suggest that sweet sorghum exhibits a good biomass yield and forage quality, due to its superior adaptability to marginal land conditions (Tang et al., 2017), and could replace maize as a livestock feed (Zerbini and Thomas, 2003; Li et al., 2015; Mishra et al., 2016). Tian et al. (2009) reported that the cultivation of sweet sorghum on non-arable lands with high outputs is the most current, auspicious solution to mitigate China's energy shortages. Ren et al. (2012) discovered that sweet sorghum had a lower energy input requirement and higher energy productivity than cotton and maize on the coastal saline-alkali lands in the northern China. Moreover, Vries et al. (2010) reported that sweet sorghum exhibited good sustainability for forage and bioenergy production in China. It should be noted that sweet sorghum was planted as the sole crop each year in the abovementioned previous studies (Linton et al., 2011; Qu et al., 2014; Maw et al., 2017). Considering the concerns of limited arable land, forage scarcity and energy shortages in China, it is urgent to establish sustainable diversified crop rotations that involve sweet sorghum to improve the efficiency of land use and crop production.

Previous literature reported that rotating sweet sorghum in cropping systems presented numerous benefits (Zegada-Lizarazu and Monti, 2011; Cutz et al., 2013; Grass et al., 2013; Borrelli et al., 2014). The cultivation of sweet sorghum as a rotation crop to fill the idle time during the sugarcane off-season in Central America could help to implement and maintain a sustainable ethanol program (Cutz et al., 2013). Zegada-Lizarazu and Monti (2011) reported that the combination of conventional crop (wheat (*Triticum aestivum* L.), maize) and new energy crop species (sweet/fiber sorghum) in rotation in the southern areas of Europe would reduce the dependence on external inputs. Such rotation would promote nutrient cycling efficiency, improve natural resources use efficiency (especially water use efficiency), maintain the long-term land productivity, and consequently increase crop yields and sustainability of production systems (Borrelli et al., 2014). A study conducted at seven sites in Germany found that energy crop production in double cropping systems had mostly higher yield stability compared with sole cropping systems (Grass et al., 2013).

To date, sweet sorghum cultivation is not well developed for bioethanol feedstock or forage use in rotation system in the North China Plain. It has a warm, temperate zone, semi-humid, monsoon climate and 60–70% of precipitation is concentrated from July to September. Winter wheat-summer maize double cropping system is the dominant cropping system in this area and accounts for 61% of the nation's wheat and 45% of maize yields (Yang et al., 2017). Considering that sweet sorghum as a thermophilous crop is similar to corn and has two main usages as feedstock of bioenergy and forage stated above, it is of high significance to establish and evaluate the sustainability of sweet sorghum - based cropping systems, including its biomass yield and quality, bioethanol yield, and energy output in the North China Plain.

The specific objectives of this study were (1) to clarify the changes in dry biomass yield and chemical composition of early-, medium-, and late-maturity cultivars of sweet sorghum grown on semi-humid arable land and saline-alkali land; (2) to evaluate the energy output and bioethanol potential of various sweet sorghum - based double cropping systems on saline-alkali land; and (3) to provide a feasible cropping system for sweet sorghum as a forage and bioenergy resource in the North China Plain.

2. Materials and methods

2.1. Site description

Two field experiments were conducted at the Shangzhuang Experimental Station (SES), Beijing (40°13´N, 116°17´E) in 2006–2007 and at the Quzhou Experimental Station (QES), Hebei (36°85´N,