Development of Corn Stover Biofuel: Impacts on Corn and Soybean Markets and Land Rotation

By

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Abstract

This paper first develops a partial equilibrium (PE) model to examine impacts of converting corn stover to biofuel on markets for corn and soybeans at the national market level. The PE model links gasoline, corn ethanol, dried distiller grains, corn, soybeans, and soybean meal markets in the presence and absence of a viable market for corn stover. The model also includes a technology which converts corn stover to bio-gasoline (a drop-in biofuel). The model evaluates profitability of the ethanol and bio-gasoline industries and assumes that these industries will expand/contract until profits reach zero. Given these assumptions and according to the predetermined supply and demand elasticities, the model determines equilibrium prices and their corresponding quantities for given exogenous variables defined in the model (such as crude oil price). The model is calibrated using data obtained for 2010 for USA economy and then solved for alternative crude oil prices in the presence and absence of a fixed subsidy of $1.01per gallon of bio-gasoline produced.

Then we used the Purdue Crop Linear Programing (PCLP) model to assess farmers' reactions to market equilibrium prices for corn, soybeans, and corn stover in the presence of a viable market for corn stover. The PCLP model determines profit-maximizing decisions for a given farm given its existing resources and estimated prices of commodities and input costs. We tuned the PCLP model according to the market clearing prices obtained from the PE model for a case when the crude oil price is $100 per barrel. Then using the tuned PCLP model we determined the optimum land allocation options for farmers.

The partial equilibrium analyses show that: 1) with no bio-gasoline subsidy a limited amount of corn stover will be converted to biofuel even at very high crude oil prices; 2) The bio-gasoline subsidy could significantly boost production of this biofuel in particular at medium and higher crude oil prices; 3) no more than 45% of available corn stover will be removed for biofuel production; 4) converting corn stover to bio-gasoline boosts corn production, increases corn-corn rotation, and decreases supply of soybeans; and 5) converting corn stover to bio-gasoline changes the soybean to corn price ratio in favor of soybeans, at least in the very short term.

The results obtained from the PCLP model show that the farm level land allocation decision is sensitive to the profitability of corn stover processing activities. When corn stover removal is introduced as a new option under the base case scenario at a corn stover price of $111 per ton) farmers allocate about 66% of their land to the corn-corn rotation and remove stover from their land. In this case corn stover is removed from 78.2% of available land at a rate of 1.18 tons per acre. If corn stover is demanded for biofuel production, then a major shift will be observed in crop rotations.

1. Introduction

First generation biofuels and their impacts on: 1) greenhouse gas emissions, 2) oil imports, and 3) markets for agricultural commodities and food prices have been examined from different angles in recent years. These studies showed that, first generation biofuels which are produced from food crops will be unable to replace a large portion of oil-based liquid fuels, because their rapid expansion could cause adverse impacts on food supply (Abbott, et al., 2011, Abbott, et al., 2008, Trostle, 2008, Zilberman, et al., 2013) and/or induce major unintended land use changes which in turn will lead to increases in greenhouse gas emissions (Hertel, 2010, Tyner and Taheripour, 2012). Instead, second-generation biofuels produced from forest or crop residues such as wood chips, corn stover, or wheat straw offer an alternative to first generation biofuels. These residue-based biofuels could have minor impacts on food prices and induce minor land use changes. In addition, they could make a major contribution in greenhouse gas emission reduction targets if removed in a sustainable method (English, et al., 2013). Another advantage for second-generation biofuels produced from agricultural residues is that they provide a potential new source of income for farmers (Thompson and Tyner, 2013). If second generation biofuels became economically viable and a massive volume of biofuels are produced from agricultural residues, it then can have major impacts on agricultural commodity markets. Corn stover is a major and abundant feedstock in the USA, which is expected to be used in biofuel production, if the technology becomes economically viable. Converting corn stover to biofuels, in a large magnitude, will generate a viable market for this feedstock and that can affect profitability of corn production versus other crops produced in USA, in particular versus soybeans. Thompson and Tyner suggest that if a viable corn stover market existed to support biofuel production, it could have a large impact on farmers' crop rotations and land allocation decisions. However, that research was done at a farm level with a given set of crop prices and ignored interaction between farm and market level variables. The purpose of this paper is to determine to what extent producing biofuels from corn stover can affect demands for and supplies of corn and soybeans and their prices at market level. In addition, it examines in what extent producing biofuel from corn stover could affect switching from corn-soybean rotation to continuous corn.

