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An Economic Analysis of Harvesting Biomass from Sorghums and Corn

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ABSTRACT

This study examines the economic potential of harvesting cellulosic biomass from corn and three types of sorghum rotated with soybeans using enterprise budgets constructed with experiment field data. The results show that harvesting of crop residue from grain sorghum, corn, and biomass from an energy sorghum that does not produce grain is economically feasible. Net returns from corn that produced grain and corn stover has the highest net return per acre. Dual purpose sorghum which produces sorghum grain and sorghum stover has the second highest net return per acre. Net returns from the other two sorghums were substantially less.

Introduction

There has been increasing interest in the potential use of cellulosic biomass for production of ethanol. Biofuel production must increase to 36 billion gallons by the year 2022, according to government mandates, with the majority of this fuel to be produced from advanced or second-generation biofuel feedstocks after 2015 (US Congress, 2007). Despite this mandate, the current production of biofuels from advanced feedstocks, including crop residue from annual crops such as sorghums and corn has been very low.




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The EPA has proposed a 3.4 billion gallon advanced biofuel production goal for the US for 2016, but only 206 million gallons is proposed to be from cellulosic ethanol, such as is derived from crop residues, up from 106 million gallons for 2015, but still quite low (US EPA, 2015). As 2022 draws closer, the urgency of establishing a lignocellulosic biofuel industry becomes more pressing. Many questions still remain as to the viability of the industry, including farm biomass production. Kansas farmers have potential to be major producers of biomass from sorghum crops for biofuels if the net returns compete with those of corn, because forage sorghums have been grown as livestock feed in the state for many years (Nelson et al., 2010). This is not a technical issue but rather an economic issue of whether selling crop residues to cellulosic ethanol plants can be profitable, and if so, which crop(s) are best suited to accomplish this.

The objective of this analysis is to estimate net returns to land and management from growing and harvesting biomass from four annual crop rotations. Soybeans were rotated with three sorghum varieties and with corn. Grain as well as crop residues were harvested from the sorghum crops and corn. Costs and net returns to land and management using enterprise budgets were compared to determine which crop rotation was the most economically feasible.

Corn stover has been compared with other biofuel feedstocks in several studies. Vadas, et al. (2008) compared corn stover with switchgrass and alfalfa in Wisconsin, finding that production costs were highest for continuous corn, but also that net profits were also greatest, compared to the other systems. Gonzalez, et al. (2011) compared corn stover with switchgrass as well as several hardwood and softwood cellulosic sources. They found that corn stover had the lowest net returns of all of the feedstocks they evaluated. Sokhansanj and Turhollow (2002) simulated corn stover harvest costs from formulas using technical coefficients. Costs, including transportation to a storage facility for square baling were estimated to be $21.40 per dry ton in 2002. Petrolia (2008) estimated costs for corn stover including transportation and reported the total costs were $44 to $66 per square bale and $55 to $77 per round bale. Economic evaluation of sorghum stovers is virtually non-existent in the research literature.

This study considers the costs and net return from both grain and biomass because crop residue biomass is a value-added product of grain production.

Data and Methods

Yields

The crops grown in rotation with soybeans [*Glycine Max* (L.)] are: Grain Sorghum (GS) [*Sorghum bicolor* (L.) Moench], Photosensitive Sorghum (PS), Dual Purpose Sorghum (DP), and Corn (C) [*Zea mays* L.]. While the experimental data is from a given field site in Kansas, the relative performance of the sorghum crops to each other and corn should hold for a wider geographic area, while specific agronomic, climatic, and environmental factors may affect the absolute results. Yields are from an agronomic field experiment over the period 2007-2011 at Manhattan located in Riley County, Kansas (Propheter, 2009; Roozeboom et al., 2011). 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, sorghum and corn biomass yields used in the economic analysis 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 to meet soil conservation requirements. To arrive at yield values for sorghum and corn biomass, this amount is subtracted from the original biomass yield each year.

