Corn Stover for Bioenergy Production: Cost Estimates and Farmer Supply Response

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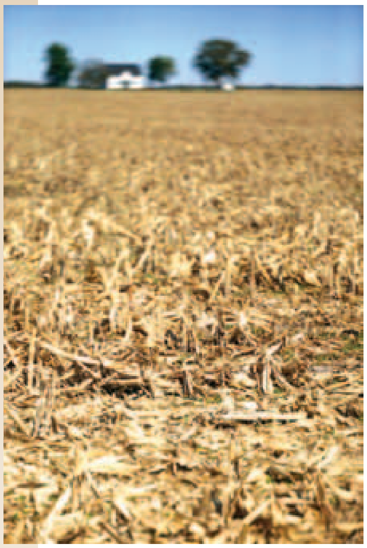

Introduction

In 2009, approximately 82% of U.S. energy consumption was from fossil fuels (U.S. Energy Information Administration, 2010). Government policy has attempted to reduce this dependency on nonrenewable energy sources through subsidies and mandates of renewable energy sources. Recent attention has been focused on "second generation" biofuels, which are not generated from food sources.

Sources of second generation biofuels include crop residues and crops that are grown solely for energy production, called "dedicated energy crops." Examples of dedicated energy crops are Miscanthus and switchgrass. By requiring fewer reallocations of resources in comparison to biofuels created from food sources, second generation biofuels may have less impact on agricultural commodity markets.

We focus on the use of corn stover, the non-grain portion of the corn crop, as a feedstock for bioenergy production. Corn stover could serve as a feedstock for biofuels, as a substitute for coal in producing electric power, or both. In addition to meeting renewable energy goals, use of corn stover for energy production may provide a new source of income for corn growers. We estimate the costs of corn stover harvest and supply, and then use that information to estimate areas of

Figure 1. *Raking, Baling, and Staging Equipment*

stover harvested and changes to farm profit at varying corn stover prices.

Harvest and Supply Process

John Deere, Archer Daniels Midland, and Monsanto Corporation (DAM) have been sponsoring field experiments on corn stover harvesting. The DAM project has harvested corn stover near Cedar Rapids, IA for the 2008, 2009, and 2010 seasons and collected information on the land, equipment, inputs, timing, and bale characteristics. In this operation, stover is collected in large round bales (approximately 0.5 tons dry weight or 0.575 tons at 15% moisture) using a raking, baling, and staging method. Figure 1 (p. 1) shows the rake (New Holland H5980), baler (Case IH RB564), and staging equipment (Bühler/Inland 2500) used by the DAM operation.

We assumed that custom harvesters would be hired to collect corn stover. Custom harvesters are third parties who collect corn stover from a corn grower's field. This eliminates the need for the corn grower to purchase his own stover harvest equipment or spend time harvesting stover. During corn grain harvest, corn stover is ejected from the back of the combine and left lying in the field. Approximately two or three days after grain harvest, individuals harvesting corn stover pass through the field with a rake, creating a windrow of corn stover. Waiting two or three days after grain harvest allows the stover to dry naturally in field. Once the windrow is created, a large round baler passes through the field, turning the windrow into corn stover bales.

We further assumed that 33% of corn stover would be raked and baled. The remaining 67% of corn stover would remain in the field to provide erosion prevention, soil carbon retention, and nutrient replacement. Nutrients lost due to the 33% of stover removed are replaced with commercial fertilizers. This removal method results in a stover harvest of approximately three large round bales (a total of 1.5 dry tons or 1.725 tons at 15% moisture) per acre of land.

Last, the bales are staged. This is the process of moving bales off the field so they can be stored or transported. We assumed stover bales would be stored in a designated area on the farm. Once bales are demanded for energy creation, they would be transported from farm storage to the biorefinery (where the stover will be converted to energy) in flatbed semi-trailers. Additional details of this process are given in the next section. It must be noted that harvest, storage, and transportation methods vary greatly.

