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Analyzing crop change scenario with the SmartScape^{TM} spatial decision support system

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ABSTRACT

Agricultural land use is increasingly changing due to different anthropogenic activities. A combination of economic, socio-political, and cultural factors exerts a direct impact on agricultural changes. This study aims to illustrate how stakeholders and policymakers can take advantage of a web-based spatial decision support system (SDSS), namely SmartScape^{TM} to either test existing crop change policies or produce effective crop change decisions using tradeoff analysis. We addressed the consequences of two common crop change scenarios for Dane county in Wisconsin, United States, (a) replacing perennial energy crops with annual energy crops and (b) replacing annual energy crops with perennial energy crops. The results suggested that converting areas under grass and alfalfa production that were located on high quality soil and flat slope to corn promoted a net-income and availability of gross biofuel. Additionally, the model outcome proposed that converting areas under corn and soy production that were located on high slope to grass promoted net-energy, phosphorus loading, soil loss, soil carbon sequestration, nitrous oxide emission, grassland bird habitat, pollinator abundance, and biocontrol. Therefore, SmartScape^{TM} can assist strategic crop change policy by comparing the tradeoff among ecosystem services to ensure that crop change policies have outcomes that are agreeable to a diversity of policymakers.

1. Introduction

1.1. Sustainability in agricultural landscape

Agricultural landscapes provide our society with a variety of valuable goods and services such as food, fiber, and animal feed (Filipe-Lucia et al., 2014; Song and Pijanowski, 2014). They also regulate the quality of water (Tayyebi et al., 2015), sequester greenhouse gases (Searchinger et al., 2008), host beneficial insects (Pekin 2013), and guaranteeing the sustainability of our heritage landscapes (Vaz, 2016). In the Midwestern of United States, agricultural areas (Pijanowski et al., 2014; Tayyebi et al., 2014a,b) have experienced considerable changes in the past decades due to new United States ethanol production regulations (Meehan et al., 2013). In 2007, the Energy Independence and Security Act mandated that production of corn grain ethanol be increased to 15 billion gallons per year (Tyner 2008). The sudden increase in corn grain demand for ethanol production contributed to a rise in grain prices. This increase in grain price was a strong incentive for agricultural intensification (Wallander et al., 2011).

Two forms of agricultural intensification have been documented in the United States. The first one involves changes in land cover, where land previously planted in perennial grasses was converted to annual row crops. For example, Wright and Wimberly (2013) showed that more than 500 million hectares of grassland were converted to corn and soy production between 2006 and 2011 in the western corn-belt of the central United States. Land cover change of this magnitude (1.0–5.4% annually) is comparable to deforestation rates of tropical forests in Brazil, Malaysia, and Indonesia. The

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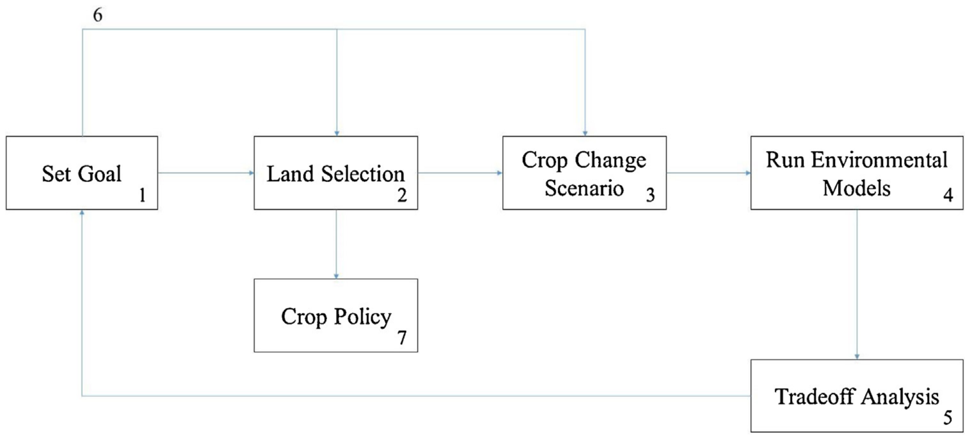

Fig. 1. Application of AmsrtScape™ to help policymakers: (1) Set goal enables users to aim what they expect from SmartScape™ (Item 1); (2) land selection enables users to select parts of the landscape using set of spatial criteria (Items 2); (3) build scenario enables users to make hypothetical crop change (Item 3); (4) users then run multiple environmental models (Item 4); (5) tradeoff analysis enables users to compare crop change scenarios with each other using a variety of visual outputs (Items 5); (6) double check goal enables user to check their goal/goals satisfied or not; and (7) users can then extract series of spatial criteria as a crop change policy.

second form of intensification involves changes in land use or land management. For example, Plourde et al. (2013) showed that the amount of row crop land in the Midwestern of the United States planted to a continuous corn rotation has doubled over the last decade. Wallander et al. (2011) showed that increases in corn production have been further facilitated by increased double cropping, where two crops of the same or different types are produced in series on the same land in the same year.