Averages of the annual grain and adjusted biomass harvest data are reported in Table 1. There were four yield observations per year for each crop that were averaged. DP and GS are both varieties of sorghum used for grain production in semi-arid regions because they are considered to have high water use efficiency (Martin, Leonard, and Stanp, 1976). PS is grown for biomass production in northern latitudes because the day length is not long enough for it to set seed (McCollum, McCuistion, and Bean, 2005). Soybeans provide a rotational crop in many farming systems in Kansas and were rotated in the experiment with the sorghum varieties and corn in this study. One of the limitations of the study is that Propheter (2009) did not report the soybean yields, so only the results for the sorghum and corn components of the rotation are included. The major assumption behind this is that soybean yields were the same in each rotation. Input costs used in the analysis for the grain sorghums and corn crops do reflect having soybeans in the rotation.

Field Operations

In the field experiment nitrogen (N), phosphorous (P), and potassium (K) were applied to all of the crops. Crops were fertilized in early spring (March or April) before planting. Weed control was accomplished with herbicides using a no-tillage system. The corn and sorghum crops were all planted with a no-till row crop planter in late spring (April or May). Harvest occurred after the crop reached maturity and had standard moisture content. Depending on the crop, this occurred in late September for sorghum and late November for corn. Seeding rates used in the analysis are from 2007 and 2008 data obtained from Propheter (2009). Typical chemical applications are from experiment field notes (Roozeboom et al., 2011).

Input Prices

Fertilizer prices are from USDA (2014). Chemical prices are from Thompson et al. (2014). Seed prices are from Dhuyvetter, O'Brien and Tonsor (2014) and Sharpe Brothers Seed Company (2014). Custom costs for field operations including planting, chemical application, and harvest are from Dhuyvetter (2014a). Both grain sorghum and corn are grown on similar quality land, so a land charge is not included. This results in the net return being a net return to land and management.

Output Prices

Grain prices reported in Table 2 are the 2014 average prices for corn and sorghum from Dhuyvetter (2014b). Initial biomass prices used in this analysis are also reported in Table 2. Biomass prices in $/ton are the average of the weekly Kansas 2013 prices from the USDA biomass report (Pitcock, 2015), because complete data for all of the biomass types for the crops in this study are not available for 2014. Prices are the average of large round and large square bales at the edge of the field.

Crop and Biomass Nutrient Replacement

Fertilization is based on replacing the nutrients removed by the grain and biomass. Grain and biomass nutrient removal data for 2008 and 2009 from Propheter (2009) was averaged over the two years to create the fertilizer recommendations for grain and biomass production as a function of harvested yields in each year. The rates reported in Table 3 are based on leaving 0.715 tons per acre of biomass on the soil. If biomass had not been removed, the fertilizer amounts for biomass in Table 3 would have not been applied. With the exception of GS, the N and K replacement rates generally decline as biomass yield declines. Fertilizer replacement rates for grain generally increase as yields increase. Corn required the highest level of N, P, and K replacement and it had the highest grain yield. The N and K fertilizer replacement rates for biomass removal are highest for PS and lowest for C. PS has the highest biomass harvest of 9.76 tons per acre, while C has the next lowest of 6.61 tons per acre. Although GS has the lowest biomass harvest of 5.57 tons per acre, it has the second highest N and K fertilizer replacement rates. Lower biomass harvests for DP and C resulted in lower N and K replacement fertilizer rates.

Biomass Harvest Costs

For sorghum crops, the biomass is assumed to be harvested using several operations including swathing, raking, baling 1,100-pound large square bales, and stacking. Corn stover is assumed to be harvested with a stalk shredder and then baled in large square bales and stacked at the edge of the field. Harvest costs are from Dhuyvetter (2014a). Large square bales are assumed in order to make transport to biomass processing facilities easier than large round bales.

Cost Allocation Procedures

Fertilizer application was only made once each year, but additional fertilizer above that needed by the grain crop had to be applied because of that removed due to biomass harvest. Therefore, the application cost for the grain and biomass was split evenly. If there was no biomass harvest, the fertilizer cost would all be allocated to the grain crop. Alternatively, there is no grain from the PS crop, only biomass, so all fertilizer application costs are allocated to biomass.

