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Assessment of Alternative Fuel Production from Switchgrass: An Example from Arkansas

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As the hunt for renewable energy sources from agriculture intensifies, many agricultural producers are contemplating what crops to grow in the foreseeable future. On the one hand, there are traditional food crops, such as soybean, corn, and wheat, which have recently enjoyed a spike in prices, primarily because of the seemingly ever-growing demands of the corn to ethanol industry. On the other hand, there are the lesser-known perennial energy crops, such as switchgrass. Although much information on various aspects of switchgrass production exists, this paper discusses the adaptation of existing production and processing information to Arkansas conditions as a potential alternative to crop production.

Key Words: biofuels, production costs, switchgrass

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As energy prices increased, so did the viability of energy production from renewable resources. Although much attention has been paid to the recent surge in corn prices as a direct result of expanding corn to ethanol production (close to $4 per bushel at the time of this writing), this change in commodity prices had implications for other commodities as well (nearly $7 and $4 per bushel for soybean and wheat, respectively). These prices represent 83%, 21%, and 32% increases compared to 1996–2005 average Arkansas prices of $2.18, $5.80, and $3.03 per bushel for corn, soybean, and wheat, respectively (U.S. Department of Agriculture, National Agricultural Statistics Service). With this surge in commodity prices, however, the attractiveness of growing alternative crops for energy production was also affected. Hence, although a lot of reports highlight the potential for both agricultural and forestry residue along with the potential for dedicated herbaceous and woody energy crops, many questions relating to the eventual adoption of these alternative sources of renewable energy remain.

At the society level, laudable attributes of lignocellulosic biomass (LCB) conversion to biofuels (primarily ethanol) as the pathway toward greater fossil fuel independence have been identified. Principally, they are as follows: i) the current underutilization of biomass as a source of energy; ii) higher net energy ratios (the amount of fossil energy equivalent produced compared with the amount required in its production) than currently attributed to corn to ethanol production; iii) the fit with liquid and storable fuel demand rather than generation of electricity or heat; iv) a more environmentally defensible carbon life cycle; v) the potential for soil and water quality improvements because of increased organic matter, reduced irrigation, and fertilizer requirements as well as runoff; vi) the potential for rural economic development; and vii) the

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production of few by-products compared with other processes, such as corn to ethanol or soybean to biodiesel.

At the producer level, the benefits of alternative energy crop production are not as evident. Higher commodity prices, as mentioned above, were needed to offset increases in production costs, such as fuel and fertilizer. Increased feed costs have hurt the livestock sector at the same time. In addition, with growing proportions of corn and soybean oil being devoted to ethanol and biodiesel production, agriculture is developing stronger links to energy prices by adding output price risk to existing dependence on variable input prices. Thus, expected variability in crude oil prices is also expected to further increase volatility in commodity prices and uncertainty about crop acreage allocation decisions. Producers may therefore be willing to entertain long-term supply contracts with biorefineries for energy crops that are less input-intensive on at least some of their acreage. The prenegotiated price to charge for this activity is the contention of this paper.

Although an ever-growing body of literature on energy production from renewable sources exists, it is difficult to provide definitive answers to storage, handling, and logistics questions associated with harvest and transport of low-value, low-density biomass commodities. Understandably, this is likely a function of the lack of commercial-scale biorefineries capable of converting LCB to ethanol in a cost-competitive fashion at the time of this writing.

Enter a potential solution to many of the above problems: a crop called switchgrass (*Panicum virgatum* L.). It is a native, non-invasive, perennial grass species that can be cultivated across a large region of the United States. Primarily because of its high LCB yield potential, drought tolerance, low fertilizer input requirements, carbon sequestration, and soil quality improvement potential, it is heralded as the principal, dedicated energy crop.

The objectives of this study were to i) document existing cost of production information for growing switchgrass in Arkansas, along with some assumptions about likely and easily adoptable production methods; ii) utilize the cost of production information to determine break-even prices for producers and/or biorefineries; iii) conduct some sensitivity analyses regarding expected harvesting and transportation costs to biomass production facilities; and iv) discuss impediments to and advantages of the adoption of switchgrass as an alternative crop in Arkansas.