To determine how a corn stover market would impact corn and soybeans markets, a deterministic partial equilibrium model is developed which links corn, soybeans, corn stover, ethanol, dried distiller grains, and gasoline markets at the USA aggregation level and determines market-clearing prices for these markets at different crude oil prices. The resulting prices were used in a linear programming model to determine how farmers would allocate their land.

2. Background

Corn and soybeans are major crops produced in the USA. These two crops covered about 48% of USA harvested areas in 2010. The harvested area under these two crops has grown from 50 million hectares in 1990 to 58.6 million hectares in 2000 and 66.1 million hectares in 2012 (Figure 1). These crops are usually produced in a corn-soybean rotation with some fluctuation around this pattern due to changes in market conditions. As shown in Figure 1 the share of corn in total harvested areas of these two crops has decreased from 54.2% in 1990 to 50% in 2000, and then again increased to about 54% in 2012. The recent increase in the share of corn in total harvested area of corn and soybean is mainly due to the expansion in corn demand for ethanol production. Due to higher demand for corn in recent years some farmers, in particular in the USA Midwest shift their planting pattern from a corn-soybean rotation to a corn-corn rotation. During the time period of 2000-2010, the harvested areas of corn and soybeans have increased by 3 million hectares and 0.9 million hectares in the Midwest. During this time period the soybean to corn price ratio, has changed from 2.54 in 2000 to 2 in 2010, in favor of corn. This indicates that some farmers move from a corn-soybean rotation to a corn-corn rotation if relative prices of these commodities, or their profitability, change in favor of corn and vice versa. Traditionally, farmers follow corn-soybean rotation in Midwest. However, some farmers deviate from the rotation rule according to the relative profitability of corn and soybeans. Converting corn stover to biofuel could change relative profitability of corn and soybeans in favor of corn, when corn stover price is higher than its production costs. Production costs of corn stover include fertilizer costs to maintain productivity of land after stover removal and collection, inventory, and transportation costs (Thompson and Tyner, 2013). These authors have concluded that if a viable corn stover market existed, it could have a large influence on farmer's crop rotation in favor of corn-corn rotation. However, they ignored the fact that relative prices of corn and soybean could be different in the presence of a viable market for corn stover.

In general, farmers follow a corn-soybean rotation to gain agronomic benefits such as nitrogen fixing and breaking pest cycles. However, some farmers deviate from it when the relative prices of corn and soybeans deviate, significantly. Consider a case where converting corn stover to biofuel is profitable, either due to market forces or government supports. In this case, farmers who produce corn and soybeans will bring profitability of corn stover collection into account. When corn stover production is a profitable operation for a farmer, then in each planting period he/she will compare gains from a joint practice of corn production following a corn stover collection process with profits from soybeans production for a set of given prices[1]. In this case, if the joint profits from corn production and corn stover process is higher than the profit from soybean production, then corn will be produced. If a large group of farmers decides

[1] In this paper it is assumed that corn and corn stover production is a single process and the farmer makes the decision at planting time. Of course a farmer can decide to produce corn at the planting time and later on he/she can decide whether to collect the corn stover or not.

to follow this choice, then the corn-corn rotation will increase among farmers, which will lead to an increase in corn production and a reduction in soybean production, other factors being constant. This could affect relative prices of corn and soybeans at market level.

In this paper we first develop a partial equilibrium model to examine impacts of converting corn stover to ethanol on markets for ethanol, gasoline, corn, corn stover, and soybeans at the USA aggregation level. The model developed in this paper is based on the model developed and used by (Tyner and Taheripour, 2008). Then we will feed the results of this model into the Purdue Crop/Livestock Linear Programing (PCLP) model (Doster, et al., 2008) to examine farmers land allocation behavior in the presence of a viable market for corn stover and test the sensitivity of the land allocation process at the farm level with respect to changes in key economic factors.

3. Models

3.1. Partial equilibrium model

The partial equilibrium model developed in this paper is an extended version of the model developed by and used in several other articles (Taheripour and Tyner, 2008, Tyner and Taheripour, 2007, Tyner, et al., August 2012, Tyner, et al., 2010). The original model follows an integrated partial equilibrium modeling structure which displays linkages among crude oil, gasoline, ethanol, and corn markets. The model captures the demand and supply sides of the corn, corn ethanol, dried distiller grains, and gasoline markets. The demand side of the corn market consists of three major corn users: foreign users (q_{cxd}), domestic uses for food and feed (q_{cdd}), and the corn ethanol industry (q_{ced}). The foreign and domestic demands for food and feed are modeled using constant price elasticity functional forms. The corn demand for the ethanol industry is $q_{ced} = y.q_{se}$. Here, y shows the corn-ethanol conversion factor and q_{se} is quantity of ethanol supply. Hence, total demand for corn is: $q_{cd} = q_{cxd} + q_{cdd} + q_{ced}$.

