Producing and Harvesting Perennial Grasses for Cellulosic Biomass versus Alfalfa in Northeast Kansas

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Introduction

For 2014, the Environmental Protection Agency (EPA) set the cellulosic biofuel standard at 33 million gallons, significantly lower than the Clean Air Act target of 1.75 billion gallons (U.S. EPA, 2015). The EPA has proposed a 2.9 billion gallon advanced biofuel production goal for the U.S. in 2015, increasing to 3.4 billion gallons for 2016, with cellulosic ethanol having a proposed volume of 106 million gallons for 2015 and 206 million gallons for 2016 (U.S. EPA, 2015). Many questions still remain as to the viability of the cellulosic biofuel industry, including farm biomass production, particularly in light of the recent drop in international energy prices. As such, the objective of this analysis was to estimate returns from growing and harvesting perennial biomass. Net returns for switchgrass [*Panicum virgatum* L.] and Big Bluestem [*Andropogon gerardii* Vitman] used for cellulosic ethanol production were compared to alfalfa [*Medicago sativa* L.] used for animal feed. Costs and net returns, using enterprise budgets, for each crop were compared.

Background

Alfalfa is a commonly grown forage crop. Big Bluestem is a native grass in Kansas used for animal feed (Knapp, 1985). USDA NRCS (2004) notes that big bluestem is the dominant grass species of the tallgrass prairie, including the Flint Hills region in eastern and central Kansas, and is a high quality forage for all classes of livestock with crude protein of 16-18%. It is also often cultivated for haymaking. Switchgrass is another native grass that is regarded as a crop that has high potential to provide biomass for cellulosic ethanol production (McLaughlin et al., 1999; Vogel et al., 1985).

Griffith, Epplin and Redfearn (2010) estimated establishment costs for switchgrass in Oklahoma to be between $155 (no-till) to $189 (conventional till) per acre, or $22-$27 per acre per year amortized over a 10-year time horizon, the same as used in this study. Total costs of establishment, maintenance, fertilizer, harvest, storage and transportation of switchgrass produced for use by a bio-refinery in Blaine County, Oklahoma were found by Griffith, Haque, and Epplin (2014) to range from $55 per ton for the base scenario to $66 per ton with higher fuel prices. Debnath, Stoecker and Epplin (2014) compared differences in producing switchgrass compared with no-till wheat in Oklahoma to determine farm-gate breakeven prices for switchgrass when environmental costs of changes in soil erosion, fertilizer runoff, and soil organic carbon are considered, finding that switchgrass has potential to provide significant environmental benefits relative to wheat, particularly on more highly erodible land.

Duffy and Nanhou (2001) estimated total costs for switchgrass production in Southern Iowa to range from $175 to $325 per acre or $50 to $135 per ton, depending on switchgrass yield and the types of soils switchgrass was grown on. Khanna, Dhungana, and Clifton-Brown (2006), estimated annualized total costs for switchgrass of $151.62 per acre, including storage and transportation but excluding land charges. Perrin et al. (2008) collected data from ten farms in North Dakota, South Dakota, and Nebraska to estimate switchgrass production costs.

Annualized costs were estimated to be $65.16 per ton. Average annual yields from Perrin el al. (2008) at 9 locations, reported in Schmer et al. (2008) ranged from 2.32-4.95 tons per acre.

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Vadas, Barnett, and Undersander (2008) compared production costs for three crop systems in Wisconsin using corn, alfalfa, and switchgrass. Production costs, net profits, and on-farm energy use were greatest for continuous corn and smallest for switchgrass, with a corn-alfalfa rotation in the middle. Gonzalez et al. (2011) found that switchgrass and corn stover had lower net returns than forest-based cellulosic sources and switchgrass had higher returns than corn stover in all scenarios examined.

Data and Methods

Yields

Yields for two perennial grasses were analyzed from an agronomic field experiment conducted from 2007 to 2011 in Manhattan, Kansas (Propheter, 2009; Roozeboom et al., 2011). The perennial grass crops were switchgrass and Big Bluestem. Four yield observations for each crop across the four replications of the experiment were averaged for each year of the study. Benchmark yields for alfalfa were obtained from Kansas Farm Management Association enterprise data for two Riley County, Kansas farms (Herbel 2013) from 2007 to 2011.