Data and Methods

Research concerning switchgrass production as well as economics of switchgrass production (Bransby et al.; Thorsell et al.; Walsh) exists. However, the production conditions and economic data used in these studies are not representative of eastern Arkansas. This paper uses information from various agronomic and economic studies and 2006 input costs (Laughlin and Spurlock; University of Arkansas Cooperative Extension Service) as well as expert opinion (West) to adjust key assumptions regarding yield, fertilizer levels, cutting frequency, equipment needs, storage costs, and transport requirements to develop expected, early adopter production practices for establishing switchgrass on cropland for Arkansas conditions. Some of these assumptions are later relaxed for sensitivity analysis to determine the impact on break-even prices.

A contentious issue surrounding switchgrass production is expected yield. Perrin et al. report average, commercial-scale, harvested yields of 0.5, 2.5, 3.2, 4.2, and 3.2 tons/acre for the year of establishment through year 5, respectively, across a number of producer fields in Nebraska, South Dakota, and North Dakota. Cassida et al. (2005b) provide a 3-year yield history of established southern lowland switchgrass varieties, including 'Alamo,' ranging from 7 to 8 metric tons of dry matter per acre in southern Arkansas. They also report on significance of lodging and concentrations of ash, nitrogen, and other chemicals in the switchgrass. A potential reason for this wide range in yield assumptions is not only the change in climatic and soil conditions, but also the number of cuts (Madakadze et al.;

Sanderson, Read, and Reed) and fertilizer levels (McLaughlin and Kszos; Muir et al.). Although Cassida et al. (2005a) used 150 lbs. of N/acre, presumably using recommendations by Muir et al., to achieve their yields with a single cutting, McLaughlin and Kszos argue that lower N levels may be more economically efficient in conjunction with late-season harvest to allow nutrients to revert back to the root system after a first frost. This comes with the added advantage of the enhanced burning properties of the switchgrass due to lower N and ash concentrations.

For these reasons, an expected per acre yield of 3 and 5 tons of dry matter on marginal cropland were assumed for the second and subsequent years in this paper by applying 75 lbs. of N per acre in April with a single harvest in October. Year 1 production is either left in the field, or harvest costs are expected to be offset by initial yield. P and K fertilizer levels were set to reflect typical soil test levels for cropland and may be slightly overstated. The contention, as yet unproven, was that producers would try to enhance the useful life of the stand with sustainable nutrition. A useful life of 12 years was assumed (West). Although the yield potential is lower than that reported by Cassida et al. (2005a), this lower level of nutrition may also reduce the incidence of lodging and associated harvest difficulties. Tables 1–3 summarize equipment and input requirements for years 1–3. The third-year information is expected to hold for the remainder of the life of the stand.

Among other significant assumptions that affect the cost of production are storage costs and harvest performance. Because of a lack of storage and transport infrastructure for hay commodities in the crop-producing region of Arkansas, the initial assumption was to use conventional hay production practices for the harvest and transport of large round bales. Immediately following harvest, the bales are moved to the edge of the field and stacked two wide with a center row on top to build a pyramid of 52 bales. These bales are further protected with tarps to prevent storage losses (tarps are secured on the sides of the bottom row of bales and are expected to wear out with five uses). Half an hour of operator labor and $400/5 years of use for tarps are assigned to this task (per 52 bale stacks each year). A 50-hp tractor with a front end loader and rear mount bale fork is expected to move 52 bales per hour to the side of the field, where slightly elevated gravel storage pads are situated to allow easy road access and less weed contamination than if stored in the middle of the field, as well as reduced storage loss due to ground moisture. These storage pads are expected to last for the useful life of the switchgrass stand with zero salvage value and an initial establishment cost of $500 per stack/pad. Note that even with these storage sites, access to bales may be compromised when climatic conditions would result in excessive rutting of the field. The biorefinery would therefore require some storage space to eliminate supply disruptions. The round baler operates at 20 bales per hour by adjusting operating speed according to crop condition (amount of switchgrass in the windrow). Similar to Thorsell et al., no raking, to reduce number of passes with the baler, is assumed. Plastic bale wrap is used to increase field operating speed and reduce storage loss (Kumar and Sokhansanj; Petrolia 2006a). Bale density at 8.5 lbs. dm/ft.^{3}, is 0.5 lbs./ft.^{3} higher than in the study of Kumar and Sokhansanj as a result of a 0.5-ft. larger bale diam. (dimensions of round bales in this study are 5 ft. wide and 5.5 ft. in diam.). With these dimensions, 1,000 lbs. of dm/bale can be achieved. At 16% moisture, these bales would weigh approximately 1,200 lbs. Similar to Kumar and Sokhansanj, I assume a 2% loss during transport and storage.

