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Hydrologic and water quality impacts and biomass production potential on marginal land

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ABSTRACT

Marginal land is proposed as viable land resources for biofuel production. However, environmental impacts of perennial biomass production on marginal lands is not clear. This study defined three marginal land types and assessed their availability and potential for biofuel production in the St. Joseph River watershed. The potential impacts were evaluated using the Agricultural Policy/Environmental eXtender (APEX) model. The total area of marginal land was estimated to be 611 km^2 covering 21.7% of the watershed. 161 and 207 million liters of bioethanol could be produced from the marginal land utilizing switchgrass and *Miscanthus*, respectively. Converting marginal land currently under corn/soybean production to switchgrass and *Miscanthus* reduced water yield by 13.4–36.3% and improved water quality by reducing soil erosion by 27%–98%. Similarly, total nitrogen losses were reduced by 30–91% and total phosphorus losses were reduced by 65–76%, respectively, at the field scales under various energy crop production scenarios.

1. Introduction

Marginal land has been proposed as a viable choice for producing biomass for advanced biofuels (Tilman et al., 2006; Cai et al., 2010; Gopalakrishnan et al., 2011). In the U.S., the Renewable Fuel Standard of 2010 (RFS2) mandated that 132 billion liters of renewable fuel by 2022 should be used in the transport sector (U.S. Environmental Protection Agency, 2010). To meet this goal, the renewable fuel production should be increased 2.7 times by 2022 from the production of 2014 (49 million liters) (Renewable Fuel Association, 2015). Choice of land resources is important for producing adequate biomass to meet biofuel development goals. The United States Department of Agriculture estimated that 27 million acres of cropland would be required to produce adequate biomass for meeting biofuel production goals (United States Department of Agriculture, 2010). Currently 35% of corn produced in the U.S. is used as feedstock for ethanol conversion (Downing et al., 2011). Further conversion of cropland to produce biomass for advanced biofuel could intensify impacts on food provisioning (Pimentel et al., 2009). Thus, marginal land is proposed for biofeedstock production because it could reduce land competition among biofuel, food, and feed production (Robertson et al., 2008; Cai et al., 2010; Kang et al., 2013a).

Marginal land has been defined in different ways across disciplines at various spatial and temporal scales (Tang et al., 2010; Liu et al., 2011; Kang et al., 2013b). For biomass production, marginal land is generally considered as land that is not actively engaged in agricultural production and could be used for biomass production without competition between food and fuel, especially perennial grasses such as switchgrass (*Panicum virgatum*) and *Miscanthus* (*Miscanthus x giganteus*) (Woodson, 2011; Bonin and Lal, 2014). The proposed definition of marginal land for biomass production includes degraded land (Campbell et al., 2008), low productivity land (Cai et al., 2010), environmentally marginal land (Gopalakrishnan et al., 2011), land with Land Capability Class (LCC) 3 to 7 (Gelfand et al., 2013), and land located along buffer areas (Engel et al., 2010). Estimates of different marginal land types' spatial distribution and biofuel production potentiality are generally conducted at

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larger spatial scales such as state (Gopalakrishnan et al., 2011), regional, and global (Cai et al., 2010). Marginal land availability may vary depending on marginal land definitions, data types and sources for area estimation, scope of research, and landscape properties (Cai et al., 2010). Methods used to estimate marginal land at a larger scale may not be applicable at smaller scales due to difference in precision of data required. Similarly, each research develops and uses its own marginal land definition suitable for its objectives and focuses. Thus, availability of marginal land should be estimated based on proper selection of data sources and clear definitions in order to provide reasonable estimates of marginal land areas available for biofuel production.

Contribution of marginal land to biofuel development also depends on yields of biomass species under consideration. Switchgrass and *Miscanthus* have been proposed as two promising dedicated biomass crops (McLaughlin et al., 2004). Switchgrass, native to the U.S., has low agricultural input requirements (fertilizer and management) and high yield potential (McLaughlin et al., 2004). It has also been reported that switchgrass can grow well on marginal land (Woodson, 2011). *Miscanthus* could have higher biomass yield than switchgrass (Heaton et al., 2004, 2008), but can be difficult to establish due to its rhizome-based propagation (Zub and Brancourt-Hulmel, 2010). These two grasses were evaluated as potential biomass feedstock in this study because of their high yield potentials.

