The Economics of Selling Crop Residue Biomass for Cellulosic Ethanol Production at the Farm Level

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Selected Paper prepared for presentation at the Agricultural & Applied Economics Association 2010 AAEA, CAES, & WAEA Joint Annual Meeting, Denver, Colorado, July 25-27, 2010

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Abstract

A partial budget decision making framework has been developed to assist crop producers in analyzing the profitability of selling cellulosic biomass from their fields for ethanol production. A multidisciplinary approach is taken in assessing the agronomic and economic factors relevant to biomass contract sales decisions – with direct application made to western Great Plains cropping systems and enterprises. Within this framework the benefits of increased revenue from cellulosic biomass contract sales and potential government assistance payments are considered against possible decreased revenue from diminished crop yields resulting from less crop residue cover and subsequent soil moisture evaporation. Increased biomass harvesting and handling are also considered, as is the cost of replacing crop nutrients removed as part of biomass harvest operations. Examples of the profitability of cellulosic biomass contract sales in center pivot irrigated corn and non-irrigated wheat enterprises are shown.

Introduction

The decision by farmers to remove crop residue biomass from their fields for cellulosic ethanol production involves a number of important agronomic and economic factors. In making this decision, farmers are likely to consider income from the sale of crop residue and their own personal motivations to contribute to broader societal energy-related goals. They are also likely to consider the agronomic costs of crop residue removal and their potential responsibilities for the physical costs of collection, harvest, storage and transportation of crop residue to cellulosic ethanol plants for processing.

Recent legislative initiatives in the United States have provided incentives to increase the use of crop residue biomass for cellulosic ethanol production. The Energy Independence and Security Act of 2007 contained a number of financial incentives and energy policy directives designed to increase cellulosic ethanol production and reduce green house gas emissions. These incentives include the Renewable Fuels Standard which requires the use of 20 million gallons of advanced or cellulosic biofuels by the year 2015. In March 2007, the U.S. Department of Energy awarded $385 million in grants aimed at jump-starting ethanol production from nontraditional sources, with funding awarded toward one cellulosic ethanol plant site to be located in Kansas. The Food, Conservation and Energy Act of 2008 provides financial assistance for cellulosic ethanol production through a) at least partial payment of crop establishment costs, b) annual payments for biomass production, c) payments for crop residue collection, harvest, storage and transportation to eligible crop producers, and d) tax incentives to cellulosic ethanol producing agribusinesses.

Recent research has examined the economic feasibility of cellulosic ethanol production at the farm level. Case studies have examined farm-level logistical issues associated with harvesting, handling and transporting cellulosic biomass feedstock for ethanol production (Idaho Straw Value Committee 2006; Hess et al., 2006, 2007; Hoskinson et al. 2007; Petrolia 2008). The adequacy of regional biomass supplies to support cellulosic ethanol production in the United States has also been examined (Graham, et al. 2007). A number of analyses have examined agronomic issues related to cellulosic biomass removal from crop production systems. Wilhelm et al. (2004) provided a comprehensive survey of agronomic research related to the effects of field crop residue removal.

In an Extension bulletin, Wortmann et al. (2008) provided applied practical information on the impact of harvesting crop residues. Nielsen (2006) and Klocke, et al. (2008, 2009) analyzed the impact of crop residue removal on soil water evaporation in western Great Plains settings. Karlen and Birrell (2008) investigated the soil and water effects of biofuel feedstock production. Petrolia (2008) provided an economic analysis of the relationship between the regional demand for corn stover and the likelihood of soil erosion problems. Although these studies examine various agronomic and economic aspects of cellulosic biomass use for ethanol production, none of them directly examines the profitability of cellulosic biomass sales from an individual crop producer's perspective.

This study utilizes a multi-disciplinary approach to identify the agronomic and economic benefits and costs to farmers of crop residue removal and sales for cellulosic ethanol production. A working group of agronomists, agricultural engineers, agricultural economists and USDA NRCS soils specialists from Kansas and Oklahoma have made contributions toward this applied research and Extension educational project. Integrated, multi-disciplinary approaches have been used to address issues related to soil fertility, soil erosion, soil-moisture losses, crop-water yield functions in irrigated and non-irrigated cropping systems that are critical to the economic viability of crop residue removal in the context of the western Great Plains region.

Based on a partial budget economic decision framework, representative economic benefit-cost scenario examples are developed for crop residue biomass contract sales in central and western Kansas and northwest Oklahoma. The end result of this research is the development of decision making spreadsheet and associated web-based decision tools for use by farmers in determining the profitability of harvesting and selling their crop residues for cellulosic ethanol production.

Biomass Contract Decision Model

This applied research uses an economic partial budget framework to quantify and compare the benefits and costs to farmers of harvesting crop residue biomass for use in cellulosic ethanol production. See the following schematic of a basic partial budge framework.