Fertilizer cost allocation is based on the amount of N, P, and K used by the grain versus that removed due to biomass harvest. Biomass fertilizer replacement rates were determined in the experiment. These are reported in Table 3. For example, the grain sorghum crop removed 56 pounds of N, 8.3 pounds of P, and 178 pounds of K per year that would have been left in the soil for grain. Therefore, the cost of these amounts of nutrients were charged to biomass production and the remainder of the cost was applied to grain. If there had been no biomass harvest, all fertilizer costs, although different, would have been for grain.

All fertilizer costs were allocated to biomass for PS, as there was no grain harvest, only biomass.

All chemical and chemical application costs were charged to the grain as these were required for grain production. These are sunk costs for grain production and should not be allocated to biomass production. There were no chemicals applied for the biomass and the biomass does not have to be harvested once the grain is produced.

Again, all chemical and chemical application costs were allocated to biomass for the PS crop, as there was no grain harvest with the PS crop, only biomass.

Two separate harvest costs are allocated, one for grain and a separate set of biomass harvesting costs as these are separate operations. In the future, there may be equipment that can make one pass through the field to harvest both.

Interest costs are interest on the variable costs allocated as described above.

Results

Grain Yields and Biomass Yields

The average grain and biomass yields are reported in Table 1. Corn (C) rotated with soybeans had the highest grain yield of all of the crops at 135.5 bushels per acre Dual purpose (DP) sorghum is second highest at 73.2 bushels per acre and is followed by grain sorghum (GS) with 66.9 bushels per acre.

Photoperiod sensitive (PS) sorghum, which has no grain yield, has the highest average biomass yield of 9.76 tons per acre (Table 1). All other crops have biomass yields below 8 tons per acre. Dual purpose (DP) sorghum had a biomass yield 7.94 tons per acre and is followed by corn (C) at 6.61 tons per acre. Grain sorghum (GS) has a biomass yield of 5.57 tons per acre.

Input and Field Operation Costs

No-till planting costs are similar for each crop (Table 4). However, seed costs are substantially higher for corn. Seed costs for GS are higher than for DP or PS, but all are much lower than for corn.

Fertilizer, chemical, and harvest costs are separable between grain and biomass production because these operations such as chemical applications are separate and nutrient replacement for grain versus nutrient replacement for biomass was determined in the experiment (Table 4). Fertilizer application occurred once during the year, so field application costs are split evenly between the grain and biomass costs.

Fertilizer costs for grain production range from $40.40 per acre for GS to $79.11 per acre for C (Table 4) and were less than the fertilizer costs associated with biomass production which range from $73.39 per acre for C to $198.54 per acre for PS. Total fertilizer costs excluding application are highest for PS ($198.54) and lowest for C ($152.50).

Chemical costs for grain production range from $24.35 per acre for DP to $48.70 per acre for GS (Table 4). Chemical costs for biomass production are only incurred for the PS crop which does not produce grain.

Harvest Costs

Grain harvest costs for the crops range from $45.30 per acre for GS to $69.44 per acre for C. The GS rotation has the lowest grain yield and C the highest (Table 1).

Biomass harvest costs range from $182.25 per acre for CC to $351.02 per acre for PS. The number of bales per acre (Table 1) affects harvest cost as well as tons per acre harvested, because the cost for stacking and baling is charged per bale. The larger the number of bales, the larger the harvest cost per acre.

Total Costs

Total grain production costs range from $196.10 per acre for GS to $318.02 per acre for C. The DP rotation has the lowest total grain production costs, largely because it has the lowest chemical costs.

Total biomass production costs range from $322.24 per acre for C to $691.16 per acre for PS. The biomass PS rotation has the highest cost because the PS crop incurred all costs for biomass production because there is no grain production. The CC rotation has the second lowest total biomass costs.

Total production costs range from $546.64 per acre for GS to $691.16 per acre for PS. C and DP have the first and second highest production costs of crops producing both grain and biomass.

Gross Returns

Grain production gross returns range from $554.27 per acre for C to $263.16 per acre for GS. C has the highest grain yield, contributing to this result.

