Assessment of Two Alternative Switchgrass Harvest and Transport Methods

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Abstract: As the search for renewable energy sources from agriculture intensifies, many agricultural producers are contemplating production of a native perennial grass species, switchgrass (*Panicum Vigratum*, L.). While much information on various aspects of switchgrass production exists, this paper discusses implications of two alternative harvesting and transportation methods that may be suitable for Arkansas conditions. Results suggested that module building compared to the simpler round baling technology may be a promising alternative.

Key Words: switchgrass, production, cellulosic biofuel, harvest, storage and transport costs

JEL Classification: Q42

Introduction

As energy prices have increased, so have the viability of energy production from renewable resources, the commodity prices as the agricultural sectors' demand has expanded from food, feed, and fiber production to the inclusion of alternative energy crops. With the expansion of the corn to ethanol industry, corn, soybean and wheat prices have increased 83, 21 and 32 percent compared to their 1996-2005 average Arkansas prices of $2.18, $5.80 and $3.03 per bushel, respectively (USDA – NASS, 2007). These increases in commodity prices, however, also helped to reduce the initial attractiveness of growing dedicated energy crops such as switchgrass as the profitability of growing soybean, corn and wheat have increased. Hence, many questions relating to eventual adoption of these alternative sources of renewable energy remain.

While many attributes of lignocellulosic biomass (LCB) conversion to biofuels (primarily ethanol) have been identified for society on the pathway toward greater fossil fuel independence, the benefits of alternative energy crop production for producers are not as evident. Potentially contentious issues are yield potential, stand life, a more efficient mode of storage, and harvest for the case of switchgrass. While much work has been done to hypothetically determine cost of harvest, storage, and transport (Amur and Sokhansanj; Thorsell et al.; Popp) the objectives of this study are to add to this literature by: i) comparing and contrasting two alternative modes of harvest that seem feasible in Arkansas; ii) using the cost of production information to determine breakeven prices for producers and/or biorefineries; and iii) discussing advantages and disadvantages related to the two modes of transport.

Data and Methods

Research concerning switchgrass production (Cassida et al., Madakadze et al., McLaughlin and Kszos; Muir et al., Perrin et al., Sanderson, Read and Reed) as well as economics of switchgrass production (Bransby et al.; Walsh; Thorsell et al.; Popp) exists. This paper uses information from these studies to hypothetically investigate the use of a module builder, common in cotton production in the Mississippi River Delta crop production region, and comparing it to an entry level large round bale storage and transport system as espoused by Popp. 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 were used.

Key assumptions surrounding switchgrass harvest, storage and transport costs as they pertain to this research are yield, operator labor availability and cost as well as harvest speed, efficiency and coordination. The base case assumes a single harvest in October at expected dry matter yields of 3 and 5 tons per acre for the second and subsequent years of production, respectively. Newly established grass is not harvested in the initial year. This yield level would be achieved with a fertilization scheme of 75 lbs of N per acre, which is intended to be sufficient to maintain stand life and yet low enough to reduce the incidence of significant lodging and allow for reasonable field drying time. Also, with these yields, a 50 MM gal per year ethanol plant can be supplied within a 50 mile radius surrounding the plant.

While cost of establishment and fertilization scheme are adopted from Popp (see Tables 1 and 2), harvesting is slightly modified in this paper by using a 12’ disc mower with conditioner and 105 hp tractor compared to a 10’ disc mower without conditioner and 75 hp tractor. This is done to ensure more adequate drying for the alternative harvest option of chopping the dry hay and use of the module building equipment and transport. Limiting assumptions for field operating speeds were the round baler producing 20 bales or 10 dry tons per hour at 16% m.c. for the round baling scenario and the forage harvester with a processing speed of 15 dry tons per hour at 12% m.c. for the module building scenario (Welch).