On the supply side, a constant return to scale Cobb-Douglas production function is used to model the supply side of the corn market. In this production function capital, labor, land, and a composite input (which represent fertilizer, pesticides, seeds, energy and other items) are used to produce corn. In this function all inputs, except the composite input, are constant in the short-run. This production function is used to determine the supply for corn, q_{cs}.

In this model, in the short-run the demand for liquid fuel, g_{gd}, only responds to its own price using a constant price elasticity functional form. However, in the long-run, demand can grow with income and population. The supply side of the fuel market is comprised of gasoline producers and ethanol producers. Gasoline supply is produced from crude oil. The supply of gasoline, q_{gos}, is a function of its price and the price of crude oil. It follows a constant elasticity functional form as well. Ethanol is produced from corn. The supply of ethanol, q_{es}, is a function of its own price and the price of corn following a constant elasticity functional form as well. In this model it is assumed that every gallon of ethanol is presumed to contain 70% of the energy of a gallon of gasoline. Hence, total supply of gasoline is: $q_{gs} = q_{gos} + 0.7*q_{es}$.

Distiller's Dried Grains with Solubles (DDGS) is a co-product of the ethanol industry. DDGS can be used as a substitute for corn and to some extent soybean meal in the livestock industry and also alleviate impacts of ethanol production on the corn market. DDGS can increase profitability of ethanol industry as well. As a substitute for corn, DDGS covers a portion of corn demand: $q_{DDGS} = \Upsilon.q_{ced}$. Here q_{DDGS} is the quantity of DDGS produced and Υ is the corn-DDGS conversion factor. The model evaluates profitability of the ethanol industry and assumes that this industry will expand/contract until profits reach zero. Given this assumption and according to the predetermined supply and demand elasticities, the model determines equilibrium prices and their corresponding quantities for corn, ethanol, and gasoline and other endogenous variables for given exogenous variables defined in the model (such as crude oil price).

Several new components are introduced into this partial equilibrium model to handle new markets for, soybeans, corn stover, and a biofuel produced from corn stover. The first component added to the model is a drop-in biofuel named bio-gasoline. This drop-in biofuel can be produced from corn stover with the following supply function: $q_{gstov} = A_{estov}(p_{pg})^{gstov}(p_{stov})^{-gstov}$. The energy content of bio-gasoline is assumed to be equal to the energy content of gasoline. In the presence of bio-gasoline, total supply of gasoline will be equal to: $q_{gs} = q_{gos} + 0.7*q_{es} + q_{gstov}$. Similar to ethanol industry, the bio-gasoline industry will expand until profits reach zero. Profits per gallon of bio-gasoline are estimated by: $\pi s = p_g - cap_{stov} - var_{stov}$. Here, cap_{stov} and var_{stov} are capital and variable costs per gallon of bio-gasoline. At equilibrium $\pi s=0$.

In the new model it is assumed that the capital costs of producing corn ethanol is zero when markets operate below the existing production capacity. However, if an expansion in capacity is required the model takes into account the required capital costs.

The supply of and demand for corn stover are added to the model as well. The supply of stover is presented by: $q_{stov} = A_{stov}(p_{stov}/c_{stov})^{estov}$. Here q_{stov} and p_{stov} represent supply and market price of stover, A_{stov} is the constant term, c_{stov} stands for production costs of stover per metric ton (including all costs items such as collection costs, costs to maintain land productivity, and transportation costs), and *estov* indicates price elasticity of supply. The production costs are divided into two segments of fixed and variable costs. The variable costs are assumed to be sensitive to changes in crude oil price to cover impacts of changes in crude oil price on collection and transportation costs of stover. The corn stover total production costs follows an increasing trend from $68 per ton at $60 per gallon of crude oil to about $100 per ton at $160 crude oil price. The demand for corn stover is determined by bio-gasoline production with the following equation: $qd_{stov}= q_{gstov} (V_{stov})$. Here V_{stov} is the conversion rate of corn stover to bio-gasoline. For details about the cost structure of the bio-gasoline industry and corn stover activity see Fiegel (Fiegel, 2012).