Benefits	Costs
A. Increased Income	C. Decreased Income
B. Decreased Costs	D. Increased Costs
Total Benefits (A + B)	Total Costs (C + D)
Net Benefit/Loss (A + B – C – D)	

Assessment of economic benefits in this framework focuses on both the monetary value of increased revenues from crop residue sales and of decreased expenses resulting from crop residue harvest and removal for common crops for both irrigated and non-irrigated enterprises. In this partial budget framework, analysis of economic costs concentrates both on how crop enterprise costs may increase and how crop revenues may decrease as a result of crop residue sales/removal. Net benefits and costs are analyzed for a typical year after the initial time period in which crop residue has been harvested.

Increased Revenues

Projections of increased revenues from crop residue contract sales are based on the terms of biomass contract sales agreements which have been made publicly available in central and western Kansas. Elements of these biomass harvest contracts include one-time signup payments, annual per acre base payments to farmers in order to reserve the option of harvesting crop residue biomass, and production payments per ton of crop residue harvested. Optional per acre payments for crop fertility replacement and for harvesting-handling logistics costs are considered. Government incentive or cost subsidization payments for cellulosic ethanol production (example: BCAP payments) can also be considered in this economic decision making framework.

Following is an illustration of the "Increased Revenues" section of a partial budget decision making worksheet developed for the western Great Plains region.

A. Increased Revenues	Per Acre	Per Field
Initial signup payment (prorated over life of contract)	$0.00	$0.00
Biomass Reservation ($0.50/ac) & Base Contract payment ($2.00/ac)	$0.00	$0.00
Biomass payment ($5 per ton)	$0.00	$0.00
Biomass nutrient removal compensation ($8 per ton)	$0.00	$0.00
In-field bale storage site: cash rent compensation	$0.00	$0.00
USDA BCAP payments (prorated over life of contract)	$0.00	$0.00
Other factors	$0.00	$0.00
A. Total increased revenues	$0.00	$0.00

Contract Specifications The biomass contract specifications represented above consist of a) an annual biomass base contract payment of $2.50 per acre, b) an annual biomass reservation payment of $0.50 per acre, c) a $5.00 per ton payment for the actual quantity of biomass removed, and d) an $8.00 per ton payment of biomass removed in compensation for crop nutrient removal. Some biomass contracts may also include initial one time signup payments of as much as $1.00 per acre or more. One-time signup payments would need to be prorated over the longer term life of a biomass sales contract (example: 10 years).

These income estimates represent actual contract specifications considered by agricultural producers in association with a planned cellulosic ethanol plant in the southwest Kansas – northwest Oklahoma region during the 2009-early 2010 period. This type of contract evaluation framework is flexible enough to allow for representation and evaluation of alternative means by which farmers could be compensated for biomass sales to cellulosic ethanol plants / producers.

Direct monetary compensation for crop nutrient removal on the basis of the amount of biomass removed would likely be adjusted to represent alternative fertilizer cost scenarios on an annual basis. Calculations of the actual amounts and costs of crop nutrient removal will be discussed in the "Increased Expenses" section below.

BCAP Payments The USDA Biomass Crop Assistance Program (BCAP) may also provide payments to agricultural producers through approved ethanol producing facilities as an incentive for the sale of cellulosic biomass for ethanol production. As represented in Kansas during the 2009-early 2010 period, these payments are for the initial two years of a longer term 10 year biomass sales contract, and would therefore need to be prorated over the life of any longer term contract.

In-field storage compensation Depending of contract specifications and the logistical approach used by particular ethanol producing companies, biomass harvested from a particular field may be temporarily stored on site on a portion of the field. To the degree that there is an increase in farm machinery traffic in that particular portion of the field due to additional crop stover harvesting, handling and removal, or even an impact on cropping patterns or productivity in that portion of the field, then additional compensation may be needed by the farmer from the ethanol producing company for the cost of these field operations on that particular part of their field. Whether this is relevant or not to a particular crop producer depends on the logistical biomass handling and storage practices employed by the biomass contract provider. Other affects from in-field crop biomass storage and handling will be discussed in the "Decreased Costs" and "Decreased Revenues" sections below.

The sum of alternative sources of revenues from crop biomass sales can be calculated on a both a per acre and a per field basis to calculate total "Increased Revenues" in this representative partial budget framework.

Decreased Expenses

Cost declines from crop residue sales include projected reductions in crop production costs on any in-field areas that are used for temporary storage of crop residues prior to the transporting them to ethanol plants for processing. Following is an illustration of the "Decreased Expenses" section of a partial budget decision-making worksheet developed in this project for the western Great Plains region.

B. Decreased Expenses	Per Acre	Per Field
In-field biomass storage site: decreased crop expenses	$0.00	$0.00
Other factors	$0.00	$0.00
B. Total decreased expenses	$0.00	$0.00

Unspent crop production costs at in-field storage site In this framework, the primary decreased expense is associated with unexpended crop production costs on potential in-field biomass storage sites. To the degree that standard tillage, seed, fertilizer, herbicide, insecticide and other crop production costs are decreased due to the presence of biomass storage in a portion of a field, then crop production expenses would decrease for the crop enterprise involved in crop biomass sales.

The sum of decreases in crop expenses resulting from crop biomass sales on both a per acre and a per field basis is calculated to find total "Decreased Expenses" in this representative partial budget framework. The sum of "Increased Revenues" and "Decreased Expenses" can then be added together to estimate the "Total Benefits" from crop biomass contract sales.

