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PREDICTING SWITCHGRASS FARMGATE AND DELIVERED COSTS: AN 11 STATE ANALYSIS

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ABSTRACT

A GIS-based modeling system was developed for analyzing the geographic variation in potential switchgrass feedstock supplies and prices. The modeling system is designed for analyzing individual U.S. states; parameters for six southern states (Alabama, Florida, Georgia, Missouri, South Carolina, Tennessee) and five midwestern states (Iowa, Minnesota, Nebraska, North Dakota, South Dakota). Potential switchgrass supplies are estimated for each state under two switchgrass technology adoption scenarios.

KEYWORDS

Feedstock; supply; GIS; transportation models; feedstock costs; delivered prices.

INTRODUCTION

Producing economically competitive bioenergy, be it electric power or liquid fuels, depends on the availability of low-cost feedstocks from energy crops. That availability will have spatial variation. We have developed a GIS-based modeling system for predicting potential switchgrass (*Panicum virgatum*) availability which captures the geographic variation in the major factors that will determine switchgrass supply and cost throughout a state. Switchgrass is a native perennial C_4 grass species that has shown great promise as an energy crop in the southeastern U.S. It has produced harvested yields on research plots of up to 36 dry tonnes/ha/yr although yields of 15 to 20 tonnes are more common. It can be harvested its second growing season and reaches maturity in its third season. While stands of switchgrass can be maintained for 20+ years, a ten-year lifetime is a reasonable estimate.

The system is intended to aid federal and state policymakers and agencies frame bioenergy policy discussion and program direction. It can aid by providing quantitative information on the likely variability in delivered switchgrass prices and supplies, and in the environmental impacts of producing switchgrass due to geographic variability in land use, crop yields, and transportation infrastructure. To date, the modeling parameters have been entered for six southern states (Alabama, Florida, Georgia, Missouri, South Carolina, Tennessee) and five midwestern states (Iowa, Minnesota, Nebraska, North Dakota, South Dakota). This paper updates previous descriptions of the modeling system (Graham *et al.,* 1996) and provides an eleven-state comparison of variability in potential supplies of switchgrass.

MODELING APPROACH

Overview

The modeling system has five basic components (Figure 1). The first component maps cropland that is potentially available for switchgrass production. The cropland map is at a 1 km^2 resolution (i.e., 1 km^2 pixel size). The second component of the system defines both expected farmgate[*] price of switchgrass production and the environmental characteristics of growing conventional crops and growing switchgrass on each 1 km^2 area. The third component calculates potential farmgate supply of switchgrass and maps marginal cost of delivering switchgrass to any destination in the state. The fourth component identifies, maps and ranks, based on

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[*] By the term "farmgate", we mean the value at the farm. The farmgate price is the price paid to the farmer before transportation is considered.

minimizing the marginal cost of delivered switchgrass, all the sites in a state where bioenergy facilities might be located. Ranking and identification take into account both facility size (i.e., annual demand for switchgrass) and inter-site competition for potential switchgrass supplies. The fifth component quantifies the changes in soil erosion, nutrient loss, runoff and pesticide movement off site that would be associated with growing the switchgrass supply for each of the predicted facility sites.

Component 1. Mapping Cropland Availability

A GIS is used to create a digital map containing the following land availability variables for each 1 km^2 pixel:

1) c - the county to which the pixel belongs
2) s - the soil group found at that pixel location
3) APCT - percent of the pixel which is cropland physically suitable for growing switchgrass
4) $ADOPT_{a=1,\ c}$ - the proportion of the cropland in county c that could be converted to switchgrass production assuming a mature bioenergy technology, and
5) $ADOPT_{a=2,c}$ - the proportion of cropland in county c that could be converted to switchgrass assuming an immature bioenergy technology.

These five variables are later used in component 3 in conjunction with yield and expected farmgate price information created in component 2 to determine the potential supply of switchgrass from a pixel. The first three variables are generated by overlaying three digital maps—a county boundary map, a soil group map, and a land use map. The fourth and fifth variables are linked to the digital map on the basis of their county identity and are generated using county-level information on the relative dominance of conventional crops in each county. The value of the fourth variable is defined as the percent of cropland in the county currently planted to the most dominant conventional cash crop. The assumption behind this variable is that even under a mature bioenergy technology and favorable prices, farmers would dedicate only as much land to switchgrass as they currently dedicate to the dominant crop in their area. The value of the fifth variable is defined as the percent of cropland in the county currently planted to minor crops (i.e., crops other than the two most dominant crops). The assumption behind this variable is that under an immature bioenergy technology even with favorable prices, farmers would only grow switchgrass on that land currently planted to minor crops. While the definitions of the two variables are somewhat arbitrary they serve to recognize that farmers reduce their risk to unforeseen weather and market variations by planting more than one crop. Thus it is appropriate in modeling potential supply to restrict switchgrass production to some subset of the cropland base.

