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Assessing uncertainty in the profitability of prairie biomass production with ecosystem service compensation

Ryan R. Noe[a,b], Elizabeth R. Nachman[a,b], Hannah R. Heavenrich[b], Bonnie L. Keeler[c], Daniel L. Hernández[d], Jason D. Hill[a,*]

[a] Department of Bioproducts and Biosystems Engineering, University of Minnesota, St. Paul, MN 55108, USA
[b] Environmental Studies, Carleton College, Northfield, MN 55057, USA
[c] Institute on the Environment, University of Minnesota, St. Paul, MN 55108, USA
[d] Department of Biology, Carleton College, Northfield, MN 55057, USA

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ABSTRACT

Compensation for ecosystem services can encourage the management of agricultural systems for a broad range of benefits beyond crop production. Here we explore how payments for carbon sequestration and phosphorus retention affect the profitability and economic competitiveness of perennial herbaceous biomass. We consider the case of converting marginal land currently in corn and soy production in southern Minnesota, United States, to native diverse prairie grown as a biofuel feedstock. We estimate the resulting changes in soil carbon storage and water quality, and the economic value of both. To test the robustness of our results, we perform Monte Carlo simulations that incorporate variability and uncertainty in our model parameters. Our analyses show that prairie biomass production on marginal lands is 22% likely to be profitable when ecosystem service compensation is included, but only 5% when it is not. This suggests that the two ecosystem services modeled here may alone be insufficient to make prairie biomass production reliably profitable. Furthermore, by using ranges of model parameters rather than point estimates, this study shows that the profitability gap between conventional row crops and prairie is too large to be closed with the two services modeled here across a range of recent economic conditions.

1. Introduction

Ecosystem services are increasingly being recognized for the economic value they provide to society. These services encompass a variety of functions, including biological regulation, habitat and refuge provision, biomass production, and mental health maintenance (Daily et al., 1997). While society benefits from these services, they are rarely directly traded in markets, with the exceptions of biomass (food, feed, and fiber) production and carbon credits. Valuing and creating clear markets for these services allows producers to be compensated for their efforts and society to benefit from increased provisioning of the services. Compensation for these services could therefore provide a means of making ecologically beneficial systems more economically competitive with intensively managed systems, but without traditional markets there is great uncertainty surrounding their value.

We examine this concept in the Midwest United States, where land-use change associated with increased intensity and area of annual row crop production is negatively impacting ecosystem services (Kremen et al., 2007; Metzger et al., 2006; Searchinger et al., 2008), including degraded water quality, decreased soil quality and retention, increased carbon (C) emissions, and loss of biodiversity (Fargione et al., 2009; Gardiner et al., 2010; McLaughlin and Walsh, 1998; Pielke et al., 2002; Polasky et al., 2010). Recent research has suggested a net loss of 530,000 ha of grassland cover to corn and soy in western Corn Belt states between 2006 and 2011 (Wright and Wimberly, 2013), in part driven by increased demand for corn and soy for biofuel production. The negative environmental impacts of corn and soy have prompted interest in perennial biomass sources such as switchgrass (*Panicum virgatum*) and high-diversity prairie biomass for bioenergy production. These have been highlighted as promising lignocellulosic feedstocks because they tend to require lower chemical and fertilizer inputs, and provide higher rates of C sequestration and nutrient retention compared to a corn-soy rotation (Tilman et al., 2006).

Although prairie biomass production has many ecological

* Corresponding author.
E-mail address: hill0408@umn.edu (J.D. Hill).

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benefits over traditional row cropping, corn and soy remain more profitable on highly productive soils (James et al., 2010; Meehan et al., 2013). Recent studies have therefore focused on using marginal and degraded lands for growing biofuel feedstocks (Gelfand et al., 2013; Tilman et al., 2006). These lands tend to be poorly suited for growing row crops due to increased erosion potential and poor soil fertility, but could be ideal locations to produce prairie biomass as a biofuel feedstock (Gelfand et al., 2013; U. S. Department of Agriculture, 2005; Brandes et al., 2016). Still, although these lands are not ideal for row crop production, they continue to be attractive to farmers for corn and soy production due to recent commodity prices, subsidies, and federal crop insurance programs (Sumner and Zulauf, 2012).

Prior work has examined the competitiveness of switchgrass compared to row crops when the value of ecosystem services of C storage and nitrogen retention are included (Chamberlain and Miller, 2012). In that study, parameter values were based on point estimates, however, and do not provide a probabilistic output that accounts for variability in crop production costs and prices, or uncertainty in ecosystem service valuation. To our knowledge, the potential economic returns, including ecosystem services, of prairie grasslands compared to corn-soy rotations have yet to be quantified in an analysis that incorporates probability distributions for the values of key model parameters.