A market for soybeans is also added to the model. In this market, the demand for soybeans is defined as: $qd_{soy}=A_{soy}(1/(p_{soy})^{esoy})$. Here qd_{soy} and p_{soy} represent demand for soybeans and its price, A_{soy} shows the constant term of the demand function, and *esoy* indicates the own price elasticity of demand for soybeans. The model determines the supply of soybeans (qs_{soy}) using the allocated land to this product (l_{soy}) from the following equation: $qs^{soy}=l_{soy}.yield_{soy}$. Here, $yield_{soy}$ represents soybean yield. The model assumes that total supply of land (l_{tot}) for corn and soybean production is fixed in the short-run. Hence, it determines areas under soybean production using the following relationship: $l_{soy}=l_{tot}-(q_{cs} /yield_{corn})$.

Finally, the model imposes a zero profit condition to allocate land between corn and soybeans. Indeed the model assumes that farmers maximize their profit when they allocate their land between corn and soybeans. It is assumed that at equilibrium: $\pi_{soy}=\pi_{corn}+\pi_{stov}$.

The revised model is calibrated using data obtained for 2010 for the US economy. For details see Fiegel (Fiegel, 2012). Then the model is solved for several alternative crude oil prices (an exogenous key variable of the model) ranging from $60 per barrel to $160 per barrel. For each crude oil price two alternative policies are tested. The first policy assumes that the government will not support converting corn stover to biofuel. The second policy assumes that the government will pay a fixed subsidy of $1.01 per gallon of bio-gasoline. Note that in both cases mentioned here we assumed that the government pays no subsidy for corn ethanol.

3.2. Farm level model

To examine impacts of having a viable market for corn stover on crop rotation at a farm level the PCLP model which is originally developed at Purdue University is used and modified. PCLP is a linear programming model which helps determine profit-maximizing decisions for a given farm according to its background activities, its existing resources, and according to current prices of commodities and input costs. The PCLP model takes specific data such as land, labor, capital, crop yields, crop prices, and detailed input costs and determines activities which maximize farmer's profits. Purdue University uses this program to help farmers in their management practices to improve their profitability. Each year a group of farmers participate in the Purdue Top Farmer Workshop and use this program to analyze their management practices according to their land, labor, and capital equipment resources and projected prices. Purdue saves anonymous farm data for educational purposes. To adapt this model a new activity called stover collection is added to this model. This activity covers all steps and their corresponding costs which are required to collect and sell corn stover to a bio-refinery at current prices. These steps and their corresponding costs are defined in detail in (Fiegel, 2012, Thompson and Tyner, 2013, Thompson and Tyner, 2011). Then the model is solved for a group of farmers who participated in the TopCrop Farmer Workshops in 2007-2010 under two alternative cases of with and without corn stover activity to find out their optimal choices under these two different cases. To tune the PCLP model with market conditions in the presence of corn stover activity, prices obtained from the partial equilibrium model are used. Then the sensitivity of the results with respect to changes in the assumptions and parameters behind the corn stover activity are examined.

4. Results

4.1. Impacts at market level

The simulation results cover a wide range of cases for many variables under all alternative scenarios developed for this paper. In what follows, we only present a collection of key results which are important for our analyses. Two key variables are outputs of corn ethanol and stover bio-gasoline under alternative cases. The simulation results presented in Table 1 show that the supply of bio-gasoline will be very limited at low levels of crude oil price in particular when the government does not support bio-gasoline production. However, with bio-gasoline subsidy, the market will produce significant amounts of bio-gasoline in particular at medium and higher crude prices. For example, when the crude oil price is around $100 per barrel, bio-gasoline production will be about 0.56 billion gallons when no subsidy is paid, and it will be about 6.33 billion gallons with subsidy. The simulation results indicate that the supply of corn ethanol increases as the crude oil price rises. The results also indicate that the bio-gasoline subsidy has a positive impact on supply of corn ethanol as well. For example, when the crude oil price is about $100 per barrel, supply of corn ethanol is about 13.71 billion gallons when there is no bio-gasoline subsidy. However, with bio-gasoline subsidy the supply of corn ethanol is about 14.31 billion gallons for the same crude oil price of $100 per barrel. This is due to the positive impact of bio-gasoline subsidy on corn supply.

In general, corn supply increases as crude oil goes up. However, the expansion in corn supply is faster in the presence of the bio-gasoline subsidy. With bio-gasoline subsidy, corn production and converting corn stover to biofuel is more attractive. For example, when the crude oil price is about $100 per barrel, corn supply is about 12.53 billion bushels with zero bio-gasoline subsidy and 12.89 billion bushels with subsidy. Under such conditions, farmers collect and supply a portion of available corn stover. For example, at the crude oil price of $100 per barrel, where the available corn stover is about 360.86 million tons in the presence of bio-gasoline subsidy, farmers only collect about 29.25% of available corn stover.