The main differences between the two harvest systems manifest themselves in the use of labor, storage protection (bale wrap and tarps), equipment intensity and final product (chopped or merely conditioned). For the round bale system potential exists for one operator to perform all functions as cutting, baling, stacking[3] and tarping[4] are performed sequentially. By contrast, harvest using the module building system requires five operators in the field at the same time (one for the harvester, two for the boll buggies used to carry the chopped forage to the module builder and two for moving and working with the module builder). Modeling these labor differences under various yield assumptions (i.e. 3, 5, 7 and 9 dry tons per acre) with the Mississippi State Budget Generator v. 6.0 (Laughlin and Spurlock) and regressing various labor, fuel and equipment ownership charges against yield revealed the following equations for labor, fuel, and capital recovery on equipment related to cutting, harvest, stacking and tarping:

Round Baling:	Labor hrs/acre = 0.172 + 0.158 * yield in dt/acre	(1)
Module Building:	Labor hrs/acre = 0.172 + 0.333 * yield in dt/acre	(2)
Round Baling:	Diesel fuel in gal/acre = 0.929 + 0.600 * yield in dt/acre	(3)
Module Building:	Diesel fuel in gal/acre = 0.929 + 1.675 * yield in dt/acre	(4)
Round Baling:	Capital recovery charge in $/acre = 2.684 + 1.976 * yield in dt/acre	(5)
Module Building:	Capital recovery charge in $/acre = 2.580 + 7.701 * yield in dt/acre	(6)

3 Stacking is performed using a 50 hp FWD tractor with loader and rear mount bale fork. Round bales are moved to the side of the field where raised gravel storage pads (established for $500 and lasting the useful life of the switchgrass stand) are located to ensure proper drainage and reduce storage losses. 52 bales are arranged in a pyramid that is 2 bales wide on the bottom and one bale on top. This work is performed at a rate of one 52-bale stack per hour.

4 Stacks and modules are protected from weather using tarps. This is estimated to require half an hour per stack for round baling using two 20’ x 48’ tarps valued at $400 and a five year useful life. For the module building option, the two module operators will tarp modules as part of their ongoing work using $125 tarps per module with a three year useful life.

Total specified cost (*TSC*) for fertilizer, herbicides, custom work, fuel, repair, tarps, storage pads and operating interest resulted in the following yield and labor dependent cost functions:

Round Baling: *TSC* in \$/acre = 74.222 + 12.060 * *y* + 0.172 * *l* + 0.158 * *l* * *y* (7)
Module Building: *TSC* in \$/acre = 71.643 + 16.005 * *y* + 0.333 * *l* + 0.171 * *l* * *y* (8)

where *y* and *l* are yield in dry tons/acre and hourly labor charges, respectively. Similar to Popp, first year establishment charges (*EC*) for switchgrass amounted to:

First year establishment charge: *EC* in \$/acre = 196.30 + 0.596 * *l* (9)

Once harvested, round bales are custom hauled at a rate of \$3.60 per loaded mile. A load consists of 26 bales -- 5' wide x 5.5' diameter at a dry matter weight of 1,000 lb. -- that are loaded and unloaded at a cost of \$1.15 per bale for each handling (Petrolia, 2006a &b). Since field access may not be guaranteed, 50% of the round bales are expected to be handled four times (load at the field, unload at the plant storage site, load at the plant and unload at the grinding station) rather than two times (load at the field and unload at the grinding station). This resulted total estimated loading and unloading charges of \$6.90 per dry ton.

By contrast, modules weighing 8.5 dry tons per module, 7' 9" wide, 9' tall and 32' in length, are custom hauled by specialized cotton module trucks. Recent work by Harrison and Johnson on module transport charges indicated fixed charges of \$17.43 per module and variable charges of \$1.22 per loaded mile for Texas gins, averaged over 2003 through 2005. An informal telephone survey of gin operators in Arkansas in 2006 resulted in a fixed charge of \$50 per module and a variable rate of \$2 per mile. The later cost assumptions were adopted in this study to reflect not only higher variable transport cost due to higher fuel prices, but also loading and unloading charges since module transporters, designed to pick up and drop off modules without additional labor or equipment, may need to handle modules more than once given similar assumptions regarding suitable field days as for the round bale scenario above. For both scenarios, 5% storage losses are assumed to occur from the time the crop is put up at the side of the field until eventual use at the plant (Kumar and Sokhansanj).