Biomass production gross returns range from $402.38 per acre for C to $764.61 per acre for PS. The PS rotation has the highest yielding biomass. The second highest gross is for DP which has the second highest biomass yield. The initial sorghum biomass price used in this analysis is $78.33 per ton, while the corn stover biomass price is $60.90 per ton (Table 2). The GS rotation has a lower biomass yield than the C rotation, but due to higher prices for sorghum biomass the GS rotation has slightly higher gross returns.

Total gross returns range from $699.56 per acre for GS to $956.65 per acre for C. The higher grain gross return of the C rotation outweighs its low biomass gross return to make it have the highest total gross. The biomass gross returns are higher for GS, and DP than their grain gross returns.

Net Returns

Grain net returns range from $67.06 per acre for GS to $236.25 per acre for C (Table 4). Biomass net returns range from $73.45 per acre for PS to $195.16 per acre for DP. The second lowest biomass net return is from C. The net returns from corn grain were higher than that from corn biomass. Alternatively, the net returns from biomass were higher than net returns from grain for the sorghums. This demonstrates that making a decision on what to produce cannot be made by looking only at grain or biomass net return alone. The net returns are influenced by the allocation of costs between grain and biomass which are explained earlier.

Total net returns range from $73.45 per acre for PS which only produces biomass to $316.39 per acre for C. DP has a lower, but very similar net return. Both C and DP had net returns that were more than double the returns of each of the other crops. Further, examining only costs is not appropriate because C, which has the highest cost, has the highest net return and GS, which has the lowest cost, has a relatively small net return.

Yield and Price Sensitivity Analysis

Breakeven yields and prices for each of the crops are calculated to determine how sensitive the net returns are to changes in yield and price. Yields and prices that would make DP have the same net return as C are also calculated because there is a very small difference in these net returns per acre. The increase in biomass yield in the PS system needed to have a net return equivalent to that of C is also determined. The initial corn price used in the analysis has a premium to sorghum of $0.16 per bushel. Projected prices for the 2014-2015 marketing year which ends September 30, 2015 have corn at $3.69 per bushel and sorghum at $3.95 per bushel (Barnaby, 2015). At these prices sorghum has a premium of $0.26 per bushel to corn. Given that the initial sorghum price in the study is $3.93 per bushel and the current projected estimate is very close at $3.95 per bushel, we use the initial sorghum price of $3.93 per bushel and a corn price that is $0.26 per bushel less at $3.67 per bushel in an additional sensitivity analysis. Net returns are also calculated using a range of biomass prices.

Because grain yield and biomass yield are related, breakeven yields for grain and biomass that cause the total net return to equal $0.00 are reported. Grain yield and biomass yields are assumed to be perfectly correlated, therefore the ratios of biomass per bushel of grain produced are held constant in the breakeven yield analysis for each crop. The ratios of biomass prices to grain prices are also assumed to be constant in the analysis.

Breakeven Yields

Breakeven yields that cause total net returns to equal $0.00 are reported in Table 5. For C, which has the highest net return, the yields could fall 33.1 percent to 90.7 bushels per acre and 4.42 tons per acre before there would be a net loss from joint production of grain and biomass. For DP the yields would have to decline to 48.1 bushels per acre and 5.22 tons per acre, a decrease of 34.3 percent.

Breakeven Price

Breakeven prices are reported in Table 6. As with yields, the prices for DP would need to decline 34.3 percent, to $2.58 per bushels of grain sorghum and $51.52 per ton of biomass, for DP to breakeven. For C, the biomass price would need to fall to $40.76 per ton with a corresponding grain price of $2.74 per bushel, a decrease of 33 percent, slightly smaller than the decrease needed for DP, since net returns were marginally higher for C.

Equating Net Returns of C and DP

Price and yield combinations that equate the net returns of the C rotation and the DP rotation are also calculated. While holding the original yields constant, the DP rotation would require prices of $3.95 per bushel and $78.77 per ton of biomass, which are $0.02 per bushel and $0.44 per ton higher than the original prices in order for the DP net return to be equal to the C net returns. While holding the original prices constant, DP would require yields of 73.62 bushels per acre and 7.99 tons per acre for biomass which are 0.42 bushels per acre and 0.05 tons per acre greater than the original yields in order for the DP net returns to be equal to C net returns. In both cases, these are very small changes, indicating how close these two systems are in profitability.

