
A Final Report Submitted to

The Southeastern Sun Grant Center

Submitted by

Dr. Chad Hellwinckel
Dr. Tristram West
Department of Agricultural Economics
University of Tennessee
310 Morgan Hall,
Knoxville, TN 37917

Project Period, 2009-2010

February 15th, 2011

This project was funded by a grant from the Southeastern Sun Grant Center with funds provided by the United States Department of Transportation, Research and Innovative Technology Administration.
Abstract
An integrated, socioeconomic-biogeophysical model is used to analyze the interactions of cap-and-trade legislation and the Renewable Fuels Standard. Five alternative policy scenarios were considered with the purpose of identifying policies that act in a synergistic manner to reduce carbon emissions, increase economic returns to agriculture, and adequately meet ethanol mandates. We conclude that climate and energy policies can best be implemented together by offering carbon offset payments to conservation tillage, herbaceous grasses for biomass, and by constraining crop residue removal for ethanol feedstocks to carbon neutral level. When comparing this scenario to the Baseline scenario, the agricultural sector realizes an economic benefit of $156 billion by 2030 and emissions are reduced by 135 Tg C-equivalent (eq). Results also indicate that geographic location of cellulosic feedstocks could shift significantly depending on the final policies implemented in cap and trade legislation. Placement of cellulosic ethanol facilities should consider these possible shifts when determining site location.
Acknowledgments

Support for this research was provided in part by a grant from the Southeastern Sun Grant Center with funds provided by the U.S. Department of Transportation Research and Innovative Technology Administration (DTOS59-07-G-00050).
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Executive Summary

The created model was used to estimate the supply potential of biomass from US agricultural and forestry lands at varying biomass and carbon prices. At very high biomass price levels, US agriculture and forestry can provide upwards of 650 million dry tons of feedstock per year. Upwards of 72 million acres of crop and pastureland are converted to dedicated biomass uses to meet this supply. Although agriculture is affected by the price of carbon, both by increasing the cost of inputs and by increasing the profitability of cropland through carbon sequestration incentives, total biomass supply potential changes very little is response to carbon prices. Yet carbon prices significantly change the mix of individual feedstocks making up total biomass supply. As carbon prices increase there is a shift away from short rotation woody feedstocks and into dedicated herbaceous feedstocks. US agriculture has the potential to sequester an additional 14 million metric tons (MMt) of carbon per year under higher carbon prices.

We used the created model to analyze the interactions of possible cap-and-trade legislation and the Renewable Fuels Standard. Five alternative policy scenarios were considered with the purpose of identifying policies that can act together to reduce carbon emissions, increase economic returns to agriculture, and adequately meet ethanol mandates. We conclude that climate and energy policies can best be implemented together by offering carbon offset payments to conservation tillage, herbaceous grasses for biomass, and by constraining crop residue removal for ethanol feedstocks to carbon neutral level. When comparing this scenario to the ‘business as usual’ scenario, the agricultural sector realizes an economic benefit of $156 billion by 2030 and emissions are reduced by 135 MMt C-equivalent (eq). Results also indicate that geographic location of cellulosic feedstocks could shift significantly depending on the final policies implemented in cap and trade legislation. Placement of cellulosic ethanol facilities should consider these possible shifts when determining site location.
Introduction

In the coming decades, the U.S agricultural sector may be asked to play a significant role in two major new policy goals of the nation – reducing dependence upon foreign oil and reducing national carbon emissions. Implementation of the first policy goal is underway with the passage of the Energy Investment and Security Act of 2007 (EISA), which established a renewable fuels standard (RFS) requiring the production of 36 billion gallons of renewable fuels by 2022 (U.S. Congress, 2007). Renewable fuels are photosynthetically derived as opposed to fossil-derived. The passage of EISA has generated rigorous debate over the issue of food versus fuel, especially after significant increases of global food commodity prices in 2008 (Martin, 2008). Congress may soon approve carbon cap-and-trade legislation that could add significant benefits and costs to the agricultural sector (USDA, 2009a). There is debate as to whether energy and climate policies will oppose one another, or whether they can act synergistically.

