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Switchgrass Harvest and Transport Comparison of Conventional Roundbaling and Hypothetical Moduling

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Introduction

As energy prices have increased, so has the viability of energy production from renewable resources. The expansion in the agricultural sector to include alternative energy crops, along with food, feed and fiber, is putting upward pressure on agricultural commodity prices. With the expansion of the corn based ethanol industry, the prices of Arkansas corn, soybean and wheat have increased 83%, 21% and 32%, compared to their 1996-2005 per bushel averages of $2.18, $5.80 and $3.03, respectively (National Agricultural Statistics Service, 2007). The increase in commodity prices has reduced the initial attractiveness of growing dedicated energy crops such as switchgrass (*Panicum virgatum*), as the profitability of growing conventional crops has increased. Therefore, many questions relating to the eventual adoption of 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. In the case of switchgrass, contentious issues include yield potential, stand life and developing an efficient mode of storage, transport and harvest. The objective of this study is to extend the past work that has been done to hypothetically estimate the costs of harvest, storage and transport (Kumar and Sokhansanj, 2007; Thorsell *et al.*, 2004; Popp, 2007; Bransby *et al.*, 2005) by: 1) comparing and contrasting two alternative modes of harvest that seem feasible in Arkansas; 2) using cost of production information to estimate breakeven prices for producers and/or biorefineries; and iii) discussing advantages and disadvantages related to the two modes of transport.

Data and Methods

Information from past research on switchgrass production (Madakadze *et al.*, 1999; Sanderson *et al.*, 1999; Muir *et al.*, 2001; Cassida *et al.*, 2005; McLaughlin and Kszos, 2005; Perrin *et al.*, 2006) and the economics of switchgrass production (Walsh, 1998; Thorsell *et al.*, 2004; Bransby *et al.*, 2005; Popp, 2007) was used to analyze and compare the two modes of transport. Use of a module builder, common in cotton production in the Mississippi River Delta crop production region, was compared to an entry level large round bale storage and transport system as espoused by Popp (2007). Input costs for 2006 (Laughlin and Spurlock, 2007; University of Arkansas Cooperative Extension Service, 2007) were used as well as expert opinion (West, 2006) to adjust assumptions regarding yield, fertilizer levels, cutting frequency, equipment needs, storage costs and transport requirements.

Key assumptions surrounding switchgrass harvest, storage and transport costs as they pertain to this research are: yield, operator labor availability and cost, harvest speed, efficiency and coordination. The base case assumes a single harvest in October at expected dry matter yields of 3 and 5 tons/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 pounds (lb) of nitrogen (N) per acre, which is intended to be sufficiently high to maintain stand life, low enough to reduce the incidence of significant lodging, and low enough to allow for reasonable field drying time. Also, with these yields, a 50 million gallon (gal)/year ethanol plant can be supported with 132,000 acres of switchgrass within a 25 mile radius of the plant.

While the cost of establishment and fertilization scheme are adopted from Popp (2007) (see Tables 1 and 2), harvesting is slightly modified in this paper by using a 12 foot (ft) disc mower with conditioner and 105 horsepower (hp) tractor compared to a 10 ft disc mower without conditioner and

[1] Popp is a professor and Hogan is an assistant professor and extension economist with the University of Arkansas Division of Agriculture, Fayetteville, Arkansas.

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

Operation/Operating Input	Size/Unit	Month	Labor (hrs)	Amount	Cost in $/Unit	Total Cost
Disk and Incorporate[a]	24 ft	September	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)	pounds			85	0.15	12.75
Potash (0-0-60)	pounds			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	pint			2	3.24	6.48
Pre-Plant 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	pounds			8	7.50	60.00
Custom Fertilizer Application				1	4.75	4.75
Urea (46-0-0)	pounds			110	0.18	19.80
Custom Air Herbicide Application				1	5.50	5.50
Atrazine 4L[c]	pint			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	pint			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 2 wheel drive (WD) tractor with cab. The charges reflect depreciation and capital costs ($10.17), repair and maintenance ($3.21) as well as fuel ($4.63 at $2.40/gallon) and hand labor ($2.04 at $8.50/hour) for situations where operator labor is insufficient. Not included are insurance and taxes (Laughlin and Spurlock, 2007).

[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 a planting depth of 0.25 to 0.50 in.

