BIOENERGY FROM SWITCHGRASS: REDUCING PRODUCTION COSTS BY IMPROVING YIELD AND OPTIMIZING CROP MANAGEMENT

Lynn Adams Kszos, Oak Ridge National Laboratory[1], Oak Ridge, TN
Samuel B. McLaughlin, University of Tennessee, Knoxville, TN
Marie Walsh, Oak Ridge National Laboratory, Oak Ridge, TN

Abstract

Dedicated bioenergy crops must be cost competitive in both agricultural and industrial sectors if they are to play a significant role in the development of biomass-based technologies. Feedstock production research has shown that production costs can be reduced through plant breeding and improved crop management. We used a cost-accounting model (BIOCOST) to evaluate the effects of increasing yield and/or decreasing inputs on switchgrass production costs. Changes from the BIOCOST baseline were derived from small-plot switchgrass trials in the southeast and southcentral U.S. BIOCOST calculations indicated that an increase in yield of 10% would decrease the cost per dry ton by about 2% or to $25-30/dt. Applying half the nitrogen currently recommended for switchgrass could reduce the production cost by as much as 15%. With reduced production costs comes improved competitiveness for switchgrass against conventional crops. We used POLYSYS, a modified agricultural sector model, to evaluate acreage on which switchgrass would compete with other major farm uses given a 10% increase in yield, a 10% decrease in cost, or both. Over the entire U.S., both changes would result in an increase of 14 million acres that could be economically competitive with alternative farm uses given a farmgate price of $35/dry ton. An increase in production acreage of that magnitude may be associated with an annual increase of over $6 B in societal values including increased farm revenues, improved soil quality, and decreased greenhouse gas emissions.

Introduction

The U.S. Department of Energy's Bioenergy Feedstock Development Program (BFDP) identified switchgrass as a model energy crop and began crop development research in 1992. The main emphasis was on developing a high-yielding, low cost switchgrass production system. Switchgrass is a native perennial grass species with potential widespread use in the United States. Our switchgrass research effort included genetics and plant breeding, regional field trials to assess performance, management studies, physiological research and development of tissue culture systems [1].

In addition to plant research, BFDP also recognized the need for economic information related to potential biomass energy crops. Perhaps the most important factor in determining the future use of dedicated energy crops is cost-competitiveness. Commercial development of bioenergy systems must be economically competitive with alternative energy systems, and provide income to farmers comparable to what they can earn from current uses of their land. In this paper, we estimate the economic impact of improving yields, reducing fertilizer inputs and decreasing the time needed to reach fully mature yields. We used the BIOCOST model to estimate changes in switchgrass production costs under different yield and management scenarios and incorporated these changes into the POLYSYS model to estimate the competitiveness of switchgrass with current agricultural land uses.

[1] Oak Ridge National Laboratory is managed by UT-Battelle, LLC for the U.S. Department of Energy under contract DE-AC05-00OR22725.

BIOCOST [2] is a budget generator model that allows users to change yields and management practices (such as fertilizer applications) to determine changes in production costs. BIOCOST estimates full economic costs including variable cash costs (e.g., seeds, fuel, fertilizer, chemicals, etc.), fixed cash costs (e.g., overhead taxes insurance, interest payments) and opportunity costs (e.g., equipment depreciation, producer's own labor, non-land capital costs and land costs). The model includes default assumptions based on the best available information on management practices and yields for commercial scale operations. Costs are $U.S. Production costs ($/dry ton or $/dt) are estimated as the net present value over a 10-year production cycle.

POLYSYS [3, 4] is a U.S. agricultural sector model that has been modified to include energy crops (switchgrass, hybrid poplar, willow). POLYSYS includes 305 supply regions, the major crops produced in the U.S. (corn, wheat, soybeans, sorghum, barley, oats, cotton, rice, alfalfa, and other hay) and food, feed, industrial and export demand for each commodity. It includes agricultural cropland currently in crop production, enrolled in the Conservation Reserve Program, idled or in pasture, and is anchored to USDA baseline projections for agricultural production. POLYSYS allocates cropland to each crop based on relative profitability subject to demand and flexibility constraints.