Component 2. Calculating Farmgate Prices and Environmental Characteristics

The model defines the farmgate price of biomass feedstock as the price ($/tonne) that would provide the farmer over the lifetime of the switchgrass crop a return to land and management equivalent to the expected return from growing the current mix of conventional crops found at that location. The model takes a Net Present Value (NPV) approach to calculating this price.

$$FP_{s,c} = (RN_{s,c} + PB) / (YS_{s}) \qquad (1)$$

where:
FP = the farmgate price of energy crop feedstock ($/dry tonne sold by the farmer)
PB = NPV of energy crop production costs over the life time of the crop ($/ha)
YS = NPV of the energy crop sold over the lifetime of the crop (paid for dry tonnes/ha)
RN = NPV of returns to land and management that could be expected from conventional crops grown on the same land over the lifetime of the energy crop ($/ha)
s = soil group
c = county

The expected yield of energy crops over the lifetime of the switchgrass stand is based on the median county-level yields found in the database ORECCL (Graham *et al.,* 1997) and soil- and climate-specific yield indices developed using the crop simulation model EPIC (Williams *et al.*,1989). It is assumed that no switchgrass is harvested for the market the first year, the second year yield is only 2/3rds that of the mature yield, the mature yield is harvested years 3 and thereafter, the lifetime of a switchgrass stand is 10 years, and 6% of the harvested yield is lost to storage before it is sold. Expected energy crop production costs (excluding land and management costs) are estimated using a regression equation derived from runs using the BIOCOST model (Walsh and Becker, 1996). These expected costs are both yield^{-} and state-specific, taking into account state-specific labor rates and farm sizes.

The expected returns to land and management from growing the location's current mix of conventional agricultural crops is calculated using eq. (2).

$$R_{s,c} = \sum_{i} [(Y_{i,s} * P_{i,c}) - C_{i}] * A_{i,c} \qquad (2)$$

where :
R = returns to land and management from current mix of conventional crops ($/ha/yr)

Y = conventional crop yield (harvested tonnes/ha/yr)
P = market price ($/tonne) of conventional crop
C= production cost ($/ha/yr) (labor, equipment, fertilizer, seed, fuel, custom operations).
A = proportion of cropland planted to crop type i
i = type of conventional crop (e.g., wheat, soybeans, etc)
c= county
s= soil group

Eq. (2) is calculated using input tables containing county-level information on the mix of conventional crops grown at the location, market prices for those crops, and production costs (excluding costs due to land and management), and soil -level information on conventional crop yields. As with energy crop yields, EPIC is used in conjunction with soils and climate information and county-level crop yield statistics to predict conventional crop yields on different soil groups. The component 2 modeling currently includes the simplifying assumption that conventional crop mixes and profitability will not change during the ten-year lifetime of the switchgrass stand. There is also no inclusion of a risk factor (e.g., the farmer might demand a higher rather than an equivalent return for producing switchgrass).

The erosion, nutrient loss, runoff and pesticide movement off-site expected from conventional crop production and switchgrass crop production in each location are calculated using the input table on the mix of crops grown in each county along with input tables on the mix of soil types used for cropland in each soil group and the EPIC output on the erosion, nutrient loss, runoff, and pesticide movement associated with growing each of the conventional crops and switchgrass on each of the soil types present in that soils group.

Component 3. Mapping the Marginal Cost of Delivered Energy Crop Feedstocks

First, the farmgate price and expected switchgrass yield values derived in component 2 are linked to the map of available cropland created in component 1 on the basis of the soil and county identities. The potential annual switchgrass supply at any pixel that could be used by a bioenergy facility is then calculated using the equation (3) and land availability variable values from the cropland map.

$$S_{q,s,c,a} = 100\text{ha/km}^2 * \text{ADOPT}_{a,c} * \text{YB}_s * \text{APCT}_q/100 \qquad (3)$$

where:
S = the amount of energy crop feedstock annually produced in the pixel (dry tonnes/yr)
ADOPT = the proportion of cropland potentially available for energy crops
YB = average annual switchgrass yield over the lifetime of the crop (tonnes/ha/yr)
APCT = percent of 1 km^2 pixel which is cropland
q = pixel identity (unique to each pixel)

s = soil group
a= adoption choice (1=mature or 2=immature)
c = county

Once the potential annual switchgrass supply and its associated farmgate price have been calculated and assigned to each pixel in the state, the cost of transporting the feedstock from that pixel to any other pixel in the state is calculated (Noon *et al.*, 1996). First, a digital road network map with two road classes, fast roads and slow roads, is overlaid onto the cropland map. Then the straight-line distance from the center of any pixel to the nearest road is calculated. It is assumed that this distance would be traveled at a slow speed. Next the shortest time path (and its associated road distance) from the center of a pixel to any other pixel is calculated. The per tonne cost of transporting the supply from the origination pixel to the destination pixel is calculated using equation 4.