Another reason for selecting perennial cellulosic grasses for biofeedstock production is their expected environmental co-benefits (Nelson et al., 2006; Costello et al., 2009; Gopalakrishnan et al., 2009). Growing perennial grass like switchgrass and *Miscanthus* can impact hydrology and water quality (Ng et al., 2010; Cibin et al., 2012; Wu et al., 2012b), ecological conditions (biodiversity and wildlife habitat), and ecosystem services (carbon sequestration). The impacts are spatially varied (Elobeid et al., 2013) and could be either positive or negative, largely depending on the properties of land cover types and management practices implemented (Engel et al., 2010). For example, increased evapotranspiration (ET) is expected with conversion of annual grain crops to perennial grasses such as switchgrass and *Miscanthus* due to their extended growing season. This may reduce soil moisture content and affect regional water resources (Hickman et al., 2010; McIsaac et al., 2010; Love and Nejadhashemi, 2011). Soil erosion could be alleviated with perennial grasses thereby reducing the amounts of sediment in streams. Nutrient loss is also expected to be reduced by growing switchgrass and *Miscanthus* when compared to annual row crops (McIsaac et al., 2010; Ng et al., 2010). However, marginal land is generally considered to pose higher environmental risks because it often slopes (Wiegmann et al., 2008). Potential environmental impacts are essential information to support policies and decisions targeting sustainable biofuel development. However, understanding on the environmental impacts from biofeedstock production on marginal land is very limited, especially at the watershed scale. Thus, it is necessary to conduct an integrated evaluation of impacts on hydrology and water quality with a focus on cultivating marginal land for second generation biofeedstock production.

The study aims to estimate the impacts of growing perennial biomass crops on marginal land in the St. Joseph River watershed. The specific goals included: 1) assessing marginal land availability in the watershed, 2) estimating total bioethanol productivity from marginal land in the watershed, and 3) quantifying the potential impacts of marginal land biomass production scenarios on watershed hydrology and water quality.

2. Methodology

2.1. Study site description

This study was conducted in the St. Joseph River Watershed located in the Midwest U.S. (Fig. 1), which is a region expected to play an important role in producing biomass for biofuel development in the U.S. The area of the St. Joseph River watershed is 2800 km^2. Land cover types in the watershed include corn/soybean land (37%), grassland (26%), forest land (12%), other agricultural land (6%), developed land (10%), wetland (8%), and open water (1%) according to the Cropland Data Layer 2010 (CDL 2010) obtained from National Agriculture Statistic Service (NASS) (http://

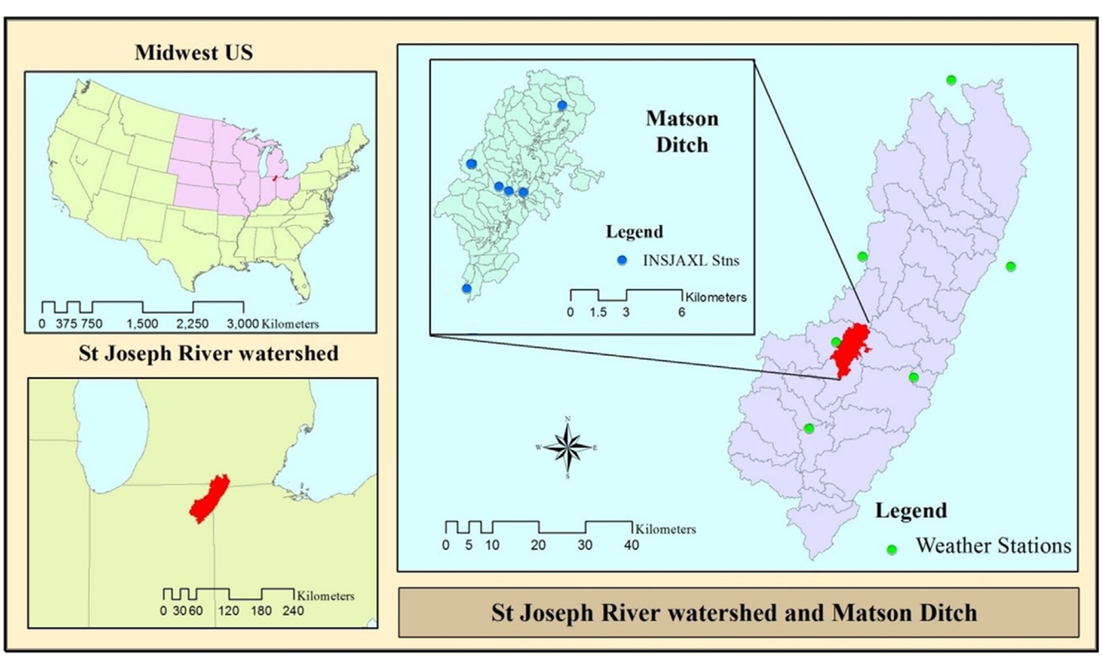

Fig. 1. The St. Joseph River and Matson Ditch watersheds (The Matson Ditch watershed is a subwatershed used in model calibration. Details are provided in Section 2.3.3).