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Assessment of the production potentials of *Miscanthus* on marginal land in China

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ABSTRACT

Miscanthus is characterized by high biomass production potential and low input requirements and therefore considered a leading candidate for second-generation energy crops. Because China has limited agricultural land resources, development of its miscanthus-based bioenergy industry must rely on the use of marginal land. This study focuses on the assessment of the production potential of miscanthus on China's marginal land, which in this context is defined as land presently not used for agricultural production, residential purposes and other social uses. Geographic Information System (GIS) techniques and model simulation are adopted to identify the productive marginal areas for miscanthus and to estimate their biomass and bioenergy production potential. The results show that although a large marginal area of $17{,}163.54 \times 10^4$ ha is available for producing miscanthus, due to the limitation of low winter temperatures and low precipitation levels in some areas, the total suitable marginal area is only 769.37×10^4 ha. The Monteith radiation yield model was used to determine the potential miscanthus yield in Chinese climatic conditions. The simulation gave actual harvestable yield levels on arable land of 18.1–44.2 t ha^{-1} yr^{-1}. Taking the environmental stresses of marginal conditions into account then gave an achievable miscanthus yield potential on marginal land of 2.1–32.4 t ha^{-1} yr^{-1} (average for the different marginal lands). Based on these achievable yield levels, the total biomass production potential on the entire marginal area is $13{,}521.7 \times 10^4$ t yr^{-1}; the bio-electricity generation and total greenhouse gas saving potential from these biomasses are 183.9 TW h yr^{-1} and $21{,}242.4 \times 10^4$ t CO_2 eq. yr^{-1}, respectively. The spatial distribution of the suitable marginal areas shows that they are mainly concentrated in the central part of Northeast China and the Loess Plateau. Both regions are recommended as priority development zones for the Chinese miscanthus-based bioenergy industry.

Contents

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1. Introduction

The substitution of fossil energy by bioenergy is a promising and multifunctional way to protect national energy security, slow down climate change and improve rural economy [1]. This is also of great interest and significance for China, which has a large gap between the demand for and supply of fossil energy. Additionally, bioenergy development is also considered a new way to promote rural economic development in China [2,3]. Hence, the Chinese government has gone to great effort to advance its bioenergy industry. In the past decade, the Chinese bioenergy market has been dominated by bio-ethanol produced from grains that had been stored for more than 3 years [4,5]. In 2008, approximately 1.5 million tons bio-ethanol were produced from maize and wheat, accounting for 79% of total biofuel production, but offsetting only 0.4% of the total annual fossil fuel consumption [6]. Even though only a small proportion of fossil fuels is replaced, there is still concern about effect on national food security [7]. For this reason, in 2007 the Chinese government stopped approving and constructing new grain-based bio-ethanol production programmes and facilities. At the same time a 'non-food' principle, which stipulates the use of non-food biomass for bioenergy generation and non-farm land for energy crop production, was set for the future bioenergy industry [8,9].

In China, non-food biomass is generally divided into the following categories: agricultural residues, forest biomass (including firewood and forest residues), manure, municipal waste and industrial waste (mainly organic wastewater). Their estimated yield potentials in Mt yr^{-1} are 728–750 [10,11], 200–220 [8,12–13], 220–280 [8,13,14], 155 [10,15] and 48,240 [10], respectively. However, this large potential can only partly be exploited due to utilization for other purposes and other limiting factors. For example, if the demand for straw for papermaking and animal feed is subtracted, the agricultural residue potential remaining for the bioenergy industry is limited to 314 Mt yr^{-1} [11], less than half of the overall potential. Furthermore, once factors such as harvest and transportation limitations are taken into account, the final amount of agricultural residues available for bioenergy production will be even lower [16,17]. This is also true for forest biomass potential, which is reduced to 28.1 Mt yr^{-1} for the bioenergy industry through the competitive use of firewood by rural residents and also due to harvest and transportation limitations [8,10]. Finally, the total annually acquirable quantity of non-food biomass for bioenergy production in China is approximately 210 Mtoe (million tons of coal equivalents) [8,10]. This amount is not sufficient to satisfy the feedstock demand of the future Chinese bioenergy industry given its aspiration to achieve 5% of gross energy consumption by 2020 (4700 Mtoe) [18]. Therefore, cultivation of energy crops is required to close the gap between biomass feedstock supply and demand. Considering the 'non-food' principle, energy crop production in China should be based on non-food energy crops and marginal land traditionally not considered agricultural land [8,9].

Miscanthus (*Miscanthus spp.*) is a promising non-food energy crop, which has origin and widespread distribution in China [19,20]. In Europe, miscanthus has been researched and developed as energy crop for over two decades and is currently used mainly for heat and electricity generation [21]. In China, crop residues are presently the main feedstock for bio-electricity generation. Lignocellulosic materials such as miscanthus biomass are currently still not used for bio-ethanol production because the technology for cellulosic ethanol production is not yet commercially available [22]. For these reasons, there has so far been no commercial effort in China to develop miscanthus as a feedstock for bioenergy generation. However, the following outstanding characteristics could make miscanthus a promising energy crop for Chinese farmers. The perennial rhizomatous miscanthus has a lifetime of over 20 years, and lower energy demands and production costs than annual energy crops such as sweet sorghum (*Sorghum bicolour* (L.) Moench) [21,23,24]. Additionally, miscanthus is characterized by a nutrient relocation mechanism [25,26], high water-use efficiency [27,28] and low susceptibility to diseases and pests [29,30]. Therefore, miscanthus has low demand for fertilizer and pesticides. Due to its C4 photosynthetic pathway, it has a high biomass production potential. In addition, its ability to grow in marginal conditions, such as drought and salinity [31,32], would make miscanthus the ideal crop for the future Chinese 'non-food' bioenergy industry.

According to an evaluation by the Chinese Ministry of Agriculture, there are 27 million ha marginal land that could be used for the cultivation of energy crops [33]. If all these resources were used to produce 1st generation energy crops (i.e. starch and sugar plants), the estimated bio-ethanol generation potential would be 74 million tons [34], assuming these crops produced economic yields on marginal land. However, not all these marginal land areas will actually be suitable for planting energy crops (including miscanthus) due to environmental stresses such as drought and cold. In addition, the areas of marginal land suitable for growing specific crops differ according to the varying environmental requirements of these crops [35,36]. For example, there are 4 million ha marginal land (mainly located in Northeast China) suitable for sweet sorghum production [37], while only 0.015 million ha (mainly located in South China) suitable for cassava (*Manihot esculenta* Crantz.) production [38]. For the most promising non-food energy crop-miscanthus, there are as yet no studies on its production potential on marginal land in China. Therefore, the objectives of this study are to assess the biomass and bioenergy production potential and the greenhouse gas (GHG) saving potential of miscanthus grown on marginal land in China. For this purpose, the marginal land area available and suitable for cultivating miscanthus in China is identified and yield potentials of miscanthus species well adapted to these land areas are modelled. Finally, the bioenergy generation and GHG saving potentials are assessed, working on the assumption that all biomass is combusted for bio-electricity generation.

2. Methodology

The biomass and bioenergy production and GHG saving potentials of miscanthus on marginal land in China were assessed in four steps:

Step 1: Identification of available marginal land (defined in Table 1). The spatial distribution (Fig. 1) and total area of marginal land available for the cultivation of miscanthus were identified.

Step 2: Identification of miscanthus yield zones. Firstly, the environmental requirements for the continuous growth of several promising miscanthus species were identified. Secondly,