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Research paper

# Planning the next-generation biofuel crops based on soil-water constraints

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ABSTRACT

Widely blended in the transportation fuels, biofuels have been generally regarded as indispensable components in the U.S. national energy portfolio. Although the current production of cellulosic biofuels has been staggering at pilot scales, it is expected that large-scale cultivation of cellulosic biofuel crops may occur when techniques for cost-effective bioconversion of lignocellulosic biomass to ethanol are available. However, it is still unclear if enough land is in existence to accommodate potential large-scale lignocellulosic crops development without negative effects on the environment and food market. The appropriate land use for the next-generation biofuel crops should be planned and allocated in a manner that the competitive use of land dedicated to food and energy production and other side effects could be minimized. This research proposes an approach of identifying the potential available land for planting switchgrass in the U.S. Midwest using a GIS-based multi-criteria analysis that combines soil and water constraint factors. The results showed that land areas of approximately 13.6 million ha are unsuitable for profitable food crops but available for switchgrass cultivation in 7 U.S. Great Plains states. The findings can assist decision-makers in formulating land use policies and related environmental management strategies.

## 1. Introduction

With rising concerns on climate change and national energy security, development and use of cleaner energy have gained growing popularity in the United States in recent decades. Among various forms of cleaner energy, biofuels (e.g., bioethanol and biodiesel) have been in the research spotlight as important means of offsetting the carbon emission [1]. With the enation of Clean Air Act (CAA) and Energy Independence and Security Act (EISA), biofuels have been mandated as indispensable components in the U.S. national energy portfolio [2]. According to the EISA, at least $1.36 \times 10^{11}$ L of biofuels, including $5.68 \times 10^{10}$ L corn-based ethanol and $6.06 \times 10^{10}$ L cellulosic ethanol (and other advanced biofuels), ought to be blended into transport fuels by 2022. Up to 2011, U.S. has reached the capacity to meet the target of the corn-grain ethanol [3].

Although U.S. has been a leading nation for producing biofuels in the world, its energy feedstock is still largely grain-based, a.k.a., the first-generation (1G) biomass. 1G biomass crops, in the form of food crops used for biofuel production, have raised tremendous concerns on its impacts on food security and the environment [4–6]. The concerns include the direct competition with land used to be dedicated for food production, indirect land use change (e.g., clearance of forests and grassland to compensate the cropland area under bioenergy production) as well as inability to achieve positive reduction in Green House Gas (GHG) emission [7]. In the past decades, most of the biomass supplies originated from the major cropping regions, especially in the Corn Belt states such as Iowa, Nebraska and Illinois.

As an alternative to grain-based biofuels, advanced biofuels such as cellulosic bioethanol have been generally regarded as carbon neutral/negative [8], albeit uncertain side effects associated with land use activities. Studies have showed a variety of environmental and socioeconomic benefits associated with cellulosic biomass compared with arable grain crops, including erosion control [9], biodiversity [10] and increased food security with less competition with primary food production [4,11]. The non-food perennial crops that are grown primarily for use as bioenergy feedstocks are often referred to as the 2$^{nd}$-generation (2G) or dedicated biomass crops [3]. Fazio and Monti [12] found that a conversion of arable lands into perennial grasslands can bring substantial reduction of $CO_2$ emission. Examples of 2G biomass crops include switchgrass, Miscanthus, mixtures of native grasses, and short-rotation woody crops such as poplar and willow. However, large-scale development of advanced fuels is currently in a relatively preliminary stage, and still far from the 2022 target. The staggering progress of the advanced biofuel development has also been manifest as the U.S. Environmental Protection Agency (USEPA) repeatedly adjusted Renewable Fuel Standard (RFS). In 2013, EPA sets the annual standard

