An Economic Analysis of Harvesting Cellulosic Biomass from Corn, Grain Sorghums, and Perennial Grasses

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ABSTRACT

This study examines the economic potential of harvesting cellulosic biomass from corn and three types of grain sorghum rotated with soybeans, and harvesting perennial grasses instead of alfalfa. This research uses enterprise budgets based on experiment field data and Kansas Farm Management Association data. The results show that harvesting of crop residue from corn and sorghum, with the exception of an energy sorghum that does not produce grain is economically feasible under 2013 prices. A corn-soybean rotation has the highest net returns per acre. The dual purpose sorghum-soybean rotation has the second highest net returns per acre. Further, the annualized average net return from two of the perennial grasses grown on land typically used for alfalfa is also positive but not as positive as alfalfa.

Subject Area: Farm Management

Keywords: Alfalfa, Corn, Cellulosic Biomass, Grain Sorghums, Perennial Grasses

INTRODUCTION

There is increasing interest in the potential to use cellulosic biomass for production of ethanol. Biofuel production must increase to 36 billion gallons by the year 2022, according to government mandates. The majority of this fuel must be produced from advanced or second-generation biofuel feedstocks after 2015 (U.S. Congress 2007). Advanced biofuel feedstocks include annual crops such as energy sorghums and perennial grasses. 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 energy sorghums for biofuels if the net returns compete with those of corn, soybeans, and alfalfa, because forage sorghums have been grown as livestock feed in the state for many years (Nelson et al., 2010).

The objective of this analysis is to estimate returns from growing and harvesting both annual and perennial biomass for potential cellulosic ethanol production. Net returns of five annual crop rotations and of three perennial crops are examined. Soybeans are rotated with five sorghum varieties and corn. Continuously cropped corn is also included for comparison. Perennial grasses, switchgrass and big bluestem are compared to a more traditional perennial crop, alfalfa.

Enterprise budgets are constructed for the annual crops; consisting of three sorghum varieties, corn, and soybeans. Enterprise budgets are also constructed for three perennial crops; consisting of switchgrass, big bluestem grass, and alfalfa. Alfalfa is used as a comparison to the perennial crops of big bluestem and switchgrass even though alfalfa is not part of the field experiment. Costs and net returns for each of these budgets are compared to determine which crop rotation is the most economically feasible. Yields and some input rates, excluding soybean yields and inputs, are from an agronomic field experiment at Manhattan located in Riley County, Kansas (Propheter, 2009; Roozeboom et al., 2011). Chemical usage, and field operations are from O'Brien and Duncan (2012; a b, and c). Nutrients removed by both grain and biomass are replaced according to the field experiment rates of removal from Propheter (2009). Alfalfa field operations, chemical, and fertilizer costs, including lime application, are from Dumler and Shoup (2012) and yields are from Herbel (2013). The budgets for the annual crops are constructed for a rotation with soybeans, with the exception of continuously cropped corn. Perennial crop costs and returns are budgeted over an assumed 10 year production horizon. Input prices are from USDA Agricultural Prices, Kansas State University farm management guides, and Sharpe Brothers Seed Company. Harvest costs are from Kansas State University farm management guides, and a Northeastern Colorado and Northwestern Kansas producer survey.

Soybeans [*Glycine max* L. Merr.] provide a rotational crop in many farming systems, and are rotated with either sorghum or corn in this study. The sorghum varieties included grain sorghum (GS), dual purpose (DP), sorghum, and photoperiod sensitive (PS) sorghum. 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 et al., 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). Corn [*Zea mays* L.] is rotated with soybeans (RC) in the experiment, which is a common practice in Northeast and North Central Kansas (NE-NC KS). Corn is also continuously cropped (CC) in the experiment.

Alfalfa [*Medicago sativa* L.] is a commonly grown forage crop in NE-NC KS and is used as a benchmark for comparison to the other perennial crops. Big bluestem [*Andropogon gerardii* Vitman] is a native grass used for animal feed and is noted as a drought resistant species (Knapp, 1985). Switchgrass is another native grass that is regarded as a crop that has high potential to provide biomass for ethanol production, and it also is a source of animal feed (McLaughlin et al., 1999; Cogel et al., 1985).