Parameters that are expected to substantially affect the cost of delivered switchgrass to a biorefinery are transport distance, relative profitability of alternative crops, stand life, and yield. Initial assumptions regarding transport were taken from Petrolia (2006a). Among these are a truck-trailer capacity of 26 bales per load and a one-way travel cost of $3.60 per mi. for distances of less than 50 mi., as well as L-shaped travel routes. The biorefinery capacity was set at 50 million gal./year at a conversion rate of 90 gal./dry ton of switchgrass. With 350 operating days, this requires ap-

Table 1. Estimated Costs per Acre for Field Operations to Establish Switchgrass on Cropland in Arkansas, 2006

Operation/Operating Input	Size/Unit	Month	Labor (hr.)	Amount	Cost in $ per Unit	Total Cost
Disk and incorporate[a]	24 ft.	Sept.	0.12	1	4.53	4.53
Custom lime	ton			1	33.00	33.00
Custom fertilizer application				1	4.75	4.75
Phosphate (0-46-0)	lbs.			85	0.15	12.75
Potash (0-0-60)	lbs.			65	0.14	9.10
Fall field preparation					Subtotal	64.13
Weed control		March				
Custom air herbicide application				1	5.50	5.50
Roundup Orig Max	pt			2	3.24	6.48
Preplant weed control					Subtotal	11.98
Seedbed preparation[b]	20 ft.	April	0.07	1	2.21	2.21
Planting	12 ft.		0.39	1	10.91	10.91
Switchgrass seed	lbs.			8	7.50	60.00
Custom fertilizer application				1	4.75	4.75
Urea (46-0-0)	lbs.			110	0.18	19.80
Custom air herbicide application				1	5.50	5.50
Atrazine 4L[c]	pt			2	1.29	2.58
Planting					Subtotal	105.75
Weed control		May				
Custom air herbicide application				1	5.50	5.50
2,4-D Amine	pt			1	1.59	1.59
Postplant weed control					Subtotal	7.09
Operating interest						9.38
Total specified expenses[d]						198.33

[a] Disking and seedbed preparation with a cultipacker as well as planting with a no-till grain drill were performed with a 105-hp 2WD tractor with cab. The charges reflect depreciation and capital costs ($10.17) and repair and maintenance ($3.21) as well as fuel ($4.63 @ $2.40/gal.) and hand labor ($2.03 @ $8.50/hr.) for situations in which operator labor is insufficient. Not included are insurance and taxes (Laughlin and Spurlock).

[b] A cultipacker is used to smooth and pack the seedbed for planting with the no-till drill, which has a grass seed box attachment for accurate measurement and placement of seed at ¼- to ½-in. planting depths.

[c] Application of Atrazine 4L is not allowed in Arkansas to date. A special license would be required to utilize this herbicide for weed control for switchgrass establishment. A similar special-use exemption was in place in Iowa at the time of writing.

[d] Total specified expenses include capital costs as well as repair and maintenance charges for tractors and equipment. Note that equipment may not be solely used for this enterprise but that typical annual usage of equipment is assumed.

proximately 1,587 dry tons of biorefinery processing per day. In turn, this translates to approximately 125 truck-trailer deliveries per day using a charge of $1.15 per bale for loading or unloading (Petrolia 2006b) with 50% of production handled four times (loading at the field, unloading at biorefinery storage, loading to storage, and unloading at grinder) versus direct unloading to the grinder from the field with just two handlings. With these assumptions, an average load and unload charge of $6.90 per dry ton was assessed in this study. Finally, using a suitable cropland availability of 450 acres per square mile and 25% of cropland in switchgrass surrounding the biorefinery, a maximum and average travel distance of 23.88 and 16.25 mi. resulted in a transport charge of $4.50 per dry ton.