Decreased Revenues

Decreased revenues from crop residue harvest include a) projected crop yield / revenue decreases resulting from soil moisture evaporation caused by removal of crop residue cover, and b) decreased crop income from areas used for temporary storage of crop residue. Under irrigated systems, depleted soil moisture caused by evaporation resulting from crop residue removal may either 1) have no impact if excess soil moisture supplies are available, 2) be replaced through additional application of irrigation water, or 3) result in deficit soil moisture conditions for the crop and subsequently cause crop yield and revenue decreases. However, for non-irrigated cropping systems, only the deficit soil moisture – decreased crop yield and revenue outcomes result if deficit soil moisture supplies are caused by crop residue removal.

Other potential crop revenue decreasing factors are 1) the potential impact of crop residue removal on wind and/or water-based soil erosion – leading to declines in cropland productivity, 2) the longer term crop production and revenue impact of soil compaction resulting from crop residue harvesting, handling and storage operations, and 3) potential revenue losses from foregone carbon credit sales. However, these economic effects are not specifically quantified in later benefit-cost scenario examples.

C. Decreased Revenues				Per Acre	Per Field
Crop yield losses	Irrigated or Non-irrigated	Deficit, Reduced or Adequate	Soil Moisture Regime	$0.00	$0.00
In-field bale storage site: lost crop income				$0.00	$0.00
Wind erosion soil / crop yield impacts				$0.00	$0.00
Water erosion soil / crop yield impacts				$0.00	$0.00
Soil compaction / crop yield impacts				$0.00	$0.00
Carbon credits: lost payment income				$0.00	$0.00
Other factors				$0.00	$0.00
	C. Total decreased revenues			$0.00	$0.00

Yield losses for irrigated and non-irrigated crop enterprises Harvesting crop residue under either irrigation (corn stover) or dryland (wheat straw) production regimes has been shown to reduce soil surface coverage with crop residue – leaving more soil surface directly open to sunlight and resulting soil moisture evaporation. Consequently, less moisture is retained in the soil profile for use by subsequent crops. "Soil water loss associated with increased crop residue removal may be the greatest short-term cost of crop residue harvest, especially under rain-fed conditions in drought-prone areas." (Klocke et al., 2009)

Under water-limiting conditions, a corn crop is expected to produce approximately 12 bushels of corn per inch of water after the 7 to 10 inches needed before any grain is produced (i.e., the vegetative stage). Under water-limiting conditions for grain sorghum, a 1 inch soil moisture deficit will reduce grain yields by approximately 11 bushels after vegetative growth stage water needs are met. For wheat, a 1 inch soil moisture deficit will reduce yields by approximately 5 bushels after vegetative growth stage moisture needs have been met. In typically moisture deficient crop production conditions as those commonly found in the western Great Plains, annual soil water losses to evaporation may be increased by 1 to 5 inches depending on the amount of residue removed from the field.

Research results from Garden City, Kansas where soil moisture losses to evapo-transpiration for an irrigated corn crop showed 4.3 inches less moisture loss with corn and wheat residue remaining on the soil surface compared to having all residue removed. The soil trapping effect of erect crop residues may also equal 1 inch or more of water available to the crop. In water deficit situations, the reduction in available soil water with crop residue harvest could often result in yield decreases of greater than 30 bu/acre in the following year. In irrigated situations, water applications and pumping costs will be increased to replace the water lost to evaporation when crop residue is removed (Klocke et al., 2009)

Water savings attributable to the presence of crop residues can have one of three impacts on income under irrigated crop production enterprises in the western Great Plains.

Situation 1: Irrigation applications in excess of crop needs (adequate crop moisture). When irrigation applications are in excess of the amount needed by crops, there are no benefits from the soil moisture conserving affects of retained crop residues. In this situation there would typically be no monetary benefit from retaining crop residue for the purpose of soil moisture conservation (except perhaps in the case where the presence of crop residue helped to preserve enough soil moisture to support the adequacy of crop moisture supplies).

Situation 2: Irrigation requirements are reduced for a fully irrigated crop from crop residue management (reduced moisture available – compensated for via supplemental irrigation). When irrigation applications are not in excess but rather allocated to meet crop needs, then the presence of soil moisture conserving crop residue will reduce the amount of irrigation water that needs to be applied to meet crop needs. The amount of irrigation expenses saved would equal the reduced cost of irrigation water pumped while still maintaining crop yields at pre-crop residue yield levels.

Situation 3: The irrigation system cannot provide enough water to meet the full water requirements of the crop (deficit moisture – inadequate to meet crop needs). In this situation, the amount of water available to the irrigated crop is less than its full water needs, resulting in crop yield reductions. Yield effects from soil moisture deficits can be substantial, with yield losses of approximately 12 bushels per acre for corn, 11 bushels per acre for grain sorghum, and 5 bushels per acre for wheat per inch of available water after crop vegetative stage water needs are met. At current market prices for grain, the financial impact of yield losses due to these soil moisture deficits can be substantial (given that the deficit conditions can be at least partially attributable to inadequate crop residue soil surface coverage).