The budgets for Big Bluestem, switchgrass, and alfalfa were based on 10 years of production. Yields for the ten-year production horizon were projected from the 2007 to 2011 experiment data. The year one yield was set equal to the annual yield of 2007, year two was the annual yield of 2008, and year three was the annual yield of 2009. Year four is the average of the annual 2008 and 2009 yields. The fifth year is the average of the annual 2008 to 2010 yields. Years six through ten are the average of the annual 2009 to 2011 yields. This method has yields increasing and then reaching a plateau, a common plant yield phenomenon (Llewelyn and Featherstone, 1997). Yield data are reported in Table 1.

Table 1: Actual 5-year Yields and Projected Yields Over the 10 Year Production Horizon (Tons per Acre).

Crop	Switchgrass Actual	Switchgrass Projected	Big Bluestem **Actual**	Big Bluestem Projected	Alfalfa **Actual**	Alfalfa Projected
Year 1	**1.99**	**1.99**	**2.03**	**2.03**	**3.01**	**3.01**
Year 2	**3.67**	**3.67**	**3.94**	**3.94**	**4.39**	**4.39**
Year 3	**4.67**	**4.67**	**2.39**	**2.39**	**3.68**	**3.68**
Year 4	**4.05**	**4.17**	**1.95**	**3.16**	**3.47**	**4.03**
Year 5	**6.15**	**4.13**	**5.57**	**2.76**	**3.48**	**3.84**
Year 6		**4.96**		**3.30**		**3.54**
Year 7		**4.96**		**3.30**		**3.54**
Year 8		**4.96**		**3.30**		**3.54**
Year 9		**4.96**		**3.30**		**3.54**
Year 10		**4.96**		**3.30**		**3.54**
Average	**4.11**	**4.34**	**3.18**	**3.08**	**3.60**	**3.67**

Field Operations

Nutrient removal, fertilizer application, and chemical use for 2007 and 2008 for the grasses were from Propheter (2009). The 2009 and 2010 fertilizer and chemical applications for the grasses were from experiment field notes (Roozeboom et al. 2011). Alfalfa field operations, chemical, and fertilizer costs were from Dhuyvetter, Dumler and Shoup (2014).

Big Bluestem and switchgrass were no-till drilled into soybean residue in May and June during the establishment year. Seeding rates in pounds of pure live seed per acre for switchgrass and Big Bluestem were 3.57 and 5.63, respectively, were from Propheter (2009). In year one (establishment), Big Bluestem and switchgrass were not fertilized, because this can lead to increased competition from weeds, which is the primary problem in establishing a stand (Penn State University). Fertilization takes place in succeeding years after the stand has been established. Only alfalfa was fertilized in year one, with 40 pounds per acre of actual phosphorus (P) and 60 pounds per acre of actual potassium (K) (Dhuyvetter, O'Brien, and Shoup, 2014). Alfalfa fertilizer rates for nitrogen (N), P, and K remained constant in each year of the ten-year production horizon.

In year two, the grasses were fertilized with 40.2 pounds of N from urea, 58.9 pounds of P from triple super phosphate and 249 pounds of K from potash (Propheter, 2009). In each subsequent year, 50 pounds per acre of N was applied to the perennial grasses over the ten-year production horizon. Additional P or K applications did not occur in the 2009-2011 experimental period. To account for P and K that were required to ensure nutrients were not limiting, an additional application occurred in year six, using the rates above.

Weed control for the grasses was accomplished in the experiment with the use of herbicides in years one and two for switchgrass, with an additional application in year three for Big Bluestem. Additional use of herbicides was not required. Alfalfa chemical use each year is from Dhuyvetter, O'Brien, and Shoup (2014). Field operation costs for seeding, chemical, and fertilizer operations are custom rates from Dhuyvetter (2014).

Harvest Costs

Custom rates for harvest operations were from Dhuyvetter (2014). These included swathing, sideraking, baling, and stacking large square bales. The costs of stacking and baling were calculated based on the number of bales per acre, a function of tons per acre and bale weights per crop for biomass. The weights used were 1,150 pounds per bale for both grasses versus 1,650 pound per bales for alfalfa. Stacking costs, but not transportation costs, were used in the economic analysis because biomass is sold at the edge of the field.

Perennial grasses were harvested once each year. Alfalfa is typically harvested four times per year in Riley County, Kansas (Llewelyn 2013). In the establishment year, alfalfa requires 60-70 days before harvest can occur (Dixon et al., 2005). Therefore, in year one, alfalfa was harvested three times instead of the typical four.