DATA AND METHODS

Averages of the annual and perennial grain and biomass harvest data reported in Tables 1 and 2 are from 2007 to 2011 for an experimental field study at Kansas State University, Manhattan KS (Propheter, 2009, Roozeboom et al., 2011). The crops are: Grain Sorghum (GS) [*Sorghum bicolor* (L.) Moench], Photosensitive Sorghum (PS), Dual Purpose Sorghum (DP), Corn rotated with soybeans (RC) [*Zea mays* L.], Continuous Corn (CC), Switchgrass [*Panicum virgatum* L.], and Big bluestem [*Andropogon gerardii* Vitman]. There are four yield observations per year for each crop that are averaged.

Annual Crop Field Operations

The GS, PS, DP, and RC rotations all include soybeans in rotation. One of the limitations of the study is that Propheter (2009) did not report the soybean yields, so it is necessary to use soybean yields for the same experiment area. Soybean [*Glycine max* L. Merr.] yields for Riley County KS are from (Roozeboom 2013) for 2007 to 2011. All soybean prices, yields, costs, and net returns which are included in the rotations do not vary from one rotation to another. Alfalfa, a perennial crop benchmark [*Medicago sativa* L.] yields are obtained from KFMA enterprise data for two Riley County Kansas farms (Herbel 2013). Nutrient removal, fertilizer application, and chemical use for 2007 and 2008 are from Propheter (2009). The 2009 and 2010 fertilizer and chemical applications are from experiment field notes (Roozeboom et al. 2011). Kansas State University farm management guides provide the inputs and field operations for alfalfa and soybeans (Dumler and Shoup, 2012; O'Brien and Duncan, 2012, c).

In the field experiment nitrogen (N), phosphorous (P), and potassium (K) was applied to all of the annual crops with the exception of soybean. Nitrogen is applied annually, while P and K are applied less frequently. Weed control is accomplished with herbicides using a no-tillage system. Annual crops are fertilized in early spring (March or April) before planting. The soybean, corn, and sorghum crops are all planted with a no-till row crop planter in late spring (April or May). Annual crop seeding rates for all sorghums, soybeans, and corn are from the respective O'Brien and Duncan (2012; a, b, and c) crop budgets. Fertilizer prices are from the USDA farm price report April edition (USDA, 2013).

Annual Crop Harvest Costs

Harvest occurred after the crop has reached maturity and has standard moisture content. Depending on the crop, this would be in late September for soybeans and sorghum and late November for corn.

Annual Crop Nutrient Replacement

Grain nutrient removal and biomass nutrient removal data for 2008 and 2009 from Propheter, 2009 is averaged over the two years to create the fertilizer recommendations for grain and biomass production as a function of harvested yields in each year.

Perennial Crop Field Operations

All chemical, fertilizer, and field operations and yields are from the field experiment for switchgrass and big bluestem. Alfalfa's field operations, chemical, and fertilizer use rates, including the lime application, are from Dumler and Shoup (2012) and yields are from Herbel (2013). Lime applications are included.

Perennial crops are no-till drilled into soybean residue in late spring and early summer (May and June) during the established year. The perennial crops seeding rates are from

(Propheter 2009). In year one (establishment) of the perennial crops, big bluestem and switchgrass are not fertilized. Only alfalfa is fertilized in year one, because it is based on the farm management guide recommendations of Dumler and Shoup (2012). Alfalfa has 40 pounds of a.i. per acre of P and 60 pounds of a.i. per acre of K per year applied (Dumler and Shoup, 2012). Alfalfa fertilizer rates for N, P, and K remained constant though the 10 year production horizon. Alfalfa needs annual fertilizer applications of phosphorus and potassium because it is harvested while the crop is still growing and the nutrients are not returned to the root system for winter dormancy. Lime application rates for alfalfa are from Dumler and Shoup (2012). Lime is also applied to alfalfa each year.

In year two, the grasses are fertilized with 40.19 lbs. of N from urea, P from 58.85 lbs. of P, TSP, and 249 lbs. of K from potash (Propheter, 2009). The 50 pounds per acre of N is applied each year to the perennial grasses over 10 year production horizon in the economic analysis. Additional P or K application data for 2009 and 2010 are not available in the experimental data. To account for P and K that is needed to ensure nutrients are not limiting, an assumption is made that one application occurred in year six, using the actual 2008 rate from the field experiment. Because the perennial grasses are harvested after physiological maturity the removal of nutrients is minimized.

The perennial grasses are harvested after physiological maturity, waiting until the plant goes dormant and the majority of the plant's nutrients have moved to the root system. Data on nutrient removal for the perennial crops in the experiment is unavailable from Propheter (2009). This minimizes the removal of nutrients. This method only works in perennial crops because the crop has evolved to prepare for its next growing season by recycling as many nutrients as possible.