Harvest and Supply Cost Estimates

Data from the DAM operation was combined with information from previous corn stover studies to generate a comprehensive cost estimate for stover supply. All costs are calculated at 15% moisture for corn stover. We estimated harvest cost as $36.63/ton and consisted of fuel use, labor, equipment (both ownership and repair), nutrient replacement, and net wrap (used to bind the bales and offer some protection during handling and storage). Figure 2 shows the partition of estimated harvest cost among these components.

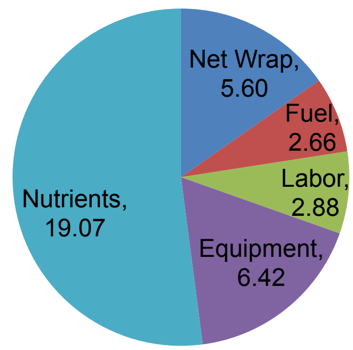

Figure 2. *Partition of Estimated Harvest Cost ($/ton at 15% moisture)*

Nutrient replacement is the largest component, representing 52% of harvest cost. Nutrient prices were estimated by fitting a trendline to 2000-2011 nutrient price data and evaluating that line at the year 2010. The resulting prices for nitrogen (N), phosphorus (P), and potassium (K) were $0.419/pound, $0.465/pound, and $0.355/pound. Fertilizer prices are volatile, and a change in their price would significantly influence the estimated harvest cost.

We assumed storage of round stover bales would take place on the farm for up to 12 months. We also assumed that bales would be stacked in a pyramid formation on top of a rock bed and covered in a tarp. The cost of the land, rock, and tarps needed for this storage method is estimated as $16.47/ ton (at 15% moisture). Once bales are needed for energy production, they are loaded onto a 53-foot flatbed semitrailer for delivery. We assumed that 26 large round bales (approximately 15 tons at 15% moisture) would be loaded onto each trailer. Loading and unloading cost includes the equipment and labor needed to load and unload the bales from the trailer and costs $6.30/ton. We used a 50-mile supply radius. Based on the average distance travelled to transport from this area and formulas from previous literature, we estimated transportation cost to be \$19.94/ton. This accounts for transporting bales from the farm to the biorefinery as well as a return trip of the transporting vehicle (backhaul).

The sum of harvest, storage, loading and unloading, and transport costs was \$79.34/ton for stover collected from a corn-soybean rotation and \$64.85/ton for stover collected from a continuous corn rotation. The cost difference is due to the assumed elimination of one tillage pass in a continuous corn rotation when corn stover is removed. Tillage tends to be more intensive in a continuous corn rotation than in a corn-soybean rotation because corn stover can build up in the field over time. If some of the corn stover is removed, tillage may not have to be as intensive. The cost savings from reduced tillage is estimated at \$25/acre (Karlen, 2011), or approximately \$14.49/ton (at 15% moisture). The partition of supply cost (includes harvest, storage, loading and unloading, and transportation to the biorefinery) for a corn-soybean rotation is illustrated in Figure 3.

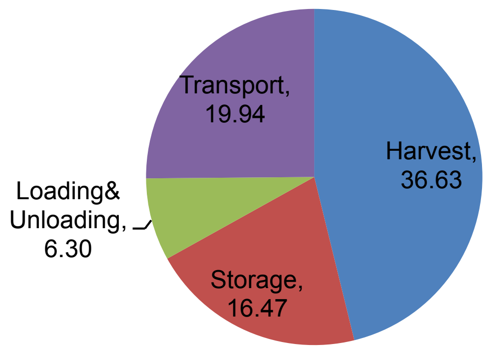

Figure 3. *Partition of Estimated Supply Cost for a Corn-Soybean Rotation (\$/ton at 15% moisture)*

Stover Price Needed to Make Stover Harvest Profitable

We simulated farm decisions using the Purdue Crop/Livestock Linear Programming (PCLP) model. With data provided by farmers on land, labor, machinery, crop yields, crop prices, input costs, and other farm resources, PCLP determines the most profitable combination of crops to grow and the optimal acreage devoted to those crops. Assuming the goal of a farmer is to maximize his profits, the results of the PCLP model are a good estimation of farm behavior. We used actual farm data from the 2007-2010 Purdue Top Farmer Crop Workshops in the model. The data sets included the land, labor, and machinery resources of the farm; the number of days suitable for working in the field during given time periods; the expected price of commodities grown (corn, soybeans, canola, barley, etc.); the crop rotation used; and the expected yield of crops grown. Twenty-five farms with a total of 63,582 acres were used for this analysis. We assumed they represent Midwest crop farms.