Given the above assumptions and the relevant total specified production costs re-

Table 2. Estimated Costs per Acre, Second-Year Production of Switchgrass in Arkansas, 2006

Operation/Operating Input	Size/Unit	Month	Labor (hr.)	Amount	Cost in $ per Unit	Total Cost
Weed control		April				
Custom herbicide application	acre			1	4.75	4.75
2,4-D Amine	pt			1	1.59	1.59
Atrazine 4L[a]	pt			2	1.29	2.58
Early-season weed control					Subtotal	8.92
Fertilizer		April				
Custom fertilizer application	acre			1	4.75	4.75
Phosphate (0-46-0)	lbs.			45	0.15	6.75
Potash (0-0-60)	lbs.			100	0.14	14.00
Urea (46-0-0)	lbs.			165	0.18	29.70
Custom fertilizer					Subtotal	55.20
Harvest		October				
Disc mower	10 ft.		0.20	1	5.86	5.86
Large round baler	1,000 lbs.		0.30	1	11.68	11.68
Bale wrap	bale			6	1.75	10.50
Stacking	acre		0.12	1	1.44	1.44
Tarp	acre		0.06	0.115	80.00	9.20
Storage pad	acre			0.115	36.79	4.25
Harvest and storage					Subtotal	42.93
Operating interest						3.39
Total specified expenses[b]						110.44

[a] Application of Atrazine 4L is not allowed in Arkansas to date. A special license would be required to utilize this herbicide for weed control for switchgrass establishment. A similar special-use exemption was in place in Iowa at the time of writing.
[b] The disc mower is operated with a 75-hp 2WD tractor with cab, and the large round baler is operated with a 105-hp 2WD tractor with cab. Stacking is performed with a 50-hp mechanical front-wheel drive tractor with a front end loader and rear mount bale fork. The charges reflect depreciation and capital costs ($12.77) and repair and maintenance ($4.23) as well as fuel ($6.23 @ $2.40/gal.). Not included are insurance and taxes (Laughlin and Spurlock).

ported in Tables 1–3, a break-even price (P) per ton of switchgrass at the edge of the field could be calculated as follows:

$$(1) \quad P = \left[\sum_{t=1}^{n} c_t \Big/ (1+i)^n \right] \Big/ y,$$

where t is year of production starting with the year of establishment through year n, the useful life of the switchgrass stand, c is the total specified cost per acre of switchgrass production indexed by year of production, i is the real discount rate of 4% per year, and y is total dry matter production in tons of switchgrass. Adding plant-size dependent transport costs, loading and unloading charges, storage losses, and a payment to the producer for land, management, and operator time will result in a price biorefineries would need to pay for switchgrass at their plant. A sensitivity analysis on transport distance and useful life of the stand could then be performed. Setting a maximum travel distance to 50 mi. one way, for example, would allow a calculation of the maximum plant size supported using the above production parameters. Changing the useful life of the stand would affect the total production of switchgrass per production cycle and thereby the average annual yield and, in turn, the expected transport costs.

Results and Discussion

Using the above parameters for the production of switchgrass, the cost of production per dry ton varied from $36.80 in year 2 of

Table 3. Estimated Costs per Acre, Second-Year Production of Switchgrass in Arkansas, 2006

Operation/Operating Input	Size/Unit	Month	Labor (hrs)	Amount	Cost in $ per Unit	Total Cost
Weed control		March				
Custom air herbicide application	acre			1	5.50	5.50
Roundup Orig Max[a]	pt			0.5	3.24	1.62
Early-season weed control					Subtotal	7.12
Fertilizer		April				
Custom fertilizer application	acre			1	4.75	4.75
Phosphate (0-46-0)	lbs.			45	0.15	6.75
Potash (0-0-60)	lbs.			100	0.14	14.00
Urea (46-0-0)	lbs.			165	0.18	29.70
Custom fertilizer					Subtotal	55.20
Harvest		October				
Disc mower	10 ft.		0.20	1	5.86	5.86
Large round baler	1,000 lbs.		0.50	1	19.47	19.47
Bale wrap	bale			10	1.75	17.50
Stacking	acre		0.21	1	2.58	2.58
Tarp	acre		0.10	0.192	80.00	15.38
Storage pad	acre			0.192	36.79	7.08
Harvest and storage					Subtotal	67.87
Operating interest						3.47
Total specified expenses[b]						133.66

[a] For production beyond the second year, early-season weed control may also be accomplished with a 0.5-pt aerial application of Roundup for control of broadleaf and grassy weeds when switchgrass is dormant. This lowers the cost of early-season weed control by $1.80/acre.