Weed control for the grasses is accomplished in the experiment with the use of herbicides in years one and two. Alfalfa chemical use each year was from the Dumler and Shoup (2012). In year one, alfalfa is harvested three times instead of the typical four. In the year of establishment, alfalfa requires 60 to 70 days before harvest can occur (Dixon et al., 2005).

Perennial Crop Harvest Costs

Custom rates for perennial field with the exception of harvesting operations are obtained from Dhuyvetter (2013). To determine custom rates for biomass harvesting, a phone survey of seven northeastern Colorado (NE CO) hay producers is conducted. These rates are from producers who have practical experience with harvesting some or all of the crops examined in this study. The individual field operation harvest costs from the survey are similar to the costs from Dhuyvetter (2013). The survey data allows for more explicit accounting of costs and is used instead of the costs from Dhuyvetter (2013).

Crop residues have different densities. The survey data is used to estimate a weight range for each type of residue. These weight ranges are averaged to create an average weight per bale for each crop. The average weight per bale is then used to determine the number of bales per acre based on the tons per acre harvested.

The costs of stacking and baling are calculated and are based on the number of bales per acre, which is a function of tons per acre and bale weights per crop for biomass. Stacking costs, but not transportation costs, are used in the economic analysis because biomass is sold at the edge of the field, FOB (free on board).

For sorghum crops which are harvested for grain, the stover is assumed to be harvested with a draper head in the opposite direction the combine traveled during the grain harvest operation to attempt to harvest the stover knocked down by the grain harvest. Sorghum crops that has no grain harvest are swathed with a rotary or sickle type conditioning head, which requires raking the windrows together for ease of baling.

Corn stover is harvested with a stalk shredder and then baled in large square bales to expedite transport to biomass processing facilities. Round bales could also be used but transporting these bales is more difficult.

Perennial grasses are harvested once each year. Alfalfa is typically harvested multiple times per year. The average number of cuttings per year in Riley County, KS is four (Llewelyn 2013). In the first year, alfalfa is harvested three times to allow for proper establishment (Dixon et al., 2005). The sequence of alfalfa harvest begins with swathing with a conditioner, then letting the crop dry down, and followed by raking. After raking, the crop is baled and stacked at the edge of the field.

Land Rental Rates

Annual crops and perennial crops have different prime, medium, and marginal land rental costs. For the purpose of the analysis the annual crop systems use prime rental rates and perennial crops systems use medium rental rates from Dhuyvetter et al. (2012). Perennial crops are typically grown on less productive ground, that may be more susceptible to erosion and growing perennial crops reduces the likelihood of erosion occurring. The prime annual cropland rental rate is $139.20 per acre. The median perennial cropland rental rate is $72.00 per acre.

Output Prices

Grain prices reported in Table 3 are the 2013 average prices for soybeans, corn, and sorghum from Dhuyvetter (2014). Average biomass prices from 2013 are used in this analysis (Table 4). Biomass prices are collected from the USDA biomass report, and the KS hay reports from 2007 to 2013 (Pitcock, 2013; Hessman and Hruska, 2013). Biomass prices, for annual crops, are the average of the weekly 2013 prices from the USDA biomass report (Pitcock, 2013).

The 2013 average weekly square bale biomass price from the KS hay report is used for the perennial crop biomass price (Hessman and Hruska, 2013). Utility grade alfalfa prices are used because these represent the lowest class of alfalfa. Switchgrass is not commonly grown or used, so there is no market price for it. Switchgrass is a relative of brome grass and brome grass prices do exist. Brome grass prices are used as a proxy. Brome grass is considered a higher quality grass and the quality of switchgrass as an animal feed has yet to be determined.

Perennial Crop Production Horizon and Data

The perennial rotations, for big bluestem, switchgrass, and alfalfa, are based on 10 years of production. Yields for the 10 year production horizon are projected from the 2007 to 2011. The year-one yield is set equal to the annual yield of 2007, year two is the annual yield of 2008, and year three is 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. Refer to Table 5 for the annual yield data.

RESULTS

Annual Crop Average Grain Yields and Biomass Yields

The average grain and biomass yield for the annual crop rotations are reported in Table 1. Corn (RC) rotated with soybeans had the highest grain yield of all of the crops at 135 bu./acre. Continuous corn (CC) is most at 100 bu./acre and is followed by dual purpose (DP) sorghum of 73 bu./acre and grain sorghum of 67 bu./acre.