Under nonirrigated or "dryland" crop production regimes, soil moisture reserves tend to be are either adequate to fully meet crop needs or not, given that the option of applying irrigation water to replace soil moisture deficits is not available. Relevant soil moisture regimes for nonirrigated crop enterprises are as follows.

Situation 1: Available soil moisture in excess of crop needs (adequate crop moisture). When available soil moisture is in excess of the amount needed by crops, there are no benefits from the soil moisture conserving affects of retained crop residues. In this situation there would be no monetary benefit from retaining crop residue for the purpose of soil moisture conservation. Note as above the caveat being the case where the presence of crop residue helped to preserve enough soil moisture to support the adequacy of crop moisture supplies in non-irrigated cropping systems.

Situation 2: Available soil moisture is inadequate to provide enough water to meet the full water requirements of the crop (deficit moisture – inadequate to meet crop needs). In this situation, the amount of water available to the non-irrigated crop is less than its full water needs, resulting in crop yield reductions. As with irrigated enterprises, at current market prices for grain, the financial impact of yield losses due to such soil moisture deficits can be substantial (again given that the deficit conditions are at least partially attributable to inadequate crop residue soil surface coverage).

Lost crop income from in-field biomass storage area Farm income foregone by not being able to produce crops on portions of a field where as yet unused biomass is being stored for later use would be designated as "decreased revenue" in a partial budget framework.

Water and wind erosion yield impacts Each farm enrolled in USDA farm programs is required to have an approved conservation plan that is to be followed by a farmer to control excessive water and wind erosion of soil resources. The long term crop yield impacts from wind or water erosion of farmland are cumulative in nature and difficult to quantify over time, but are understood to be substantial if allowed to occur. Farmer's conservation plans are focused on the management of crop residue over time over typical sequences of crops. To the degree that the retaining or preservation of crop residue on fields is required to control potential water and wind erosion, it may very well limit farmer's ability to sell that same crop residue for use in ethanol production.

Water erosion control effects on allowable crop residue removal For water erosion control, a general minimum recommendation is that 2 – 3 tons per acre crop residue coverage be left on the soil surface to maintain soil organic matter with conservation tillage or no-till conservation systems. On soils with low erodibility potential, leaving 2-3 tons per acre for maintenance of soil organic matter should be sufficient to prevent erosion from exceeding 5 tons of soil / acre. More crop residue can be harvested under no-till compared with tilled conditions, and with terraces compared with no terraces. The USDA-Natural Resource Conservation Service (NRCS) water erosion estimator RUSLE2 can be used to determine the average amount of crop residue needed to provide sufficient ground cover to limit soil loss to no more than 5 tons per acre per year.

Wind erosion control effects on allowable crop residue removal Wind erosion that may result from removal of crop residue / biomass from irrigated or non-irrigated cropland would be expected to have an intermediate to longer term impact on soil quality. Consequently, the damage to soil productivity would be expected to long-term in nature absent any specific catastrophic wind erosion events. The USDA-NRCS generally requires ground covers on cropland of at least 30 percent to reduce wind erosion by 70 percent. Ground covers of 60 percent are estimated to be sufficient to reduce wind erosion by 90 percent.

The USDA-NRCS Wind Erosion Prediction System (WEPS) can be used to calculate crop residue needed to prevent soil loss from wind erosion of more than 5 tons per acre per year. Under rain-fed, tilled conditions in some western Corn Belt areas, it may not be possible to remove any crop residues and still maintain these standards. Under no-till production practices, 1 to 2 tons/acre of crop residue cover is adequate to keep erosion to less than 5 tons per acre per year for low erodibility soils, while 1.5 to 2.5 tons per acre of crop residue is needed for the moderately erodible soil. As a general recommendation, the WEPS program estimates that about 20% less crop residue is needed to control wind erosion with irrigated than with rain-fed continuous corn in parts of the western Great Plains region.

Soil compaction effects on crop yields over time Given the limited time period for harvest of crop stover (i.e., likely within weeks of fall row crop or summer wheat crop harvests), the possibility of wet soil conditions during these same time periods, and the economic incentive to use large, high capacity crop stover harvesting machines to conduct these operations, it is likely that soil compaction may result from crop residue harvest operations. As with the costs of water and wind erosion costs, the cumulative impacts of soil compaction on crop yields are challenging to quantify in short term time periods, but have the potential to substantially impact crop yield and crop enterprise profitability in the long run.

Reduced carbon credit income To the degree that crop residue is harvested and removed from fields rather that left as is, potential income is lost from the sale of carbon credits. The sale of such credits are currently available on a voluntary basis to interested agricultural producers, but are not required absent a change in energy and agricultural policy in the United States.

The sum of alternative sources of decreased income due to crop biomass sales can be calculated on a both a per acre and a per field basis to calculate total "Decreased Revenues" in this representative partial budget framework.

Increased Expenses

Projected increases in costs from crop residue removal include a) expenses related to crop residue harvest, handling, storage, and transportation, and b) additional crop nutrient replacement expenses. Potential additional costs required to prepare in-field temporary storage for harvested biomass may be a relevant consideration.