The biorefinery capacity was set at 50 million gallons/year at a conversion rate of 90 gallons/dry ton of switchgrass. With 350 operating days, this requires approximately 1,587 dry tons of biorefinery processing per day. Finally, using a suitable crop land availability of 450 acres per square mile and 25% of crop land in switchgrass surrounding the biorefinery, a maximum and average travel distance of 24.23 and 16.49 miles were calculated using L shaped travel patterns and an equal spatial distribution of switchgrass fields on the land surrounding the plant.

Given the above assumptions and relevant total specified production costs reported in Equations 7 to 9, a breakeven price (*P*) per ton of switchgrass at the edge of the field could be calculated as follows:

$$P = \left[\sum_{t=1}^{n} c_t / (1+i)^n \right] / y \qquad (10)$$

where t is year of production starting with the year of establishment through year n, the 12 year useful life of the switchgrass stand, c are the yield- and year of production dependent total specified cost per acre of switchgrass production, i is the real discount rate of 4% per year and y is total dry matter production in tons of switchgrass. Adding transportation charges that are dependent on plant size, loading and unloading charges, storage losses and a payment to the producer for cash rent on land and labor resulted in a price biorefineries would need to pay for switchgrass at their plant. Land rent was set at $75 per acre for well-drained land of marginal quality but suitable for switchgrass production. Labor charges were set at $8.50/hour similar to a recent study conducted by National Agricultural Statistics Service (USDA – NASS, 2006).

Results and Discussion

Using the above parameters for production of switchgrass, a yield of 3 dry tons per acre in year 2 and a yield of 5 dry tons per acre in years 3 through 12, the prorated cost of production per dry ton varied from $39.48 (round bales) to $46.62 (modules) for switchgrass at the side of the field including cash rent and labor charges. Adding transport, storage losses, loading and unloading charges resulted in a breakeven cost at the biorefinery of $52.92 and $60.81 for the round bale and module systems, respectively. This essentially implies that biorefineries would need to pay an additional $7.89 per dry ton to have material at the plant in chopped rather than unprocessed form. Also, using the above assumptions, the plant would need to process 128 truck loads of round bales or 196 modules per day. Both systems require approximately 132,000 crop acres in switchgrass in the 1,174 square mile area surrounding the plant.

Clearly the advantage of the module system is the ability to provide chopped material to the plant in a form where it can be easily metered for the production process using equipment similar to that of current gins. A minor advantage is that the module building system only requires a single tarp compared to tarps and bale wrap used for the round baling system. On the other hand, the major difficulties associated with module building are uncertainties about whether and how well switchgrass modules will last in the field as well as the high labor and equipment intensity compared to the more easily adoptable round baling technology. In Arkansas, haying equipment is common in the Western part of the state whereas, module building equipment is prevalent in the Eastern part of the state. An added problem is the low moisture requirement which may severely reduce the amount of switchgrass that can be harvested using this technology given typical Arkansas fall weather patterns. Finally, the 8.5 dry ton capacity of the module is merely an estimate that remains to be tested in the field. The ability to store more or less product would change costs significantly.

Conclusions

Given the above presentation, several issues will likely remain unresolved until commercial scale field experiments are conducted. These are: i) can chopped switchgrass be compacted in modules; ii) what kind of moisture content is required to maintain acceptable storage losses; iii) how long can round bales and modules last in the field and/or at what storage losses; iv) how easily are round bales of switchgrass that have been stored then ground under varying ambient air moisture and temperature conditions once delivered to the plant; v) will rural infrastructure support the number of trucks required per day; vi) what happens to the bale wrap once used; and vii) will sufficient skilled labor be available for the short harvest window especially for the module building system? Even with these questions largely unanswered, it is likely that both harvesting technologies may be used once switchgrass processing facilities are established.

References

Bransby, D.I., H.A. Smith, C.R. Taylor and P.A. Duffy. "Switchgrass Budget Model: An Interactive Budget model for Producing and Delivering Switchgrass to a Bioprocessing Plant." Industrial Biotechnology 1(2005):122-125.

Cassida, K. A., J. P. Muir, M.A. Hussey, J.C. Read, B.C. Venuto and W.R. Ocumpaugh. "Biomass Yield and Stand Characteristics of Switchgrass in South Central U.S. Environments." *Crop Science* 45(2005b):673-681.

