Field Crops Research 215 (2018) 12–22

Contents lists available at ScienceDirect

Field Crops Research

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

# Sorghum biomass and quality and soil nitrogen balance response to nitrogen rate on semiarid marginal land

Chaochen Tang[a,b], Xiaolin Yang[a,b,*], Xu Chen[a,b], Asif Ameen[a,b], Guanghui 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:*
Sweet sorghum
Biomass sorghum
Quality components
Theoretical ethanol yield
Net soil nitrate accumulation

ABSTRACT

An understanding of biomass yield and quality response to N supply is essential to breeding and cultivation of sorghum (*Sorghum bicolor* (L.) Moench) for the production of bioethanol or forage. A two – year field experiment was conducted in 2013 and 2014 on semiarid marginal land in Inner Mongolia (39°10′N, 109°53′E) to determine the effects of N fertilizer rate (0, 60, 120, and 240 kg ha$^{-1}$) on biomass yield and quality of sweet sorghum (GT-8) and biomass sorghum (GN-11), and on soil conditions. Results indicated that (1) biomass yield, leaf/stem ratio, and crude protein (CP), protein yield, theoretical ethanol yield (TEY), and soil net $NO_3^-$-N accumulation of both sorghum varieties in 2013 and 2014 significantly increased with the increasing N fertilizer rate from 0 to 240 kg ha$^{-1}$, whereas dry matter ratio and relative feed value (RFV) varied inversely with the N application rates. (2) Compared to biomass sorghum (GN-11), sweet sorghum (GT-8) demonstrated significant enhancement of forage quality components including CP, dry matter digestibility (DMD), dry matter intake (DMI), total digestible nutrients (TDN), net energy for lactation ($NE_L$), and RFV, with stems exhibiting higher forage quality than leaves. Biomass sorghum (GN-11) exhibited better performance for bioenergy production, with an average biomass yield of 7.9 t ha$^{-1}$ and TEY of 3046.7 L ha$^{-1}$ averaged across all N rates. (3) Annual average amount of net $NO_3^-$-N accumulation in 0–90 cm layers of two years significantly increased when fertilizer N exceeded 120 kg N ha$^{-1}$. In short, N fertilizer of 60 kg ha$^{-1}$ is recommended to sweet sorghum for the forage production and 120 kg N ha$^{-1}$ to biomass sorghum for bioenergy feedstock sustainability, respectively, meanwhile to prevent the soil degradation on semiarid marginal lands.

## 1. Introduction

Sweet sorghum and biomass sorghum have recently been viewed as the ideal candidate feedstock crops for generation of both forage and non-food bioethanol. These crops have low input requirements and are particularly well-adapted to marginal growth conditions such as water deficits, salinity, alkalinity, and other constraints (Rooney et al., 2007; Teetor et al., 2011; Vasilakoglou et al., 2011; Qu et al., 2014). Bioenergy developed from sweet and biomass sorghum has played an important role in contributing to the overall energy supply, while concurrently reducing carbon dioxide ($CO_2$) emissions (Zhou and Thomson, 2009). Zhang et al. (2010) reported that 78.6 × $10^4$ ha of marginal land was available for large scale cultivation of sweet sorghum in China. Meanwhile, the shortage of forage, especially green fodder and roughage, has become a limiting factor for the sustainable management of China's livestock industry (Zhang et al., 2017).

Due to China's limited cultivatable land resources, biofuel feedstock production has been limited to marginal lands to avoid land-use competition with food crops to maintain greater food security (Tang et al., 2010; Cai et al., 2011; Zhuang et al., 2011). Previous studies reported that sorghum exhibits a good biomass quality and could replace corn as livestock feed due to sorghum's superior adaptability to semiarid marginal land conditions (Zerbini and Thomas, 2003; Li et al., 2015; Mishra et al., 2016). Thus, the cultivation of sweet sorghum and biomass sorghum on marginal lands with minimal inputs and high outputs is currently the most auspicious solution to overcome both China's energy shortages as well as the country's forage scarcity (Tian et al., 2009). Soil fertility management is considered important to facilitate the rapid development of sorghum cultivation on marginal lands (Anderson et al., 2013).