While bio-gasoline production elevates demand for and supply of corn, it negatively affects supply of soybeans because corn and soybeans compete for limited land in particular in the short run. The simulation results indicates that supply of soybeans decreases when crude oil and consequently bio-gasoline production goes up, under both cases of with and without bio-gasoline subsidy. The supply of soybeans goes down faster in the presence of bio-gasoline subsidy. Reduction in supply of soybeans increases its market price and its relative price compared to corn price. Figure 2 highlights changes in the soybean to corn price ratio when crude oil price is changing, for both cases of with and without bio-gasoline subsidy. The relative price remains around 2.2 as crude oil price increases when the government does not support production of bio-gasoline. However, it grows to 3.2 as the crude oil price approaches $160 per barrel in the presence of bio-gasoline subsidy. Of course, this is only a short run result, and we would expect to see other crop adjustments (not in the PE model) in the real world.

From the partial equilibrium analyses provided in this section we can conclude that: 1) with no bio-gasoline subsidy a limited amount of corn stover will be converted to biofuel even at a very high crude oil price level; 2) The bio-gasoline subsidy could significantly boost production of this biofuel in particular at medium and higher crude oil prices; 3) under scenarios developed here, no more than 45% of available corn stover will be removed for biofuel production; 4) converting corn stover to bio-gasoline boosts corn production, increases corn-corn rotation, and decreases supply of soybeans; and 5) converting corn stover to bio-gasoline changes corn to soybean price ratio in favor of soybeans, at least in the very short term.

In our partial equilibrium analyses we examined market behavior for a wide range of crude oil prices. To assess impacts of converting corn stover to bio-gasoline on farmers' behavior at farm level we use the simulation results related to crude price of $100 per barrel with the bio-gasoline subsidy. We selected this case because bio-gasoline will not be produced without the government subsidy, and the crude oil price is expected to be around $100 per barrel in the near future (U.S. Department of Energy, 2012).

4.2. Impacts at farm level

To examine impacts of a viable market for corn stover at a farm level we tuned the PCLP model with market clearing prices obtained from the PE model as described above. We then made the following experiments for each farm to assess its response with respect to changes in key economic variables:

i. Base case, no stover removal,
ii. Base case, with stover removal with tuned market prices in the presence of bio-gasoline subsidy under status quo assumptions on tillage costs, soybeans and corn yield, cost associated with corn stover activity, and harvesting technology,
iii. No saving in tillage costs,
iv. Change in yield due to change in rotation, known as *yield drag*,
v. Reduction in corn stover price
vi. Change in corn stover harvesting technologies,
vii. Impacts of new harvesting technology but no savings in tillage costs.

The first case provides a status quo situation where there is no market for corn stover. The second case evaluates impacts at farm level in the presence of a market for corn stover. In this case it is assumed that: 1) corn-corn rotation with stover removal reduces tillage costs by $25 per acre; 2) corn-corn rotation does not affect corn and soybean yields; 3) corn stover farm price and corn stover delivery price are about $85.40 per ton, and $111.80 per ton, respectively; and 4) farmers will use rake and bale system to remove corn stover. In cases *iii* to *vii* these basic assumptions are relaxed. In case *iii* it is assumed that corn-corn rotation with stover removal does not reduce tillage costs. Case *iv* takes into account the fact that corn-corn rotation can affect yield. In case *v* the farm level and delivery prices used in the base case are reduced by 20%. Case *vi* investigates impacts of using a new technology to remove corn stover. This technology is known as the corn-rower. Compared to the rake and bale system, this technology eliminates the need to rake the stover after harvesting corn and in general reduces the costs of stover activity (Fiegel, 2012). Finally, the last case assumes that farmers will use the corn-rower technology to harvest corn stover, but this technology does not reduce tillage costs.