Harrison, D and J. Johnson. "How many? How far? A study of module truck costs". Presentation at the 2007 Beltwide Cotton Conference in New Orleans, LA, Jan 9-12.

Kumar, A. and S. Sokhansanj. "Switchgrass (*Panicum vigratum*, L.) delivery to a biorefinery using integrated biomass supply analysis and logistics (IBSAL) model." *Bioresource Technology* March 2007:In Press.

Laughlin, D. and S. Spurlock. Mississippi State Budget Generator v 6.0. Software, User's Manual and Forage Budgets. http://www.agecon.msstate.edu/laughlin/msbg.php (Accessed January, 2007).

Madakadze, I.C., K.A. Stewart, P.R. Peterson, B.E. Coulman and D.L. Smith. "Cutting Frequency and Nitrogen Fertilization Effects on Yield and Nitrogen Concentration of Switchgrass in a Short Season Area." *Crop Science* 39(1999):552-557.

McLaughlin, S.B. and L.A. Kszos. "Development of Switchgrass (*Panicum virgatum*, L.) as a Bioenergy Feedstock in the United States." *Biomass and Bioenergy* 28(2005):515-535.

Muir, J. P., M. A. Sanderson, W. R. Ocumpaugh, R. M. Jones and R. L. Reed. "Biomass Production of 'Alamo' Switchgrass in Response to Nitrogen, Phosphorus and Row Spacing." *Agronomy Journal* 93(2001):896-901.

Perrin, R.K., K.P. Vogel, R. Mitchell and M.R. Schmer. "Switchgrass for Biomass: Commercial-Scale Production Costs in the Northern Great Plains." *Program and Abstracts, 8th Symposium on Biotechnology for Fuels and Chemicals*, 2006, p. 55.

Petrolia, D.R. "The Economics of Harvesting and Transporting Corn Stover for Conversion to Fuel Ethanol: A Case Study for Minnesota." Staff paper P06-12. Dept. of Applied Econ., University of Minnesota, Minneapolis, August 2006a. http://agecon.lib.umn.edu/cgi-bin/detailview.pl?paperid=23488 (Accessed January, 2007).

Petrolia, D.R. "Ethanol from Biomass: Economic and Environmental Potential of Converting Corn Stover and Hardwood Forest Residue in Minnesota." Selected paper for American Agricultural Economics Association Meetings, Long Beach, California, July 23-26, 2006b.

Popp, M. "Assessment of Alternative Fuel Production from Switchgrass: An Example from Arkansas." Invited Paper, Southern Agricultural Economics Association meetings in Mobile, AL, Feb. 3-8, 2007.

Sanderson, M. A., J. C. Read and R.L. Reed. "Harvest Management of Switchgrass for Biomass Feedstock and Forage Production." *Agronomy Journal* 91(1999):5-10.

Thorsell, S, F.M. Epplin, R.L. Huhnke, C.M. Taliaferro. "Economics of a Coordinated Biorefinery Feedstock Harvest System: Lignocellulosic Biomass Harvest Cost." *Biomass and Bioenergy* 27(2004):327-337.

Walsh, M.E. "US Bioenergy Crop Economic Analyses: Status and Needs." *Biomass and Bioenergy* 14(1998):341-350.

Welch, J. Personal Communication. University of Arkansas Cooperative Extension. Lonoke County, January 2007.

West, C. Personal Communication. Department of Crop, Soil and Environmental Science. University of Arkansas, September 2006.

University of Arkansas Cooperative Extension Service. Various Cost of Production Budgets. http://www.aragriculture.org/forage_pasture/budgets/default.htm (Accessed January 2007).

USDA. National Agricultural Statistics Service (NASS). Planted and Harvested Acreage with Yield, Price and Production for Arkansas Various Crops. http://www.nass.usda.gov/QuickStats/Create_Federal_All.jsp (Accessed January 2007).

USDA. National Agricultural Statistics Service (NASS). Farm Labor. November 2006. http://usda.mannlib.cornell.edu/usda/current/FarmLabo/FarmLabo-11-17-2006_revision.pdf (Accessed February 2007).