[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. Add $3.04 if operator labor is charged at $8.50/hour.

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

Operation/Operating Input	Size/Unit	Labor (hrs)	Amount	Cost in $/Unit	Total Cost
Weed Control[a]					
Custom Herbicide Application	acre		1	4.75	4.75
2,4 – D Amine	pint		1	1.59	1.59
Atrazine 4L	pint		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)	pounds		45	0.15	6.75
Potash (0-0-60)	pounds		100	0.14	14.00
Urea (46-0-0)	pounds		165	0.18	29.70
Custom Fertilizer				Subtotal	55.20
Harvest[b]					
			--- Round Baling ---		
Disc Mower Conditioner	12 feet	0.17	1	6.23	6.23
Large Round Baler	1,000 pounds	$y/10$[c]	1	$3.89 \times y$	$3.89 \times y$
Bale wrap			$y \times 2$	1.75	$3.50 \times y$
Stacking		$y/26$	1	$0.12 + 0.47 \times y$	$0.12 + 0.47 \times y$
Tarp		$y/52$	$y/26$	80.00	$3.08 \times y$
Storage Pad			$y/26$	36.79	$1.42 \times y$
			--- Module Building ---		
Disc Mower Conditioner	12 feet	0.17	1	6.23	6.23
Hay Chopper/Harvester		$y/15$	1	$6.06 \times y$	$6.06 \times y$
Boll Buggies		$y/7.5$	1	$5.30 \times y$	$5.30 \times y$
Module Builder	8.5 tons	$y/7.5$	1	$3.98 \times y$	$3.98 \times y$
Tarp			$y/8.5$	41.67	$4.90 \times y$
Operating Interest					
Round Baling			1	$3.22 + 0.055 \times y$	$3.22 + 0.055 \times y$
Module Building			1	$3.20 + 0.062 \times y$	$3.20 + 0.090 \times y$

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 mechanical front wheel drive (MFWD) tractor with front end loader and rear-mount bale fork.

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

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 (dt)/hour at 16% moisture content (MC) for the round baling scenario and the forage harvester with a processing speed of 15 dt/hour at 12% MC for the module building scenario (Welch, 2007).

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, including cutting, baling, stacking[2] and tarping[3] which can be 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 dt/acre) with the Mississippi State Budget Generator v. 6.0 (Laughlin and Spurlock, 2007) 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:

$$\text{Labor hours/acre} = 0.172 + 0.158 \times \text{yield in dt/acre} \quad (1)$$

Module Building:

$$\text{Labor hours/acre} = 0.172 + 0.333 \times \text{yield in dt/acre} \quad (2)$$

Round Baling:

$$\text{Diesel fuel in gal/acre} = 0.929 + 0.600 \times \text{yield in dt/acre} \quad (3)$$

Module Building:

$$\text{Diesel fuel in gal/acre} = 0.929 + 1.675 \times \text{yield in dt/acre} \quad (4)$$

Round Baling:

$$\text{Capital recovery charge in \$/acre} = 2.684 + 1.976 \times \text{yield in dt/acre} \quad (5)$$

Module Building:

$$\text{Capital recovery charge in \$/acre} = 2.580 + 7.701 \times \text{yield in dt/acre} \quad (6)$$

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:

$$TSC \text{ in \$/acre} = 73.974 + 12.133 \times y + 0.172 \times l + 0.158 \times l \times y \quad (7)$$

Module Building:

$$TSC \text{ in \$/acre} = 73.834 + 20.056 \times y + 0.172 \times l + 0.333 \times l \times y \quad (8)$$

where y and l are yield in dry tons/acre and hourly labor charges, respectively. Similar to Popp (2007), first year establishment charges (*EC*) for switchgrass amounted to:

First Year Establishment Charge:

$$EC \text{ in \$/acre} = 196.30 + 0.596 \times l \quad (9)$$

Once harvested, round bales are custom hauled at a rate of $3.60/loaded mile. A load consists of 26 bales – 5 ft wide by 5.5 ft in diameter at a dry matter weight of 1,000 lb – that are loaded and unloaded at a cost of $1.15/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 in total estimated loading and unloading charges of $6.90/dt.