Photoperiod sensitive (PS) sorghum which has no grain yield has the highest average biomass yield of 10.48 tons/acre. All other (Table 1) annual crops had biomass yields below 10 tons/acre. Dual purpose (DP) sorghum has a biomass yield 8.66 tons/acre and is followed by rotated corn (RC) at 7.32 tons/acre. Sorghum (GS) had a yield of 6.29 tons/acre. Continuous corn has the lowest biomass yield of 5.73 tons/acre.

Costs for Annual Crops

Fertilizer chemical costs and harvest are separable between biomass and grain production because these operations such as nutrient replacement for grain is separate from nutrient replacement for biomass for (Table 6).

Fertilizer and chemical cost for grain production ranges from \$35.79 acre of rotation for PS to \$152.12 per acre of rotation for CC. The RC rotation has the second highest grain fertilizer and chemical cost. Each rotations fertilizer requirements for grain nutrient replacement are based on the yield of that crop and the content of nutrients removed in the given grain.

Fertilizer and chemical cost for biomass production ranges from \$41.70 per acre of rotation for RC to \$134.69 per acre of rotation for PS. The biomass rotation (the PS rotation) has grain that is produced but not harvested; this grain is harvested in the biomass and contributed to the biomass rotation's high fertilizer and chemical costs. The grain crops only have biomass nutrient replacement in the biomass production costs, which is determined by the biomass yields of the crops and the crop harvested. The higher the biomass yield the higher the cost of nutrient replacement.

The total fertilizer and chemical costs ranges from \$151.63 per acre of rotation for RC to \$230.95 per acre of rotation for CC. The PS rotations has the second highest total fertilizer and chemical costs, respectively. The corn crop's chemicals are the most expensive and the sorghum’s chemicals are the least expensive. The PS rotation has the second highest total chemical and fertilizer costs, respectively, due to their relatively high biomass yields. The relative size between biomass and grain fertilizer and chemical requirements varies across all rotations.

Harvest Costs for Annual Crops

Grain harvest costs for the rotations ranged from \$21.50 per acre of rotation to \$52.89 per acre of rotation; with the PS rotation having the lowest and with the RC rotation having the maximum (Table 6). The RC rotation has high grain yields and the CC rotation is the second highest yielding rotation. The PS rotation only has grain harvested for the soybean portion of the rotation. These differences are based solely on yield, with higher yielding crops incurring higher per acre costs.

Biomass harvest costs range from \$111.87 per acre of rotation for GS to \$199.15 per acre of rotation for CC. The CC crop has the highest quantity of bales produced but not the highest tons per acre. The number of bales per acre is the variable harvest cost term that is the most important, because there is a cost for stacking and baling associated with bales per acre. The CC and RC bales are the densest, which leads to lower numbers of bales per acre versus sorghum bales. The biomass PS rotation also incurs higher costs due to different field operations. The biomass PS rotation used both swathing and raking operations while rotations including grain production used only draper head swathing.

Total harvest costs (both grain and biomass costs collectively) range from \$153.88 for GS per acre of rotation to \$248.24 for CC per acre of rotation. These cost differences are due mainly to differences in yields. The CC rotation has the highest biomass harvest cost, which is triple its grain harvest cost, and is as large or larger than four rotations total harvest costs. The costs of harvesting biomass are larger than the costs of grain harvest.

Total Costs for Annual Crops

Total grain production costs range from $163.76 per acre of rotation for PS to $463.20 per acre of rotation for CC. The RC rotation has the second highest total grain production cost. The CC rotation has the highest grain fertilizer and chemical costs, the second highest biomass harvest cost, and relatively high seed costs. The PS rotation has the lowest total grain production costs, because soybean is the only grain portion of this rotation.

Total biomass production costs range from $172.53 per acre of rotation for RC to $414.20 per acre of rotation for PS. The GS rotation has the second and third lowest total biomass cost, respectively. The CC rotation has the second highest total biomass costs, respectively. The biomass PS rotation has the highest cost because the PS crop incurred all costs for biomass production. The biomass production costs are mainly a function of yield, and bale density.

Total production costs range from $521.47 per acre of rotation for GS to $750.23 per acre of rotation for CC. The DP rotation has the second total production cost. The CC rotation has the highest grain fertilizer and chemical costs, the highest biomass harvest costs, and the second highest grain harvest cost; these are all dependent on yield.