Equating net returns of PS to C while holding original prices constant, the PS rotation would require a yield increase of 3.11 tons per acre from 9.76 to 12.87, an increase of nearly 32 percent and probably not technically feasible.

Change in Corn Price Relative to Grain Sorghum

When corn is priced $0.26 per bushel less than the price of grain sorghum, the net return of C declines from $316.39 per acre to $259.48 per acre. Although, the net return from corn grain is still higher than the net return from corn stover, the total net return for C is $52.53 per acre less than DP in this situation. The C net return remains substantially larger than GS or PS. For C to have an equivalent net return as GS using the original prices for grain sorghum and biomass, the corn price would need to decline to $2.88/bu. from $4.09/bu. The last time average corn prices were at or below $2.88 was in the 2005-2006 marketing year.

A Single Biomass Price

Biorefiners may pay a single price for biomass whether or not it is from corn or grain sorghum, therefore net returns are reported for seven biomass prices ranging from $65 to $125 per ton in $10 increments. This eliminates the price advantage of sorghum biomass in the original analysis. Table 7 shows that the C rotation is the most profitable rotation at all levels, but the difference in net returns between C and DP rotation declines as the price of biomass rises. At a biomass price of $98/ton and above the net returns of PS are larger than GS. Under a single biomass price of $95/ton (at the midpoint) and the original grain sorghum price, corn price would need to decline to $1.905/bu. for C to be equivalent to GS.

Summary

The results show that harvesting of grain and crop residue from grain sorghum and corn is economically feasible for each of the four systems evaluated. Corn (C) grown in rotation with soybean has the highest net return per acre and the dual purpose (DP) grain sorghum in rotation with soybean has the second highest net return per acre under a variety of price conditions. However, if sorghum grain price has a premium to corn grain as has been the case for the 2014-2015 marketing year, then DP has a higher net return than C. Both of these crops had net returns that were substantially higher than the net returns of the other crops for each price scenario. The sensitivity analysis shows that the initial results are robust.

The question of whether grain producers would desire to go to the additional effort of harvesting crop stover following grain harvest is unclear, but the results of this study indicate that there are potential economic returns to doing so and that they should consider the possibility of adding this to their production portfolio. Although our sensitivity analysis held the ratio between grain and biomass prices constant, as the production of cellulosic ethanol increases from its current low level to higher levels, it is likely biomass prices will increase relative to grain. Therefore, the profitability of harvesting crop residues will increase relative to grain.

Further, there would not be a great deal of additional investment in equipment, since many crop producers in Kansas already have haying equipment, or could obtain custom harvest services. But there may be other constraints such as limited time during harvest season or other enterprises that need attention of the operator which could keep them from harvesting stover following grain harvest. New technologies which allow for one-pass harvest of grain and stover may also better allow farmers to produce and sell stover.

One other issue that was not considered in this study is the distance to market for the stover and how that affects localized prices. This analysis assumes a local market within a radius close enough for the stover to be transported at a cost that is economically feasible to maintain a market. Not all areas in Kansas have access to such a market at this point.

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Table 1. Average grain and biomass yields.

Crop[a]	Grain (Bushels per Acre)	Biomass (Tons per Acre)	Biomass (Bales per Acre)
GS	66.9	5.57	10.13
PS	0.0	9.76	17.75
DP	73.2	7.94	14.45
C	135.5	6.61	11.25

[a] Grain Sorghum (GS), Photosensitive Sorghum (PS), Dual Purpose Sorghum (DP), and Corn (C).

Table 2. 2014 grain and biomass prices.

Crop	Grain $ per Bushel	Biomass $ per Ton
Sorghum	$3.93	$78.33
Corn	$4.09	$60.90

Table 3. Annual fertilizer replacement based on grain and adjusted biomass removal (pounds per acre).

	Crop[a]			
	GS	PS	DP	C
Grain N	36	-	39	68
Grain P	14	-	15	24
Grain K	19	-	22	34
Biomass N	56	92	50	40
Biomass P	8.3	19.9	8.6	6.0
Biomass K	178	262	172	91

[a] Grain Sorghum (GS), Photosensitive Sorghum (PS), Dual Purpose Sorghum (DP), and Corn (C).