Input Prices

Fertilizer prices were from USDA (2014). Chemical prices were from Thompson et al. (2014). Seed prices were from Dhuyvetter, O'Brien, and Tonsor (2014) and Sharp Brothers Seed Company (2014). Costs for field operations including planting, chemical, and fertilizer application were from Dhuyvetter (2014). Land charges for all crops were a cash rental rate of $95.60 per acre, assuming medium quality land was utilized (Taylor, 2015).

Output Prices

Biomass prices used in this analysis are reported in Table 2. Perennial biomass prices were from the Kansas Hay Report by Hessman and Hruska (2014). Alfalfa prices were for "Good"

quality alfalfa. Brome grass prices were used as a proxy for switchgrass as there was no market price for switchgrass available. Brome grass is considered a higher quality grass than Big Bluestem and the quality and value of switchgrass as an animal feed has yet to be determined. In addition, these prices don't reflect the cost of transportation to a processing facility so farm gate prices may be different. This means that prices used in this study for the perennial grasses may be overvalued, a situation that is dealt with using sensitivity analysis.

Table 2: 2014 Biomass Prices ($/Ton)

Crop	$ per Ton
Alfalfa – Good Quality	$185.00
Big Bluestem	$114.00
Switchgrass (Brome)	$124.00

Results

Yields

Switchgrass had the highest average projected ten-year yield of 4.34 tons per acre per year followed by alfalfa with 3.67 tons per acre per year and Big Bluestem at 3.08 tons per acre per year (Table 1).

Amortized Costs per Acre

Costs were amortized over the ten-year production period using a 3.40% annual real discount rate. Amortized fertilizer, chemical, and seed costs totaled $68.07, $67.45, and $69.41 per acre for alfalfa, switchgrass, and Big Bluestem, respectively (Table 3). Amortized field operation costs for applying chemicals, fertilizer, and planting the crop were $8.35, $8.36, and $9.02 per acre for switchgrass, alfalfa, and Big Bluestem, respectively. The years in which chemicals and fertilizers were applied are indicated in Table 4. Planting occurred only in year one for all crops.

Amortized total input costs were $76.43, $75.29, and $78.43 per acre for alfalfa, switchgrass, and Big Bluestem, respectively. These small differences were due to the grasses not having applications of fertilizer and chemical applications in the first year, different numbers and rates of fertilizer applications in years two through ten, different numbers and rates of chemical applications. Amortized harvest costs were $143.84, $187.95, and $192.43 per acre for Big Bluestem, switchgrass, and alfalfa, respectively, due to differences in yield and bale weight.

Amortized total variable costs, including all input and harvest costs, were $222.27, $263.74, and $268.86 per acre for Big Bluestem, switchgrass, and alfalfa, respectively. The yield differences, which affect harvest costs, as well as different annual applications of fertilizer and chemicals were the main reasons for the cost differences.

Amortized total costs including variable costs plus interest on variable costs, and a land charge were $328.34, $371.16, and $376.44 per acre for Big Bluestem, switchgrass, and alfalfa, respectively. Alfalfa had the highest total cost because it had the second highest fertilizer, chemical, and seed cost, as well as the highest harvest cost.

Amortized Returns per Acre

Gross returns were also amortized over the ten-year production period using a 3.40% annual real discount rate. Amortized gross returns were $360.46, $547.90, and $702.17 per acre for Big Bluestem, switchgrass, and alfalfa, respectively (Table 3). Although the yield for switchgrass was higher than that for alfalfa (Table 1), the price for alfalfa was significantly higher resulting in alfalfa having the highest gross return.

Amortized net returns were $32.15, $176.74, and $325.73 per acre for Big Bluestem, switchgrass, and alfalfa, respectively. Alfalfa performed well due to having the second highest yield and highest price. Big Bluestem had the lowest cost, but also has the lowest yield and price which resulted in the lowest net return.

Amortized Costs per Ton

Amortized total input costs were $17.46, $20.83, and $25.46 per ton of biomass for switchgrass, alfalfa, and Big Bluestem, respectively (Table 3). Switchgrass had the lowest field operation costs per acre and the highest yield, which resulted in the lowest cost per ton. Big Bluestem had the lowest yield, which resulted in the highest cost per ton.