Gross Returns for Annual Crops

Grain production gross returns range from $399.25 per acre of rotation for PS to $797.94 per acre of rotation for RC. Soybeans have the highest price per bushel at $13.72 per bushel and the sorghum crops' grain price is the lowest at $5.34 per bushel. The RC rotation has high corn yields coupled with a $5.88 per bushel price and the standard soybean gross return. The high corn yield and a price which is $0.54 per bushel higher than sorghum made the RC rotation a better performer than the other rotations. The DP rotation has the second highest grain net return. The CC rotation has the third highest grain returns, although it has the highest corn yields, but does not have the standard soybean return. The PS rotation has the lowest grain return, due to soybeans being the only crop which is harvested for grain.

Biomass production gross returns range from $222.97 per acre of rotation for RC to $410.31 per acre of rotation for PS rotation. Sorghum biomass prices are $78.33 per ton, while corn stover biomass prices are $60.90 per ton. The CC rotation has the highest yielding biomass, but due to lower prices per ton it has less revenue than the PS and SS rotations. The GS rotation has a lower biomass yield than the RC rotation, but due to higher prices for sorghum biomass the GS rotation has slightly higher gross returns.

Total gross returns range from $809.55 per acre of rotation for PS to $1,020.92 per acre of rotation for RC. The CC and DP rotations have the second and third highest gross returns, respectively. The higher grain gross returns of the RC rotation overcome its low biomass gross returns. The grain gross returns in all grain rotations are higher than the biomass gross returns with the exception of PS.

Net Returns for Annual Crops

Grain net returns range from $124.17 per acre of rotation for CC to $397.59 per acre of rotation for RC (Table 6). The CC rotation has the highest total cost for grain, but has the second highest grain gross return. The RC rotation has the second highest total cost for grain, but its gross return for grain is over double its total cost for grain. The soybeans of the PS biomass rotation have higher grain net returns than the CC rotation.

Biomass net returns range from $(3.90) per acre of rotation for PS to $113.79 per acre of rotation for DP. The RC rotation has the second lowest biomass net return. The SS rotation has the second highest biomass net return. The CC rotation out-yielded the DP rotation but due to slightly higher costs and a lower biomass price it does not perform well. The PS biomass rotation has the highest per acre costs and variable costs per ton.

Total net returns range from $185.82 per acre of rotation for CC to $448.03 per acre of rotation for RC. The DP rotation has the second highest net return, and the PS rotation has the second lowest net return. The RC and DP rotations have the highest total net returns because of relatively low biomass production costs and relatively high gross grain returns. The grain net returns of the RC rotation are much higher than its biomass net returns and, because the RC rotation performs well in grain yields and grain gross returns, it is the highest net returns. The PS rotation has net returns that are only from the soybean crop's net returns, which performed as well or better than some grain rotations. The CC rotation has high costs associated with it having relatively high biomass yields, but it does not have the highest grain gross returns to offset the high biomass costs.

Summary of Annual Crops

The RC rotation has the highest total net return and the DP rotation has the second highest net return. The CC rotation has the lowest net return.

Perennial Crop Average Yield

Switchgrass has the highest average yield of 4.11 tons/acre/year followed by alfalfa by 3.60 tons/acre/year and by big bluestem of 3.18 tons/acre/year (Table 2).

Amortized Costs per Acre for Perennial Crops

Amortized fertilizer, chemical, lime, and seed costs are $87.11, $87.81, and $92.35 per acre for alfalfa, switchgrass, and big bluestem, respectively (Table 7). The switchgrass and big bluestem crops have fertilizer applications delayed until year two, while alfalfa has fertilizer applications every year. Lime is applied every year for switchgrass, big bluestem, and alfalfa.

Amortized field operation costs for applying chemicals, fertilizer, and planting the crop are $7.72, $7.73, and $8.34 per acre for switchgrass, alfalfa, and big bluestem, respectively. Big bluestem has two more applications of chemical than alfalfa and one more application than switchgrass. Big bluestem has chemical applications in years one, two, and three. Alfalfa only has chemical applications in year one, and switchgrass has chemical applications in years one and two. Alfalfa has fertilizer applications every year, while switchgrass and big bluestem have fertilizer applications every year but year one.

Amortized total input costs are $94.83, $95.53, and $100.69 per acre for alfalfa, switchgrass, and big bluestem, respectively. These differences are due to grasses not having applications of fertilizer and chemical applications in the first year, different numbers of applications in year three, and different rates of application.

