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Land requirements, feedstock haul distance, and expected profit response to land use restrictions for switchgrass production

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ABSTRACT

Energy crop production has been proposed for land of poor quality to avoid competition with food production and negative indirect land use consequences. The objective of this study was to determine the land area requirements, biomass transportation distance, and expected profit consequences of restricting switchgrass biomass production, for use as biofuel feedstock, to marginal land relative to unrestricted land use. The USA soils capability classification system was used to differentiate between high quality land and land of marginal quality. Fifty years of historical weather data were used in combination with a biophysical simulation model to estimate switchgrass biomass yield distributions for land of different quality for counties in the case study region. A mathematical programming model was designed and solved to determine the economic consequences. For the levels of biofuel price considered ($0.50, $0.75 and $1.00/L), and a 262.5 M L/year biorefinery modeled, restricting land use to marginally productive capability Class IV soils, increases the quantity of land optimally leased by 42 to 52%; increases biomass trucking total transportation distance by 115 to 116%; and reduces the expected net returns by $11 to $15 M/year compared to when land use is unrestricted. In the absence of government restrictions, for-profit companies are not likely to limit energy crop production to land of marginal quality.

1. Introduction

The production of energy crops such as switchgrass (*Panicum virgatum* L.) in the USA was envisioned as a way to reduce the cost of government funded set aside and land retirement programs that had been implemented to reduce what had been described as an excess capacity problem. It was assumed that most of the land in these programs was of lower quality and that it could be put to productive use growing biomass crops that could then be converted to valuable products. For example, McLaughlin et al. wrote "…the rationale for developing lignocellulosic crops for energy is that…poorer quality land can be used for these crops, thereby avoiding competition with food production on better quality land..." (McLaughlin et al., 1999, p. 293). In which case, the indirect land use issue, confronted when highly productive land is used to produce grain for conversion to ethanol resulting in land elsewhere on the globe converted from grassland to grain production, as described by Searchinger et al. (2008) and others (Leal et al., 2013; Winchester and Reilly, 2015; Wise et al., 2014, 2015), would not be an issue.

Searchinger et al. (2008) reported that "…biofuels from switchgrass, if grown on USA corn lands, increase (greenhouse gas) emissions by 50%…". Leal et al. (2013) found that bioenergy crop production could result in significant greenhouse gas emissions. Wise et al. (2014) also concluded that dedicated energy crop production would result in land use changes with increased greenhouse gas emissions. Winchester et al. (2015) reported that meeting USA Federal Aviation Administration targets for renewable jet fuel would also result in increased greenhouse gas emissions. However, Bhardwaj et al. (2011) and Dauber et al. (2012) reported that bioenergy crops could provide environmental benefits if grown on less productive land. Dodder et al. (2015) reported that a hypothetical energy portfolio that includes cellulosic biofuels would result in less greenhouse gas emissions and lower food prices. Djomo et al. (2015) studied 40 potential bioenergy production systems and found that the technologies have the potential to reduce greenhouse gas emissions by 8 to 114% relative to fossil fuels even with the inclusion of the direct and indirect land use changes.

A number of other studies have concluded, or assumed, that since millions of hectares (ha) of marginal land exist, much of it could be converted relatively easily from current use to the production of switchgrass (Perlack et al., 2005; Liu et al., 2011; Gelfand et al., 2013). For

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example, in a highly aggregated study, Perlack et al. (2005) estimated that more than 20 million USA ha of low quality land could be converted to biomass production with minimal effects on food, feed, and fiber production. If the land is marginal and not currently used intensively to produce food, feed, and fiber crops, it follows that conversion to switchgrass would not impact land use elsewhere and hence negate concern regarding the environmental consequences of indirect land use. However, prior to completely dismissing the indirect land use issue for dedicated energy crops such as switchgrass grown on marginal land, several issues remain to be resolved.

First, there is no universally accepted definition of marginal land (Richards et al., 2014). Second, in the USA and many other countries, most land suitable for switchgrass production is privately owned. Private owners have to have an incentive to establish switchgrass on their land. Third, while government incentives may be in place and used, in the USA, the construction of a switchgrass biomass to biofuel biorefinery requires an investor, or group of investors, to provide the capital necessary to build a plant. Prudent investors would require a business plan for providing a daily flow of biomass throughout the year for the expected life of the biorefinery. Fourth, switchgrass yields are variable. A planted land area may produce more biomass than can be processed in some years and insufficient biomass in others. Given the expected yield variability across years, determining the optimal quantity of land to bid from current use and convert to switchgrass is not a trivial matter. Fifth, restricting switchgrass production to marginal land will have economic consequences. Land use restrictions may reduce the profit potential and inhibit investment in cellulosic biorefineries. Information regarding the economic consequences of restricting land use to that of marginal productivity relative to enabling switchgrass production on high quality as well as marginal land is limited.