$$TC\{x,y\} = KF + KD * DIST\{x,y\} + KT * TIME\{x,y\} \tag{4}$$

where:
TC{x,y} = the cost of transporting switchgrass from pixel x to pixel y ($/dry tonne)
KF = fixed cost of loading and unloading switchgrass ($/dry tonne)
KD = distance dependent cost ($/dry tonne-km one way)
KT = time dependent cost ($/dry tonne-hour one way)
DIST{x,y} = Road distance between pixel x and pixel y (km one way)
TIME{ x,y} = Travel time between pixel x and pixel y (hours one way)

KF, KD, and KT are derived using a transport model which assumes bale sizes are the same as those used by BIOCOST, labor rates are region specific, and the transportation is done by a trucking firm which supports the bioenergy facility and can utilize its equipment fully.

Once the per tonne cost of transporting switchgrass from one pixel to any other pixel has been calculated, the marginal cost of supplying a specific amount of switchgrass to any destination is calculated. The marginal cost algorithm ranks (from lowest to highest) the delivered cost (farmgate price + transport cost) of all the supplies from pixels within the state and calculates the cumulative potential supply of switchgrass from those ranked pixels. The marginal cost of supplying x amount of switchgrass to the destination is the delivered cost of switchgrass from the pixel that would supply the xth dry ton of switchgrass. The algorithm is run for all destinations (i.e., every pixel) in the state to create a surface map of delivered marginal switchgrass costs for a specified switchgrass amount. Different maps can be created by specifying different switchgrass amounts or assuming a different energy crop adoption rates.

Component 4. Mapping Sites Where Bioenergy Facilities Might be Co-located.

In mapping the optimal locations of multiple bioenergy facilities one must account for the fact that switchgrass resources used for one facility are not available to another facility. Thus to determine where and how many bioenergy facilities might be sited at what switchgrass cost, we take the following approach. We calculate the marginal cost of supplying switchgrass to a location in the same fashion as in component 3 but we exclude farmgate supplies that are already being used to meet the demands of another location. Potential bioenergy facility locations are selected sequentially based on lowest delivered marginal switchgrass cost. For example, the first bioenergy facility location is the pixel identified in component 3 as having the lowest marginal delivered switchgrass cost in the state. The farmgate supplies shipped to that pixel are then removed from the map (set to zero). The marginal cost algorithm is rerun and the next lowest cost location is identified and the farmgate supplies shipped to that location are removed from the map. This step is repeated until the potential farmgate switchgrass supplies have all been allocated. The siting algorithm mimics the situation where the bioenergy facility has long-term contracts with farmers to produce switchgrass and these contracts are not renegotiated when another facility is sited in the area. Component 4 also creates a tabular file which gives each pixel's predicted switchgrass yield, farmgate price, transportation cost, soil group identity, county identify, and the identity of the facility which the pixel supplies.

Component 5. Quantifying Environmental Changes Due to Switchgrass Production

The tabular pixel file from component 4 is combined with adoption rate information from component 1 and predictions of conventional crop and switchgrass environmental characteristics from component 2 to quantify the environmental changes associated with growing switchgrass to supply each of the facilities identified in component 4. These predictions can be given as either absolute or percent changes associated with producing energy crops on land that was formerly dedicated to conventional crops.

RESULTS - POTENTIAL SWITCHGRASS SUPPLIES

Potential switchgrass supplies vary with state and technology scenario (Table 1). The midwestern states with their vast acreages of cropland can produce greater switchgrass supplies than the southern states. But this difference diminishes considerably under the immature technology scenario because minor crops occupy proportionately much more acreage in the south.

Table 1. Potential state energy crop supplies assuming all cropland available, cropland comparable to that occupied by the dominant current crop, cropland comparable to that occupied by minor crops. In million tons (tonnes) per year.

State	All cropland	mature/dominant	immature/minor
Alabama	14.4 (12.8)	8.2 (7.4)	2.7 (2.5)
Florida	0.4 (0.4)	0.2 (0.2)	0.1 (0.1)
Georgia	20.2 (18.3)	9.5 (8.6)	6.2 (5.6)
Iowa	126.7 (115.0)	75.3 (68.3)	2.6 (2.4)
Missouri	70.5 (64.0)	34.9 (31.6)	14.1 (12.8)
Minnesota	90.6 (82.1)	48.2 (43.7)	13.1 (11.9)
Nebraska	91.8 (83.3)	57.8 (52.4)	12.2 (11.0)
North Dakota	90.6 (82.2)	56.0 (50.8)	16.4 (14.9)
South Carolina	8.9 (8.1)	3.8 (3.5)	2.9 (2.6)
South Dakota	43.1 (39.1)	23.1 (21.0)	11.1 (10.1)
Tennessee	23.2 (21.1)	11.6 (10.5)	4.9 (4.4)

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