Methods and Materials

Field-Trial Data

Regional default yields and selected management practices contained in BIOCOST are shown in Table 1. Reasonable alternatives to the default variables of yield and fertilizer application (**Table 1**) were determined using yield and management data from long-term switchgrass projects conducted by Virginia Polytechnic Institute and State University (VPI; Blacksburg, VA) and Auburn University (Auburn, AL). Researchers at VPI established a multi-site variety study at eight locations in the southeast in 1992 (**Figure 1**). Small plots (2 x 7 m) received no irrigation and a single annual nitrogen application ranging from 50-100 kg/ha. Plots were harvested once each year in November. Average dry matter yield (1992-2001) ranged from a low of 8 Mg/ha to 18.9 Mg/ha (Fig. 2) [5]. The best variety in 2001, averaged for all sites, yielded 16.7 Mg/ha compared to the BIOCOST default assumption of 13.1 Mg/ha (**Figure 2**). The highest site/variety for 2001 was for Alamo at the Blacksburg B site with a yield of 27.4 Mg/ha [5].

Table 1. Default parameters in BIOCOST model which were changed to evaluate impact on switchgrass production cost. Costs are $U.S. Production costs are net present value over 10-year production cycle.

Default Input Parameter	Region[a]						
	Lake States	Corn Belt	South east	Appala-chia	North Plains	South Plains	North east
Yield (dt/acre)	4.8	5.98	5.49	5.84	3.47	4.30	4.87
Nitrogen/yr (lb/dt yield)	20	20	20	20	20	25	20
First year yield (% of mature harvest)	30	30	30	30	30	30	30
Second year yield (% of mature harvest	67	67	67	67	67	67	67
Production cost ($/dt)	29.32	26.29	27.98	26.69	31.12	29.54	30.73

[a]Northeast = VT, RI, PA, NY, NJ, NH, MA, MD, DE, CT; Appalachia = WV, VA, NC, KY, TN; Southeast = SC, GA, FL, AL, AR, LA, MS; Cornbelt = IA, MO, IL, IN, OH, MN, WI, MI; North Plains = ND, SD, NE, KS; South Plains = OK, TX; West = ID, MT, WY, NV, UT, CO, AZ, NM, WA, OR, CA.

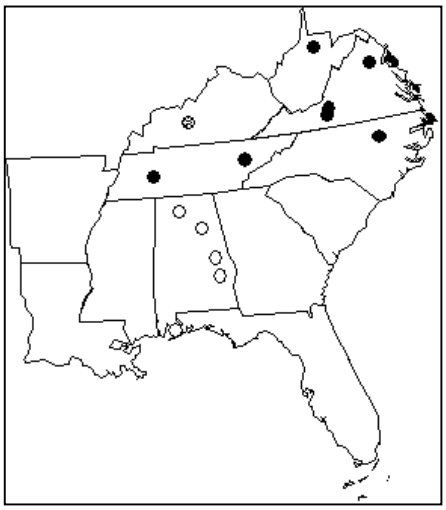

Figure 1. Locations of switchgrass variety trials conducted by Virginia Polytechnic Institute and State University (black dots; Dr. David Parrish) and Auburn University (white dots; Dr. David Bransby).