The objective of this study is to determine the land area requirements, biomass transportation distance, and expected profit consequences of restricting switchgrass biomass production, for use as biofuel feedstock, to marginal land relative to unrestricted land use. To achieve the objective, a working definition of marginal land is presented. Fifty years of historical weather data are used in combination with a biophysical simulation model to estimate switchgrass biomass yield distributions for land of different quality for counties in a case study region. A mathematical programming model is designed and solved to determine the economic consequences.

2. Soil classification

In the USA, soils are classified into eight soil capability classes (Norton, 1939). This classification system may be used to provide a definition of marginal land. Classes V–VIII have limitations impractical to remedy that restrict their use to range, forestland, wildlife, and/or esthetic purposes. Class I soils have slight, and Class II soils have moderate limitations for crop production. Thus, Class I and II soils could be used to produce switchgrass but they are clearly not marginal. Class III soils have severe limitations that reduce the choice of plants and/or require special conservation practices. Class III soils could be considered as marginal. Class IV soils have very severe limitations that restrict the choice of plants and/or require very careful management. Class IV soils are clearly marginal relative to Classes I and II. Thus, for purposes of determining the consequences of restricting crop production for biorefinery feedstock to marginal USA land, either Class IV, or both Classes III and IV, could be defined as marginal.

3. Modeling framework

The modeling effort is based on the assumption that an investor or group of investors would develop a business plan and secure the financing to construct a biorefinery designed to use switchgrass biomass exclusively. For a given biorefinery technology, differences in cost to produce biofuel across locations could largely be attributed to differences in cost of providing a flow of feedstock throughout the year. Given the cost to transport biomass, investors could be expected to select a supply region for a biorefinery location based on expectations regarding the cost to provide a continuous flow of the required quantity of feedstock.

A case study region was identified based on findings of a regulatory impact analysis conducted by the United States Environmental Protection Agency (2010). The United States Environmental Protection Agency (2010) estimated potential feedstocks and biorefinery locations for fulfilling the 2022 cellulosic ethanol mandates included in the USA Energy Independence and Security Act (EISA). In the assessment projections, only 6% of the cellulosic ethanol feedstock requirements were projected to be met by switchgrass. The EPA projected that 85% of the switchgrass could be produced and processed in the state of Oklahoma.

Seven of the nine USA switchgrass biorefinery locations identified by United States Environmental Protection Agency (2010) were in Oklahoma. For the present case study, a biorefinery siting was chosen near Okemah, in Okfuskee County, the geographical center of three of the seven Oklahoma locations identified by EPA (United States Environmental Protection Agency, 2010; Debnath et al., 2014, 2015). A 150 km radius around the biorefinery location is used as the potential feedstock supply shed of the biorefinery encompassing 30 Oklahoma counties (Fig. 1).

An economically efficient switchgrass biomass to biofuel production system would require coordination of feedstock production and transportation with processing. The biorefinery could engage in production contracts with farmers (Epplin et al., 2007). Alternatively, the biorefinery could vertically integrate by acquiring control of a sufficient quantity of land with long-term leases such that the expected annual yield on the leased area would be sufficient to fulfill expected annual biorefinery feedstock requirements. Other options such as a closed-membership producer cooperative could be implemented (Katz and Boland, 2002; Jensen et al., 2011). In either case, prior to investing, prudent investors could be expected to require that use rights would be secured to a sufficient land area. Further, the expected annual biomass yield on the secured land would be available for delivery to fulfill expected annual biorefinery feedstock requirements at or below the expected cost estimate described in the business plan.

Based on experience with the USA Conservation Reserve Program (CRP), Oklahoma landowners are willing to engage in long term contracts that provide an annual lease payment (Osborn et al., 1995). This history suggests that at some annual rental rate, land could be bid from existing use (Okwo and Thomas, 2014). A company could enter into long-term leases with landowners and establish stands of switchgrass. Long-term land leases would facilitate coordination of switchgrass biomass production and transportation logistics required to provide an efficient flow of feedstock throughout the year. If the annual feedstock requirements of the biorefinery and annual switchgrass yield were known with certainty, it would be straightforward to determine the quantity of land to lease. However, switchgrass biomass yields vary from year-to-year. In years with unfavorable switchgrass production weather, yields in the feedstock supply shed of the biorefinery may be low, and if too few hectares are leased, production from the leased land may be insufficient to meet the needs of the biorefinery. In other years, more biomass may be produced on the leased land than can be processed. However, in every year, payments must be made for all land leased.

Conceptually, the expected objective of the investors would be to maximize expected net returns or to maximize the return on their investment. Based on this conceptual framework, the land area selected, leased, and seeded to switchgrass, would be determined and fixed in year zero, simultaneously with construction of the biorefinery. In year one and subsequent years, biomass production on the fixed land area would vary depending on environmental conditions. Thus, a nested