Logistical costs related to crop residue harvest and handling are determined by the farmer's responsibilities under the terms of the crop residue – biomass sales contractual agreement. Crop nutrient replacement costs result from the need to replace the nitrogen, phosphorous, potassium and possibly other crop nutrients that are contained in the crop residue removed in the biomass harvesting operations. Biomass removal contracts may offer a compensating payment for crop fertility replacement. To the degree that site preparation costs are required for in-field crop residue storage area, they would be included as an additional cost on an annually depreciated basis.

D. Increased Expenses	Per Acre	Per Field
Biomass harvest, baling, handling costs	$0.00	$0.00
Crop fertility replacement: net costs	$0.00	$0.00
In-field biomass storage site preparation & maintenance costs	$0.00	$0.00
Other increased expenses	$0.00	$0.00
D. Total increased expenses	$0.00	$0.00

Harvest, baling and handling costs The logistical costs of performing additional field operations associated with selling crop residues are perhaps the most transparently recognizable increased expenses to crop producers. Fortunately, custom rate surveys are available to provide cost information on such field operations as raking of crop residues, baling, and hauling of crop residues to temporary in-field storage areas or even beyond to an ethanol plant. Additional costs may need to be considered, such as adjustments and/or modifications to combines to allow for crop residues to be dropped in more uniform "windrows" or continues piles following grain harvesting operations. More uniform windrows of crop residue may subsequently allow for more efficient harvest of crop stover in biomass harvesting and retrieval operations.

Crop fertility replacement costs The removal of crop residues from fields results in a reduction in the availability of the crop nutrients contained in those crop residues for succeeding crops to use. Crop nutrients such as nitrogen (N), phosphorous (P), potassium (K), and sulfur (S) are contained in the crop residues being removed. If not fully replaced in the crop soil profile horizon, reductions in crop yields and crop enterprise income are likely to occur. Consequently, the market value of removed N-P-K and other crop nutrients are a relevant "increased expense" of crop residue removal for cellulosic biomass sales, along the any relevant additional fertilizer application costs that may occur.

Standard recommended replacement rates for N-P-K and other necessary crop nutrients due to biomass removal can be obtained from objective University or independent research. The amount of N-P-K and sulfur contained in one ton value of crop residue from various sources is as follows (Wortmann et al., 2008).

Corn	17 lbs. N, 4 lbs. P_2O_5, 50 lbs. K_2O, 3 lbs. S per ton of crop residue
Grain Sorghum	17 lbs. N, 4 lbs. P_2O_5, 50 lbs. K_2O, 3 lbs. S per ton of crop residue
Soybeans	17 lbs. N, 3 lbs. P_2O_5, 13 lbs. K_2O, 2 lbs. S per ton of crop residue
Wheat	11 lbs. N, 3 lbs. P_2O_5, 15 lbs. K_2O, 2 lbs. S per ton of crop residue
Lime replacement	1 ton corn residue = 35 lbs of lime

Applying current market prices for fertilizer to these amounts of fertilizer and then multiplying by the tonnage of crop residue removed, the market value of crop nutrients removed in crop residue for cellulosic biomass contract sales for ethanol production can be calculated. Application costs for additional, compensating N-P-K fertilizer may be negligible if the extra fertilizer is applied amounts to only a marginal increase in the amount of fertilizer regularly applied during field operations.

The means of crop fertility compensation may vary by contract and ethanol producing company. The cellulosic biomass contract provided may choose to compensate farmers by paying them a flat, market-determined crop nutrient compensation fee (as in the example contract specifications illustrated in the "increased revenues" section above). Alternatively, the contract provider may choose to compensate biomass sellers for nitrogen removal by providing them with "coupons" or "credits" to local fertilizer sales agribusinesses for offsetting nitrogen fertilizer purchases. Phosphorous, potassium, sulfur and other crop nutrients may be provided in this same manner, or the contract provider may choose to provide at least some of these crop nutrients to farmers from the bi-products of their grain or cellulosic ethanol plant production processes (if they are available).

In-field biomass storage site preparation & storage costs If temporary in-field storage is used in the logistical process of handling and short term storage of cellulosic biomass, then any storage site preparation and annual maintenance costs will be a relevant "increased expense" for the crop producer. Such costs would be especially relevant if road surfaces need to be prepared that would be impervious to wet field conditions and capable of handling heavier biomass loading equipment and/or trucks. These costs would be irrelevant if all biomass is removed from fields to centrally located, larger scale biomass storage facilities immediately after crop biomass is harvested.

The sum of alternative increases in costs resulting from crop biomass sales on a both a per acre and a per field basis is calculated to find total "Increased Expenses" in this representative partial budget framework. The sum of "Decreased Revenues" and "Increased Expenses" can then be added together to estimate the "Total Costs" from crop biomass contract sales in this partial budget framework. The net benefit or cost of contractual sales of cellulosic biomass for ethanol production is calculated by subtracting "Total Cost" from "Total Benefits".