Amortized harvest costs are $127.93, $165.77, and $167.27 per acre for big bluestem, alfalfa, and switchgrass, respectively. Harvest costs are a function of yields and bale densities. Due to switchgrass and big bluestem bales weighing less than an alfalfa bale, the grass crops' harvest cost per acre are higher if tons per acre are equal among the crops (1150 pounds per bale for the grasses versus 1650 pounds per bale for alfalfa). Switchgrass has an average yield that is 0.51 tons per year per acre higher than alfalfa and also has lower density bales, which leads to higher harvest costs.

Amortized total variable costs, including all input and harvest costs, are $228.62, $260.60, and $262.80 per acre for big bluestem, alfalfa, and switchgrass, respectively. The yield differences, and different annual applications fertilizer and chemicals are the main reason for the cost differences.

Amortized total costs, including variable cost and a land rental charge, are $314.63, $347.65, and $349.93 per acre for big bluestem, alfalfa, and switchgrass, respectively. Alfalfa has the second highest total cost because it has the second highest fertilizer, chemical, and seed cost, and the second highest harvest cost.

Amortized Returns per Acre for Perennial Crops

Amortized gross returns are $442.66, $619.80, and $684.23 per acre for big bluestem, switchgrass, and alfalfa, respectively (Table 7). The prices are $140.00 per ton for big bluestem and switchgrass, and $180.27 per ton for alfalfa. The alfalfa price is $40.27 per ton higher than the big bluestem and switchgrass prices, which causes alfalfa to have higher gross returns than switchgrass has even though the average yield of switchgrass is higher.

Amortized net returns are $128.03, $269.88, and $336.57 per acre for big bluestem, switchgrass, and alfalfa, respectively. Switchgrass performed well due the highest perennial crop yield, gross return and the second highest biomass price. Big bluestem has the lowest cost, but also has the lowest yield which resulted in the lowest net returns.

Amortized Costs per Ton for Perennial Costs

Amortized total input costs are $18.39, $21.63, and $27.34 per ton of biomass for switchgrass, alfalfa, and big bluestem, respectively (Table 7). Switchgrass has the lowest field operation costs per acre and the highest yield, which results in the lowest cost per ton. Big bluestem has the lowest yield, which increased per ton costs.

Amortized harvest costs are $32.20, $34.73, and $37.81 per ton of biomass for switchgrass, big bluestem, and alfalfa, respectively. Big bluestem has the lowest yields and the lowest harvest cost per acre. Switchgrass has the highest per acre harvest costs, but due to its high yield it has the lowest harvest cost per ton. Alfalfa has the second highest harvest cost per acre but due to the second highest yield it has the highest harvest cost per ton.

Amortized total variable costs, including all input and harvest costs, are $50.59, $59.43, and $62.07 per ton of biomass for switchgrass, alfalfa, and big bluestem, respectively. The low yields of big bluestem cause big bluestem to have to second highest total variable cost per ton. With alfalfa having the highest harvest cost per ton and the second highest total input cost per ton alfalfa has the highest total variable cost.

Amortized total costs, including variable cost and a land rental charge, are $67.37, $79.29, and $85.42 per ton of biomass for switchgrass, alfalfa, and big bluestem, respectively.

Amortized Returns per Ton for Perennial Crops

Amortized gross returns are $119.32, $120.18, and $156.05 per ton of biomass for switchgrass, big bluestem, and alfalfa, respectively (Table 7). Switchgrass has higher yields and higher revenue per acre than big bluestem, but due to higher yields its gross returns per ton are slightly less than big bluestem. Alfalfa has a price that is $40.27 per ton higher than both switchgrass and big bluestem, which causes it to have higher gross returns per ton.

Amortized net returns per ton are $34.76, $51.96, and $76.76 per ton of biomass for big bluestem, switchgrass, and alfalfa, respectively. Yield is the major difference between big bluestem and switchgrass. Alfalfa has the highest net return per ton because it has the highest price and the second highest yield.

Summary of Perennial Crops

The alfalfa crop has the highest net return and big bluestem has the lowest net return, using per acre and per ton measures. Switchgrass is the highest yielding crop but due to a $40.27 per ton higher alfalfa price, switchgrass has only the second highest net return per acre and net return per ton crop.

Price and Yield Sensitivity Analysis

Price and yield sensitivity on net returns is performed on each crop rotation. Grain yield and biomass yield are assumed to be perfectly correlated. Yields are varied at given grain and biomass price levels to estimate the yield impact on net returns. Biomass prices and grain prices are assumed to be perfectly correlated. Prices are varied at given grain yield and biomass yield levels to estimate the price impact on net return. Prices and yields are varied together by increasing and decreasing the values used in the original analysis by increments of 5%, 10% and 25%.