PCLP chooses among the crop rotations specified by farmers in the Top Farmer Crop Workshop plus continuous corn production with stover removal and a corn-soybean rotation with stover removal. Adding stover to the crop rotations considered by PCLP provides another economic activity for the farm to choose. We included the costs of stover harvest and storage, approximately \$53.10/ton for stover removed from a corn-soybean rotation and \$38.61/ton for stover removed from a continuous corn rotation. We did not include loading, unloading, and transport in the PCLP model. It is possible that biorefineries will control transportation to ensure a steady delivery of stover that matches the plants' processing capacity. By excluding loading, unloading, and transport costs from the PCLP results, we assumed the cost is the same regardless of who actually does the transport. The sum of loading, unloading, and transport is estimated as \$26.24/ton and can be added back to get the delivered cost of stover.

Adjusting Results to Show Penalties for Bale Quality

Due to differences in soil type, weather patterns, harvest method, and storage techniques, the ash and moisture content of corn stover bales will vary by farm and by year. Ash is dirt and debris that may be collected with the stover. Bales containing excessive ash or high moisture content are less suitable as a feedstock for creating bioenergy. It is likely that biorefineries purchasing corn stover as a feedstock will penalize farms when bales contain ash or moisture levels exceeding an acceptable range.

To account for these penalties, we weighted the PCLP results based on the bale grades, penalties, and probabilities summarized in Table 1 (p. 4). We calculated bale penalties using differences in preprocessing costs (\$/ton) for bales of differing moisture levels (Muth, 2011). Preprocessing involves grinding the stover into smaller pieces before the energy conversion process begins. Biorefineries encounter higher preprocessing costs when bales have high moisture or high ash content, so they are likely to penalize farmers for supplying them with these low quality bales. We based

Table 1. *Bale Grades, Penalties, and Probabilities*

Category	*Moisture*	*Ash*	*Penalty*	*Probability*
Grade 1	<20%	<10%	$0/ton	61.44%
Grade 2	≥20% and <28%	<15%	$8/ton	29.20%
Grade 3	≥28% and <36%	<15%	$17/ton	0.83%
Grade 4	≥36%	>15%	100% of price	8.52%

probabilities on the moisture and ash content of bales collected from the DAM operation during 2009 and 2010 after being adjusted for changes that occur during storage. From historic data, we determined that the probability of weather being similar to 2009 weather was twice as likely as it being like 2010. We applied that weight to the actual data to calculate probabilities. We reduced moisture by 32.21% from the level at time of harvest and increased percent ash 5.2% from the level at time of harvest (Shinners et al., 2011). This better reflects the moisture and ash in the stover bales once delivered to the biorefinery.

We applied the penalties described above to the results by weighting the corn stover supply curve based on the penalties and probabilities in Table 1. At a stover price of $80/ton, for example, a Grade 1 bale would receive $80/ton, a Grade 2 bale would receive $72/ton, a Grade 3 bale would receive $63/ton, and a Grade 4 bale would receive $0/ton. The weighted supply curve for $80/ton would then be the sum of supply at $80/ton multiplied by the probability of a Grade 1 bale, supply at $72/ton multiplied by the probability of a Grade 2 bale, supply at $63/ton multiplied by the probability of a Grade 3 bale, and supply at $0/ton multiplied by the probability of a Grade 4 bale. The same method was used to weight profit and farm participation results. Accounting for these bale quality penalties provides a better reflection of the price farmers will receive for the actual corn stover bales supplied to a biorefinery.

