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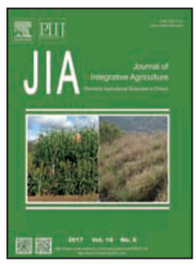

REVIEW

Switchgrass as a bioenergy crop in the Loess Plateau, China: Potential lignocellulosic feedstock production and environmental conservation

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Abstract

A large portion of the Loess Plateau of China is characterized as “marginal” with serious land degradation and desertification problems. Consequently, two policies, Grain for Green and Western Development Action were established by the Chinese government in response to the demand for ecological protection and economic development in the Loess Plateau. These policies are designed to increase forest cover, expand farmlands, and enhance soil and water conservation, while creating sustainable vegetation restoration. Perennial grasses have gained attention as bioenergy feedstocks due to their high biomass yields, low inputs, and greater ecosystem services compared to annual crops. Moreover, perennial grasses limit nutrient runoff and reduce greenhouse gas emissions and soil losses while sequestering carbon. Additionally, perennial grasses can generate economic returns for local farmers through producing bioenergy feedstock or forage on marginal lands. Here, we suggest a United States model energy crop, switchgrass (*Panicum virgatum* L.) as a model crop to minimize land degradation and desertification and to generate biomass for energy on the Loess Plateau.

Keywords: sustainability, bioenergy crop, soil erosion, Loess Plateau, switchgrass

1. Introduction

The Loess Plateau is a region in North-Central China (Yan *et al.* 2014) that spans seven regions: Gansu, Henan, Inner Mongolia, Ningxia, Shaanxi, Shanxi, and Qinghai (Ichizen *et al.* 2005; Ma *et al.* 2011). The Loess Plateau is located in the northern part of the country, from 34° to 41°N latitude, and 103° to 113°W longitude (Zhu *et al.* 1983). The climate of the Loess Plateau fluctuates, partially due to the extreme changes in elevation and landscapes that include peaks, terraced areas, and valleys (Xie *et al.* 2016). The Loess Plateau is named for its predominant soil type, as a majority of the area is composed of deep, dense loess soil (Yan *et al.* 2014).

Agriculture has been a key part of the Loess Plateau for over 6 000 years and agricultural land makes up 75% of the Loess Plateau, including cultivated land, garden

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plots, forestland, and grassland regions (An *et al.* 2014). Approximately 70% of agricultural land is on a substantial slope, which leads to erosion and poses a major challenge for Loess Plateau agriculture (An *et al.* 2014). Poor management of the Loess Plateau over the years has led to lower agricultural productivity, and limited pasture for grazing animals in the region (Yamamoto and Endo 2014).

Erosion is a major problem in the Loess Plateau. In fact, erosion is so intense that approximately 1.32 billion tons of silt from farmlands reach the rivers each year (Li 2004). In alternative terms, the average annual soil erosion rate was 3 355 Mg km^{-2} yr^{-1} in 2010. Annually, 60% of the plateau experiences some degree of erosion, with the average erosion rate being 1 cm yr^{-1} (Zheng and Wang 2014). The high erosion rates are a result of the combination of farming on steep slopes and the fact that loess soil induces water runoff, as its low permeability creates a hardened, water resistant surface (Yamamoto and Endo 2014; Zheng and Wang 2014). Both wind and water contribute to soil erosion in the Loess Plateau (Zheng and Wang 2014). Current crop production practices may contribute to the erosion issues, as approximately three-fourths of the agricultural production land utilizes deep plowing as the predominant tillage method. Additionally, ground can remain uncovered for three to eight months due to cycles of crop production (An *et al.* 2014). An alternative approach that would minimize erosion is to establish perennial biomass crops in areas that are susceptible to erosion and lower productivity. According to results of U.S. field research, establishment of perennial biomass crops could reduce soil erosion relative to conventional annual crops (Cook and Beyea 2000). Therefore, China could make use of perennial energy crops for energy security and soil preservation in the Loess Plateau (Liu *et al.* 2016).

In 1999, the Chinese government created the Grain for Green Program in an attempt to address the challenges faced by Loess Plateau farmers and the high rate of erosion in the region; the policy was updated in 2002 (Li 2004; An *et al.* 2014). Under the policy, the government provides subsidies to farmers in the affected areas if they agree to convert croplands into grasslands, forest areas, or fruit tree crops, creating a more permanent vegetation to help slow erosion rates (Li 2004). The policy led to the conversion of 7.7 million ha of highly erodible farmland to permanent vegetation nationwide between 1999 and 2002 (Li 2004).

China has been experiencing rapidly increasing demands for energy as a result of exponential economic growth since 2002 (Nakada *et al.* 2014). For example, China burned 2.2 billion tons of coal in 2005 alone (Editorial Committee of China Energy Yearbook 2005–2006). Currently, coal makes up 70% of the energy used in China, creating air pollution that impacts the overall air quality (Chan and Yao 2008). In order for China to meet its growing energy needs and to help air quality, investments have been made in alternative energy, including one of the world's largest biomass power plants located in China, built in 2012 (Nakada *et al.* 2014). Such infrastructure will require a stable supply of biomass feedstock, such as perennial energy crop. A perennial energy crop as an alternative feedstock needs to provide environmental benefits while offering similar or better economic feasibility than fossil fuels and must be available in quantities large enough to provide a net energy gain (Hill *et al.* 2006). For example, in the U.S., the Renewable Fuel Standard 2 set a goal of producing 80 billion liters of advanced biofuels which reduces greenhouse gas emissions by 50% relative to fossil fuels (75 FR 14670; EPA 2010).

In an attempt to proactively address these issues on the Loess Plateau, the governments of Shaanxi and Gansu provinces have announced and implemented similar policies called Planning for the Development of Bioenergy in Rural Areas from 2007 to 2020 and 2011 to 2015, respectively. Both policies mentioned are utilizing biomass-based materials for energy production in rural areas (Shaanxi Province Development and Reform Commission 2007). As of 2010, in the Gansu Province, grass- and stover-based biomass material only accounted for 4.5% of the "wood fuel" resource, and "wood fuel" accounted for 14.5% of the total household energy consumption (Gansu Rural Energy Office 2010). According to the Gansu Province policy, within five years, development of bioenergy, together with solar energy, was projected to enhance the efficiency of energy usage by 5% (Gansu Rural Energy Office 2010). With clean conversion technologies, establishing dedicated bioenergy crops such as switchgrass (*Panicum virgatum* L.) on marginal and convertible (i.e., Grain for Green) areas in the Loess Plateau could provide biomass material to meet the target goals and provide extra income for local farmers (State Forest Bureau 2011; National Development and Reform Commission 2012).

The purpose of this review is to provide a summary of current switchgrass research, and to apply findings from around the world to the Loess Plateau. This report will give a foundation for future research regarding switchgrass for biomass production on the Loess Plateau. The topics covered will assist with selecting appropriate genetic resources, such as cultivars for specific environmental conditions, agronomic management of the crop for successful establishment, an overview of benefits for the environment, with the ultimate goal of maximizing biomass yield and profits while preserving and improving soil quantity and quality.

2. The Loess Plateau region

2.1. Landscape and geology

The Loess Plateau spans a region of more than 60 million