Nitrogen (N), the main nutrient for $C_4$ plant productivity (Hao et al., 2014), plays a critical role in cell division during the plant growth (Stals and Inzé, 2001). Previous studies have shown that the N deficit of marginal land soils leads to lower sorghum biomass due to reductions in leaf area, chlorophyll index, and photosynthetic rate (Zhao et al., 2005; Hirel et al., 2007; Mahama et al., 2014). While addition of N fertilizer is

* Corresponding author at: College of Agronomy and Biotechnology, China Agricultural University, No. 2, Yuanmingyuan West Road, Haidian District, Beijing 100193, China.
*E-mail address:* yangxiaolin429@163.com (X. Yang).

http://dx.doi.org/10.1016/j.fcr.2017.09.031
Received 14 August 2017; Received in revised form 22 September 2017; Accepted 25 September 2017

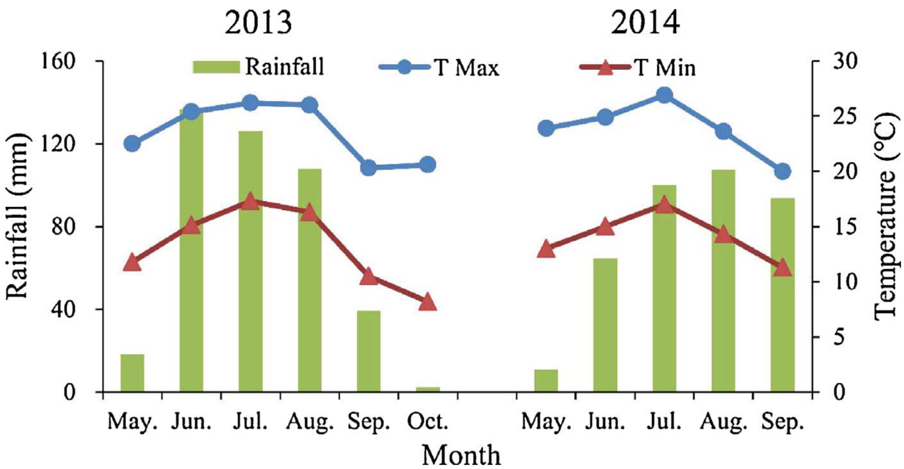


**Fig. 1.** Monthly precipitation and temperature during the growing seasons in 2013 and 2014 at the study site.

known to boost the aboveground biomass yield (Amaducci et al., 2004; Anderson et al., 2013), N fertilizer overuse resulted in genitive environmental impacts, such as the pollution by nitrate ($NO_3^-$-N) leaching and nitrous oxide ($N_2O$) emissions (Miller and Cramer, 2004; Ramu et al., 2012), as well as increasing production costs (Marsalis et al., 2010). Thus, coordination of sorghum N demand with N supply is critically important to maximize economic efficiency, optimize biomass quality, and minimize loss of soil $NO_3^-$-N and environmental pollution (Schroder et al., 2000; Zhu et al., 2000; Rooney et al., 2007; Cui et al., 2008; Meki et al., 2017).

Previous studies of biomass yield and bioethanol production of sweet sorghum have exhibited considerable variation in the optimum N rates found. For example, Adams et al. (2015) reported that the application of 70 kg N $ha^{-1}$ was sufficient to achieve an optimal total biomass yield of 20.8 t $ha^{-1}$ of sweet sorghum on sandy land in Florida. In an earlier study, Tamang et al. (2011) had reported that the optimal N fertilizer rate to achieve the highest total dry matter and bioethanol yields was 108 kg N $ha^{-1}$ for four sorghum varieties grown in Texas on sandy clay loam soil. Maw et al. (2016) demonstrated that the dry matter and theoretical bioethanol yields of sweet sorghum were significantly influenced by the N treatments, with corresponding maximum values of about 19.7 t $ha^{-1}$ and 7488 L $ha^{-1}$, respectively, at an N rate of 168 kg N $ha^{-1}$ in central Missouri on a silt loam soil. Kurai et al. (2015) reported that sweet sorghum grain and stalk yields increased with N fertilizer rate, but increased significantly only up to 90 kg N $ha^{-1}$ in a semiarid climate. Aboveground biomass yield of sorghum was reported to be less than 5.0 t $ha^{-1}$ in semiarid tropics when no N fertilization was applied (Kurai et al., 2015).