Results

We used PCLP to analyze a base case and four alternative cases. All cases included the basic outputs from PCLP plus an adjustment for stover moisture and ash penalties based on an estimate of the likelihood of each grade of stover delivered. The four cases for sensitivity analysis were the following:

- No reduction in tillage for continuous corn
- An increase in the price of soybeans to reflect a change in relative prices
- Addition of a yield drag for continuous corn
- Harvest cost reduction due to new harvest technologies

Base Case – PCLP Outputs with Moisture and Ash Adjustment

Farms will not harvest corn stover until the stover price exceeds the costs of harvest and storage. Even after all costs are met, it is possible that farms will not harvest corn stover due to higher benefits of other crop alternatives (such as wheat, soybeans, or milo). After adjusting for the likelihood of bale quality penalties, the PCLP results indicated that corn stover would be supplied by four of the 25 farms at a price of $40/ton, 12 farms at $50/ton, 19 farms at $60/ton, and 23 farms at $70/ton and greater. At all stover prices, there is an 8.52% chance that stover bales will be Grade 4 quality and receive no payment. Therefore, some farms may choose not to harvest stover regardless of the stover price.

PCLP predicts which crops the farm should plant on its acres in order to maximize profits. Comparing these results at varying stover prices allowed us to see how production changes as stover price rises. Figure 4 (p. 5) summarizes the allocation of acres in the base case at each stover price considered. "Cont. Corn" represents acres allocated to continuous corn production without stover removal, "CC+Stover" represents acres allocated to continuous corn production with stover removal, "Corn-Bean" represents acres allocated to a corn-soybean rotation without stover removal, "CB+Stover" represents acres allocated to a corn-soybean rotation with stover removal, "Soybean" represents acres producing soybeans, and "Other" represents acres producing crops other than corn and soybeans (such as wheat or milo).

Corn stover was first harvested from existing continuous corn acres, suggesting the importance of the $25/acre savings in reduced tillage in the continuous corn rotation. Stover was then harvested from existing corn-soybean acres. As the stover price rose, more corn acres were in-

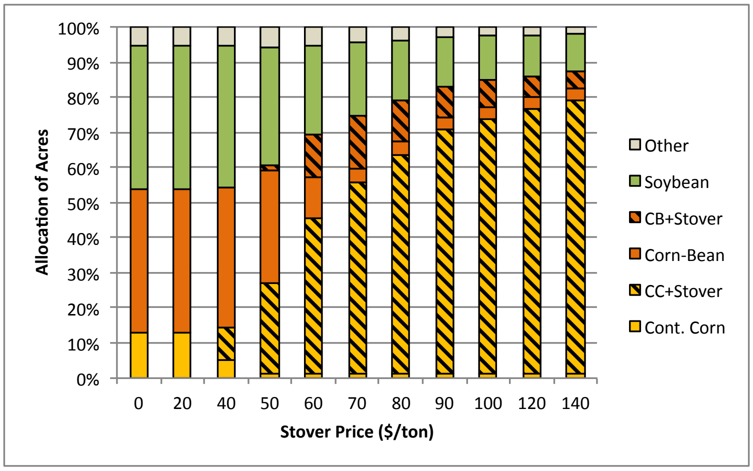

Figure 4. *Allocation of Crop Acres, Base Case*

cluded in the optimal crop mix. Acres devoted to non-corn crops (such as wheat, soybeans, and milo) decreased as a consequence. While 46% of the 63,582 acres were devoted to non-corn crops at a stover price of $0/ton, 31% of acres were producing non-corn crops at $60/ton, and only 21% of land was allocated to non-corn production at a stover price of $80/ton. These results suggest that at high enough corn stover prices, farms will not only harvest corn stover but will allocate more acres toward corn production in order to earn revenues from corn stover supply.

The additional revenues from corn stover had a significant impact on farm profit. At a stover price of $80/ton, aggregate profit for the 25 farms was 34% greater than before stover was supplied. 72,758 tons of corn stover were harvested at this price. The 25 farms studied contain 63,582 total acres, so stover harvest amounted to 1.14 tons/acre of farmland when stover price was $80/ton. Figure 5 illustrates the estimated supply curve for corn stover, which shows how many tons of corn stover will be harvested from the 25 farms at a given price. The quantity harvested increases as price increases. Once the stover price exceeds $80/ton (indicated on Figure 5), harvest quantity does not react as strongly to stover price. The steepness of the supply curve shows this happening, and it signifies that the farm is running out of land, labor, and machines as more corn stover is harvested. In some instances, an increase in the farm's labor and/or machinery resources would likely result in more corn stover harvest.