While the above experiments are tested for individual participant farmers, in what follows we report the results obtained from the pool of participant farmers. The key simulation results are shown in Table 2. This table shows that in the base case when there is no stover removal activity, participant farmers allocate their land mainly to corn-soybean rotation or only prefer to produce soybeans. In this case farmers only allocate about 14.7% of their land to the corn-corn rotation. However, when corn stover removal is introduced as a new option under the base case scenario farmers allocate about 66% of their land to the corn-corn rotation and remove stover from their land. In this scenario about 15.8% of available land will remain in corn-soybean rotation. In this case corn stover will be removed from 78.2% of available land at a rate of 1.18 tons per acre. This shows that if corn stover is demanded for biofuel production, then a major shift will be observed in corn rotation. The rest of the scenarios show sensitivity of these results with respect to the assumption behind the base case. The results of case *iii* indicate that when corn-corn rotation does not reduce tillage cost, then only 37.7% of available land will be used in corn-corn rotation with corn stover removal. Corn-soybean rotation with stover removal and only soybean will have significant shares (27.9% and 28.5, respectively) in this case. The results obtained from case *iv* emphasize that yield drag does not affect the results of the base case significantly. Case *v* which assumes stover price is 20% lower than the base case provides results similar to case *iii* which projects higher tillage costs for the case of corn-corn rotation with stover removal. The next case, which examines the impacts of a lower cost of stover removal technology, indicates a relatively high share of 54% for corn-corn rotation with stover removal. Finally, the last case indicates that if the corn-rower technology does not reduce tillage coasts, we are then essentially back to a situation similar to the case *iii* where we removed tillage costs savings.

5. Conclusions

With a viable corn stover market and stover at a farm price of $85.40/ton, the large majority of farmers in the PCLP data set found it profitable to harvest stover in the base case. The sensitivity cases demonstrated how farmer behavior might change under different assumptions. We recognize, of course, that every farm is different with different soil types, management, equipment, etc. Clearly, PCLP captures some but not all of these differences.

Figure 3 displays the allocation of acres for each scenario. The figure shows that most farms chose to profit from continuous corn rotation with stover removal. Only in the cases of reduced tillage savings and decrease in stover price does corn-soybean with stover removal and soybean production increase. These results may be interpreted as meaning that if a viable stover market developed, we could see an increase in corn-corn rotation in the Midwest. We might see more soybeans grown in other areas. In fact the data from recent years shows this trend already beginning to happen.

Table 2 displays the results for the base case and the five sensitivity cases. Twenty-three of 25 representative Midwest farms harvest stover. Twenty-three farms also would harvest stover for all given sensitivity cases except with the reduced stover price, where 21 found it profitable with the new price.

Acknowledgments

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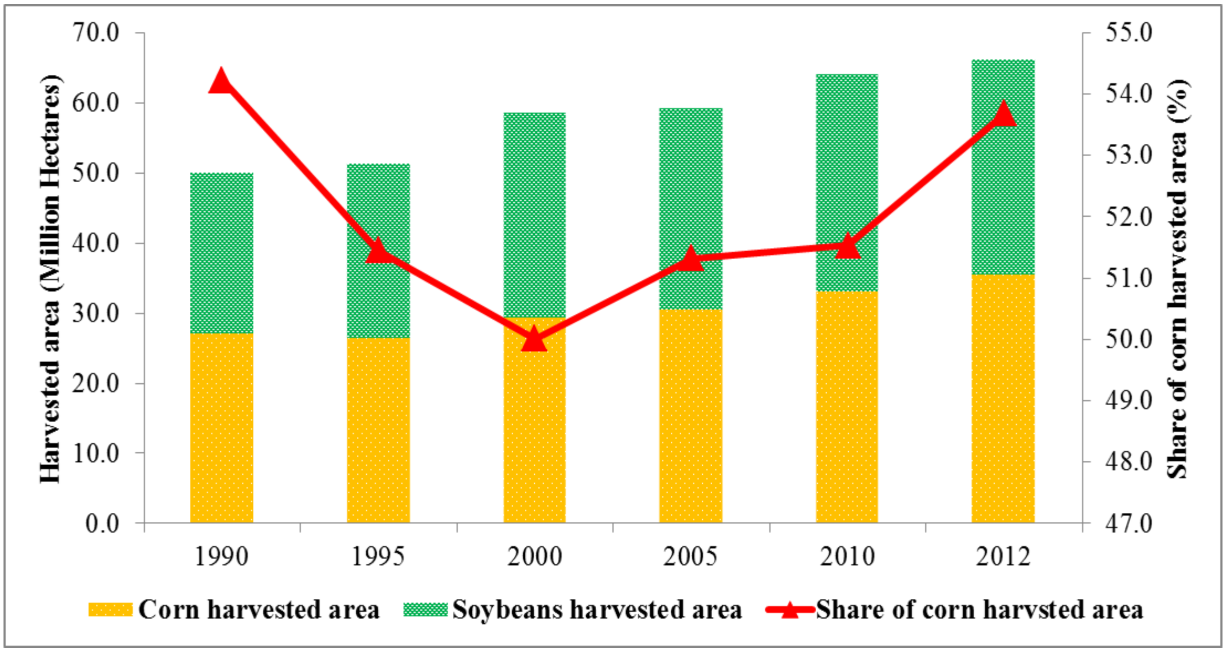