Amortized harvest costs were $43.31, $46.70, and $52.43 per ton of biomass for switchgrass, Big Bluestem, and alfalfa, respectively. Switchgrass had the highest yield which led to the lowest harvest cost per ton.

Amortized total variable costs, including all input and harvest costs, were $60.77, $72.17, and $73.26 per ton of biomass for switchgrass, alfalfa, and Big Bluestem, respectively. The low yields caused Big Bluestem to have the second highest total variable cost per ton. Alfalfa had the highest harvest cost per ton and the second highest total input cost per ton, resulting in the highest total variable cost.

Amortized total costs were $85.52, $102.57, and $106.60 per ton of biomass for switchgrass, alfalfa, and Big Bluestem, respectively.

Amortized Returns per Ton

Amortized gross returns were $117.03, $126.24, and $191.33 per ton of biomass for Big Bluestem, switchgrass, and alfalfa, respectively (Table 3). Switchgrass had a higher yield and higher price per ton than Big Bluestem. Alfalfa had a price that was much higher than both switchgrass and Big Bluestem, resulting in higher gross returns per ton.

Amortized net returns per ton were $10.44, $40.72, and $88.75 per ton of biomass for Big Bluestem, switchgrass, and alfalfa, respectively. Although alfalfa costs were substantially higher than switchgrass and yields somewhat lower, its price is also much higher, resulting in the highest net return, despite higher costs than switchgrass.

Table 3: Perennial Crop Cost in $ per Acre and $ per Ton.

	Amortized Cost and Returns ($ per Acre)		
	Switchgrass	**Big Bluestem**	**Alfalfa**
Seed	$3.42	$5.38	$1.35
Fertilizer	$61.86	$61.86	$56.79
Chemicals	$2.15	$2.17	$9.96
Field Operations	$8.35	$9.02	$8.36
Total Input Cost	$75.78	$78.43	$76.46
Harvest Costs	$187.95	$143.84	$192.43
Total Variable Costs	$263.74	$222.27	$268.89
Total Costs	$371.16	$328.34	$376.44
Gross Returns	$547.90	$360.46	$702.17
Net Returns	$176.74	$32.12	$325.73
	Amortized Cost and Returns ($ per ton)		
	Switchgrass	**Big Bluestem**	**Alfalfa**
Seed	$0.79	$1.75	$0.37
Fertilizer	$14.25	$20.08	$15.47
Chemicals	$0.50	$0.70	$2.71
Field Operations	$1.92	$2.93	$2.28
Total Input Cost	$17.46	$25.46	$20.83
Harvest Costs	$43.31	$46.70	$52.43
Total Variable Costs	$60.77	$72.17	$73.27
Total Costs	$85.52	$106.60	$102.57
Gross Returns	$126.24	$117.03	$191.33
Net Returns	$40.72	$10.43	$88.75
Total Tons (10 years)	43.42	30.79	36.65
Average Tons per Year	4.34	3.08	3.67

Table 4. Years In Which Fertilizer or Chemical Applications Occurred.

	Switchgrass	Big Bluestem	Alfalfa
Chemicals	1, 2	1, 2, 3	1-10
Fertilizer			
N	2-10	2-10	NA
P	2, 6	2, 6	1-10
K	2, 6	2, 6	1-10

Yield and Price Sensitivity Analysis

Breakeven yields and prices for each of the three crops were calculated to determine how sensitive the net returns were to changes in yield and price. Yields and prices that would make switchgrass and Big Bluestem have the same net return as alfalfa were also calculated.

Breakeven yields must decline to 2.36, 2.68, and 1.73 tons per acre for switchgrass, Big Bluestem and alfalfa, respectively (Table 5). These are relatively large yield declines equivalent to 46%, 13%, and 53% from the original average yield used in the analysis for switchgrass, Big Bluestem, and alfalfa, respectively. Switchgrass and alfalfa clearly have more robust results than Big Bluestem, which only needs to have a 13% yield decline in order for a zero net return to occur.

