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Switchgrass procurement strategies for managing yield variability: Estimating the cost-efficient D (downtime cost) L (land to lease) frontier

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ABSTRACT

Lignocellulosic biorefineries that plan to use switchgrass (*Panicum virgatum* L.) biomass exclusively will encounter both temporal (across years) and spatial (across locations within a given year) variability in feedstock production. Long term land leases could be employed to facilitate feedstock availability for the expected life of the biorefinery. If the quantity of land leased is based on average yields, in some years more biomass will be produced than can be processed. In other years feedstock production on the leased land may be insufficient to prevent biorefinery downtime. An optimal strategy for identifying which land to lease and seed to switchgrass, while considering yield variability and the opportunity cost of biorefinery downtime, is the focus of the research. The objective is to determine for a given biorefinery location the least-cost quantity, quality, and location of land to lease for alternative estimates of biorefinery downtime cost due to variable switchgrass yields. Fifty years of weather data are used to simulate switchgrass yield distributions for a case study region. An innovative mathematical programming model is developed and used to reveal the cost-efficient D (Downtime Cost) L (Land to Lease) frontier for a 2 Gg d^{-1} biomass capacity biorefinery. If interyear storage is not permitted, 60,492 ha would be required to insure that the biorefinery run at full capacity every year given the estimated yield distributions. However, for some circumstances, it would be optimal to produce switchgrass on only 49,464 ha and idle the biorefinery for some days in low biomass production years.

1. Introduction

In 2007, the USA Congress passed the U.S. Energy Independence and Security Act (EISA). EISA mandates that, if produced, 60.57 hm^3 of cellulosic biofuels be marketed annually by 2022 [1,2]. To meet this mandate a significant quantity of lignocellulosic feedstocks from dedicated perennial energy crops such as switchgrass (*Panicum virgatum* L.) would be required.

Procurement of biomass from dedicated perennial energy crops such as switchgrass will be fundamentally different

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and much more challenging than procuring corn (*Zea mays* L.) grain. Schmidgall et al. [3] surveyed grain-ethanol biorefineries and found that 88% of respondents reported that they had easy access to feedstock and 91% reported that feedstock was readily available all of the time and could be obtained on the spot market. A similar feedstock production and delivery infrastructure does not exist for potential cellulosic biorefineries designed to use switchgrass biomass exclusively. Prior to investing millions of dollars in a biorefinery, due diligence would require a business plan for providing a flow of feedstock to the facility for its expected life. A single biorefinery would require that several thousand hectares within reasonable distance of the proposed biorefinery be bid from existing use and seeded to switchgrass.

Based on experience with the U.S. Conservation Reserve Program (CRP), U.S. land owners are willing to engage in long term contracts that provide an annual lease payment [4–7]. This history suggests that at some price substantial quantities of land could be bid from existing use. In the absence of government restrictions, a company could enter into long term leases with land owners and establish as many hectares of switchgrass as required for the biorefinery. Nickerson et al. [8] report that 44% of U.S. farm land is not owned by farmers. In some states less than half of farm land is owned by farmers. Many of these land owners could be expected to be indifferent between leasing their land to farmers who use it to produce livestock or conventional crops, or to an integrated biorefinery that uses it to produce switchgrass biomass.

Long term land leases would facilitate coordination of switchgrass biomass production, harvest, and transportation logistics required to provide an efficient flow of feedstock. For example, a biorefinery designed to process 2 Gg d^{-1} would require 83 Mg per hour; approximately five truck loads every hour, 24 h per day for the life of the biorefinery. Failure to provide feedstock would result in costly disruptions of biorefinery operations. If the annual feedstock requirements of the biorefinery and annual switchgrass yield were known with certainty, it would be straightforward to determine the number of hectares 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 hectares may be insufficient to meet the needs of the biorefinery. Since switchgrass biomass cannot be anticipated to be available from spot markets, the biorefinery may be forced to shut down for a period of time. Each idled day for lack of feedstock will have economic consequences. The net opportunity cost of a forced idle day (downtime cost) will depend on the lost revenue as well as on fixed production costs that cannot be avoided.

Selection of a biorefinery location and identification of land to lease for the production of feedstock will be critical decisions in determining the economic success of a switchgrass biomass processing facility. Prior research has developed methods for determining optimal biorefinery locations [9–12]. Case studies have been conducted to determine feedstock production locations when expected switchgrass yields are assumed to be the same in each field each year [13–22]. However, most of these studies have ignored both temporal (year-to-year) and spatial (across fields within year) switchgrass yield variability.

Debnath et al. [23] considered switchgrass yield variability and developed a model that could be used for a specific region and biorefinery location to determine the least-cost quantity and location of land to lease. They used biophysical model [24,25] and historical weather data to simulate switchgrass yields for each of three land capability classes for each of 30 counties in their case study region for each of 50 years. The model was used to determine how the optimal quantity and location of land to optimally lease would change if they assumed that the average yield was obtained in each of the 50 years versus an assumption that sufficient land should be leased so that biorefinery feedstock requirements would be fully satisfied even in the worst case year (based on historical weather data). However, Debnath et al. [23] did not evaluate the opportunity cost of idling the plant due to insufficient feedstock. They did not consider the economic tradeoff between the cost of leasing sufficient land to insure adequate feedstock production in every year versus the cost of leasing less land and incurring the cost in some years of a forced idling of the biorefinery (downtime cost) due to insufficient feedstock.

The present research study builds on and extends the work of Debnath et al. [23] to further address the consequences of switchgrass yield variability. The objective is to determine for a given biorefinery location the least-cost quantity, quality, and location of land to lease for alternative estimates of biorefinery downtime cost due to variable switchgrass yields produced on leased land. Two models are developed. One does not permit storage across feedstock production seasons. The second model includes the option to store across seasons. Both models are presented and solved with switchgrass biomass yield data simulated from 50 years of weather data for the case study region. The models are used to determine the optimal number of idle days, and the optimal quantity, quality, and location of land to lease, as a function of the biorefinery downtime cost. Findings from the two models can be compared to determine the expected economic consequences of switchgrass biomass storage across feedstock production seasons.

2. Mathematical programming models

An innovative model is developed for a given biorefinery location that enables determination of the optimal quantity, quality, and location of land to lease (L) considering yield variability, for a given level of biorefinery downtime (D) opportunity cost. The estimate of the opportunity cost of downtime may be parameterized to trace out the DL frontier; that is the Downtime Cost–Land to Lease frontier. A second model that enables year-to-year storage along with the downtime is also formulated. Findings from the DL frontier model may be compared to findings from the year-to-year storage model to determine the circumstances for which using storage across years would be warranted. The two models encompass both spatial (across land class and across counties within each year) and temporal (across years) biomass yield variability.