Irrigated Corn Example

An example calculation of the benefits and costs of selling cellulosic biomass from a western Great Plains center pivot irrigated corn enterprise under the contract specifications in this model shows a net profit of $0.82 per acre or $102.27 per field (Figure 1). For illustrative purposes, it is assumed that 1 additional inch of irrigation water was applied to compensate for the soil moisture lost as a result of removing crop residue for sale as biomass. Key assumptions are as follows.

<u>Contract Specifications</u>:	
Annual biomass contract base payment	= $2.50 per acre
Annual biomass contract reservation payment	= $0.50 per acre
Annual biomass contract production payment	= $5.00 per ton
Annual biomass crop nutrient removal payment	= $8.00 per ton
Irrigated corn acres	= 125 acres
Irrigated corn yield	= 200 bushels per acre
Corn price	= $3.50 per bushel
Corn grain harvest index (%)	= 50% (grain % of total crop mass)
Corn residue harvest index (%)	= 50% (residue % of total crop mass)
Pounds of corn stover harvested per acre per year	= 3,318 lbs. (1.66 tons) per acre
Large square bales harvested per acre per year	= 2.0 bales (1,659 lbs.) @ 20% moisture
Farmer biomass fieldwork costs (side raking post harvest)	= $4.21 per acre
Other corn residue harvest operations	Responsibility of biomass contractor
Crop nutrient replacement costs per acre (Nitrogen & phosphorous loss from biomass harvest in western Great Plains)	= $12.88 per acre
Irrigation moisture regime	= Irrigated Scenario #2 (Adequate with supplemental irrigation)
Additional irrigation water applied	= 1 inch per acre of irrigated corn
Corn yield response per inch of available water	= 12 bushels per acre inch
Cost of application per inch of water	= $5.80 per acre inch applied
Total benefits per acre	= $24.07 per acre
Total benefits per field	= $3,008.18 per field
Total costs per acre	= $23.25 per acre
Total costs per field	= $2,905.51 per field
Net benefit per acre	= $0.82 per acre
Net benefit per field	= $102.27 per field

These results are sensitive to a number of critical assumptions. If instead of harvesting and selling 1.66 tons of biomass per acre from this irrigated corn enterprise, half that amount or 0.83 tons (1 large bale) per acre was removed for sale, then a net loss of $3.53 per acre (loss of $440.74) would occur.

Assumptions regarding the adequacy of soil moisture supplies for irrigation corn production are critical to these results. If instead of 1 inch of irrigation water applied to fully supply crop water needs, an additional inch of irrigation water were needed (a total of 2 inches), then net returns would be reduced by $5.80 per acre (the cost of pumping 1 additional inch of irrigation water per acre at a cost of $5.80 per acre inch).

If instead of being able to fully meet the full moisture needs of the irrigated corn crop with supplemental water application, a water deficit situation existed, then financial losses resulting from crop residue removal and resulting soil moisture depletion would be sizable. If an irrigation water deficit scenario existed, then for each one inch of water that the corn crop was short of reaching its full water needs, a 12 bushel yield loss would occur. At $3.50 per bushel, irrigated corn revenues would decrease by $42.00 per acre (i.e., $3.50 per bushel multiplied by 12 bushels per acre for each 1 inch of water deficit).

This model assumes no BCAP program payments in the first two years of the cellulosic biomass sales contract. If substantial BCAP incentive payments to farmers were available, it could increase the projected profitability of cellulosic biomass sales for two years, but would then have no positive impact on farmers net returns unless policy changes were made to extend such payments into the future.

Non-irrigated Wheat Example

An example calculation of the benefits and costs of selling cellulosic biomass from a western Great Plains non-irrigated wheat enterprise under the contract specifications in this model shows a loss of $20.07 per acre or $3,211.61 per field (Figure 2). For illustrative purposes, it is assumed that soil moisture supplies were 1 inch short of supplying of the full water needs of the wheat crop, with this deficit resulting from the removal of removing wheat crop residue for sale as biomass. These environmental and soil moisture conditions would be commonly representative of the western sections of Kansas and Oklahoma, but less representative of the central parts of each state where rainfall and soil moisture supplies are more likely to fully supply crop needs. Key assumptions are as follows.

<u>Contract Specifications</u>:	
Annual biomass contract base payment	= $2.50 per acre
Annual biomass contract reservation payment	= $0.50 per acre
Annual biomass contract production payment	= $5.00 per ton
Annual biomass crop nutrient removal payment	= $8.00 per ton
Non-irrigated wheat acres	= 160 acres
Non-irrigated wheat yield	= 45 bushels per acre
Wheat price	= $5.00 per bushel
Wheat grain harvest index (%)	= 50% (grain % of total crop mass)
Wheat residue harvest index (%)	= 50% (residue % of total crop mass)
Pounds of wheat stover harvested per acre per year	= 1,659 lbs. (0.83 tons) per acre
Large square bales harvested per acre per year	= 1.0 bale (1,659 lbs.) @ 20% moisture
Farmer biomass fieldwork costs (side raking post harvest)	= $4.21 per acre
Other corn residue harvest operations	Responsibility of biomass contractor
Crop nutrient replacement costs per acre (Nitrogen & phosphorous loss from biomass harvest in western Great Plains)	= $3.79 per acre
Non-irrigated soil moisture regime	= Non-irrigated Scenario #2 (Deficit to total crop moisture needs)
Deficit amount of soil water versus crop needs	= 1 inch per acre of dryland wheat
Wheat yield response per inch of available water	= 5 bushels per acre inch
Total benefits per acre	= $13.28 per acre
Total benefits per field	= $2,125.24 per field