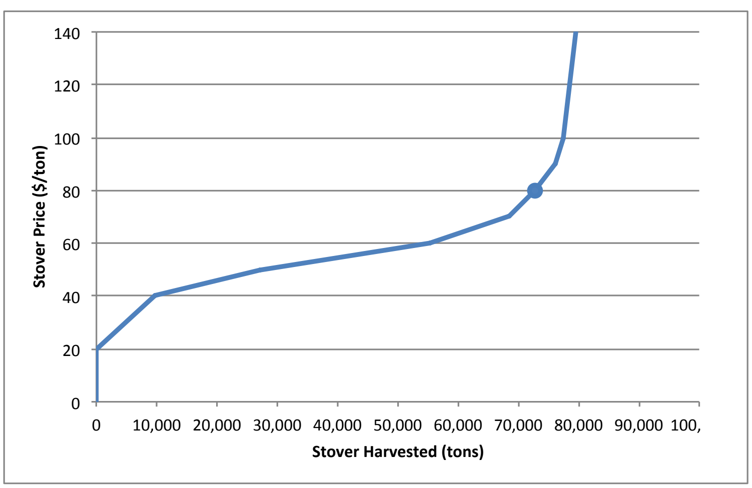

Figure 5. *Corn Stover Supply, Base Case*

No Reduction in Tillage

The $25/acre savings from reduced tillage in the base case may not be realistic for all farms. Management practices, soil types, and weather patterns differ by farm, so it is uncertain how an individual farm's tillage activities will be influenced by the removal of corn stover. We generated a new set of PCLP results assuming no savings from reduced tillage. The cost of stover harvest and storage used in the model was $53.10/ton for both continuous corn production and a corn-soybean rotation. All other parameters and methods were identical to the base case.

As expected, profit and quantity supplied decreased from the base case results. At a stover price of $80/ton, profits were 8.9% lower than in the base case, and 57,775 tons of stover were harvested (a 25.9% reduction). This signifies a harvest rate of 0.91 tons/acre. These results suggest that the ability to reduce tillage after stover removal in a continuous corn rotation is a significant factor in a farm's decision to harvest stover.

Changes in land allocation differed from the base case. While stover was initially collected from continuous corn acres in the base case at $40/ton, stover was not collected until $50/ton when tillage savings did not exist. At that price, farms collected stover from corn-soybean acres. In both scenarios, acres devoted to corn production increased as the stover price rose.

Relative Change in Corn and Soybean Prices

The base case results suggest that farms may use more acres for continuous corn production as stover price rises. To accommodate this increase in corn production, non-corn acres must decrease. This change in farm production will tend to increase the supply of corn and decrease the supply of non-corn commodities, likely leading to a decrease in corn prices and an increase in prices of other commodities. To get an indication of the impact of non-corn commodity prices on stover supply, we increased the soybean price entered in the PCLP model by 20%. This signifies a relative price change between corn and non-corn commodities. All other parameters were identical to the base case. The results of this case provide only an indication of what would happen with a relative corn-soybean price change. A partial equilibrium analysis would be required to get a more comprehensive picture.

With the soybean price increase, more acres are devoted to soybean production at every stover price. When stover price is $0/ton, 3,041 additional acres of soybeans are produced with the soybean price increase than in the base case. This results in $2,470,047 more profit with the soybean price increase. To separate the effects of profit changes due to corn stover harvest and profit changes due to the soybean price increase itself, it is important to look at the profit from stover: the difference between farm profit at stover price $0/ton and a given stover price. At $80/ton, profit from stover was $1,265,727 higher in the base case. 7,300 more acres were devoted to soybean production when stover price is $80/ton and the soybean price increase is present. This decreases the potential for stover supply and the resulting profits. 64,593 tons of stover were harvested at $80/ton with the soybean price increase, resulting in a stover harvest rate of 1.02 tons/acre.