Perrin et al. (2008) collected switchgrass yield and input data for five years from ten farms in North Dakota, South Dakota, and Nebraska, which was extrapolated to a ten-year horizon. The average yield was 3.12 tons per acre. Khanna, Dhungana, and Clifton-Brown (2006) used a ten-year simulation model to predict switchgrass yields for Illinois. The average switchgrass yield was 3.80 tons per acre. The average switchgrass yield in this study was 4.34 tons per acre or 1.22 tons per acre greater than those from Perrin et al. (2008) and 0.54 tons per acre greater than Khanna, Dhungana, and Clifton-Brown (2006). The switchgrass yield of 4.34 tons per acre was within the range of 3.99 to 5.79 tons per acre reported by Vadas, Barnett, and Undersander (2008). All of these yields are well above the breakeven yield noted above. Part of the reason for the somewhat higher average switchgrass yield in this study may be that all biomass with the exception of some stubble was removed from the field during harvesting of the experimental plots. It is unlikely a farm manager would remove all biomass from the field due to soil conservation objectives. Therefore, switchgrass and Big Bluestem yields are adjusted downward to account for this.

According to Gallagher and Baumes (2012), 0.715 tons per acre of biomass should be left on the field for soil conservation objectives. To arrive at yield values for switchgrass and Big Bluestem, this amount was subtracted from the original yield each year. This resulted in new average yields of 3.62 tons per acre for switchgrass and 2.36 tons per acre for Big Bluestem. Alfalfa yields were actual farm yields harvested with typical harvest equipment rather than the biomass harvested “by hand” in the experimental plots. Under these conditions net returns for Big Bluestem and switchgrass decrease to -$25.37 per acre and $111.86 per acre, respectively. Although switchgrass was still profitable, alfalfa is significantly more profitable under this scenario, supporting the robustness of the results of this study.

Under the original yield conditions, breakeven prices are $84.00 per ton for switchgrass, $103.84 per ton for Big Bluestem and $99.18 per ton for alfalfa (Table 5). Under the adjusted yield conditions breakeven prices are $93.60 per ton for switchgrass and $124.47 per ton for Big Bluestem.

Price sensitivity was also conducted to determine what prices would be needed for switchgrass and Big Bluestem to have the same net return as alfalfa. Under the conditions where switchgrass and Big Bluestem harvested yields were adjusted downward for soil conservation purposes, the switchgrass price must be $182.13 per ton, slightly less than the price of alfalfa. However, Big Bluestem must be worth $259 per ton, which is a very high price.

In the event Big Bluestem stubble is enough to meet soil conservation requirements without leaving 0.715 per ton of harvested grass on the field, the price would need to be $206.86 per ton. If this is also true of switchgrass stubble, the price of switchgrass would be lower than that of alfalfa at $157.72 per ton.

Table 5. Breakeven Yields and Prices.

	Switchgrass	Big Bluestem	Alfalfa
Breakeven Yield (tons per acre)	2.36	2.68	1.73
	[-46%]	[-13%]	[-53%]
Breakeven Price ($ per ton) without Yield Adjustment	$84.00	$103.84	$99.18
	[-32%]	[-9%]	[-46%]
Breakeven Price ($ per ton) with Yield Adjustment	$93.60	$124.47	NA
	[-25%]	[+9%]	

Summary and Conclusions

Switchgrass and alfalfa both have positive amortized net returns when the yield adjustment for soil conservation sensitivity analysis is conducted. Breakeven prices for Big Bluestem are the highest of the three crops at both yield levels. Alfalfa had the largest net returns of the three crops under all conditions, presented here. Switchgrass was consistently the second most profitable alternative; however producer likely have less knowledge of how to properly manage stands of switchgrass. Switchgrass may not be easy to establish at the farm field scale and may require some re-seeding which was not reflected in the costs included in this study. Further, inability to harvest switchgrass at the optimum time in a farm field scale situation due to variable weather conditions, unlike in this study, may result in lower farm level yields. As such, on-farm yields may be lower and harvest costs for switchgrass higher than estimated in this analysis due to increased wear and tear on harvest equipment and difficulty for the operator in making optimal management decisions due to lack of knowledge, making switchgrass relatively less profitable than found in this study.

Rivers (2013) states that expected ethanol plant gate prices will need to range from $60 to $100 per ton of biomass in the near future for cellulosic ethanol plants to remain profitable. Transportation costs will make the farm gate prices even lower depending on the cost per ton-mile and transportation distance. Given the results of this study, these expected prices would not be enough to make switchgrass or Big Bluestem produced for ethanol feedstocks more profitable than alfalfa for cattle feed. In the short-run, it appears that land that could be used for producing and baling any of the three crops will most likely be used by farm managers in northeast Kansas to produce alfalfa.

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