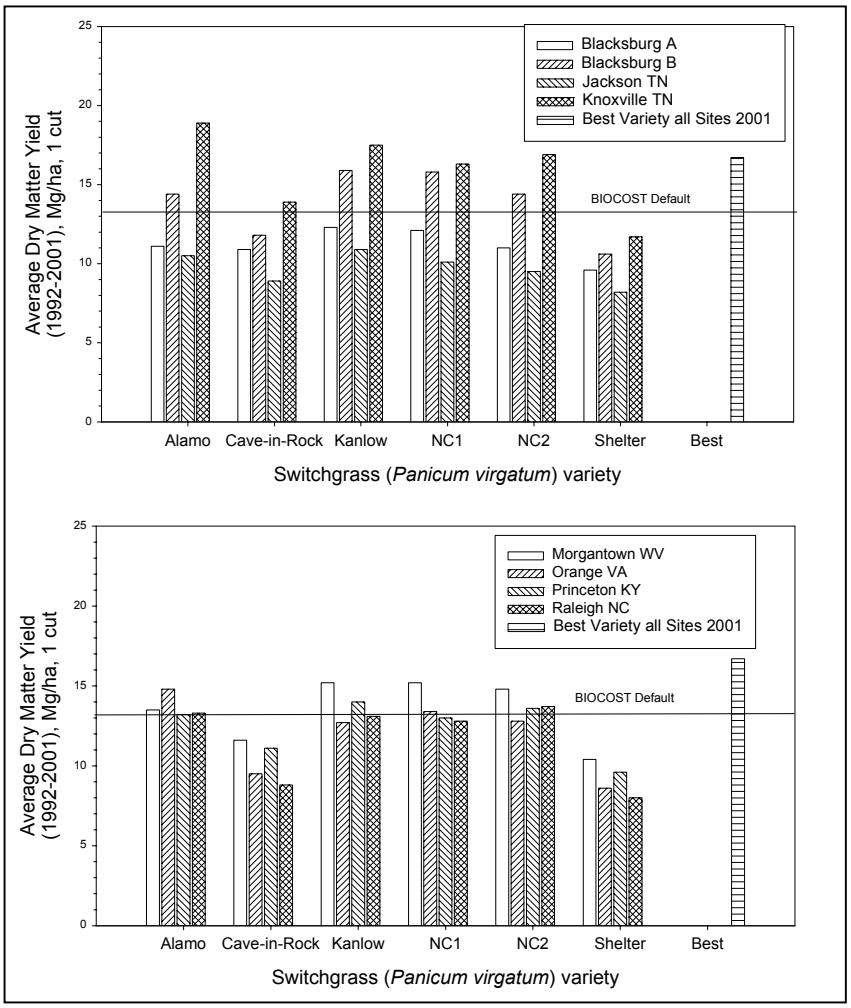

Figure 2. Yield of switchgrass varieties at locations. BIOCOST default yield for Appalachia from Walsh and Becker [2].

Auburn established similar trials at 5 sites in Alabama in 1992 (**Figure 1**). Small plots (1.5 x 6.1 m) received no irrigation and a single annual nitrogen application of 225 kg N/ha. Plots were harvested once each year in October. Average annual dry matter yields (1994-2000) of 3 varieties at 5 sites ranged from a low of 5 Mg/ha to 15.8 Mg/ha (**Figure 3**) [6]. The best variety in 2000, averaged for all sites, yielded 13.9 Mg/ha compared to the BIOCOST default assumption of 12.3 Mg/ha. The highest site/variety for 2000 was for Kanlow at the Sand Mountain site with a yield of 24.6 Mg/ha [6].

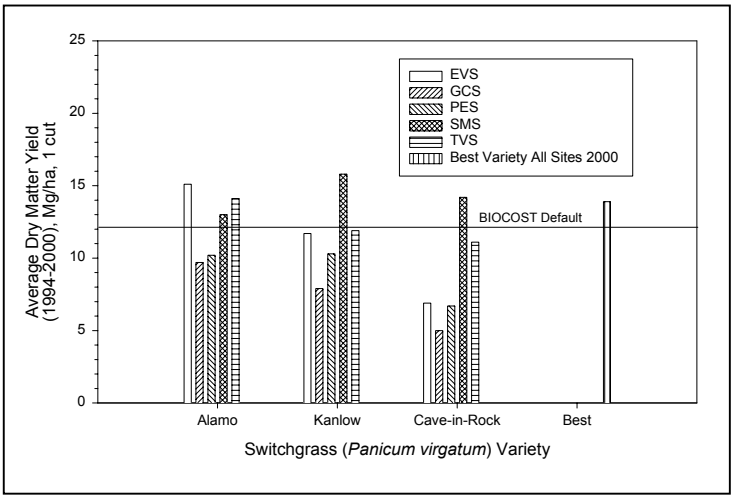

Figure 3. Yield of switchgrass varieties at Auburn University locations. BIOCOST default yield for Southeast from Walsh and Becker 1996.

Improved plant material from a BFDP funded breeding program at Oklahoma State University has also been evaluated by VPI. A comparison of the yields of the new varieties with a standard variety (e.g., Alamo or Kanlow) demonstrates that breeding alone has improved yields of the new southern lowland varieties by 5-20% (**Figure 4**). The average (1999-2001) annual dry matter yield of the best new variety at a site in Orange, Virginia was 17.9 Mg/ha.