In this study, we examine the role that payments for ecosystem services can play in making ecologically beneficial systems profitable and competitive. We advance the state of science by examining the uncertainty of the underlying parameters and by providing a probabilistic output for the profitability of potential crops. Our first research objective is to compare the profitability and cost competitiveness of prairie to a corn-soy rotation, both with and without the C storage and phosphorus (P) retention values associated with each land cover. Our second is to quantify the uncertainty in the difference in profitability between prairie and corn-soy rotation on marginal lands.

We compile enterprise budgets of both corn-soy rotations and prairie biomass feedstocks, and quantify and value ecosystem services associated with prairie replacing a corn-soy rotation on marginal lands in southern Minnesota. Our analysis uses parameter values found in the literature and a spatially-explicit model (Integrated Valuation of Ecosystem Services and Tradeoffs; InVEST). The InVEST suite of models has been used to quantify changes in ecosystem services in a variety of land-use scenarios (Gardiner et al., 2010; Kovacs et al., 2013; Nelson et al., 2009; Polasky et al., 2012). To account for uncertainty in the parameters, we use a stochastic model to estimate the profitability and relative competitiveness of a corn-soy rotation and prairie biomass with and without consideration of C storage and P retention. We also use a Monte Carlo simulation to investigate the key sources of parameter uncertainty in this comparison.

2. Methods

2.1. Study area

The study focused on 81,090 ha of marginal lands in 43 counties in southern Minnesota under corn-soy rotation in 2010 (Fig. S1). Marginal lands were defined using the United States Department of Agriculture's (USDA) National Soil Survey Handbook's Land Capability Classification (Johnson et al., 2012; Meehan et al., 2010), which groups soils on their ability to serve as cropland over time without degradation. Class IV soils were selected for this analysis because they have "very severe limitations that restrict the choice of plants or that require very careful management, or both." These constraints include a combination of moderate to steep slopes, high to severe susceptibility to erosion, shallow soils, low moisture-holding capacity, low fertility, and moderate to severe salinity or sodium. Class I–III soils were eliminated on the basis of corn and soy being strong economic competitors on these more fertile lands, and Class V soils and above were eliminated on the basis that restrictions such as stoniness, frequent flooding, and very steep slopes would severely restrict the ability of farmers to harvest biomass from them.

2.2. Land use/land cover scenarios

The 2010 USDA Cropland Data Layer was used to create both a baseline 2010 land use/land cover (LULC) map and an alternative biomass production scenario. In preparing the baseline LULC dataset, we aggregated the original 133 land classifications into one of seven broad classifications based on similarity of land cover (Table S1). All land classified as corn or soy was assumed to be in a two-year corn-soy rotation as this is the dominant practice in the domain (Osteen et al., 2012). In the alternative scenario, all of the corn-soy rotation land on class IV soil was converted to prairie.

2.3. Corn, soy, and prairie production costs

To estimate farm-gate production costs, we compiled university Extension enterprise budgets for corn, soy, hay, and diverse-species prairie from Minnesota, Wisconsin, and Iowa from 2008 to 2013 to capture a variety of regionally appropriate production practices. Hay budgets were modified by changing fertilizer and chemical practices to match the prairie production methods described by Tilman et al. (2006). Land rents were based on National Agricultural Statistics Service (NASS) county averages for pasture to represent the marginal quality of the targeted land. Production costs and returns for prairie were annualized over 20-years using an interest rate of 6%. Transportation costs and subsidies for crop insurance were not included in this analysis.

2.4. Corn and soy yields and prices

The distribution of corn and soy production revenue was created using 2008–2012 NASS yield and price data. NASS county yield estimates were adjusted to reflect targeting of marginal land by using the non-irrigated crop yields attribute of the spatially-explicit Soil Survey Geographic Database 2.2 (SSURGO) (Soil Survey Staff, 2011; USDA-NASS, 2014). The ratio between the county average SSURGO yields and actual county average NASS yields was used to adjust yields on marginal land, which are available only in SSURGO, to better reflect variation due to variables not included in SSURGO, such as climate. Commodity price data were from monthly Minnesota averages reported by NASS from January 2008 to May 2013 (USDA-NASS, 2014).

2.5. Prairie biomass price and yield

Biomass price was estimated from crude oil prices from January 2008 to May 2013 using the method of Jiang and Swinton (Jiang and Swinton, 2009), which uses an established relationship between the price of gasoline and crude oil, and adjusts for the energy content difference and the value of ethanol as a fuel additive. This value represents the willingness to pay (WTP) of the refinery for biomass exclusive of transportation costs. Though rare, the WTP for biomass can fall to zero if oil prices are low enough. While producers would likely seek other markets under these circumstances, it was included in simulations to represent the risk of participation in a developing market. A distribution of likely biomass yields was obtained from a survey of studies in and near southern Minnesota (Table S2). We assumed no yield for the first