By contrast, modules weighing 8.5 dt/module, 7 ft 9 inches (in) wide, 9 ft tall and 32 ft in length, are custom hauled by specialized cotton module trucks. Recent work by Harrison and Johnson (2007) on module transport charges indicated fixed charges of $17.43 per module and variable charges of $1.22/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/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, 2007).

[2] Stacking is performed using a 50 hp four wheel drive 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 two bales wide on the bottom and one bale on top. This work is performed at a rate of one 52-bale stack per hour.

[3] 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 ft by 48 ft 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.

The biorefinery capacity was set at 50 million gal/year at a conversion rate of 90 gal/dt of switchgrass. With 350 operating days, this requires approximately 1,587 dt of biorefinery processing/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 management resulted in a price biorefineries would need to pay for switchgrass at their plant. Land rent was set at $75/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 (2006).

Results and Discussion

Using the above parameters for production of switchgrass, a yield of 3 dt/acre in year two and a yield of 5 dt/acre in years three through twelve, the prorated cost of production per dry ton varied from $39.49 (round bales) to $46.64 (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 $52.93 and $58.74 for the round bale and module systems, respectively. This essentially implies that biorefineries would need to pay an additional $5.81/dt 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. Expanding the yield range, as shown in Figure 1, resulted in similar cost differential across harvest methods.

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

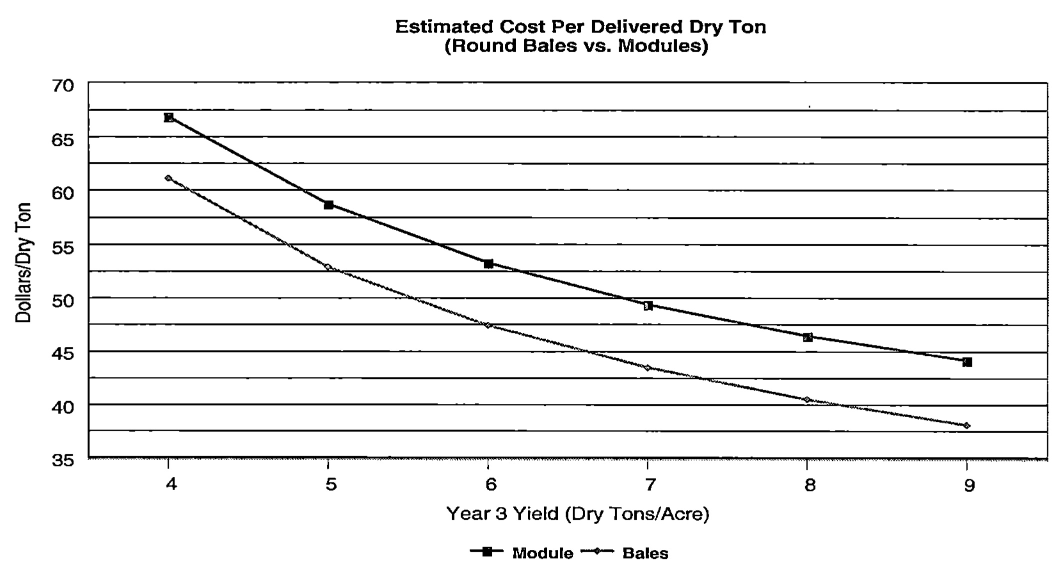

Figure 1: Hypothetical Comparison of Delivered Cost of Switchgrass Using an Extended Yield Range for Round Baling vs. Module Building Harvest and Transport Scenarios.
Note: The above holds for a labor charge of $8.50/hr, land rental at $75/ac, stand life of 12 years and year 2 yields at 60% of the yield potential achieved by year 3. The cost differential widens from $5.72/dt to $5.99/dt for the yields plotted above. Note that fertilizer expenses are not increased to increase yield, so that the above results would liken the effect of genetic improvements in switchgrass yields and/or different growing conditions.

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 dt 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 analysis, several issues will likely remain unresolved until commercial scale field experiments are conducted. These are: 1) can chopped switchgrass be compacted in modules; 2) what kind of moisture content is required to maintain acceptable storage losses and allow for cost-efficient conversion to ethanol; 3) how long can round bales and modules last in the field and/or at what storage losses; 4) how easily are round bales of switchgrass processed at varying ambient air moisture and temperature conditions after they have been stored; 5) will rural infrastructure support the number of trucks required per day; 6) what happens to the bale wrap once used; and 7) 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.

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