In June 2009, the American Clean Energy Security Act (ACES) was passed by the U.S. House of Representatives, and a similar cap-and-trade bill is under debate in the U.S. Senate (US House of Representatives, 2009). This legislation would cap the total amount of CO₂eq emissions from industry at a set annual amount, while allowing industry to purchase carbon offsets if they exceeded the cap. The recipient of the carbon offset payment would have to reduce CO₂eq by an equal amount so that economy-wide CO₂eq emissions do not exceed the cap. Under ACES, some agricultural practices that reduce carbon emissions could be eligible to receive carbon offset payments. The Peterson Amendment of ACES lists several agricultural management practices that may become eligible for offset payments, including conservation tillage, manure management, afforestation, and carbon sequestration in grasslands. Offset payments would be an economic benefit to the agricultural sector. Inclusion of specific agricultural management practices within the final offset payment program, however, is currently open for debate. Countering the benefits of carbon offset payments, cap-and-trade legislation will also increase input costs to agriculture—as industries which produce inputs will face increased costs associated with emitting carbon, and pass those increases onto farmers. Although farmers are exempt from a direct cap on their emissions, most industries that supply agricultural inputs are not. The net effect of cap and trade on the agricultural sector will be determined by the interplay of eligible offsets and input cost increases.
There is uncertainty over the interplay of biofuel and carbon policies, as to whether the two policies will oppose one another, or whether they can act synergistically. The successful interplay between these two policies depends critically on what management practices are finally approved as eligible offsets. For example, meeting EISA biomass ethanol requirements could be made more difficult if production costs are increased under cap-and-trade, and there are no offsets offered to carbon sequestration gains from biomass production. Likewise, the ACES goal of reducing carbon emissions could be made more difficult if large amounts of crop residues are harvested for biomass ethanol—potentially leading to a reduction in soil carbon stocks and emitting CO₂ to the atmosphere.

This paper evaluates alternative offset eligibilities within ACES and their effect upon the success of biofuel policy, carbon policy, and farm income. Our purpose is to identify carbon offset and biomass policies that could act synergistically to: (a) meet EISA feedstock supply and ethanol production requirements with minimal burden upon food prices, (b) reduce net carbon emissions at low cost, and (c) increase net economic benefits to the agricultural sector. To do this, we evaluate incremental additions of management practices that could be eligible for receiving carbon offset payments and then measure their effects. This paper evaluates five scenarios for comparison (Table 1).
Table 1. Scenario definitions.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline</strong></td>
<td>• EISA mandates fulfilled</td>
</tr>
<tr>
<td></td>
<td>• no cap and trade</td>
</tr>
<tr>
<td><strong>No Biomass</strong></td>
<td>• no cellulosic ethanol</td>
</tr>
<tr>
<td></td>
<td>• no cap and trade</td>
</tr>
<tr>
<td><strong>Offset1</strong></td>
<td>• EISA mandates fulfilled</td>
</tr>
<tr>
<td></td>
<td>• carbon offset payments for conservation tillage</td>
</tr>
<tr>
<td></td>
<td>• carbon offset payments for afforestation</td>
</tr>
<tr>
<td><strong>Offset2</strong></td>
<td>• EISA mandates fulfilled</td>
</tr>
<tr>
<td></td>
<td>• carbon offset payments for conservation tillage</td>
</tr>
<tr>
<td></td>
<td>• carbon offset payments for afforestation</td>
</tr>
<tr>
<td></td>
<td>• carbon offset payments for grasses grown for energy feedstocks</td>
</tr>
<tr>
<td><strong>Offset2_Cpositive</strong></td>
<td>• EISA mandates fulfilled</td>
</tr>
<tr>
<td></td>
<td>• carbon offset payments for conservation tillage</td>
</tr>
<tr>
<td></td>
<td>• carbon offset payments for afforestation</td>
</tr>
<tr>
<td></td>
<td>• carbon offset payments for grasses grown for energy feedstocks</td>
</tr>
<tr>
<td></td>
<td>• residue harvesting carbon-constrained</td>
</tr>
</tbody>
</table>

Because EISA has already been signed into law, the **Baseline** scenario, which meets EISA ethanol mandates, can be considered the business-as-usual to which all others will be compared. The **No Biomass** scenario assumes that cellulosic ethanol technology does not develop as anticipated and therefore the cellulosic ethanol requirement of EISA is not met. **No Biomass** still assumes 16 billion gallons of conventional corn-grain derived biofuels will be produced, which is the amount the USDA estimates will be produced by 2018 (United States Department of Agriculture, 2009b). **No Biomass** scenario also assumes that a climate bill is not passed and therefore there are no offered carbon offset payments.