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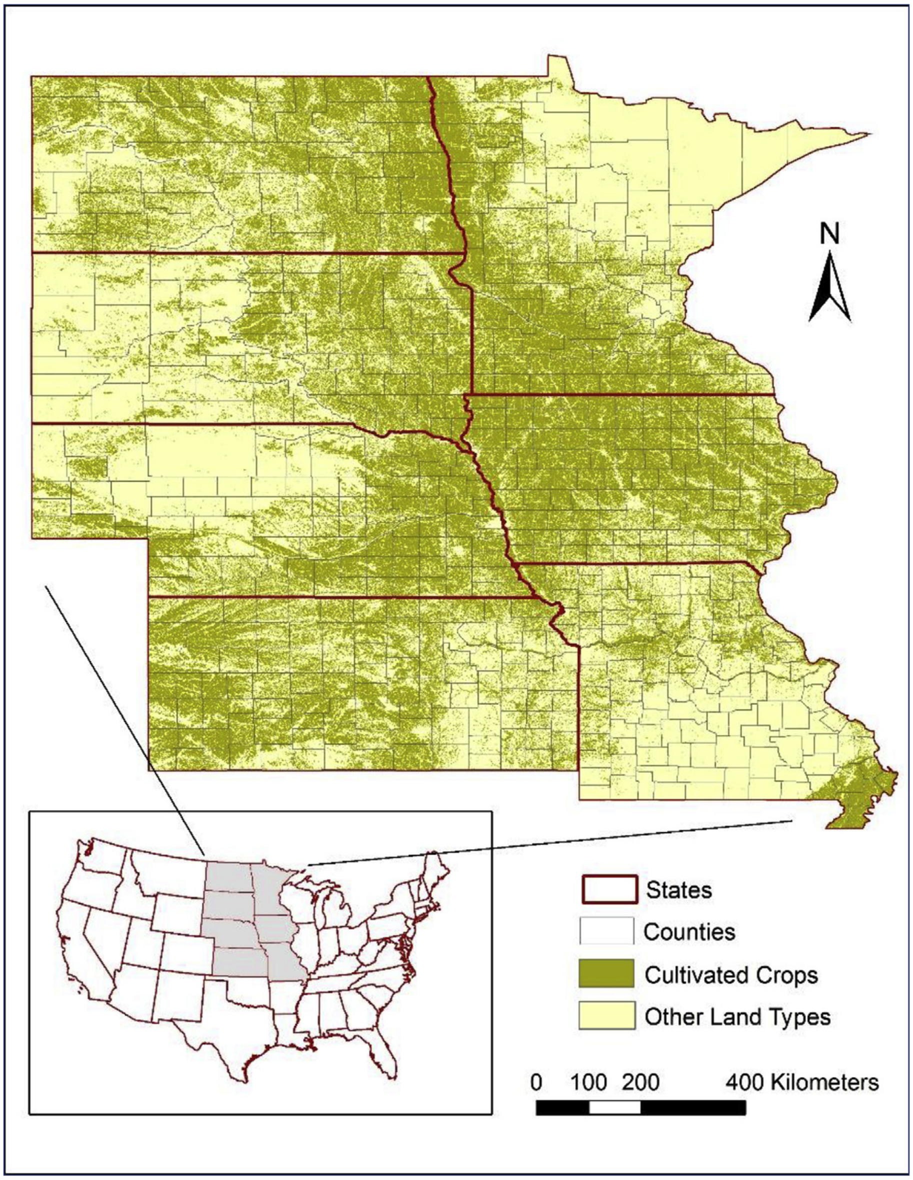


**Fig. 1.** The study region and the distribution of major crops in this area.

of RFS2 for cellulosic biofuels as merely $2.27 \times 10^7$ L (equivalent to 6 million U.S. gallons) [13]. For 2014, EPA proposed $6.44 \times 10^7$ L (equivalent to 17 million U.S. gallons), still significantly lower than the legislative target [14]. From this respect, it is essential to accelerate the development of the 2G biofuels.

Although cellulosic biofuel is not as cost-competitive as petroleum-based fuels at present, it is anticipated that the advancement in cellulosic bioconversion techniques will continue. If a major technological breakthrough occurs to allow cost-effective production of bioenergy, 2G biomass crops are expected to be planted widely with a viable bioenergy market. The question is where to grow these 2G biomass feedstock in a large scale if the industrial bioconversion were cost effective? How should we prioritize the land occupation with lower disruption to the existing food production and higher environmental benefits?

Historically, there were several paths to accommodate new biomass production, such as the land conversion for biomass cultivation and use of the marginal land [15]. It is critical to identify the land areas, where cellulosic biomass cropping is not only technically and economically feasible but has minimized disturbance to food production [16]. Although dedicated bioenergy production may be achieved via land conversion from existing crop production and/or natural habitats, marginal or abandoned agricultural land has been widely considered as important and sustainable means of achieving large-scale 2G biomass production [17,18]. Studies showed that 2G biomass crops are adaptive to marginal or abandoned agricultural land [19,20]. Perennial crops such as switchgrass were originally cultivated to help maintain soil. Vigorous perennial herbaceous stands reduce water runoff and sediment loss and favor soil development processes by improving soil cover, soil structure, organic matter, and water contents [9]. Compared with food crops, cellulosic fuel crops such as switchgrass and miscanthus generally requires much less water to grow, and thus suitable to partially replace the dryland crops. In a life cycle assessment of different bioenergy crops, annual cropping systems, such as corn, consume 900 $m^3$ per hectare [12]. For perennial cropping systems, such as switchgrass, giant reed, Miscanthus and cardoon, their consumption is no more than 500 $m^3$ per hectare. Although research showed the yields of Miscanthus are positively correlated with the soil water abundance [21], the 2G energy crops are generally more resistant to the water limitation than the row crops. Therefore, in this study we consider the land areas, susceptible to a range of natural resources constraints and marginal to food production, as desirable locations for 2G biomass production, because the utilization of these areas to cultivate 2G