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

Operation/ Operating Input	Size/ Unit	Month	Labor (hrs)	Amount	Cost in $ per Unit	Total Cost
Disk & Incorporate[a]	24’	Sep	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		Mar				
Custom Air Herbicide Appl				1	5.50	5.50
Roundup Orig Max	pt			2	3.24	6.48
Pre-Plant Weed Control					Subtotal	11.98
Seedbed preparation[b]	20’	Apr	0.07	1	2.21	2.21
Planting	12’		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 Appl				1	5.50	5.50
Atrazine 4L[c]	pt			2	1.29	2.58
Planting					Subtotal	105.75
Weed Control		May				
Custom Air Herbicide Appl				1	5.50	5.50
2,4 – D Amine	pt			1	1.59	1.59
Post-Plant Weed Control					Subtotal	7.09
Operating Interest						9.37
Total Specified Expenses[d]						198.33

Notes:

[a] Disking, seedbed preparation using a cultipacker as well as planting with a no-till grain drill were performed using a 105hp 2WD tractor with cab. The charges reflect depreciation and capital costs ($10.17), repair and maintenance ($3.21) as well as fuel ($4.63 @ $2.40/gal) and hand labor ($2.03 @ $8.50/hr) for situations where 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 that has a grass seed box attachment for accurate measurement and placement of seed at ¼ to ½” planting depth.

[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.

Table 2. Yield (*y*) Independent and Dependent Field Operations and Estimated Costs per Acre for Weed Control, Fertilizer and Windrowing of Switchgrass in Arkansas, 2006.

{tc "Table 1. Estimated Costs per Acre, Maintaining Established Fescue and Bermuda Grass for Grazing in Arkansas, 2005 " \f D }

Operation/ Operating Input	Size/ Unit	Labor (hrs)	Amount	Cost in $ per Unit	Total Cost
Weed Control[a]					
Custom Herbicide Application	acre		1	4.75	4.75
2,4 – D Amine	pt		1	1.59	1.59
Atrazine 4L[b]	pt		2	1.29	2.58
Early Season Weed Control				Subtotal	8.92
Fertilizer					
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[b]					
			--- Round Baling ---		
Disc Mower Conditioner	12’	0.17	1	6.23	6.23
Large Round Baler	1,000 lb	*y*/10[c]	1	3.89 * *y*	3.89 * *y*
Bale wrap			*y* * 2	1.75	3.50 * *y*
Stacking		*y*/26	1	0.12 + 0.47 * *y*	0.12+0.47 * *y*
Tarp		*y*/52	*y*/26	80.00	3.08 * *y*
Storage Pad			*y*/26	36.79	1.42 * *y*
			--- Module Building ---		
Disc Mower Conditioner	12’	0.17	1	6.23	6.23
Hay Chopper/Harvester		*y*/15	1	6.06 * *y*	6.06 * *y*
Boll Buggies		*y*/7.5	1	5.30 * *y*	5.30 * *y*
Module Builder	8.5 tons	*y*/7.5	1	3.98 * *y*	3.98 * *y*
Tarp			*y*/8.5	41.67	0.55 * *y*
Operating Interest					
Round Baling			1	3.22 + 0.055 * *y*	3.22 + 0.055 * *y*
Module Building			1	3.20 + 0.062 * *y*	3.20 + 0.062 * *y*

Notes:

[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 during switchgrass establishment. A similar special use exemption was in place in Iowa at the time of writing. For years 3 through 12, the herbicide complement changes to 0.5 pints of Roundup Orig Max applied in March when switchgrass is dormant. This lowers the cost of early season weed control by $1.80/acre and changes the time of application to March from April. Fertilizer is applied in April.

[b] The disc mower conditioner, round baler and boll buggies are operated with a 105hp 2WD cab tractor. The harvester and module builder use a 170 and 150 hp 2WD cab tractor, respectively. Round bale stacking is performed using a 50hp MFWD tractor with front end loader and rear-mount bale fork.

[c] Labor requirements are based on operating capacities of 10 dry tons/hour for the large round baler, 15 dry tons/hour for the hay harvester and 26 dry tons/hour for stacking. Costs per unit include equipment capital recovery (4% real p.a.), repair and fuel ($2.40 per gal) but no charges for labor, insurance or taxes. These charges are yield (*y*) dependent.