The remaining three scenarios define potential outcomes of ACES that will be compared to the **Baseline** scenario. The **Offset1** scenario meets EISA and offers carbon offset payments to reductions in tillage intensity and increased afforestation, which are two of the more likely agricultural management practices to become eligible for carbon offset payments. The **Offset2** scenario offers offset payments to perennial herbaceous grasses grown for energy crops, in addition to payments included in **Offset1**. Because grasses used as cellulosic feedstocks produce
additional below-ground biomass, significant soil carbon accumulation can occur, even with the above ground biomass being harvested and removed (McLaughlin et al., 2002). The Offset2_Cpositive adds the requirement that residue removal from grain crops can only occur if soil carbon is kept steady or increasing in quantity. The constraint on residue removal is to avoid biofuel policy acting in the opposite direction of carbon policy and releasing carbon from the soil and into the atmosphere.

Previous research has estimated biomass supply potentials (McCarl and Schneider, 2001; Walsh, 2004; English et al., 2006a; English et al., 2006b; De La Torre Ugarte et al., 2007). Most of these studies did not consider the impact and interactions of potential carbon offset payments in determining the quantities, type, and location of biomass sources. Recent studies have analyzed the economic impact of the proposed climate change legislation upon the agricultural sector as a whole (Outlaw et al. 2009, United States Department of Agriculture, 2009a). These studies included offset payments to conservation tillage, reductions in methane and nitrous oxide, and afforestation. They conclude that climate change legislation may slightly benefit the agricultural sector. Our analysis expands upon these previous studies by including cellulosic feedstocks within the scope of the study, and including the possibility that herbaceous cellulosic feedstocks could be eligible for offset payments.

**Methodology**

The analytical tool used to conduct this analysis is an integrated socioeconomic-biogeophysical model. The integrated model is driven by data on economics, soil attributes, crop rotation, land management, and energy consumption. The economic core of the model is a modified version of the University of Tennessee’s Policy Analysis System model (POLYSYS), which is a partial equilibrium displacement model that iterates annually and simulates results until the year 2030 (Ray et al., 1998a; De La Torre Ugarte et al., 1998; De La Torre Ugarte and Ray, 2000). We describe here the POLYSYS model, carbon dynamics linked to the POLYSYS model, and offset payments associated with land management.

**Socio-economic modeling**

The POLYSYS modeling framework can be conceptualized as a variant of an equilibrium displacement model (EDM), that has been previously developed to simulate changes in
economic policy, agricultural management, and natural resource conditions, and to estimate the resulting impacts from these changes on the US agricultural sector (Ray et al., 1998b; Lin et al., 2000; De La Torre Ugarte and Ray, 2000). At its core, POLYSYS is structured as a system of interdependent modules simulating (a) crop supply for the continental US, which is disaggregated into 3110 production regions; (b) national crop demands and prices; (c) national livestock supply and demand; and (d) agricultural income. Variables that drive the modules include planted and harvested area, production inputs, yield, exports, costs of production, demand by use, farm price, government program outlays, and net realized income. Crops currently considered in POLYSYS include corn, grain sorghum, oats, barley, wheat, soybeans, cotton, rice, hay, and herbaceous and woody cellulosic feedstocks.

POLYSYS anchors its analyses to US Department of Agriculture (USDA) published baseline of projections for the agriculture sector, which are endogenously expanded from the USDA ten-year baseline projection period through 2030 for this analysis (United States Department of Agriculture, 2009b). Changes in agricultural land use, based on cropland allocation decisions made by individual farmers, are primarily driven by the expected productivity of land, the cost of crop production, the expected economic return on the crop, and domestic and world market conditions. When provided with data for production inputs, changes in yields, and incentive levels that would accompany carbon management options, POLYSYS can be used to estimate potential changes in land use.