Following another way to measure cropping results, previous studies have provided the valuable information relating to biomass quality of various sorghum cultivars (Oliver et al., 2005; Bean et al., 2013). In these studies, N fertilization had a significant impact on the crude protein (CP) content and CP yield (Anfinrud et al., 2013), mirroring results of Hoffman et al. (2001), which indicated that N applications of 120–240 kg N $ha^{-1}$ boosted feed CP content to higher levels to support rapid weight gains and milk yields. In contrast, other studies of sorghum grown on agricultural land demonstrated that N fertilization had no significant effect on quality components, including non-structural carbohydrate content, neutral detergent fiber (NDF), acid detergent fiber (ADF), cellulose, hemicellulose, lignin, and net energy for lactation ($NE_L$) (Amaducci et al., 2004; Marsalis et al., 2010; Anfinrud et al., 2013). However, N fertilizer did significantly influence soil $NO_3^-$-N accumulation (Liu et al., 2003; Sharma et al., 2012), which is important because soil $NO_3^-$-N is the primary form of N absorbed by plants and represents soil N supply capacity (Nelson and Selby, 1974; Zhu and Chen, 2002; Shi et al., 2012). Hao et al. (2014) reported that 20%-50% of soil $NO_3^-$-N was taken up by crops at an optimal N rate. Bring in an additional dimension, Barbanti et al. (2006) reported that a concentration of soil $NO_3^-$-N of 58.9 g $cm^{-3}$ was found in leach water within a 0–90 cm soil depth across N applications of 0–120 kg $ha^{-1}$ during monitoring for a period of two years.

Overall, N application recommendations are influenced by plant genotype, soil nutrient supply capability, and water supply, as well as by the intended use of the crop (Barbanti et al., 2006; Tamang et al., 2011; Erickson et al., 2012; Holou and Stevens, 2012). However, reports of the optimized N applications for biomass sorghum have been rare. Furthermore, little is known about biomass quality of sweet sorghum and biomass sorghum planted on marginal land soils. Therefore, in this work we explored the effect of N management on sorghum biomass yield and quality, as well as on soil $NO_3^-$-N accumulation during sorghum growth on marginal land. The specific objectives of this study were (1) to evaluate the biomass yield and quality of sweet sorghum and biomass sorghum in responses to various N application rates; (2) to optimize N fertilizer rate for bioethanol and forage production; and (3) to examine the effects of N fertilization rates on soil $NO_3^-$-N accumulation during cultivation of two sorghum varieties on marginal land.

## 2. Materials and methods

### 2.1. Experiment site

A two year field experiment was conducted on a sandy abandoned in Ordos (39°10′N, 109°53′E), Inner Mongolia in North China in 2013 and 2014. The site is characterized by a semiarid climate typical of the region's marginal lands and is suitable for large scale sorghum planting for either bioethanol biomass (Zhang et al., 2010) or livestock forage production (Wang et al., 2011). The annual mean precipitation is 348.3 mm (of which 70% occurs from July to September) with the potential evaporation of 2506 mm. The annual average temperature (T) is 6.2 °C, with a monthly minimum of −13 °C in January and a maximum of 38 °C in July. The frost-free period ranges from 130 to 160 days. The monthly precipitation and temperature at this site during the sweet and biomass sorghum growing periods were collected from a nearby meteorological station and are shown in Fig. 1. The soil type at the experimental site is typically sandy (approximately 90%) with a pH of 8.0, salt content of 2.1 g $kg^{-1}$, organic matter content of 0.7 g $kg^{-1}$, total nitrogen content of 0.5 g $kg^{-1}$, available phosphorus of 6.2 mg $kg^{-1}$, and available potassium of 54.7 mg $kg^{-1}$ within the top 30 cm soil depth after averaging values for both experimental years (Table 1). No previous crop had been planted on this land before this experiment began.