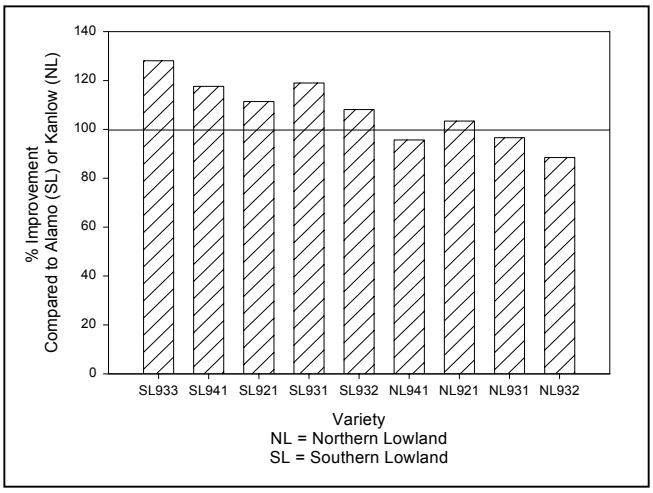

Figure 4. Percent improvement of switchgrass varieties from breeding program at Oklahoma State University (Dr. Charles Taliaferro) planted at Orange Virginia (Virginia Polytechnic Institute and State University, Dr. David Parrish). Southern lowland varieties are compared to Alamo; northern lowland varieties are compared to Kanlow.

Another factor that has a significant impact on cost is the amount of fertilizer applied to switchgrass plots. In order to determine a reasonable reduction in nitrogen application from the BIOCOST default of 20-25 lb/dt yield (equivalent to approximately 100 kg N/ha), we evaluated management data from VPI and Auburn University. At VPI, there is evidence that in a one-cut management system, 50 kg N/ha is adequate for maintaining established plots. Plots established in 1992 which received 100 kg/ha were subdivided in 1997 and received either no nitrogen or 50 kg/ha for two years. In the one-cut system, three locations had no decrease in yield in response to no added nitrogen in 1997 or 1998 [7]. In subsequent years all one-cut plots at VPI's 8 locations received only 50 kg N/ha with no observed decline in yield through 2001 [5]. At Auburn University, a study was begun in 1999 to evaluate the effect of three fertilizer levels (0, 56, and 112 kg N/ha) applied at three different frequencies (every year, every other year, every third year). Preliminary data from 1999 and 2000 indicates a reduction in yield at 0 and 56 kg N/ha; however yield data cannot be fully evaluated until the treatments are fully established and several years of data are available [6].

Successful establishment is paramount to the future use of switchgrass as a dedicated energy crop. In 1992, typical first year yields were 30% of mature yield and second year yields were 70% of mature yield; thus the default assumptions in BIOCOST of 30% and 67% respectively. In 1998, researchers at Virginia Tech established small plots with improved material and compared to third year yield data, achieved a first year yield of 70% and a second year yield of 100%.

Methodology and Results

The management and variety trial research data provide guidance regarding changes in switchgrass management practices and yields that can potentially be achieved at a commercial rather than research scale. To estimate the impact of these changes on the cost of producing switchgrass relative to default assumptions, the following scenarios were run in BIOCOST:

- Increase mature yield by 10% and 25%,
- Decrease nitrogen application rate by 50%,
- Increase first year yield to 50% of mature yield and second year yield to 100% of mature yield.

Increasing the yield decreased production cost in all regions, but the magnitude varied widely among regions. For a 10% increase in mature yields, regional production costs decrease by 1.5 to 3.5%, and for a 25% increase in mature yields, regional production cost decreases range from 2.2 to 7.5% (**Figure 5**). Increasing yields from the initially low BIOCOST default yields in the North Plains leads to the largest decreases in production costs ($/dt). Diminishing returns from increasing yields that are initially high, lead to smaller decreases in production costs in the Corn Belt and Appalachia. Figure 6 shows the production cost impacts of combining changes in yields (mature yield, and first and second year yields) with decreasing nitrogen application rates. The greatest decrease in cost (relative to default values) would be accomplished with a reduction in nitrogen fertilizer. In combination, the management and yield changes decrease switchgrass production costs by 13.7% in the North Plains to 17% in the South Plains (**Figure 6**). Production costs ($/dt) ranged from $22.5/dt in Appalachia to $26.0/dt in the Northeast representing a savings of $3.60 to $5.00/dt.