In addition to 130 million hectares of cropland, POLYSYS also allows for the conversion of 48 million hectares of pastureland. We assume that all livestock forage lost to crop production upon pastureland is made up by requiring a portion of the converted pasture to be used for hay production. This amount is equal to the county-level ratio of hay to pasture yield. Pastureland is excluded from land conversion in regions where forage yields are 80% or greater than hay yields. We also exclude pastureland from conversion in counties where irrigation is used extensively. The net present value of bioenergy crop production must overcome the regional rental rate of pasture for conversion to occur (De La Torre Ugarte et al., 2007; De La Torre Ugarte et al., 2009).

To meet EISA mandates, cellulosic feedstocks are considered in the model, including herbaceous grasses, coppice (e.g., willow) and non-coppice (e.g., poplar and pine) woody crops, crop residues, and woody residues. Feedstock yields and costs of production are unique to the
county level (Nelson, 2002; Nelson et al., 2003; Gunderson et al., 2008). The feedstock module endogenously meets EISA ethanol requirements by incrementally increasing feedstock prices until sufficient feedstocks are supplied. Further detail on the cellulosic module can be found in earlier studies (English et al., 2006a; De La Torre Ugarte et al., 2007; Walsh et al., 2007; De La Torre Ugarte et al., 2009).

**Modeling carbon dynamics**

For this analysis, we disaggregated POLYSYS to the county level, where representation of cropping activities has been expanded to include conventional-tillage, reduced-tillage, and no-tillage operations. The model makes use of over 3,500 unique regional crop budgets, which are based on regional differences in crop production operations. These ‘operation budgets’ list a daily schedule of all machinery and production inputs used to produce each crop. Both direct and indirect energy and carbon emissions of have been tied to each input of the operation budgets (Nelson et al., 2009). The model can, therefore, estimate changes in production emissions under assumptions of land use changes.

Several layers of biogeophysical data were integrated to develop a model capable of estimating changes in soil organic carbon (SOC) at the sub-county level. Regional carbon management response curves (West et al., 2003), STATSGO soils data (United States Department of Agriculture, 1994) and Landsat land cover data (Homer et al., 2007) were integrated to determine potential changes in SOC associated with each unique combination of soil type, crop type and crop management (West et al., 2008). The amount of carbon that can be sequestered under land management practices, such as conservation tillage or herbaceous grass production, are based on regionally unique soil conditions and previous land use. Experimental data on the carbon changes under conservation tillage were collected and integrated into the model in earlier studies (West et al., 2008; Hellwinckel et al., 2010). Preliminary estimates of soil carbon change for bioenergy crops have been included for this analysis (Table 2).

POLYSYS allows for land use shifts to afforestation on both cropland and pastureland if the net returns generated from offset payments to afforestation are greater than the net returns of alternative land uses. POLYSYS afforestation budgets are based on the planting of high yield species with an average growth rate of 5 Mg C ha\(^{-1}\) yr\(^{-1}\) (Perlack et al., 2010).
Table 2. Estimated annual soil carbon accumulation under change in management practices.

<table>
<thead>
<tr>
<th>Land use</th>
<th>Annual carbon accumulation rate following change in management practice (% of initial soil carbon)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No tillage*</td>
</tr>
<tr>
<td>Corn</td>
<td>1.035</td>
</tr>
<tr>
<td>Soybeans</td>
<td>1.035</td>
</tr>
<tr>
<td>Sorghum</td>
<td>0.320</td>
</tr>
<tr>
<td>Cotton</td>
<td>0.320</td>
</tr>
<tr>
<td>Wheat</td>
<td>0.930</td>
</tr>
<tr>
<td>Barley</td>
<td>0.930</td>
</tr>
<tr>
<td>Rice</td>
<td>0.930</td>
</tr>
<tr>
<td>Oats</td>
<td>0.930</td>
</tr>
<tr>
<td>Hay</td>
<td>1.845</td>
</tr>
<tr>
<td>Herbaceous energy crop on cropland</td>
<td>Na</td>
</tr>
<tr>
<td>Herbaceous energy crop on pastureland</td>
<td>Na</td>
</tr>
<tr>
<td>Woody energy crop on cropland</td>
<td>Na</td>
</tr>
<tr>
<td>Woody energy crop on pastureland</td>
<td>Na</td>
</tr>
</tbody>
</table>

*aThis rate is multiplied by county weighted base soil carbon level to estimate actual quantities of carbon accumulation.