Table 4. Costs and returns per acre.

	Crop[a]			
	GS	PS	DP	C
Planting	$20.29	$20.29	$20.29	$20.40
Seed	$20.25	$5.33	$7.54	$90.18
Fertilizer Application – Grain	$2.98	$0.00	$2.98	$2.98
Fertilizer Application – Biomass	$2.98	$5.95	$2.98	$2.98
Fertilizers – Grain	$40.40	$0.00	$50.40	$79.11
Fertilizers – Biomass	$127.41	$198.54	$121.23	$73.39
Total Fertilizer Costs	$167.81	$198.54	$171.63	$152.50
Chemical Application – Grain	$12.02	$0.00	$12.02	$12.02
Chemical Application – Biomass	$0.00	$36.68	$0.00	$0.00
Chemicals – Grain	$48.70	$0.00	$24.35	$33.88
Chemicals – Biomass	$0.00	$36.68	$0.00	$0.00
Total Planting, Seed, Fertilizer, and Chemical Costs	$275.01	$303.46	$241.78	$314.94
Harvest – Grain	$45.30	$0.00	$48.09	$69.44
Harvest – Biomass	$209.12	$351.02	$289.53	$235.74
Total Input and Field Operation Cost - Grain	$189.93	$0.00	$165.66	$308.01
Total Input and Field Operation Cost - Biomass	$339.51	$669.40	$413.74	$312.10
Total Input and Field Operation Cost	$529.44	$669.40	$579.40	$620.11
Interest – Grain	$6.17	$0.00	$5.38	$10.01
Interest – Biomass	$11.03	$21.76	$13.45	$10.14
Total Interest	$17.21	$21.76	$18.83	$20.15
Total Cost – Grain	$196.10	$0.00	$171.04	$318.02
Total Cost – Biomass	$350.54	$691.16	$427.19	$322.24
Total Cost	$546.64	$691.16	$598.23	$640.26
Gross return – Grain	$263.16	$0.00	$287.89	$554.27
Gross return – Biomass	$436.40	$764.61	$622.35	$402.38
Total Gross Return	$699.56	$764.61	$910.24	$956.65
Net Return – Grain	$67.06	$0.00	$116.85	$236.25
Net Return – Biomass	$85.86	$73.45	$195.16	$80.14
Total Net Return	$152.91	$73.45	$312.01	$316.39

[a] Grain Sorghum (GS), Photosensitive Sorghum (PS), Dual Purpose Sorghum (DP), and Corn (C).

Table 5. Joint breakeven yields for grain and biomass.

Crop[a]	Grain (Bushels per Acre)	Biomass (Tons per Acre)
GS	52.3	4.36
PS	0.0	8.82
DP	48.1	5.22
C	90.7	4.42

[a] Grain Sorghum (GS), Photosensitive Sorghum (PS), Dual Purpose Sorghum (DP), and Corn (C).

Table 6. Joint breakeven prices for grain and biomass.

Crop[a]	Grain ($ per Bushel)	Biomass ($ per Ton)
GS	$3.07	$61.24
PS	$0.00	$70.82
DP	$2.58	$51.52
C	$2.74	$40.76

[a] Grain Sorghum (GS), Photosensitive Sorghum (PS), Dual Purpose Sorghum (DP), and Corn (C).

Table 7. Net returns ($ per acre) at various biomass prices.

Biomass Price $ per Ton	Crop[a]			
	GS	PS	DP	C
$65	$78.63	$-56.70	$206.08	$348.48
$75	$134.34	$40.91	$285.53	$409.56
$85	$190.05	$138.52	$364.97	$475.63
$95	$245.76	$236.13	$444.42	$541.70
$105	$301.47	$333.74	$523.87	$607.78
$115	$357.18	$431.35	$603.32	$673.85
$125	$412.89	$528.96	$682.77	$739.92

[a] Grain Sorghum (GS), Photosensitive Sorghum (PS), Dual Purpose Sorghum (DP), and Corn (C).