[b] The disc mower is operated with a 75-hp 2WD tractor with cab, and the large round baler is operated with a 105-hp 2WD tractor with cab. Stacking is performed with a 50-hp mechanical front-wheel drive tractor with a front end loader and rear mount bale fork. The charges reflect depreciation and capital costs ($19.73) and repair and maintenance ($6.15) as well as fuel ($9.11 @ $2.40/gal.). Not included are insurance and taxes (Laughlin and Spurlock).

production to $26.73 in year 3. Although fertilizer cost and field operations are essentially the same for years 2 and 3, the higher yield in year 3 increased per acre cost of bale wrap and storage tarps as well as time involvement and fuel requirements. The added yield lowered the total specified cost per ton, however. Prorating the cost of production over the 12-year useful life led to a break-even price of $24.66/dry ton of switchgrass stored at the edge of the field.

Sensitivity analysis on the useful life of the stand and maximum transport distance led to interesting results. Shortening the stand life to 6 years between reestablishments, the prorated cost of production increased to $32.74/dry ton and lowered the average annual yield from 4.42 to 3.83 dry ton/acre. At the same time, variable transport charges increased from the $4.50/dry ton to $4.82/dry ton (due to the lower average yield), further highlighting the sensitivity of break-even prices to yield assumptions and spatial dynamics of transportation. Changing the transport distance to a maximum distance of 50 mi. one way increased the transport charge to $9.32 per dry ton and, at the same time, increased the annual capacity of a biorefinery to 219.24 million gallons.

Adding the $6.90 load/unload charge, the transport charge of $4.50, and the storage losses of $0.49 to the $24.66/dry ton, a biorefinery would need to pay $36.55/dry ton delivered to the plant. This figure does not include any payments to the farm operators' time involvement or returns to land. On the basis of historical cash rent for dryland soybean production and a premium for a long-term commitment, if the producer targets $100 per acre returns mainly to land but also to some management (note the relatively low time requirements per acre per year in Tables 2 and 3), an additional $17.85/dry ton would be required.

It is the opinion of this author that, even if the above issues regarding yield uncertainty, fertilizer requirements, and stand life are resolved, a number of additional issues remain. These include expectations regarding i) the relative profitability of switchgrass compared with conventional crops, given the long-term commitment of likely supply contracts to biorefineries, i.e., is $100 per acre for land and operator time and management sufficient or excessive? ii) the value that should be assessed for expected improvements in soil quality, reduced runoff, and provision of wildlife habitat; iii) uncertainty about carbon credit payments and establishment of switchgrass biorefineries; iv) the risks involving storage and/or potential crop losses that exist with the potential for excessive rainfall during the harvest window as well as the risk of fire prior to or during harvest; v) weed control issues in switchgrass; and vi) other energy crop alternatives and crop rotations that may require only annual commitments (e.g., sweet sorghum, corn, canola).

Conclusions

Switchgrass production is receiving increasing interest by producers in Arkansas for a number of reasons. Among them are not only increasing input prices (primarily fuel and fertilizer), but also environmental concerns, not the least of which is the reduction in available irrigation water and soil quality deterioration with existing crop rotations. Switchgrass production, considered soil quality improving and less input-intensive in terms of fertilizer, fuel, labor, herbicide, and irrigation than most other crop alternatives suitable for the region, is expected to relieve some pressures, not only on tightening agricultural profits but also declining agricultural land and water resources. The analysis presented above was intended to highlight the cost of production issues. Given, admittedly, a large number of educated assumptions for this commodity, many producers are potentially interested in but apprehensive about the yield uncertainty and relative profitability of this crop; a sense of hesitation, given the calculations presented above, is shared by this author. The paper aggregated information from relevant studies to provide producers and biorefineries a glimpse at what initial prices to charge/pay for switchgrass if a biorefinery with an annual 50-million-gallon capacity were established in Arkansas with the initial technological assumptions made. Undoubtedly, switchgrass yield improvements, carbon credits, and harvest/storage/transport cost-efficiencies will lower this paper's estimate in the future.

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