Figure 1: Corn and Soybean harvested areas, 1990-2012

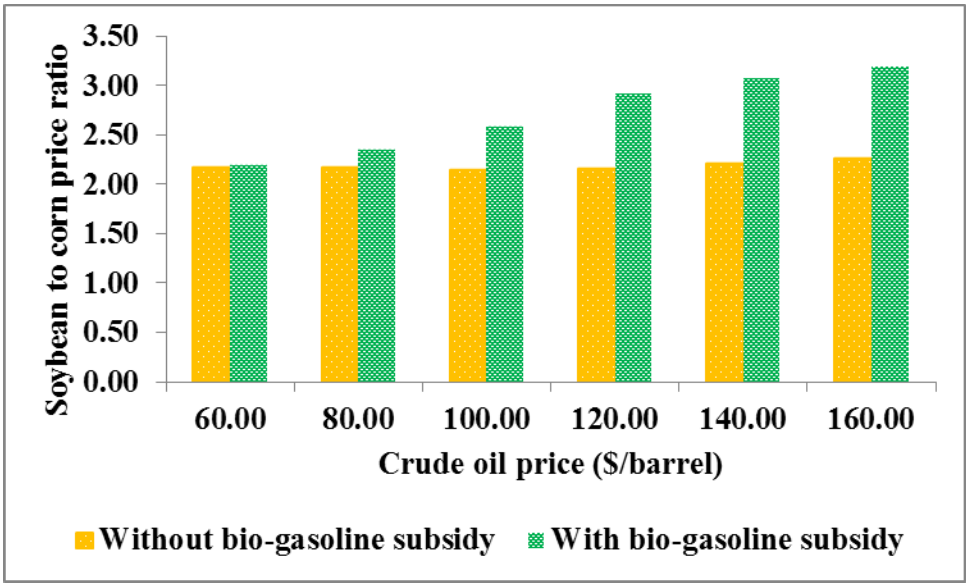

Figure 2: Projected soybeans to corn price ratio with and without bio-gasoline subsidy