Total costs per acre	= $3.36 per acre
Total costs per field	= $5,336.84 per field
Net cost per acre	= $20.07 per acre
Net benefit per field	= $3,211.61 per field

The critical assumption in these results is that soil moisture availability is deficit or inadequate to meet the wheat crop's total moisture needs by 1 inch, and that the soil moisture deficit situation was due to soil moisture loss caused by removal of wheat residue for sales to fulfill a cellulosic biomass ethanol production contract. Alternatively, if soil moisture needs were fully adequate to meet the wheat crop's needs, then net returns per acre would increase by $25.00 per acre (i.e., 5 bushels per acre multiplied by 1 inch of moisture per acre multiplied by $5.00 per bushel). Such conditions with adequate moisture favoring wheat production (but also favoring wheat disease development) are more likely to occur in the central part of Kansas and at least the north central part of Oklahoma. However, if instead of only a 1 inch moisture deficit, the wheat crop was 2 inches short of meeting its moisture needs (again, due to crop residue removal), then the results would be catastrophic from an economic point of view for the wheat enterprise.

As with irrigated corn, if the amount of wheat straw to be harvested were halved (down to 829 pounds or 0.41 tons per acre), then a net loss in revenue for cellulosic wheat sales would occur (i.e., returning a net loss of $23.57 per acre and of $3.771.40 for the full 160 acre field. And, as for irrigated corn this model assumes no BCAP program payments in the first two years of the cellulosic biomass sales contract.

Model Development Directions

The overall structure of this model of the profitability of cellulosic biomass sales by farmers for ethanol production is general enough in nature to be applied to other crop-related enterprises in other regions besides the western Great Plains. In doing so, issues that affect crop production, soil moisture levels, and the impacts of crop residue removal may or are likely may not to be as critical on a year to year basis in regions of more abundant rainfall. To the degree that soil moisture deficits are less of an inhibiting factor to crop production in other areas of North America, cellulosic ethanol production may be more profitable (all else being equal).

In its current form this model represents monoculture crop production practices (i.e., the continuous production of one crop over the life of the contract period). Although this assumption may be reasonable for irrigated corn production in the western Great Plains, it is far less reasonable for non-irrigated wheat production in this same region. Future versions of this model will need to account for the possibility of non-monoculture irrigated and especially non-irrigated cropping systems.

This model also assumes that crop residue is harvested from these acres annually – an assumption that may or may not be consistent with the yet to be revealed practices of cellulosic ethanol producing agribusiness interests in the western Great Plains.

Another area of needed improvement in this model is that it currently assumes equal valuation of net benefits, costs and returns over the life of a cellulosic ethanol production contract – with no accounting for the time value of money. Future versions of this model need to better represent the time value of money in evaluating the profitability of cellulosic biomass production – sales contracts over the life span of the associated contract.

Finally, the USDA's Natural Resource Conservation Service (NRSC) plays a major, somewhat "behind the scenes" role in determining the profitability of these cellulosic biomass sales contracts. The USDA NRCS has the final authority in determining the amount of crop residue that can be harvested from any farm enrolled by in USDA farm programs (given that each such farm is required to have an approved soil conservation plan). Restated, the maximum amount of crop residue that can be harvested and sold for cellulosic ethanol production on almost every acre of cropped land in the United States will be determined by the USDA NRCS in a manner consistent with the conservation plan of each farmer's field. Fields at

Figure 1. Irrigated Corn Example for Cellulosic Biomass Sales in the Western Great Plains

Annual Biomass Contract Benefits			Annual Biomass Contract Costs		
A. Increased Revenues	Per Acre	Per Field	**C. Decreased Revenues**	Per Acre	Per Field
Biomass Reservation ($0.50/ac) & Base Contract payment ($2.00/	$2.50	$312.50	In-field bale storage site: lost crop income (Section VIII)	$0.36	$45.00
Biomass payment ($5 per ton) (Section II)	$8.29	$1,036.80	Carbon credits: lost payment income (Undefined)	$0.00	$0.00
Biomass nutrient removal compensation ($8 per ton) (Section II)	$13.27	$1,658.88	Crop yield losses (Section IX) Irrigated reduced soil moisture regime	$5.80	$725.00
In-field bale storage site: cash rent compensation (Section VIII)	$0.00	$0.00	Wind erosion soil / crop yield impacts (Undefined)	$0.00	$0.00
Carbon credits: payment income (Undefined)	$0.00	$0.00	Water erosion soil / crop yield impacts (Undefined)	$0.00	$0.00
	$0.00	$0.00		$0.00	$0.00
A. Total increased revenues	$24.07	$3,008.18	**C. Total decreased revenues**	$6.16	$770.00
B. Decreased Expenses			**D. Increased Expenses**		
In-field bale storage site: decreased crop expenses (Section VIII)	$0.00	$0.00	Biomass harvest, baling, handling costs (Section VII)	$4.21	$526.25
	$0.00	$0.00	In-field bale storage site: storage site costs (Section VIII)	$0.00	$0.00
	$0.00	$0.00	Crop fertility replacement: net costs (Section VI)	$12.88	$1,609.66
	$0.00	$0.00		$0.00	$0.00
	$0.00	$0.00		$0.00	$0.00
B. Total decreased expenses	$0.00	$0.00	**D. Total increased expenses**	$17.09	$2,135.91
	Per Acre	Per Field		Per Acre	Per Field
Total Benefits: (A + B) =	$24.07	$3,008.18	**Total Costs: (C + D) =**	$23.25	$2,905.91