The results from BIOCOST were incorporated into POLYSYS to determine how changes in switchgrass yields and production costs affect the competitiveness of switchgrass with alternative agricultural land uses. Research data and BIOCOST results indicate that it is reasonable to assume that in the near term,

- Switchgrass yields can be increased by 10% and
- Switchgrass production costs can be decreased by 10%.

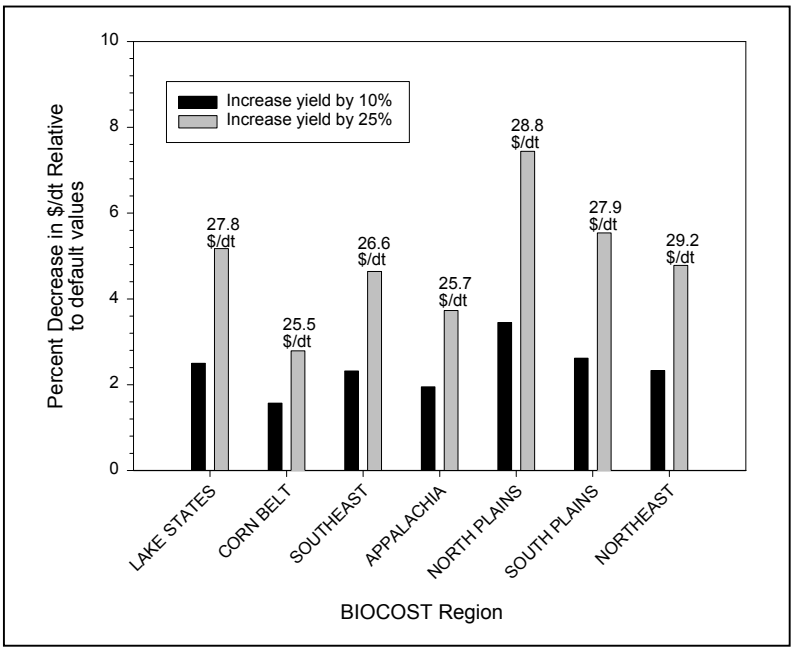

Figure 5. Predicted percent decrease in production cost of switchgrass using BIOCOST. Production cost shown above bars.

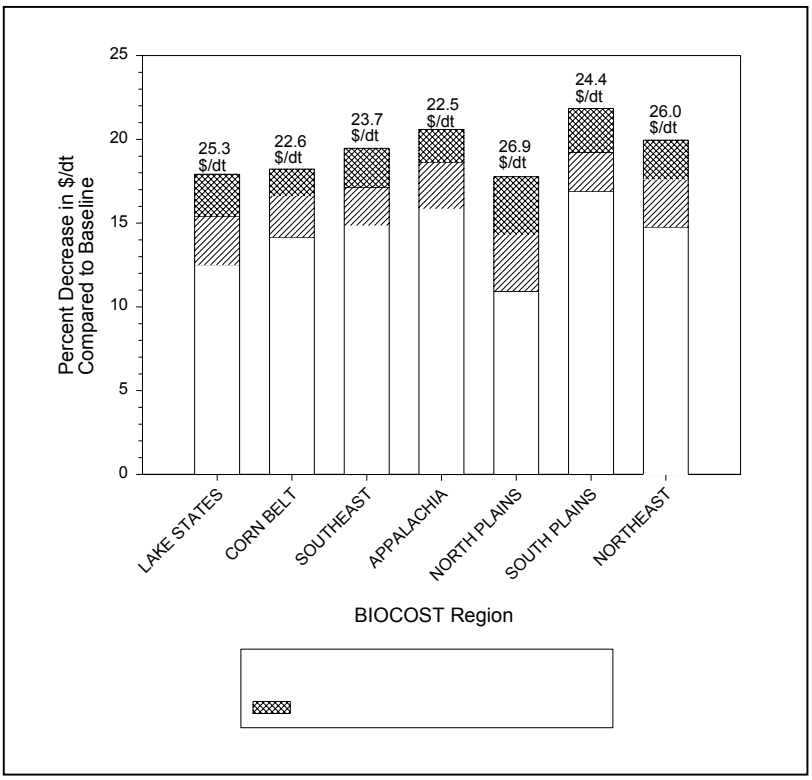

Figure 6. Relative percent decrease in production cost of management and yield options estimated using BIOCOST. Total of each bar does not represent total percent decrease. Production cost predicted with BIOCOST shown above each bar.