Annual Crop Sensitivity

The DP and RC rotations have positive net returns over the whole range of prices and yields in the sensitivity analysis. The GS rotation has a negative net return when price and yield falls to 75% of the original price and yield; for all other combinations of prices and yields the GS rotation has positive net returns.

When price for the PS rotation is 75% of the original price, the PS rotation has negative net returns for all yields that are less than 95% of the original yield. When price for the CC rotation is 75% of the original price, the CC rotation has negative net returns for all yields less than 125% of the original yield. When yield for the CC rotation is 75% of the original yield, the CC rotation has negative net returns for all prices that are less than the original price.

Equating Net Returns of RC and DP

Price and yield combinations that equate the net returns of the RC rotation and the DP rotation are also calculated.

While holding the original prices constant, the DP rotation would require a yield that is between 105% and 110% of the original yield in order for the DP rotation's net returns to be approximately equal to the RC rotation's net returns at the original price and yield. While holding the original yield constant, the DP rotation would require a price that is approximately 110% of the original price in order for the DP net returns to be approximately equal the RC rotation's net returns at the original price and yield.

While holding prices constant, the RC rotation would require a yield that is between 95% and 90% of the original yield in order for the RC rotation's net returns to be approximately equal to the DP rotation's original price and yield net returns. While holding original yield constant, the RC rotation would require a price that is between 95% and 90% of the original yield in order for the RC rotation's net returns to be approximately equal to the DP rotation's net returns at the original price and yield.

Perennial Crop Sensitivity Analysis

Switchgrass and alfalfa have positive amortized net returns per ton over the whole range of prices and yields in the sensitivity analysis. When prices for big bluestem are 75% of the original price, big bluestem has negative net returns when the yield is less than 95% of the original yield.

Annual Crop Rotations versus Perennial Crops

Perennial crops are not directly comparable to annual rotations due to differences in land rental rates. Perennial crops' land rental rates are set equal to annual rotations' land rental rates to facilitate a ranking comparison of all the crops and rotations in this study.

Allow if it is likely that perennial crops will be produced on lower quality land setting the land rental rates of the perennial crops equal to the land rental rates of the annual rotations allows the perennial crops amortized net returns per acre to be compared to the annual rotations net returns per acre of rotation.

Alfalfa has amortized net returns of $271.23 per acre when perennial land rental rates are equal to the annual rotation's land rental rates and when 2013 average prices are used. Alfalfa's net returns rank above the RC and PS rotations' net returns. Switchgrass and big bluestem has net amortized net returns of $204.53 per acre and $32.68 per acre, respectively. The big bluestem net returns are less than the net returns of all the annual rotations. Switchgrass has net returns that are greater than only the CC rotation.

Summary

The results show that harvesting of crop residue from corn and grain sorghum is economically feasible with the exception of an energy sorghum that does not produce grain. The corn-soybean rotation has the highest net returns per acre and the dual purpose sorghum-soybean rotation has the second highest net returns per acre. Further, the annualized average return from two of the perennial grasses grown on land typically used for alfalfa land is also positive, but not as positive as alfalfa.

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Table 1: Average Grain and Biomass Yields for Annual Crop Rotations 2007-2011.

	Bushels per Acre	Biomass Tons per Acre	Bales per Acre
GS	66.96	6.29	11.43
PS	0.00	10.48	19.05
DP	73.25	8.66	15.75
RC	135.52	7.32	12.46
CC	99.83	5.73	9.74
Soybeans	58.20	0.00	

Grain Sorghum (GS), Photosensitive Sorghum (PS), Dual Purpose Sorghum (DP), Corn rotated with soybeans (RC), Continuous Corn (CC)

Table 2: Perennial Crop Average Yield 2007-2011 (Tons/Acre).

Crop	Switchgrass Yield	Big Bluestem	Alfalfa Yield
Average	4.11	3.18	3.60

Table 3: 2013 Average Grain Prices for Annual Crops ($/bushel)

Crop	Price
Soybeans	$13.72
Corn	$5.88
Sorghum (all)	$5.34

Table 4: Average 2013 Biomass Prices ($/ton)

Crop	2013 Average Price
Sorghum Straw	$78.33
Corn Stover	$60.90
Utility Alfalfa	$180.27
Brome	$140.27
Big Bluestem	$140.00

Table 5: Perennial Yields Projected Over the 10 Year Production Horizon.