Yield Drag

Many agronomists agree that yields for rotated corn are higher than those for continuous corn production. This is called "yield drag" and is likely due to differences in residue quantities, nutrients, and disease threats associated with the two rotations. Yield drag is not indicated in the farmer supplied data for seven of the 25 farms studied. For these seven farms, continuous corn yield is greater than or equal to the yield of rotated corn.

We adjusted yield data for the 25 farms to reflect yield drag. We used the rotated corn yield from the original data and calculated continuous corn yield as a percentage of the rotated corn yield. We based adjustments on yield drag on data in crop budgets published by Purdue University, Iowa State University, and the University of Illinois. Imposing the yield drag resulted in reduced harvest quantity and lower profit, signaling that farms reported a continuous corn yield that was higher than predicted by agronomists. At $80/ton, harvest quantity was 2,835 tons less than in the base case and profit from stover was $745,747 less than in the base case. 69,923 tons of stover were harvested at $80/ton, resulting in a stover harvest rate of 1.10 tons/acre.

New Harvest Technologies

Various equipment companies are developing new machinery with the intent of increasing the efficiency of stover supply. These machines are likely to reduce the cost and time requirements of stover harvest. To estimate the effects such machines may have on stover supply, we reduced the harvest cost entered in the PCLP model by 25%. In the base case, harvest cost (not including nutrient replacement) was $30.27/acre. The harvest cost was reduced to $22.70/acre for this scenario.

Due to the harvest cost reduction, farms harvested more corn stover at a lower price than in the base case. As expected, farm profit was greater when harvest cost decreased. Profit from corn stover was $1,493,508 greater than in the base case at a stover price of $80/ton. At this price, stover quantity increased by 2,425 tons due to the reduction in harvest cost. 75,183 tons of stover were harvested at $80/ton, resulting in a stover harvest rate of 1.18 tons/acre.

Conclusions

As a byproduct of corn production, corn stover is a readily available resource. Harvesting, storing, and transporting the material, however, have significant cost. Results from a linear programming model considering 25 real Midwest farms indicates that it may be profit-maximizing for some farms to harvest and supply corn stover at prices above $40/ton. Recall that with no stover, continuous corn represented 13% of total area, corn-soybeans 41%, and other crops 46%. In all scenarios, the land allocated to corn production increased as stover price rose. Maximum farm participation was reached when the stover price was $80/ton. Table 2 (p. 7) summarizes the results of each scenario at a stover price of $80/ton. Using this stover price, the cost of harvesting, storing, loading and unloading, and transporting corn stover to a biorefinery is $106.24/ton (at 15% moisture).

The quantity harvested and profit from stover were greatest in the new technology scenario, where harvest cost was reduced by 25%. This supports the importance of further research on corn stover collection methods. Quantity and profit were lowest in the scenario where tillage savings did not exist. Reducing land preparation costs is just one

Table 2. *Summary of Scenarios at $80/ton*

	Base Case	*No Reduction in Tillage*	*Soybean Price Increase*	*Yield Drag*	*New Harvest Technologies*
Farms Participating	23	23	23	23	23
% BC+Stover Acres	11.79%	29.61%	22.85%	11.94%	9.59%
% CC+Stover Acres	62.64%	28.23%	42.49	61.72%	67.77%
Stover Harvest Acres	48,144	37,421	42,287	47,658	50,032
Tons of Stover	72,758	57,775	64,593	69,923	75,183
Harvest Rate(tons/ac)	1.14	0.91	1.02	1.10	1.18
Profit from Stover($)	5,816,818	3,786,971	4,551,091	5,071,071	7,310,326

example of how stover harvest could be beneficial to the corn growing operation. We must remember that farmers control the supply. They will only engage in stover harvest if it is profitable for them to do so. Although corn stover is a crop residue, it is not free. There are real and substantial costs to using corn stover as a feedstock for energy production. The results of the research reported here provide real world-based estimates of the costs and benefits farms would incur when harvesting stover.

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