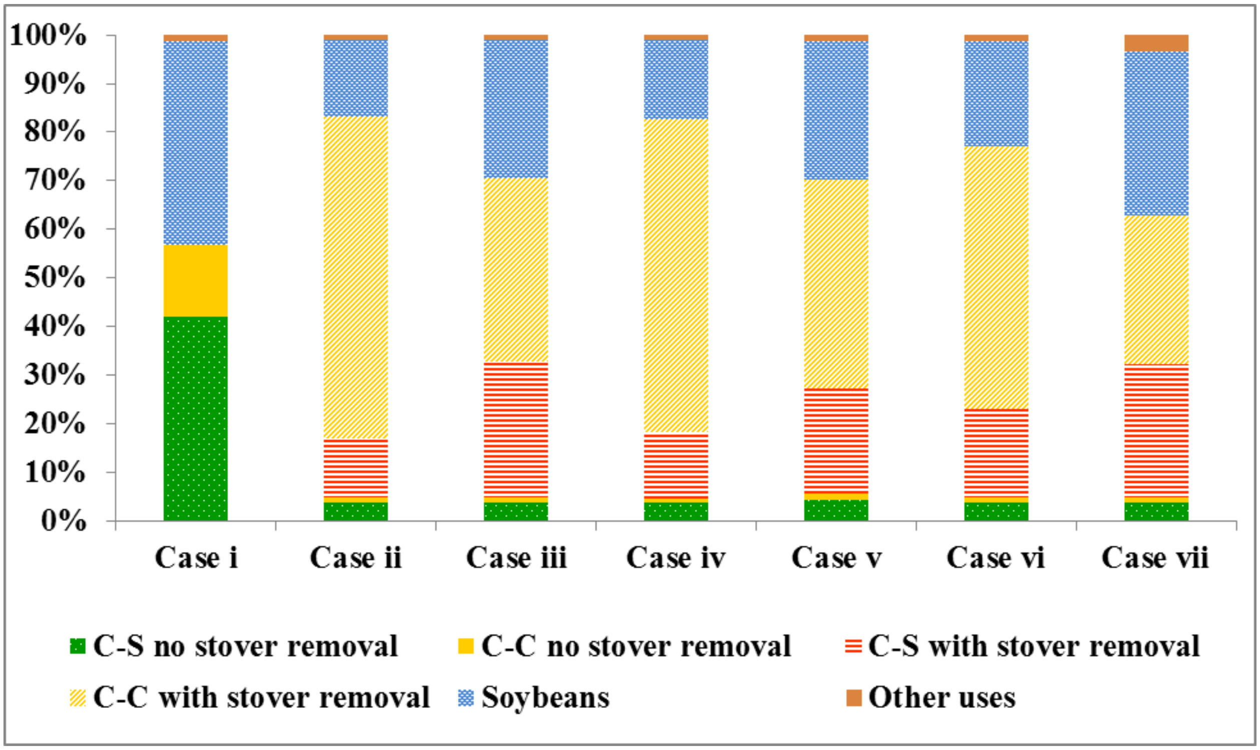

Figure 3: Land allocation for each scenario

Table 1: Key simulation results obtained from partial equilibrium model

Description	Base 2010	Crude oil scenarios					
Crude oil price ($/barrel)	76.69	60.00	80.00	100.00	120.00	140.00	160.00
Case I: With no subsidy per gallon of bio-gasoline							
Ethanol supply (billion gallons)	13.23	7.00	12.06	13.71	14.25	16.70	18.77
Bio-gasoline supply (billion gallons)	0.00	0.01	0.11	0.56	1.60	2.55	3.49
Corn supply	12.45	11.19	12.21	12.53	12.64	13.16	13.61
Available corn stover (million tons)	348.52	313.22	341.74	350.80	354.04	368.54	381.01
Removal rate of corn stover (percent)	0.00	0.04	0.51	2.66	7.51	11.51	15.28
Soybeans supply (billion bushels)	3.33	3.69	3.40	3.31	3.27	3.13	3.00
Corn harvested area (million acres)	81.40	73.16	79.82	81.93	82.69	86.08	88.99
Soybeans harvested area (million acres)	76.60	84.84	78.18	76.07	75.31	71.92	69.01
Corn price ($/bushel)	5.18	4.22	5.00	5.32	5.39	5.79	6.13
Corn stover price $/ton)	0.00	26.14	47.00	68.81	88.69	101.61	112.75
Soybeans price ($/bushel)	11.30	9.21	10.85	11.46	11.69	12.82	13.92
Soybean to corn price ratio	2.18	2.18	2.17	2.15	2.17	2.21	2.27
Case II: With $1.01 subsidy per gallon of bio-gasoline							
Ethanol supply (billion gallons)	13.23	6.34	11.88	14.31	15.65	18.20	20.24
Bio-gasoline supply (billion gallons)	0.00	2.32	4.17	6.33	8.44	9.67	10.67
Corn supply	12.45	11.07	12.27	12.89	13.31	13.87	14.32
Available corn stover (million tons)	348.52	309.93	343.66	360.86	372.67	388.41	400.86
Removal rate of corn stover (percent)	0.00	12.47	20.20	29.25	37.74	41.48	44.37
Soybeans supply (billion bushels)	3.33	3.72	3.38	3.20	3.08	2.92	2.80
Corn harvested area (million acres)	81.40	72.39	80.27	84.28	87.04	90.72	93.63
Soybeans harvested area (million acres)	76.60	85.61	77.73	73.72	70.96	67.28	64.37
Corn price ($/bushel)	5.18	4.10	4.66	4.70	4.49	4.75	4.99
Corn stover price $/ton)	0.00	83.11	98.11	111.76	123.75	132.68	140.97
Soybeans price ($/bushel)	11.30	9.05	10.97	12.20	13.17	14.65	16.00
Soybean to corn price ratio	2.18	2.21	2.35	2.60	2.93	3.08	3.21

Table 2. Land allocation patterns for alternative scenarios examined using PCLP model at farm level

(Figures are shares in total acreage in percent except otherwise noted)

Description	Base with no stover	Base with stover	No tillage savings	Yield drag	Reduction in stover price	New Harvest technology	New Harvest technology with no tillage savings
Corn-soybean acreage with no stover removal	42.0	3.6	3.6	3.6	4.3	3.6	3.6
Corn-corn acreage with no stover removal	14.7	1.3	1.3	0.8	1.3	1.3	1.3
Corn-soybean acreage with stover removal	0.0	12.2	27.9	13.8	21.5	18.2	27.4
Corn-corn acreage with stover removal	0.0	66.0	37.7	64.2	43.2	53.9	30.5
Soybeans acreage	42.0	15.8	28.5	16.4	28.4	21.8	33.8
Other uses	1.3	1.2	1.0	1.1	1.3	1.2	3.4
Total acreage participating in workshop	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Stover harvest acres	0.0	78.2	65.6	78.0	64.8	72.1	57.9
Stover removal rate (tons / acres)	0	1.18	1.01	1.15	0.99	1.93	1.57

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