Despite the importance of balancing multiple ecosystem services for sustainable development, agricultural landscapes tend to be configured to maximize only provisioning services, such as crop production, as these generate goods that can be sold in existing markets, yielding income for producers. This resulted in dominance by annual crops and a marked decline in other services that are often poorly quantified and undervalued (Carpenter et al., 2009). As such, crop policy promoting bioenergy crop production must be also compatible with other valuable ecosystem services (Meehan et al., 2013). Thus, public policy currently involves tradeoffs, and policymakers face the challenge of understanding the relative value of these tradeoffs to achieve multidimensional goals. To judge the effect of policy options on sustainability, we need a new, integrated approach that simultaneously considers environmental, social, and economic outcomes and their complexity (Foley et al., 2005; Tayyebi et al., 2014a,b,c).Establishing a sustainable system requires a consensus definition of sustainability. Generally, sustainability describes the ability to meet current needs not jeopardizing the capacity of future generations to meet their needs (Rowe et al., 2009). The Ecological Society of America (2008) concluded that, to be environmentally sustainable, production of biofuels must not negatively affect energy flow, nutrient cycles, and ecosystem services. The Global Bioenergy Partnership (2011) has developed a list of 24 indicators to evaluate the sustainability of bioenergy systems.

1.2. Spatial decision support systems

While several scientific models are available to determine effects of crop on any single ecosystem service, these models are seldom used by policymakers (McIntosh et al., 2007; Tayyebi et al., 2011; Tayyebi and Pijanowski, 2014). Following reasons might be critical for this lack of adoption: (a) policymakers and model builders tend to speak in different languages and view problems through different conceptual lenses, (b) cultural barriers are immanent. For example, policymaking has a long history, within which computer models are a recent arrival. Thus, there is an institutional momentum that slows adoption of model-based approaches to policymaking (Geertman 2006), (c) technical barriers impede the adoption. For instance, the user interface is very important to uptake of decision support systems (Van Delden et al., 2011). Modeling tools are not likely to be used unless they look and feel like other familiar software packages (McIntosh et al., 2007), (d) another factor that slows adoption is missing functionality for synthesis and presentation of results (Uran and Janssen 2003). In sum, effective spatial decision support systems (SDSSs) are most likely to be created and adopted through an iterative effort, which brings together scientists and decision makers. This type of group effort seems more likely to promote user-friendly tools that are intentionally built to answer fundamental practical questions. Finally, these tools should be transparent and well documented (Van Delden et al., 2011), which is crucial for practical usage and acceptance.

SDSSs facilitate crop policy development where multiple criteria have to be taken into account (Figueira et al., 2005). SDSSs have been employed as a powerful tool for regional management problems related to forest (Fürst et al., 2013), water quality (Arnold and Fohrer, 2005) and air quality (Tayyebi et al., 2010). In this respect, SDSSs are promising to achieve a balance between multiple ecosystem services if they can incorporate spatial and temporal data and use environmental models to simulate the consequence of crop change (Pijanowski et al., 2009; Jokar Arsanjani et al., 2013). We have recently developed SmartScape™, a novel SDSS on the web,[1] allows planners to evaluate the effects of bioenergy crop production using numerous sustainability criteria (e.g., soil carbon, phosphorus loading, biodiversity support, net-income) in a geographically-explicit fashion. This study aims to illustrate how policymakers can use SmartScape™ to produce effective crop change decisions. We specifically quantify the consequences of two crop change scenarios in Dane county, Wisconsin (United States). While the first scenario replaces perennial energy crops with annual energy crops, the second one replaces annual energy crops with perennial energy crops.

2. SmartScape™

SmartScape™ has an interactive, user-friendly interface for strategic crop change planning and scenario building quantitatively and visually using "what if" types of questions. We worked closely

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[1] http://gratton.entomology.wisc.edu/smartscape.