*bAbove-ground biomass is harvested for bioenergy feedstock.

* Represents change from conventional tillage to no tillage and reduced tillage respectively.

Na is Not Applicable.

Sources: conventional crops—West and Post (2002); hay—Conant et al. (2001); bioenergy crops—West (2009)

Offered offset payments to any biomass crop are tied to the quantities of carbon that a management practice can sequester. Offset payment induced changes in soil carbon, along with changes in farm production emissions, result in county-level estimates of net carbon flux to the atmosphere from agricultural activity. Net carbon flux includes changes in soil carbon stocks, CO₂ emissions from crop production inputs, and N₂O emissions.

Under the Offset2_Cpositive scenario, we maintain soil carbon levels by limiting the amount of crop residues that can be harvested. This increases the amount of residues that must be retained on the ground over estimates that only control for wind and rain erosion. We employed residue retention estimates that maintain soil carbon levels based on the results of Wilhelm et al. (2007).
Carbon Prices and Offset Payments

We assume EPA projections on annual carbon market prices, which increase to $27 Mg CO$_2$ by 2030 (Environmental Protection Agency, 2009). Due to market transaction costs, aggregator costs, and verification costs, the farmer does not receive the full carbon market value as an incentive. Over the last several years, farmers receiving offsets through the Chicago Market Exchange have received 87% of the carbon market value, or rather, there is a 13% wedge between market carbon price and farmer incentive levels (Clark, 2009). In modeling ACES, we assume that as the market matures, aggregator costs will be reduced to a 10% price wedge between offset market carbon price and incentive level received by the farmer.

The market price of carbon affects the input costs of crop production. The two are linked by the estimated total carbon emissions associated with each management practice. As carbon price increases, crop production inputs that have a higher embodied level of carbon emissions will increase in cost. For all inputs except fertilizers, we assume that 100% of the carbon market price is transferred to the embodied carbon within production inputs. Fertilizer costs are not affected by carbon price because, under ACES, fertilizer manufactures will, in effect, qualify for exemption from the cap on carbon emissions. Subtitle A of Title IV of ACES allows for an emissions allowance rebate program for trade or greenhouse gas-intensive sectors of the economy. Fertilizer manufacturing is a greenhouse gas-intensive industry and would qualify (U.S. House of Representatives, 2009).
Results

National Impacts

The performance of the policy scenarios can be evaluated in terms of relative ability to satisfy the overall policy objectives of reducing net carbon emissions, supplying low cost feedstocks, and increasing economic returns to agriculture. In comparing the scenarios, \textit{Offset2\_Cpositive} ranks first in both economic and climate benefits (Table 3). Although its maximum feedstock price rises to $65 \text{dry Mg}^{-1}$, it is still able to meet EISA mandates at acceptable costs (Clark et al., 2007). \textit{Offset2\_Cpositive} reduces net carbon flux by 135 Tg Ceq, and increases net economic returns to the agricultural sector by $158$ billion over a 20-yr time span. Although the restriction on residue harvesting in the \textit{Offset2\_Cpositive} scenario limits the revenue stream from residue harvesting, it surprisingly has significant total net returns benefits over \textit{Offset2}—As residue harvesting is restricted in the \textit{Offset2\_Cpositive} scenario, the burden of meeting EISA mandate shifts from residue harvesting to herbaceous grass production. Land competition increases and 2.4 million hectares of cropland are diverted to grasslands for bioenergy feedstocks. Increased land competition causes crop prices to rise by approximately 6\% and raise net returns enough to eclipse the fall in residue returns by over 117 billion dollars over the 20-yr period.