	Per Acre	**Per Field**
Net Profitability of Cellulosic Biomass Contract:		
Total Benefits (A + B) Less Total Costs (C + D) =	$0.82	$102.27

Figure 2. Non-irrigated Wheat Example for Cellulosic Biomass Sales in the Western Great Plains

Annual Biomass Contract Benefits			Annual Biomass Contract Costs		
A. Increased Revenues	Per Acre	Per Field	**C. Decreased Revenues**	Per Acre	Per Field
Biomass Reservation ($0.50/ac) & Base Contract payment ($2.00/	$2.50	$400.00	In-field bale storage site: lost crop income (Section VIII)	$0.36	$57.60
Biomass payment ($5 per ton) (Section II)	$4.15	$663.55	Carbon credits: lost payment income (Undefined)	$0.00	$0.00
Biomass nutrient removal compensation ($8 per ton) (Section II)	$6.64	$1,061.68	Crop yield losses (Section IX) Nonirrigated deficit soil moisture regime	$25.00	$4,000.00
In-field bale storage site: cash rent compensation (Section VIII)	$0.00	$0.00	Wind erosion soil / crop yield impacts (Undefined)	$0.00	$0.00
Carbon credits: payment income (Undefined)	$0.00	$0.00	Water erosion soil / crop yield impacts (Undefined)	$0.00	$0.00
	$0.00	$0.00		$0.00	$0.00
A. Total increased revenues	$13.28	$2,125.24	**C. Total decreased revenues**	$25.36	$4,057.60
B. Decreased Expenses			**D. Increased Expenses**		
In-field bale storage site: decreased crop expenses (Section VIII)	$0.00	$0.00	Biomass harvest, baling, handling costs (Section VII)	$4.21	$673.60
	$0.00	$0.00	In-field bale storage site: storage site costs (Section VIII)	$0.00	$0.00
	$0.00	$0.00	Crop fertility replacement: net costs (Section VI)	$3.79	$605.64
	$0.00	$0.00		$0.00	$0.00
	$0.00	$0.00		$0.00	$0.00
B. Total decreased expenses	$0.00	$0.00	**D. Total increased expenses**	$8.00	$1,279.24
	Per Acre	Per Field		Per Acre	Per Field
Total Benefits: (A + B) =	$13.28	$2,125.24	**Total Costs: (C + D) =**	$33.36	$5,336.84

	Per Acre	Per Field
Net Profitability of Cellulosic Biomass Contract:		
Total Benefits (A + B) Less Total Costs (C + D) =	($20.07)	($3,211.61)

less risk to wind and water erosion will be allowed to harvest and sell greater amounts of cellulosic biomass to generate crop income. Conversely, the opposite will be true for fields deemed by the USDA NRCS to be more erodible or at risk to soil degradation due to inadequate crop residue cover.

Conclusions

With existing financial incentives and U.S. energy policy directions, there is clear support for farmers in the western Great Plains and nationwide to become more involved in crop residue sales for cellulosic ethanol production. Although relevant agronomic and economic factors vary across the U.S., this farmer-level decision framework is adaptable for use in various regions of the country. The economic impact of crop residue removal on soil moisture depletion and subsequent crop yields is likely to vary across the United States and Canada based on soil properties, adequacy of soil moisture supplies, and other factors. In the typically rainfall deficient region of the western Great Plains it is expected that marked crop production and revenue declines would result from any loss of deficiency of soil water to meet crop production needs. However, in other parts of the North America which typically have adequate or even excess rainfall to meet crop production needs, harvesting crop residue could possibly increase soil moisture evaporation and may either have only limited effects on subsequent crop growth or even possibly improve it due to increased soil moisture evaporation and less saturated soil moisture conditions during critical periods of field work.

Both the physical agronomic principles and the approach taken to represent the economic benefits and costs in this model may be of interest to those seeking to evaluate the profitability of cellulosic biomass contract sales on a local or regional level. Questions of how best to represent crop enterprise returns over time, of how to represent the income effects of foregone carbon credits, and of how to flexibility represent the various crop residue sales contract terms available from across the U.S. still need to be addressed. Finally, the means by which University faculty from various areas and institutions in North America may be able to work together to make both spreadsheet and web-based versions of this type of decision tool more useful for farmers in different states may be of interest to session participants.

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