Running these scenarios separately, and in combination, in POLYSYS provides an estimate of how many acres of cropland could be more profitable in switchgrass production than in their current uses. The baseline assumptions in POLYSYS assume a farm-gate price of $35/dt and yield and management practices consistent with the BIOCOST default assumptions. Under these assumptions, 28.7 million acres of cropland are estimated to be more profitable in switchgrass production.

Increasing yields by 10% increases switchgrass acres by 4.15 million for a total of 32.85 million acres (a 15% increase). Decreasing production costs by 10% results in a 10.96 million acre increase in switchgrass production for a total of 39.66 million acres (a 40% increase). Simultaneously increasing yields by 10% and decreasing production costs by 10% increases switchgrass acres to 42.75 million acres (an increase of 14.05 million acres above baseline). Acres increase the most in the Corn Belt, and North and South Plains (**Table 2**). Relatively small changes in switchgrass yields and production costs can have significant impacts on the economic competitiveness and production of switchgrass relative to current uses of agricultural croplands.

Table 2. POLYSYS estimate of additional cropland acres that could be more profitable in switchgrass production than in their current uses given three scenarios: (1) 10% increase in switchgrass yield, (2) 10% decrease in switchgrass production cost, and (3) both (1) and (2).

	Additional switchgrass production acreage over baseline[a]		
Region[b]	(1) 10% increase in yield	(2) 10% decrease in production cost	Both (1) and (2)
Northeast	35,091	208,570	271,417
Appalachia	152,882	410,301	509,600
Southeast	224,739	818,831	812,145
Cornbelt	1,734,715	3,395,518	5,075,436
North plains	1,019,126	3,517,933	4,680,414
South plains	480,586	2,049,841	2,061,798
West	507,076	558,461	634,707
Total	4,154,215	10,959,455	14,045,517

[a]Baseline POLYSYS prediction of 28.7M acres in switchgrass production at farmgate price of $35/dt.
[b]Northeast = VT, RI, PA, NY, NJ, NH, MA, MD, DE, CT; Appalachia = WV, VA, NC, KY, TN; Southeast = SC, GA, FL, AL, AR, LA, MS; Cornbelt = IA, MO, IL, IN, OH, MN, WI, MI; North plains = ND, SD, NE, KS; South plains = OK, TX; West = ID, MT, WY, NV, UT, CO, AZ, NM, WA, OR, CA.

Summary

The analysis indicates that production costs of switchgrass could decrease by as much as 17 % or $5/dt with improvements in management practices and use of high yielding varieties. Decreases in production costs and/or increases in yield are estimated to increase the acres of land that would be competitive with existing agricultural uses by 15-40% at a farmgate price of $35/dt. While research data is available primarily from research plots rather than commercial scale operations, the analysis uses conservative changes in yield and production costs to account for these differences. This analysis demonstrates the economic benefit of a plant breeding program designed to improve yield and crop management programs designed to maximize yield and establishment while minimizing nitrogen inputs. The economic value of increased switchgrass production such as that shown by this is analysis is not limited to the increased monetary gain to the farmer, but includes increases in values to society. The benefits of bioenergy systems that use switchgrass could include near-zero net emissions of greenhouse gases, improved soil and water quality, and increased net economic returns to a rural economy. A recent analysis by McLaughlin [8] estimates that for a farmgate price of $40/dt (farmgate) the non-market

value of switchgrass could reduce net fuel price to near zero. The benefits would include an increase of $6 billion in farm returns and a displacement of 44-159 Tg/year of greenhouse gas emissions.

Acknowledgment. This work was funded by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy.

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