Table 3. Comparison of policy scenario effects on cumulative net carbon flux, biomass price, and net returns to agriculture from 2010 to 2030.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Net carbon flux (Tg Ceq)</th>
<th>Max biomass price ($ \text{dry Mg}^{-1}$)</th>
<th>Ag net returns (Bil$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>497</td>
<td>54</td>
<td>4,023</td>
</tr>
<tr>
<td>No biomass</td>
<td>543</td>
<td>0</td>
<td>3,759</td>
</tr>
<tr>
<td>Offset1</td>
<td>436</td>
<td>55</td>
<td>4,033</td>
</tr>
<tr>
<td>Offset2</td>
<td>411</td>
<td>54</td>
<td>4,064</td>
</tr>
<tr>
<td>Offset2_Cpositive</td>
<td>362</td>
<td>65</td>
<td>4,181</td>
</tr>
</tbody>
</table>

The \textit{Offset2\_Cpositive} scenario also has large carbon benefits over the \textit{Offset2} scenario. When biomass feedstocks shift to herbaceous grasses in the \textit{Offset2\_Cpositive} scenario, soil carbon accumulates belowground while the above ground biomass is harvested. Over a 20-yr period, an additional 49 Tg Ceq of emissions are reduced over \textit{Offset2} scenario. Part of the
reduction in emissions also comes from no-till land that has forgone residue harvesting and is therefore accumulating soil carbon.

The Offset1 scenario has less benefits than both the Offset2 and Offset2_Cpositive scenarios. By offering incentives only to conservation tillage, 2.3 million ha transition to conservation practices by 2030, reducing emissions by an additional 61 Tg Ceq over Baseline scenario. Land use and prices remain similar to Baseline, so that the net return gains of $10 billion are mostly the result of offset payments alone.

The only scenario that has negative impacts on net returns and carbon benefits is the No Biomass scenario, where we test what may occur if the cellulosic ethanol industry does not develop. Under this scenario, net returns fall by $263 billion over 20 years, and an additional 46 Tg Ceq are emitted from agriculture over Baseline scenario. Without biomass crops coming into production to meet EISA mandates, less land is planted to carbon sequestering perennial grasses, land use competition decreases, and prices fall. Because the Offset2_Cpositive scenario performs well in terms of the three policy objectives, further analysis focuses on the Offset2_Cpositive scenario and differences from the Baseline scenario.

Although afforestation was included in this analysis, no movement of cropland or pastureland into afforestation occurred at carbon prices at or below EPA’s 2030 estimate ($27 MgCO₂⁻¹). Agricultural lands would begin to convert to afforestation at prices above $40 MgCO₂⁻¹.

**Regional Impacts**

The regional production effects of limiting residue harvesting to quantities that maintain or increase soil carbon are evident when comparing county level residue production of the Baseline and Offset2_Cpositive scenarios (Fig. 1). In the Baseline scenario residue harvesting is estimated to occur over a broad geographic area, with large amounts being harvested in the Corn Belt of Indiana, Illinois and Iowa, and also within the Red River Valley of the North and South Dakota and Minnesota. In the Baseline scenario, residue quantities are only constrained by wind and water erosion, therefore more regions are able to profitably harvest residues for feedstocks. In the Offset2_Cpositive scenario, where soil carbon levels must remain constant, residue harvesting is limited to areas of the Corn Belt and a few counties in the western regions where
corn is irrigated. As the additional constraint is added to maintain soil carbon levels, harvestable quantities of residues are eliminated in all but the most flat and productive land.

![Fig 1. Potential quantities of crop residues harvested for ethanol feedstocks in 2025 under (a) Baseline and (b) Offset2_Cpositive scenarios in units of dry biomass.](image)

As residue harvesting is limited by in the Offset2_Cpositive scenario, the burden of meeting the EISA cellulosic feedstock mandate shifts to herbaceous grasses. The large change in geographic production of feedstocks is evident when comparing the regional distribution of all biomass feedstocks between the Baseline scenario and the Offset2_Cpositive scenario (Fig. 2). In the Baseline scenario, biomass feedstock production is widely dispersed with several significant areas of high productivity including the Great Plains, Corn Belt, and the Cumberland region of Tennessee and Kentucky. In the Offset2_Cpositive scenario, biomass feedstock production becomes more concentrated in those areas well suited to herbaceous grass production. The concentration of biomass production on the Great Plains expands southward and eastward into Texas and Missouri as slightly higher feedstock prices bring more land into grass production. Woody dedicated energy crops, such as poplars and willows, do not come into production at projected biomass prices.
The significant increase in herbaceous grass production in the Offset2_Cpositive scenario results in an annual gain of 12.5 Tg C to the nation’s soils in 2025. Figure 3 indicates that large gains in soil carbon occur in the Dakotas, Iowa, Ohio and Texas. There are no regions that lose soil carbon under Offset2_Cpositive. Gains occur both in regions where more herbaceous grasses are grown, and also in regions where residue harvesting is forgone. If residue harvesting is forgone on land in conservation tillage, then gains in soil carbon will occur.

