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Sustainable Land Management for Bioenergy Crops

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Abstract

We provide insights from a five year National Science Foundation project focused on the development of spatially explicit maps of sustainable, regional "hot spots" for the large scale deployment of perennial bioenergy crops (e.g., miscanthus and switchgrass) in the United States. With environmental and economic sustainability as principal constraints, our approach integrates climate, land surface, ecosystem, and economic models. We identify "hot spots" (high suitability areas) where there is evidence of atmospheric cooling without a corresponding deterioration of water resources (e.g., significant soil moisture reduction) and simulate biomass yields on marginal lands that become inputs to our economic optimization model.

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1. Background and project rationale

Renewable energy sources derived from biomass, including biofuels, remain an important ingredient in our transition to a sustainable, low-carbon economy. The sustainability of different biofuel pathways depends on the availability of suitable feedstocks, infrastructure, and are subject to policy and market forces. These need to be evaluated regionally and in an integrated manner. Perennial bioenergy crops (e.g., miscanthus and switchgrass) are thought to be more sustainable than their food-crop counterparts as biofuel feedstocks. In evaluating the sustainability of large-scale deployment of these crops, we need to consider both environmental and economic

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sustainability of these cropping systems. As part of a five-year National Science Foundation (NSF) Water, Sustainability and Climate (WSC) project, our goal is to identify regional "hot spots" (areas of high suitability) for the large scale deployment of perennial bioenergy crops in the United States (US) that are both environmentally and economically sustainable.

The sustainability of crop-based biofuels is closely linked with their land use impacts at the feedstock cultivation stage. Such land use can influence climate through biogeophysical and biogeochemical pathways. Biogeophysical effects arise from changes to surface albedo and vegetation characteristics (e.g. leaf-area), which directly alter surface energy balance, momentum, and moisture fluxes [1]. Biogeochemical effects represent changes in chemical composition of the atmosphere, which primarily occur due to changes in surface-atmosphere greenhouse gas (GHG) exchange; e.g., land is both a source and sink for carbon dioxide (CO_2) [2]. Thus, large-scale land use associated with crop-based biofuels has the potential to alter regional and global climatic processes and should be carefully considered by policy makers and planners. It is equally important to consider how the changes in land use to accommodate crop-based biofuels affect the mix of goods and services (food, fiber, fuel, freshwater, recreation) provided by land.

Over a decade of research has revealed that use of corn (or other staple grains) to produce biofuels has significant environmental and socioeconomic consequences [3-10]. A key concern has been the use of food crops as biofuel feedstock results in competition for land (and water) between food and fuel sectors. For example, following the introduction of the Renewable Fuel Standard (RFS) in the US in 2005, the amount of corn diverted for biofuel production corresponded to about 5% of food calories from global grain consumption at the height of the ethanol boom in 2007-2008 [11]. Over short time scales, use of corn for biofuel production has contributed to higher crop commodity prices [11] and worldwide food shortages [5]. Over longer time scales, previously uncultivated lands would have to be transformed into croplands to meet the higher corn demand with additional unintended consequences on global climate [7], negating any emission benefits from biofuels and potentially generating a substantial carbon debt [6-12]. For example, deforestation related sugarcane or oil palm plantations would release large quantities of CO_2. The use of annual row crops for biofuels also has an enormous water footprint compared to petroleum-based fuels, with the added concern of runoff and leaching of fertilizers and pesticides to surface water resources [13].

Although not yet available at commercial scale, the cellulosic biofuels from dedicated perennial bioenergy crops- - miscanthus and switchgrass in particular - can replace grain-based ethanol and provide several key advantages:

- Substantially lower GHG emissions (less than one-fourth of gasoline or corn-ethanol) than annual row crops used for biofuels [14]. Their root systems help sequester carbon [15-17], with less need for nitrogen-based fertilizers. Additionally, their yields remain higher relative to corn [18].
- Similar or better water use efficiency compared to corn [19]. Total water use for biofuels derived from perennial grasses is comparable to that of petroleum-based fuels assuming no irrigation and a thermochemical conversion [20-21].
- Reduced tilling requirement and less intensive agricultural management, since their extensive root system remains intact for a number of years.
- Limited or no interference with food production systems. The competition for land between food and fuel sectors can be further reduced if perennial bioenergy crops are planted on marginal lands [6], [22-29].

These benefits, however, have generally not been considered in a holistic manner that considers not only the potential of perennial bioenergy crops for lowering emissions of greenhouse gases (GHGs), but also their impacts on surface and sub-surface water, climate, feedstock yield, and associated economic valuation [30-32].

In particular, regional climate assessments are needed to examine the varying impacts of appropriate bioenergy crop deployment over distinct regions [28], as bioenergy crop cultivation could increase to 65 million hectares globally by 2030 [33]. Such an expansion in biomass cultivation would significantly alter the landscape, with direct impacts on the overlying climate [34] and sub-surface hydrology [35]. For example, [36] showed that replacing annual row crops with perennial bioenergy crops could produce a direct cooling effect of 1-2ºC at local-to-regional scales via enhanced evapotranspiration. This finding suggests an undesirable trade-off between atmospheric cooling and reduced soil moisture with potentially serious consequences for water resources [36-37]. Therefore, the hydro-climatic impacts of land use and land cover change (LULCC) associated with biofuels are as important as emissions avoided from offsetting fossil fuel use. In addition, the cultivation of perennial bioenergy crops without any irrigation is necessary to ensure water sustainability.

In absence of commercial-scale, longitudinal data on yields for these crops, models need to use the most realistic