Crop	Switchgrass Yield (tons/acre)	Switchgrass Yield (Bales/acre)	Big Bluestem Yield (tons/acre)	Big Bluestem Yield (Bales/acre)	Alfalfa Yield (tons/acre)	Alfalfa Yield (Bales/acre)
Year 1	1.99	3.47	2.03	3.53	3.01	3.64
Year 2	3.67	6.38	3.94	6.86	4.39	5.32
Year 3	4.67	8.12	2.39	4.15	3.68	4.46
Year 4	4.17	7.25	3.16	5.50	4.03	4.89
Year 5	4.13	7.18	2.76	4.80	3.84	4.66
Year 6	4.96	8.62	3.30	5.74	3.54	4.29
Year 7	4.96	8.62	3.30	5.74	3.54	4.29
Year 8	4.96	8.62	3.30	5.74	3.54	4.29
Year 9	4.96	8.62	3.30	5.74	3.54	4.29
Year 10	4.96	8.62	3.30	5.74	3.54	4.29

Table 6: Cost and Returns by Annual Crop Rotation

	GS	PS	DP	RC	CC
Fertilizer and Chemicals – Grain per Acre	$91.77	$35.79	$93.87	$109.93	$152.12
Fertilizer and Chemicals – Biomass per Acre	$73.55	$134.69	$67.59	$41.70	$78.84
Total Fertilizer and Chemicals per Acre	$165.31	$170.48	$161.45	$151.63	$230.95
Harvest Cost per Ton of Biomass	$35.59	$34.73	$34.81	$34.25	$34.79
Variable Cost per Ton of Biomass	$60.90	$65.79	$52.05	$47.12	$50.13
Harvest – Grain per Acre	$42.00	$21.50	$43.25	$52.89	$49.08
Harvest-Biomass per Acre	$111.87	$181.92	$150.71	$125.40	$199.15
Total Harvest (Grain + Biomass) per Acre	$153.88	$203.42	$193.96	$178.30	$248.24
Interest Grain per Acre	$6.01	$2.96	$6.12	$8.22	$10.39
Interest Biomass per Acre	$6.03	$10.85	$7.09	$5.43	$9.03
Total Interest per Acre	$12.03	$13.81	$13.21	$13.65	$19.43
Total Cost Grain	$330.02	$163.76	$333.48	$400.35	$463.20
Total Cost Biomass	$191.45	$414.20	$225.39	$172.53	$287.03
Total Cost per Acre	$521.47	$577.96	$558.87	$572.88	$750.23
Gross Return – Grain per Acre	$578.06	$399.25	$594.86	$797.94	$587.38
Gross Return – Biomass per Acre	$246.23	$410.31	$339.18	$222.97	$348.68
Gross Return per Acre	$824.29	$809.55	$934.04	$1,020.92	$936.05
Net Return – Grain per Acre	$248.04	$235.49	$261.38	$397.59	$124.17
Net Return – Biomass per Acre	$54.78	$(3.90)	$113.79	$50.44	$61.65
Net Return per Acre	$302.82	$231.59	$375.17	$448.03	$185.82

Table 7: Perennial Crop Comparison in $/acre and $/ton.

	Amortized Cost and Returns ($/acre)		
	Switchgrass	**Big Bluestem**	**Alfalfa**
Fertilizer, Chemical, and Seed Cost	$87.81	$92.35	$87.11
Field Operations	$7.72	$8.34	$7.73
Total Input Cost	$95.53	$100.69	$94.83
Harvest Costs	$167.27	$127.93	$165.77
Total Variable Costs	$262.80	$228.62	$260.60
Total Costs	$349.93	$314.63	$347.65
Gross Returns	$619.80	$442.66	$684.23
Net Returns	$269.88	$128.03	$336.57
	Amortized Cost and Returns ($/ton)		
	Switchgrass	Big Bluestem	Alfalfa
Fertilizer, Chemical, and Seed Cost	$16.90	$25.07	$19.87
Field Operations	$1.49	$2.26	$1.76
Total Input Cost	$18.39	$27.34	$21.63
Harvest Costs	$32.20	$34.73	$37.81
Total Variable Costs	$50.59	$62.07	$59.43
Total Costs	$67.37	$85.42	$79.29
Gross Returns	$119.32	$120.18	$156.05
Net Returns	$51.96	$34.76	$76.76
Total Tons (10 years)	$43.42	$30.79	$36.65
Average Tons per Year	$4.34	$3.08	$3.67