Net crop returns increase significantly in most regions when moving from the Baseline scenario to the Offset2_Cpositive scenario (Fig. 4). This includes regions where residue harvesting has been curtailed within the Offset2_Cpositive scenario. Although potential residue harvesters would lose revenue from not harvesting and selling crop residues, they would gain revenue from two other mechanisms. First, if the farmers are using conservation tillage, the farmers would receive offset payments for the soil carbon gain that occurs in their fields. Second, the farmers would be receiving higher commodity prices for their conventional crops. As the burden of meeting EISA is shifted to herbaceous grasses, land competition increases, the amount of land in conventional crops decreases, and prices rise. The combination of these revenue streams increases net returns above what they could earn from residue harvesting.

Results indicate that some western areas where livestock dominates the agricultural sector would see declines in net returns as feed prices increase.
Fig 3. Annual soil carbon gain from conservation tillage and grassland sequestration in 2025 under the (a) Baseline and (b) Offset2_Cpositive scenarios.

Fig 4. Difference in net crop returns in 2025 between Baseline and Offset2_Cpositive scenarios.
A decrease in annual carbon emissions is estimated to occur as a result of meeting EISA mandates in the *Baseline* scenario (Fig. 5), without any carbon offset payments offered. The development of cellulosic technology reduces emissions by 6 Tg Ceq yr\(^{-1}\) below the *No biomass* scenario by 2030. If offset payments are offered to conservation tillage, an additional 6 Tg Ceq yr\(^{-1}\) are avoided. Offset payments offered to herbaceous grass production reduces emissions by an additional 2 Tg Ceq yr\(^{-1}\). Placing residue harvesting restrictions within the *Offset2_Cpositive* scenario further reduces carbon emissions by 4 Tg Ceq yr\(^{-1}\), with a total reduction of 11 Tg Ceq yr\(^{-1}\) between the *Baseline* and *Offset2_Cpositive* scenarios.

In comparing the annual net returns of the scenarios, if cellulosic technology does not develop as expected, as represented in the *No_biomass* scenario, land use competition declines, and market returns decline by $26 billion annually below *Baseline* by 2030 (Fig 6). If offset payments are offered to only conservation tillage, then there will likely be little gain in net returns to the agricultural sector (*Offset1*). If offset payments are offered to both conservation tillage and herbaceous grasses, the net returns will slightly increase (*Offset2*). If, in addition to the offset payments, residue harvesting was restricted as in the *Offset2_Cpositive* scenario, net returns would increase by $14 billion annually above *Baseline*. These significant gains occur as a result of a rise in commodity prices caused by land competition as the burden of meeting EISA is shifted to herbaceous grasses.
Fig 5. Annual net carbon flux to the atmosphere from U.S. major crop agriculture under alternative policy scenarios.

Fig 6. Annual total net returns to U.S. agriculture under alternative policy scenarios.
Discussion

With ACES already passed in the House of Representatives and a similar bill under debate in the Senate, there is concern over whether cap-and-trade legislation will hinder the goals of the nation’s biofuel policy set forth in EISA by increasing input costs and diverting land to afforestation. Farmer groups have also voiced concern over whether cap-and-trade legislation will economically benefit the agricultural sector (Corn and Soybean Digest, 2010; Winter, 2010). Results of this study suggest that a policy which offers offset payments to conservation tillage and herbaceous grass production, and restricts residue removal to keep soil carbon from declining (Offset2_Cpositive scenario), can provide adequate feedstocks to meet EISA while simultaneously building soil carbon and increasing farmer net returns. Under this scenario, the bioenergy and climate policies would act synergistically to yield greater benefits to both agricultural net returns and reductions in carbon emissions than either policy alone. Producers who may not directly receive the benefits of offset payments could still see significant economic gains through higher commodity prices. Even in the Midwest, where carbon restrictions limit residue harvesting, there is an estimated increase in net returns under the Offset2_Cpositive scenario. The benefits of Offset2_Cpositive scenario occur by shifting the burden of meeting EISA from crop residues to herbaceous grasses. Farmers then reap additional carbon offset payments and higher commodity prices as a result of increased land competition. Agriculture would see an average increase in net returns of $7.9 billion yr\(^{-1}\) above Baseline over the next 20 years, while net atmospheric carbon emissions would be reduced by an additional 6.75 Tg Ceq yr\(^{-1}\) below Baseline scenario.

Such a policy would significantly alter the projected geographic location of feedstock production, therefore cellulosic ethanol manufactures should consider these possible shifts before major investments are made. With EISA legislation alone (Baseline scenario), a large number of ethanol facilities would likely be located in the residue-dense Corn Belt, but with the addition of cap and trade legislation, our analysis indicates that more ethanol facilities could likely be located in the grassland areas of the southern Great Plains. Exact feedstock potential is highly dependent upon what the final legislation permits and restricts.
Part II:  
Supply Curves

Summary
At very high biomass price levels, US agriculture and forestry can provide upwards of 650 million dry tons of feedstock. Although agriculture is affected by the price of carbon, both in the cost of inputs and the profitability of cropland through carbon sequestration incentives, total biomass supply potential changes very little in response to carbon prices. Yet carbon prices do significantly change the mix of individual feedstocks. As carbon prices increase there is a shift away from short rotation woody feedstocks and to dedicated herbaceous feedstocks. US agriculture has the potential to sequester an additional 14 million metric tons of carbon per year under higher carbon prices.

![Graph showing total US feedstock supply curves at 4 levels of carbon prices](image)

Figure 7. Total US feedstock supply curves at 4 levels of carbon prices. As carbon prices increase, the total feedstock supply curve changes very little.
Figure 8. Switchgrass production curves at 4 levels of carbon prices. As carbon prices increase, the supply potential at a given feedstock price increases also. This is due to farmers receiving carbon incentives for the belowground biomass generated by switchgrass.

Figure 9. Crop residue production curves at 4 levels of carbon prices. At lower biomass prices, carbon incentives act to reduce crop residues, as farmers receive carbon incentive for leaving residues in fields to build soil carbon. At prices above $50 per dry ton, the profit from harvesting residues outweighs the profit from carbon incentives, therefore there is very little difference between the supply curves at higher biomass prices.
Figure 10. Short rotation woody tree production at 4 levels of carbon incentives. The supply curves shift downward at increasing carbon prices as switchgrass displaces short rotation woody trees.

Figure 11. Biomass supplied from woody residues and standing tree harvests. The supply curves are identical at all levels of carbon price. Collection of woody residues or standing tree harvests do not receive carbon incentives.
Figure 12. Acres in dedicated biomass crops at 4 levels of carbon incentives. As carbon prices increase, the amount of land in dedicated crops also increase. This is due to switchgrass receiving incentives for increases in soil carbon. The total amount of dedicated biomass acreage remains fairly constant across all carbon price levels.

Figure 13. Acres afforested at 4 levels of carbon prices. As carbon prices increase, more land is converted to forest to receive carbon incentives. At each carbon price level, the amount of afforestation decreases as biomass price increases.
Figure 14. Net carbon flux curves indicating the MMtC released from agriculture as biomass prices increase. Four curves correspond to 4 levels of carbon prices. At a given carbon price, as biomass prices increase, net flux of carbon decreases slightly. At a given biomass price, as carbon prices increase, net flux of carbon decreases. Both high carbon prices and biomass prices act to
Table 4. Feedstock production, acreage of feedstock and afforestation, and carbon emissions under levels of both carbon and biomass price.

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References


De La Torre Ugarte, DG, BC English, CM Hellwinckel, RJ Menard, and ME Walsh (2007) Economic Implications to the Agricultural Sector of Increasing the Production of Biomass Feedstocks to Meet Biopower, Biofuels, and Bioproduct Demands. Research Series 08-01. University of Tennessee, Institute of Agriculture, Department of Agricultural Economics, University of Tennessee, Knoxville.


Appendices

Publications:

Presentations:


Conferences Attended: