Implications of a Carbon-Based Energy Tax for U.S. Agriculture

Uwe A. Schneider and Bruce A. McCarl

Policies to mitigate greenhouse gas emissions are likely to increase energy prices. Higher energy prices raise farmer costs for diesel and other fuels, irrigation water, farm chemicals, and grain drying. Simultaneously, renewable energy options become more attractive to agricultural producers. We consider both of these impacts, estimating the economic and environmental consequences of higher energy prices on U.S. agriculture. To do this we employ a price-endogenous agricultural sector model and solve that model for a range of carbon-tax–based energy price changes. Our results show mostly positive impacts on net farm income in the intermediate run. Through market price adjustments, fossil fuel costs are largely passed on to consumers. Additional farm revenue arises from the production of biofuels when carbon taxes reach $30 per ton of carbon or more. Positive environmental benefits include not only greenhouse gas emission offsets but also reduced levels of nitrogen leaching.

Key Words: energy tax, greenhouse gas policy, U.S. agricultural sector, bioenergy, mathematical programming

Demand for climate change mitigation and greenhouse gas emission reduction policies has increased over the last decade. Such policies if implemented will generally lead to increased prices of fossil fuels since in the United States fossil fuel use accounts for approximately 84 percent of greenhouse gas emissions (U.S. Environmental Protection Agency 2004). While the pursuit of greenhouse gas mitigation may lead to income opportunities for agriculture in the form of sequestration and emission management contracts (McCarl and Schneider 2000), such opportunities have been controversial in international negotiations, and it is uncertain how these opportunities will play a role when all details have been worked out. Thus, we chose to examine the effects of carbon prices on energy prices only where agriculture is largely a passive party, as discussed in McCarl and Schneider (2000). This assumption was also employed by Peters et al. (2001) in their economic analysis of U.S. agriculture and the Kyoto Protocol.

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Higher fuel prices will have consequences for many sectors of the economy through increased production costs and associated commodity price changes. Previous studies have estimated the impacts of carbon-tax–induced increases on energy prices in U.S. agricultural production costs and farm income. Particularly, some have predicted severe negative effects on farm income. For example, the study by Francl, Nadler, and Bast (1998) addressed the implications of a 25 cents per gallon fuel tax using a budgeting-based analysis. Therein they found that farmer's net income would fall substantially. Smaller impacts were found by Antle et al. (1999), who simulated economic effects of energy prices on Northern Plains grain producers using an econometric model that allowed for acreage substitution but held prices constant. Two additional studies were undertaken that used price-endogenous agricultural sector models. The above-mentioned study by Peters et al. (2001) estimated that net cash returns for U.S. crop and livestock producers would decline by 0.3, 2.1, and 4.1 percent at carbon taxes of $14, $100, and $200 per ton of carbon equivalents (tce), respectively. Konyar and Howitt (2000) estimate a 2.3 percent increase in farmers' net revenue at a carbon equivalent price of $348 per ton. In all of the above studies the effect of fuel prices on the possibilities to produce biofuels was neglected.

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This study extends the previous work by

- integrating biofuel feedstock production possibilities,
- linking agricultural adjustments to environmental impacts, and
- employing a price-endogenous U.S. agricultural sector model, which differs methodologically from the tools used in some of the previous analyses.

Methodological differences include (a) the use of non-linear constant elasticity demand curves as opposed to the assumptions of infinitely elastic demand in Francl, Nadler, and Bast (1998) and Antle et al. (1999) or linearly decreasing demand in Peters et al. (2001) and Konyar and Howitt (2000), (b) the historical crop mix approach to aggregation (Onal and McCarl 1991) as opposed to the positive mathematical programming approach used by Peters et al. (2001) and Konyar and Howitt (2000), (c) simultaneous consideration of feed processing and livestock raising activities as opposed to the crop-only studies of Antle et al. (1999) and Konyar and Howitt (2000), and (d) a detailed international trade representation (Chen and McCarl 2000) for major agricultural commodities as opposed to all the other studies.

Given the above-mentioned modifications, we will reassess the agricultural sector impacts of increased energy prices arising from carbon-emission–based tax regulations. The tax is assumed to be unilaterally implemented in the United States. We will report economic surplus changes, price adjustments, agricultural management responses, and environmental consequences including changes in agricultural carbon sinks, non–CO_2-related greenhouse gas emissions, erosion, and nutrient runoff. We assume that agriculture is only an indirect participant in climate change mitigation policies. Thus, we will not include credits or penalties for changes in soil carbon stocks, methane and nitrous oxide emissions, and other environmental qualities.

Methodology and Assumptions

To simulate farm sector response to increased energy prices, we use the Agricultural Sector and Mitigation of Greenhouse Gas (ASMGHG) model. This mathematical-programming–based model is an extension of earlier versions of the Agricultural Sector Model (ASM) as documented in Baumes and McCarl (1978), Chang et al. (1992), Schneider (2000), and Schneider and McCarl (2002). Crop and livestock production activities are endogenous variables in ASMGHG with exogenously specified input and output coefficients. The complete set of agricultural activities (Table 1) covers not only current technologies but also potential options that might become attractive under certain policy scenarios. An ASMGHG solution yields a simulation of prices, production, consumption, and international trade in 63 U.S. regions for 22 traditional and 3 perennial energy crops, 29 animal products, and more than 60 processed agricultural products. Trade relationships are integrated between and within the United States and 28 major foreign trading partners (Chen and McCarl 2000) for 8 major traded commodities. The spatial scope of ASMGHG is summarized in Table 2.

Environmental impacts (Table 3) are integrated by linking ASMGHG to results from biophysical simulation models. Region-, crop-, and management-specific impacts on soil carbon sequestration, nitrogen and phosphorus runoff and percolation, and soil erosion are computed using the Environmental Policy Integrated Climate (EPIC)[1] (Williams et al. 1989) crop simulator. Afforestation is incorporated into ASMGHG through a forestry response curve (Schneider and McCarl 2002) generated using the Forest and Agricultural Sector Optimization Model (FASOM) (Adams et al. 1996; Alig, Adams, and McCarl 1998).

The general mathematical structure of ASMGHG is documented in Schneider and McCarl (2002). Details on the implementation of major greenhouse gas mitigation strategies are given in Schneider (2000) and Schneider and McCarl (2003). Details on emission estimates from fossil fuel usage are given in the section below. To analyze the agricultural impacts of carbon-emission–based energy taxes, we compute the increase in farm input costs by multiplying the carbon tax with the carbon emissions associated with different inputs. The carbon tax levels were also translated into a

[1] For this study, we used EPIC Version 8120. Details about this version are available from the EPIC team or the related web page at http://www.brc.tamus.edu/blackland/.

Table 1. Agricultural Management Alternatives in ASMGHG

Decision parameter	Available options in ASMGHG
Crop choice (index c)	Cotton, corn, soybeans, winter wheat, durum wheat, hard red winter wheat, hard red and other spring wheat, sorghum, rice, barley, oats, silage, hay, sugar cane, sugar beets, potatoes, tomatoes, oranges, grapefruit, switchgrass, willow, hybrid poplar
Irrigation alternatives[a]	No irrigation Full irrigation
Tillage system alternatives[a]	Conventional tillage (< 15% plant cover) Reduced tillage (15–30% plant cover) Zero tillage (> 30% plant cover)
Fertilization alternatives[a]	Observed nitrogen fertilizer rates Nitrogen fertilizer reduction corresponding to 15% stress Nitrogen fertilizer reduction corresponding to 30% stress
Animal production choice	Dairy, cow-calf, feedlot beef cattle, heifer calves, steer calves, heifer yearlings, steer yearlings, feeder pigs, pig finishing, hog farrowing, sheep, turkeys, broilers, egg layers, and horses
Feed mixing choice	1,158 specific processes based on 329 general processes differentiated by 10 U.S. regions
Livestock production alternatives	Four different intensities (feedlot beef), two different intensities (hog operations), liquid manure treatment option (dairy and hog operations), BST treatment option (dairy)

[a] Irrigation, tillage, and fertilization alternatives are contained in index j.

price increase in the value of bioenergy feedstocks. Subsequently, we solved ASMGHG for a wide range of carbon tax levels and assessed changes relative to a zero carbon tax baseline.

Farm-Level Cost Changes Under Carbon-Based Energy Taxes

Agricultural enterprises use fossil fuels directly or indirectly in numerous ways. Machinery operations, irrigation water pumping, application of fertilizers and pesticides, and grain drying consume the bulk of crop-management–related energy (Hrubovcak and Gill 1997). The change in production expenditures in ASMGHG is generally calculated as

$$\text{(1)} \qquad \Delta \mathbf{x}_{r,c,s,j} = \sum_g [\mathbf{p}_g^{\text{CE}} \cdot \sum_f \mathbf{a}_{f,r,c,s,j}^{\text{Inp}} \cdot \sum_{ff} (\mathbf{s}_{ff,f,r,c,g} \cdot \mathbf{CE}_{ff,r,g})] ,$$

where $\Delta \mathbf{x}_{r,c,s,j}$ represents the per-acre cost change differentiated by region (index r), crop (index c), land type (index s), and management alternative (index j); $\mathbf{p}_g^{\text{CE}}$ represents the hypothetical carbon equivalent price imposed on regulated greenhouse gas emission accounts (index g); $\mathbf{a}_{f,r,c,s,j}^{\text{Inp}}$ represents the per-acre use of agricultural production factor (index f) by region, crop, land type, and management alternative; $\mathbf{s}_{ff,f,r,c,g}$ represents the net requirement of fossil fuel type (index ff) per unit of agricultural production factor by region and crop; and $\mathbf{CE}_{ff,r,g}$ represents the net emissions by greenhouse gas account and region from one unit of each relevant fossil fuel type. Details on data sources and computations of individual terms in equation (1) are given below.

The first term on the right-hand side of equation (1) is $\mathbf{p}_g^{\text{CE}}$—the carbon price or tax. The current level is zero, but energy or climate policies could lead to positive carbon prices in the future. To address the uncertainty of future climate change mitigation policies, we solve ASMGHG under a wide range of hypothetical carbon prices, from \$0 to \$500 per tce. While prices as high as \$500 per tce equivalent appear unlikely, they are useful to show trends and to gain model insight. In addition, the computational cost of additional price scenarios beyond the expected price range is negligible.

Input use coefficients $\mathbf{a}_{f,r,c,s,j}^{\text{Inp}}$ and fuel requirements $\mathbf{s}_{ff,f,r,c,g}$ are established for major agricultural production factors (index f). These include directly used fossil fuels (index ff) and other inputs

Table 2. Spatial Scope of ASMGHG

Region class	Class elements	Associated ASMGHG features
Non-U.S. world regions[a]	Canada, East Mexico, West Mexico, Caribbean, Argentina, Brazil, Eastern South America, Western South America, Scandinavia, European islands, Northern Central Europe, Southwest Europe, France, East Mediterranean, East Europe, Adriatic, former Soviet Union, Red Sea, Persian Gulf, North Africa, West Africa, South Africa, East Africa, Sudan, West Asia, China, Pakistan, India, Bangladesh, Myanmar, Korea, South East Asia, South Korea, Japan, Taiwan, Thailand, Vietnam, Philippines, Indonesia, and Australia	Excess demand and supply function parameter for 8 major crop commodities; transportation cost data; computation of trade equilibrium
U.S.	United States	Demand function parameters for crop, livestock, and processed commodities
Major U.S. regions (10)	Northeast, Lake states, Corn Belt, Northern Plains, Appalachia, Southeast, Delta states, Southern Plains, Mountain states, and Pacific states	Feed mixing and other process data; labor endowment data
Minor U.S. regions (63)	Alabama, Arizona, Arkansas, Northern California, Southern California, Colorado, Connecticut, Delaware, Florida, Georgia, Idaho, Northern Illinois, Southern Illinois, Northern Indiana, Southern Indiana, Western Iowa, Central Iowa, Northeastern Iowa, Southern Iowa, Kansas, Kentucky, Louisiana, Maine, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, Missouri, Montana, Nebraska, Nevada, New Hampshire, New Jersey, New Mexico, New York, North Carolina, North Dakota, Northwestern Ohio, Southern Ohio, Northeastern Ohio, Oklahoma, Oregon, Pennsylvania, Rhode Island, South Carolina, South Dakota, Tennessee, Texas–High Plains, Texas–Rolling Plains, Texas–Central Blackland, Texas–East, Texas–Edwards Plateau, Texas–Coastal Belt, Texas–South, Texas–Transpecos, Utah, Vermont, Virginia, Washington, West Virginia, Wisconsin, and Wyoming	Crop and livestock production data and activities; land type and water resource data
Land types (6)	Agricultural land: land with wetness limitation, low erodible land (erodibility index [EI] < 8), medium erodible land (8 < EI < 20), highly erodible land (EI < 20); pasture; forest	Land endowments; cost, yield, and emission data adjustment

[a] The international regional resolution differs across the eight traded crops. For livestock and processed crop commodities, one rest-of-the-world region is used.

(f $\notin$ ff) whose manufacturing processes require large amounts of fossil fuel based energy. Direct uses in this analysis include fuel for tractors and self-propelled machinery, and on-farm energy for irrigation and grain drying. Indirect uses of fossil fuels refer to off-farm requirements during the manufacturing or delivering process of agricultural inputs. In this study, we integrate data for off-farm fuel consumption for manufacturing of fertilizer and pesticides. Because of data deficiencies, fossil energy embodied in other agricultural inputs, such as farm machinery and housing, is not included. More details on computation of both the $\mathbf{a}^{\text{Inp}}_{f,r,c,s,j}$ and $\mathbf{s}_{ff,f,r,c,g}$ coefficients are given below for each relevant input category.

The final term in equation (1), $\mathbf{CE}_{ff,g}$, refers to net carbon emissions from directly or indirectly used primary fossil fuel based energy sources. Numerical values for these coefficients were developed based on recent reports of the U.S. Department of Energy (2002). In particular, the assumptions for net emissions in ASMGHG amount to 2.77 kg CE per gallon of diesel, 2.26 kg CE per gallon of gasoline, 14.86 kg CE per thousand cubic feet of natural gas, and 10.97 kg CE per thousand cubic feet of liquefied petroleum gas. Electricity is, for modeling purposes, also regarded as a primary energy source. However, the net carbon emission coefficients differ across U.S. states depending on the average regional fuel input composition in electrical power plants. For example, one kilowatt hour of electricity causes net emissions of 278 g per CE in North Dakota, 233 g CE in Iowa, 103 g CE in South Carolina,

Table 3. Environmental Accounts in ASMGHG

Account type	Account elements
Greenhouse gas emission accounts affected by energy tax policy (index g)	Carbon emissions from on-farm fossil fuel use for agricultural machinery (fuelc), carbon emissions from irrigation (irrgc), carbon emissions from grain drying (drygc), carbon emissions from fertilizer manufacture (fertc), carbon emissions from pesticide manufacture (pestc), greenhouse gas emission offsets from bioenergy
Greenhouse gas emission accounts not affected by energy tax policy	Soil carbon changes, carbon sequestration from afforestation, methane emission from rice cultivation, nitrous oxide emissions from nitrogen applications, methane emissions from ruminant animals, methane emissions from livestock manure, nitrous oxide emissions from livestock manure, methane emission savings from livestock manure digestion
Other environmental accounts not affected by energy tax policy	Soil erosion through wind and water, nitrogen and phosphorus losses from surface runoff, subsurface flow, percolation, immobilization, and other processes

181 g CE in Texas, and 35 g CE in Oregon, with a U.S. average of 166 g CE.

On-farm fossil fuel use. Fossil fuels, primarily diesel, are combusted on-farm to operate tractors and agricultural machinery. ASMGHG uses information from cost and return budgets (Benson et al. 1997) to determine the direct fossil fuel use requirements for the portrayed regions, crops, land types, and management practices. Thus, the $a^{\text{Inp}}_{ff,r,c,s,j}$ coefficients are values directly taken from the production surveys. Fossil fuel shares are trivial, with $\mathbf{s}_{ff,f,r,c,g=\text{“fuelc”}} = 1|_{ff=f}$ and $\mathbf{s}_{ff,f,r,c,g} = 0|_{ff\neq f}$.

Irrigation. Energy used for irrigation includes fuel needed to pump ground and surface water plus fuel needed to apply the water on the field. These emissions vary depending on location and irrigation system. In ASMGHG, the irrigation intensity $\mathbf{a}^{\text{Inp}}_{f=\text{"irrH}_2\text{O"},r,c,s,j}$ is specified in feet per acre and contained in the cost and return database for crop budgets. Total fossil fuel requirements for irrigation water ($\mathbf{s}_{ff,f=\text{"irrH}_2\text{O"},r,c,g=\text{"irrgc"}}$) are determined using information from the cost and return crop budgets and special irrigation surveys (U.S. Department of Commerce 1994).

Grain drying. To compute the fossil energy consumption for post-harvest drying of grains, two types of information are established: first, the average moisture content to be removed by the drying operation, and second, the amount of fossil energy needed to remove one point of moisture. In turn, moisture points per acre are calculated using

$$\mathbf{a}^{\text{Inp}}_{f=\text{"drying"},r,c,s,j} = \Delta\mathbf{m}^{\%\text{H}_2\text{O}}_{r,c,j} \cdot \mathbf{a}^{\text{Comm}}_{r,c,s,j}, \tag{2}$$

where $\Delta\mathbf{m}^{\%\text{H}_2\text{O}}_{r,c,j}$ represents the average number of moisture percentage points removed per unit of grain yield, and $\mathbf{a}^{\text{Comm}}_{r,c,s,j}$ represents the per-acre grain yield. All coefficients are indexed as shown in equation (2). The energy requirements $\mathbf{s}_{ff,f=\text{“drying”},r,c,g=\text{“drygc”}}$ to dry one unit of corn or rice by one moisture percentage point are taken from Bern (1998), Brees (2003), and Thompson (1999). Energy requirements for other grains such as wheat, soybeans, and sorghum are assumed to equal those for corn, with adjustments made for different bushel weights.

Fertilizers. Fertilization is an energy-intensive process involving the use of energy for fertilizer manufacturing and fertilizer application. Off-farm fuel requirements from manufacturing are computed as the product of the fertilization rate $\mathbf{a}^{\text{Inp}}_{nt,r,c,s,j}$ (*nt* = nutrient index) times $\mathbf{s}_{ff,nt,g=\text{“fertc”}}$, the indirect fuel use requirement per unit of fertilizer [equation (1)]. The basic fertilizer rates $\mathbf{a}^{\text{Inp}}_{nt,r,c,s,j}$ are taken from the cost and return crop budgets. The fossil energy requirements to manufacture one unit of fertilizer ($\mathbf{s}_{ff,nt,g=\text{“fertc”}}$) depend on the type of manufacturing process chosen. In ASMGHG, a weighted average per nutrient is used, based on computations by Bhat et al. (1994). Note that the $\mathbf{s}_{ff,nt,g=\text{“fertc”}}$ coefficients are not indexed over region and crops. Fuel combusted during the application of fertilizer is part of the on-farm fossil fuel use account described above.

Greenhouse gas emissions from fertilizer arise not only from the above-described energy use but also from other sources. Particularly, fertilizer impacts soil carbon sequestration and nitrous oxide emissions through crop growth, residue decomposition, pH alterations, nitrification, de-nitrification, and air volatilization. These impacts are estimated through EPIC simulations and integrated into ASMGHG's soil carbon and nitrous oxide emission accounts. Due to our assumed policy design, soil carbon and nitrous oxide emissions are only accounted, not taxed.

Pesticides. ASMGHG also uses accounts for energy associated with pesticide applications. Particularly, the manufacturing of pesticides involves energy from a series of chemical reactions such as heating, stirring, distilling, filtering, drying, and similar processes. Pesticides are formulated as active ingredients before finally being packed for commercial release. We use four data sources to approximate fuel requirements per acre associated with the application of pesticides. First, each crop production budget contains an estimate of the expenditure on herbicides (hc), fungicides (fc), and insecticides (ic). Second, a database compiled by the USDA National Agricultural Statistics Service (NASS) gives the average amount of pesticide use in terms of active ingredients ($\hat{\mathbf{a}}^{\text{Inp}}_{ai,pc,r,c,t}$) by state and crop during the period 1990 to 2000 (Bennett 2002). Third, we employ Bhat et al.'s (1994) estimate of the net energy requirement ($\mathbf{s}_{\text{“energy”},ai}$) for 32 active pesticide ingredients (index ai). Fourth, the shares of individual energy sources of fossil fuel type f ($\mathbf{s}_{ff,ai,g=\text{“pestc”}}$) embodied in each active ingredient are taken from Green (1987).

To calculate the fossil fuel intensity of pesticide applications, we develop an estimate of average per-acre use of active ingredient by crop, region, and management alternative ($\mathbf{a}^{\text{Inp}}_{f=ai,r,c,s,j}$), and the amount of each fossil fuel type per unit of active ingredient ($\mathbf{s}_{ff,ai,g=\text{“pestc”}}$). We assume relative shares of active ingredients for each crop and each region to be constant across all management alternatives but allow total amounts to vary. Then, we use management-specific data on total expenditures on herbicides, fungicides, and insecticides to estimate the per-acre use of active ingredients for alternative management practices. In particular, we use

$$(3)\qquad \mathbf{a}^{\text{Inp}}_{ai,r,c,s,j} = \sum_{pc}\left(\frac{\mathbf{x}_{pc,r,c,j}}{\bar{\mathbf{x}}_{pc,r,c}}\cdot \bar{\hat{\mathbf{a}}}^{\text{Inp}}_{ai,pc,r,c}\right),$$

where $\mathbf{x}_{pc,r,c,j}$ is the expenditure on pesticides (index $pc, \{pc\} = \{hc, ic, fc\}$), $\bar{\mathbf{x}}_{pc,r,c}$ the crop area weighted average expenditure over all management practices [see equation (4)], and $\bar{\hat{\mathbf{a}}}^{\text{Inp}}_{ai,pc,r,c}$ the active ingredient rate compiled by NASS (2002) averaged over a ten-year history [see equation (5)].

$$(4)\qquad \bar{\mathbf{x}}_{pc,r,c} = \frac{\sum_j (\mathbf{x}_{pc,r,c,j}\cdot \text{CROP}_{r,c,s,j})}{\sum_j \text{CROP}_{r,c,s,j}}$$

$$(5)\qquad \bar{\hat{\mathbf{a}}}^{\text{Inp}}_{ai,pc,r,c} = \frac{\sum_t \hat{\mathbf{a}}^{\text{Inp}}_{ai,pc,r,c,t}}{\sum_t 1}.$$

The share of each fossil fuel type on each active ingredient $\mathbf{s}_{ff,f=ai,r,c}$ is calculated as the product of energy requirement $\mathbf{s}_{\text{“energy”},ai}$ from Bhat et al. (1994) times individual shares $\mathbf{s}_{ff,ai}$ from Green (1987).

Renewable Fuel Options

ASMGHG integrates economic and net emission data on several renewable fuel technologies. These technologies include the production of switchgrass, willow, or hybrid poplar and their use as feedstocks for electrical power plants. In addition, ethanol production opportunities from corn and cellulose conversions of switchgrass, willow, and hybrid poplar are considered following Schneider and McCarl (2003). For each carbon tax scenario, we adjusted the market price for bioenergy crops upward by the product of carbon tax times carbon offset per acre of biofuels feedstock produced. The carbon offset factors were based on life cycle comparisons between biofuels and fossil fuels.

Bioenergy Market Penetration

Adoption of bioenergy technologies depends on several critical factors (Roos et al. 1999) including business integration, scale effects, competition effects, national and local policies, and public opinion. The first oil crisis to result in higher energy prices, in 1973, did not immediately provide sufficient conditions for a large adoption of U.S. bioenergy plantations. However, it initiated the Brazilian sugar-based alcohol program (Puppim de Oliveira 2002), which increased the consumption of ethanol between 1976 and 1986 more than 50 times (Moreira and Goldemberg 1999). At the time of the second oil crisis, in 1979, the U.S. Congress enacted the Public Utility Regulatory Policies Act (PURPA), encouraging small non-utility producers to generate electricity by using co-generation techniques or renewable fuels. As a result of this regulation, the share of biomass power in the state of Maine rose quickly in the late 1980s and early 1990s (Roos et al. 1999), reaching 25 percent in 1992. This relatively large implementation was triggered by a combination of high oil prices, tax subsidies for bioenergy producers from PURPA, a relatively positive public opinion for bioenergy, and a perception that oil prices would remain high.

To address market penetration barriers in ASMGHG, we use regionally specific limits on biomass use in power plants. In particular, the maximum power generation in trillion Btu amounted to 91.49 for the Northern Central regions, 221.54 for the Northeast, 88.22 for the Southern Central regions, and 176.45 for the Southeast. These values reflect the maximum industry capacity for biomass-based power in 2020 predicted by the Energy Information Administration (Haq 2003).

Agricultural Sector Results

Increased energy prices affect agriculture in multiple ways. These impacts include crop choice and crop management adjustments at the farm level, agricultural market adjustments with feedbacks to agricultural producers and consumers, and environmental consequences. In representing our results, we focus on the national impacts regarding changes in producers' and consumers' surplus, input usage, tillage system adoption, greenhouse gas emission levels, and erosion.

A description of a few characteristics of ASMGHG and their ramifications on the results is useful for accurate interpretation of the output from the analysis:

- ASMGHG is a static model and its solutions represent an intermediate-run equilibrium in the agricultural sector after complete crop and livestock adjustment to demand and supply shifts, which are induced by policies or new technologies. Thus, the impacts of higher prices for fossil fuel based energy are simulated as if they were fully in place.
- ASMGHG allows choice of crop mix, tillage method, irrigation, and fertilization level, as well as levels of consumption, processing, and international trade. Higher energy costs incurred by U.S. producers encourage not only adoption of energy-sparing crop and livestock management in the United States but also reduce affected commodity demand and U.S. net exports.
- Technological adjustments in ASMGHG are limited by currently available options. Thus, the impacts from switching to more fuel efficient tractors and machinery are not taken into account, but tillage changes to reduce fuel use and crop mix changes are allowed.
- ASMGH is a price-endogenous model, which reflects demand curves for exported and domestically consumed products. Changes in production costs are matched by changes in crop sale prices. Consequently, higher energy prices are likely to transfer into higher consumer prices.
- Throughout this analysis we assume that input providers can pass on all energy tax related cost increases to farmers and that they will not alter the input manufacturing process, substituting either within energy sources or between energy and non-energy inputs.

Consumer and Producer Surplus Impacts

Consumer and producer surplus changes in response to energy taxes are directly reflected by changes in the value of ASMGHG's objective function. Consistent with economic theory, total surplus declines as the price of energy increases. A $25 per tce tax applied to fossil energy types, for example, costs the agricultural producers and consumers in the United States and in foreign regions about $1.3 billion annually, an amount equivalent to 2.8 percent of $46.4 billion, the observed net farm income in 2000 (NASS 2002). At this energy tax level, governmental revenue accounts for 89 percent or about $1.15 billion, while the remaining 11 percent or about $150 million constitutes deadweight losses. The sum of deadweight losses plus policy administration costs measures the minimum environmental gains for a policy to be preferred over the zero energy tax baseline.

Increased energy costs do not only reduce total agricultural surplus, they also affect the distribution of surplus between different agricultural market segments. Consumers of agricultural products incur the biggest absolute losses (Figure 1). Aggregate producers' net surplus decreases for carbon taxes between $0 and $30 per tce relative to the zero tax base situation. The lowest point occurs at $20 per tce, where only about 50 percent of a $1 billion producers' cost change is passed to U.S. and international consumers (Figure 2). For energy taxes above $25, production of biofuels begins to become profitable and soon leads to positive farm income effects relative to the base situation.

ASMGHG results can be compared to those from other analyses. Francl, Nadler, and Bast (1998) estimate a 24 percent reduction in farm income under a $111 per ton carbon tax—a substantially different estimate than we get at similar tax levels. The negative producer impact is largely due to their exclusion of market price adjustments, their omission of biofuel opportunities, and their much higher estimates for price increases in fertilizer and pesticide prices. Antle et al. (1999) simulated economic effects of energy prices on Northern Plains grain producers. For a $110 carbon tax they estimated variable costs to rise between 3 and 13 percent. Note that the authors allow for acreage substitution but hold commodity prices constant and omit biofuels. Such assumptions likely make the producer impacts more negative.

Our results are also somewhat different from estimates of Peters et al. (2001), who predict that U.S. agricultural producers would lose $253 million at a tax of $14 per tce, $1.8 billion at a tax of $100 per tce, and $3.6 billion at a tax of $200 per tce. ASMGHG estimates are relatively close for the low tax level scenario, with an estimated producer surplus loss of $298 million at a comparable tax rate of $15 per metric tce. At higher energy tax levels, ASMGHG computes positive producer impacts amounting to $601 million at a tax of $100 per tce, and $2.1 billion at a tax of $200 per tce. The agricultural sector analysis by Konyar and Howitt (2000) estimates a 2.3 percent increase in farmers' net benefit at a carbon equivalent price of $348 per ton. Based on ASMGHG's $350 per tce scenario results, we calculate an 11 percent income increase due to both biofuel production (a factor not present in Konyar and Howitt 2000) and related price increases for traditional commodities.

Economic surplus changes are related to market adjustments. As shown in Figure 3, energy taxes decrease crop and livestock production levels and increase commodity prices. Because we did not impose energy taxes on foreign countries, U.S. agricultural exports also decline. Rising commodity prices explain in part why our farm income changes are less negative than those from studies with constant prices. At higher carbon prices, enhanced biofuel production creates a double effect of generating a new source revenue and at the same time pushing up traditional commodity prices.

Biomass Power Capacity and Farm Income Impacts

The results presented in this analysis portray relatively tight market penetration limits for biomass power. To address the uncertainty of these restrictions, we conducted a sensitivity analysis, where on one end we allowed no biomass power at all and on the other end we assumed no regional capacity limits on biomass processing power plants. In between these two extremes, we also imposed regional capacity maximums as predicted by the U.S. Energy Information Administration (Haq 2003) for various time horizons. Figure 4 shows selected results of this exercise. For low carbon tax levels, the magnitude of market penetration limits is irrelevant because energy crops are inferior to other land use options. However, as carbon taxes increase, energy crops become attractive and the impact of biomass penetration limits becomes more and more distinct. At a $100 per tce tax, net producer surplus changes range between $1.7 billion losses (no energy crops) and $24.6 billion gains (no capacity limit on biomass power).

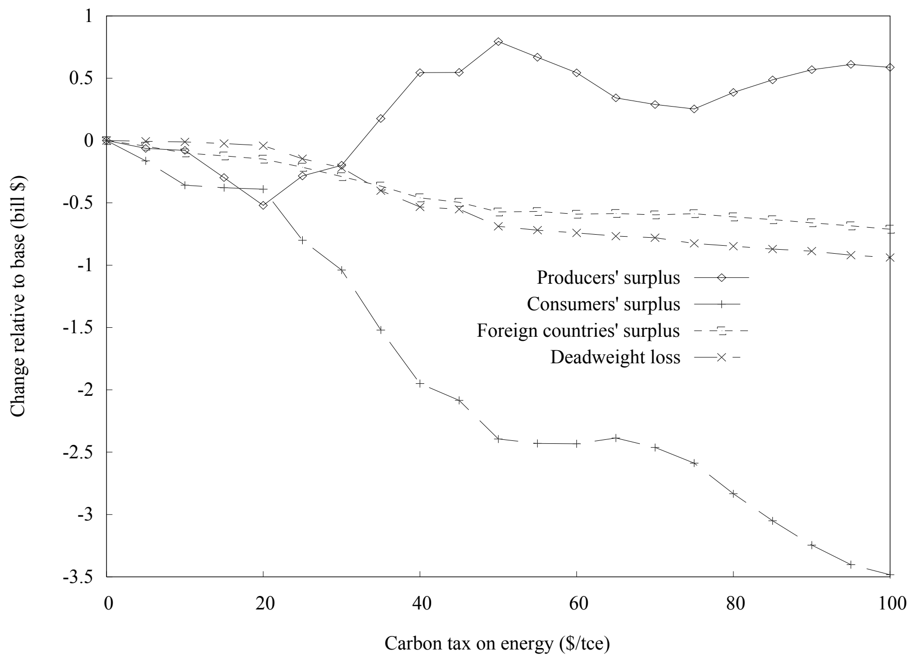

Figure 1. Economic Surplus Impacts of U.S. Carbon-Based Energy Taxes on the Agricultural Sectors of the United States and Foreign Trading Partners

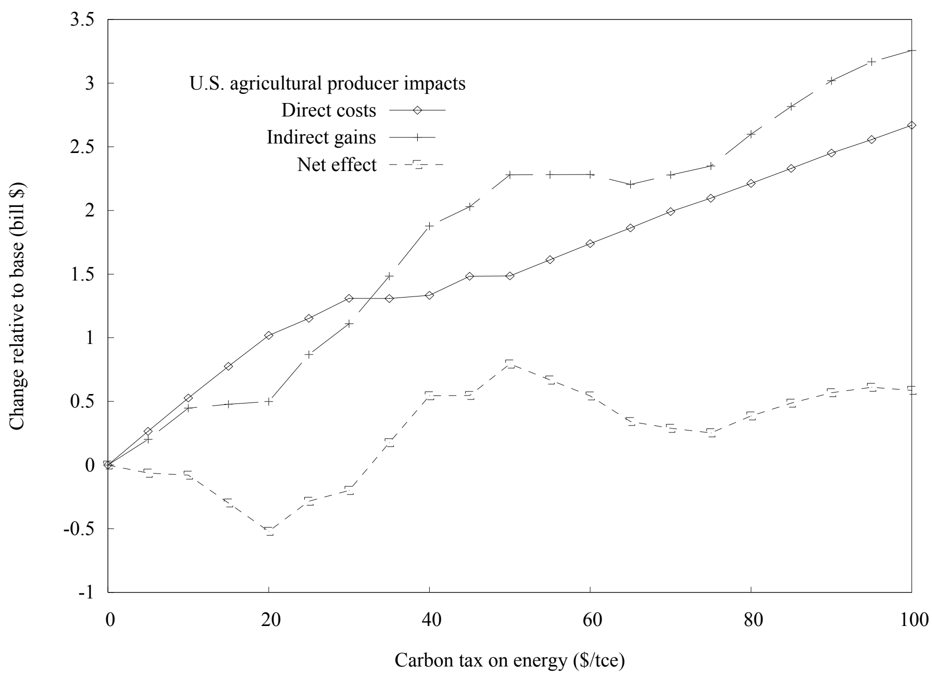

Figure 2. Impacts of Carbon-Based Energy Taxes on U.S. Agricultural Producers

Notes: Direct cost impacts include increased input expenditure minus increased bioenergy revenues related to carbon tax and emission levels. Indirect gains include economic net benefits resulting from adjustments in resource usage, commodity supply, and market prices.

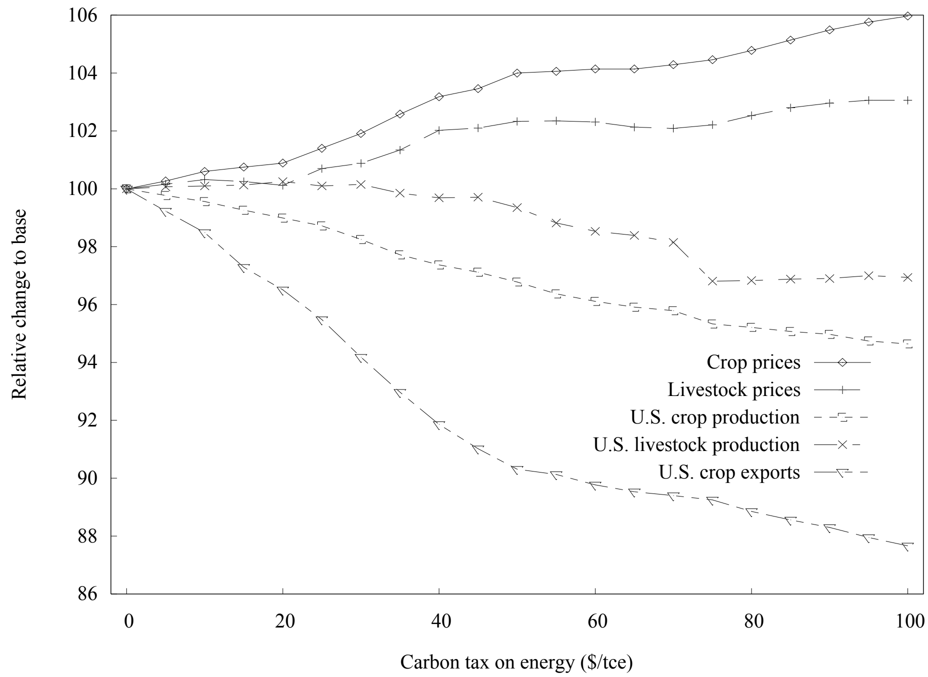

Figure 3. Agricultural Market Adjustments in Response to U.S. Carbon Taxes on Energy

Note: Price and quantity changes for individual crop and livestock commodities were aggregated using the Fisher indexing method.

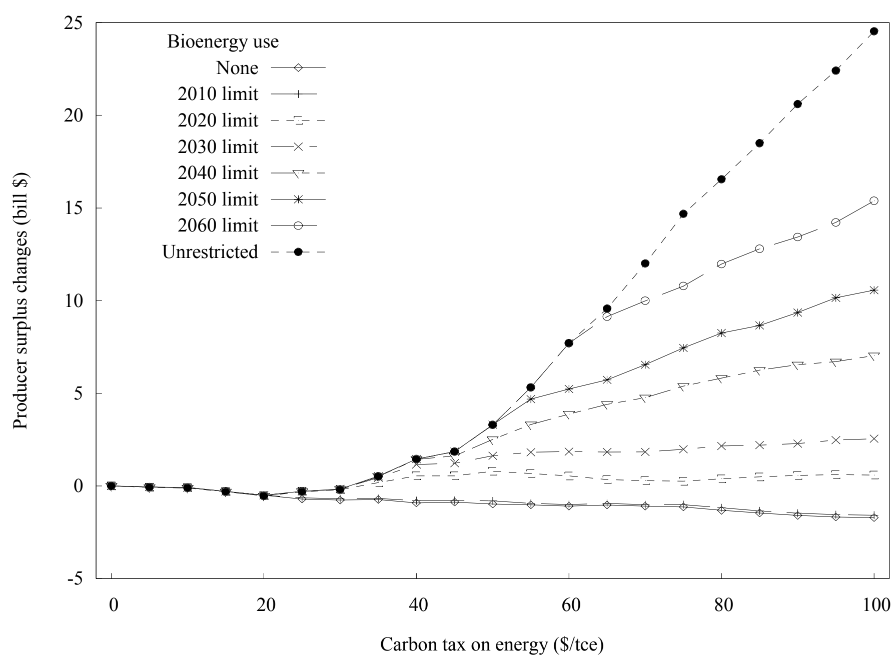

Figure 4. Sensitivity of U.S. Agricultural Producer Surplus Impacts to Different Energy Tax Levels and Different Bioenergy Market Penetration Limits

Note: The "2020 limit" line corresponds to the "Producers' surplus" line in Figure 1 and the "Net effect" line in Figure 2.

Impacts on Crop Management and Environmental Indicators

How does the imposition of energy taxes affect the optimal crop and land use choice and management intensity? As shown in Tables 4 and 5, the distribution of agricultural land between traditional crops, pasture, and energy crop plantations remains fairly unchanged for tax levels below $25 per tce. However, higher tax levels lead to increases in bioenergy feedstock plantations at the expense of traditional cropland and pasture. Without market penetration limits for biomass power (Table 5), these increases are substantial, amounting to cropland shares of 7, 25, and 43 percent at tax levels of $50, $100, and $350 per tce, respectively.

The decline in traditional cropland leads to crop mix alterations and to adjustments with respect to irrigation, tillage, and fertilizer intensity. At lower tax rates, we observe a slight decrease in irrigation and fertilization. Tillage systems remain fairly unchanged. At higher tax levels, the response depends on the magnitude of biomass power generation. With relatively little acreage devoted to energy crop plantations (Table 4), traditional crops are managed less intensively as energy becomes more expensive. However, different responses are observed when energy crop plantations occupy a relatively large area (Table 5). Irrigation and nitrogen fertilization on traditional cropland increase for tax levels above $50 per tce. Conventional tillage increases for medium tax levels but decreases slightly if taxes are above $100 per tce.

Aggregate greenhouse gas emission impacts are also listed in Table 4 and Table 5. Carbon source reductions include emission reductions from machinery use, irrigation, grain drying, and fertilizer and pesticide manufacturing. Biofuel offsets are net emission savings resulting from replacements of fossil fuel energy. Savings in these two greenhouse gas accounts are directly promoted by energy tax policies. Soil carbon sequestration and methane and nitrous oxide emissions, on the other hand, are not directly affected. Changes in these unregulated accounts represent positive or negative externalities to energy tax policies.

Comparing values between Table 4 and Table 5, we find relatively similar emission decreases for carbon sources. However, this match is spurious because different mechanisms cause this relatively similar result. Particularly, if little area is devoted to energy crops, carbon source reductions arise mainly from a decrease in traditional crop management intensity. If, on the other hand, a large area is devoted to energy crops, carbon source reductions result mainly from an area reduction of intensively managed crops. The assumption about possible market penetration of biomass has a strong impact on the amount of bioenergy generated. For an energy tax of $100 per ton of carbon, biomass power is ceilinged at a level 0.6 Btu Quads (Table 4) but yields 5.5 Btu Quads when the market restrictions are imposed (Table 5).

The response of the unregulated GHG accounts shows that soil carbon sequestration on traditional cropland is generally higher with bioenergy limits than without. In both cases, soil carbon values decrease for medium-level energy taxes but increase again for very high tax levels. The behavior corresponds relatively well to the simulated change in tillage intensity. Nitrous oxide and methane emissions from livestock decrease as energy becomes more expensive and do so even more if a lot of bioenergy can be generated. Again, large energy crop plantations decrease acreage of traditional crops, which in turn leads to higher prices for livestock feeds. As a result, the number of livestock decreases, and so do associated emissions.

Non greenhouse gas related environmental impacts include soil erosion and nutrient emissions and are listed in the last section of Table 4 and Table 5. Erosion on traditional cropland increases slightly at low energy tax levels but decreases at higher energy tax levels. Note that at low tax levels, there is no substantial shift in overall tillage. However, erosion is not just a function of overall tillage but involves complex interactions of crop, management, topography, and weather. Estimates of nitrogen and phosphorus emission impacts on traditional croplands are mostly negative, implying additional environmental gains.

In interpreting our results on erosion and nutrient emission impacts, two qualifications must be made. First, while traditional crop yields are different for different land qualities, we do not have such differentiating information for energy crops. Because erosion and nutrient emission coefficients are strongly correlated with land qualities,

Table 4. Average Land Use and Environmental Impacts of Higher Energy Prices with 2020 Market Penetration Limits for Biomass Power

		Carbon tax level on fossil-fuel–based energy in $/tce								
Impact indicator	Unit	0	10	25	50	75	100	200	350	500
Agricultural land use										
Traditional crops	10^6 acres	323.2	322.8	321.0	315.5	313.2	312.9	305.7	303.0	297.3
Corn acreage	%	100.0	99.7	99.3	98.2	95.7	94.5	90.7	85.1	83.0
Soybean acreage	%	100.0	100.3	100.4	98.7	99.4	99.5	97.6	99.0	97.0
Wheat acreage	%	100.0	100.0	99.0	97.4	97.8	97.9	96.5	95.8	92.8
Sorghum acreage	%	100.0	98.8	98.1	93.5	89.9	91.5	86.7	90.4	90.0
Rice acreage	%	100.0	94.7	79.2	68.9	64.5	64.1	49.1	45.7	44.2
Barley acreage	%	100.0	99.9	100.0	100.2	99.4	99.1	104.4	105.9	106.4
Silage acreage	%	100.0	99.2	98.9	95.9	95.3	95.4	93.0	95.5	90.4
Hay acreage	%	100.0	100.2	100.6	99.1	98.5	99.7	98.2	98.4	96.8
Pasture	10^6 acres	397.8	398.3	398.2	397.4	399.7	400.0	407.1	409.9	415.5
Energy crops	10^6 acres	0.0	0.0	1.8	8.2	8.1	8.2	8.2	8.2	8.2
Switchgrass	10^6 acres	0.0	0.0	1.8	8.0	8.0	8.1	8.2	8.1	8.1
Hybrid poplar	10^6 acres	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Willow	10^6 acres	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.1	0.1
Traditional crop land management										
Conventional tillage	%	67.1	66.6	67.6	66.8	69.9	66.4	54.6	43.2	38.3
Reduced tillage	%	28.5	29.1	28.1	27.9	24.6	23.8	9.7	6.3	5.5
Zero tillage	%	4.4	4.3	4.4	5.3	5.5	9.7	35.7	50.6	56.2
Irrigation	%	17.2	16.6	15.6	14.5	13.4	12.3	9.1	6.4	5.1
Intensive nitrogen	%	73.6	62.3	61.6	62.4	62.1	61.8	61.3	60.3	58.4
Nitrogen fertilizer	kg/acre	26.3	24.2	23.8	23.4	23.0	22.9	22.0	20.9	20.0
Phosphorus fertilizer	kg/acre	4.4	4.0	3.9	3.9	3.8	3.8	3.7	3.5	3.3
Greenhouse gas emission abatement impacts										
CO_2 source reductions	mmtce		2.0	4.3	6.5	8.3	9.5	14.7	18.7	21.3
Biofuel offsets	mmtce		0.0	4.0	17.3	17.3	17.3	17.3	17.3	17.3
Bio-energy	10^{15} Btu		0.0	0.1	0.6	0.6	0.6	0.6	0.6	0.6
Soil sequestration	mmtce		0.5	-0.3	1.1	0.0	4.3	24.6	37.5	46.9
Livestock $N_2O + CH_4$	mmtce		-0.1	-0.1	0.2	0.8	0.7	-1.2	-1.8	-2.9
Crop $N_2O + CH_4$	mmtce		1.0	1.3	1.8	2.1	2.1	3.1	3.8	4.4
Total GHG reduction	mmtce		3.4	9.2	27.0	28.5	34.0	58.6	75.6	87.1
GHG externality	%		67.3	10.3	12.9	11.2	26.6	82.7	109.5	125.3
Other environmental impacts from traditional crop land										
Erosion	Δ%/acre		2.7	3.9	2.2	2.1	1.1	-11.9	-17.0	-18.9
N percolation	Δ%/acre		-4.9	-7.5	-10.9	-12.2	-12.6	-18.9	-18.8	-20.5
N subsurface flow	Δ%/acre		-11.0	-13.0	-14.3	-15.0	-16.2	-17.6	-19.5	-20.2
N surface runoff loss	Δ%/acre		-0.6	-3.1	-2.2	-2.3	-2.4	-1.0	2.6	3.1
P loss with sediment	Δ%/acre		-0.3	0.6	-1.8	-2.2	-3.0	-8.4	-16.4	-20.7

our results may over- or understate erosion estimates in cases where the assumption of equal energy crop yields on different land qualities is violated. Second, we lack erosion and nutrient emission coefficients for energy crops and thus analyze related impacts only on traditional cropland. This may understate the true environmental co-effects because the dense permanent cover of

Table 5. Average Land Use and Environmental Impacts of Higher Energy Prices with No Market Penetration Limits for Biomass Power

		Carbon tax level on fossil-fuel–based energy in \$/tce								
Impact indicator	Unit	0	10	25	50	75	100	200	350	500
Agricultural land use										
Traditional crops	10^6 Acres	323.2	322.8	321.0	306.0	276.2	261.5	220.8	205.4	199.3
Corn acreage	%	100.0	99.7	99.3	94.2	84.9	78.2	58.9	52.2	48.6
Soybean acreage	%	100.0	100.3	100.4	94.6	79.7	71.7	48.9	41.7	39.7
Wheat acreage	%	100.0	100.0	99.0	95.5	89.5	87.9	78.5	73.0	71.5
Sorghum acreage	%	100.0	98.8	98.1	88.3	81.5	84.8	82.3	77.4	79.5
Rice acreage	%	100.0	94.7	79.2	64.4	43.0	41.6	39.2	38.2	37.1
Barley acreage	%	100.0	99.9	100.0	101.3	98.5	96.5	95.9	93.9	92.4
Silage acreage	%	100.0	99.2	98.9	91.8	83.2	77.4	60.4	49.3	45.9
Hay acreage	%	100.0	100.2	100.6	97.2	91.1	88.8	84.3	80.2	77.7
Pasture	10^6 Acres	397.8	398.3	398.2	392.7	382.9	379.6	377.8	377.5	377.5
Energy crops	10^6 Acres	0.0	0.0	1.8	22.3	62.0	79.9	122.4	138.2	144.2
switchgrass	10^6 Acres	0.0	0.0	1.8	19.9	57.2	73.9	72.5	87.0	73.6
hybrid poplar	10^6 Acres	0.0	0.0	0.0	0.0	0.0	0.0	37.4	38.6	57.9
willow	10^6 Acres	0.0	0.0	0.0	2.4	4.8	6.1	12.5	12.6	12.6
Traditional crop land management										
Conventional tillage	%	67.1	66.6	67.6	70.2	78.2	78.4	75.5	71.4	71.2
Reduced tillage	%	28.5	29.1	28.1	25.6	17.2	14.5	4.5	3.2	2.7
Zero tillage	%	4.4	4.3	4.4	4.2	4.5	7.1	20.1	25.4	26.1
Irrigation	%	17.2	16.6	15.6	14.8	19.3	20.7	26.7	28.6	29.7
Intensive nitrogen	%	73.6	62.3	61.6	63.8	69.0	72.4	77.5	79.4	80.1
Nitrogen fertilizer	kg/acre	26.3	24.2	23.8	23.5	24.2	24.5	26.5	25.7	25.4
Phosphorus fertilizer	kg/acre	4.4	4.0	3.9	3.9	4.0	4.1	4.2	4.1	4.0
Greenhouse gas emission abatement impacts										
CO_2 source reductions	mmtce		2.2	4.5	7.9	10.5	12.1	16.7	19.5	20.7
Biofuel offsets	mmtce		0.0	4.0	48.7	129.3	164.7	250.8	275.7	287.6
Bio-energy	10^{15} Btu		0.0	0.1	1.6	4.3	5.5	8.4	9.2	9.6
Soil sequestration	mmtce		0.6	-0.3	-2.3	-9.7	-8.4	2.6	7.2	7.7
Livestock $N_2O + CH_4$	mmtce		0.0	-0.1	2.8	5.4	6.1	7.0	7.9	8.7
Crop $N_2O + CH_4$	mmtce		1.1	1.5	2.3	3.2	3.6	4.6	5.6	5.9
Total GHG reduction	mmtce		4.0	9.6	59.4	138.7	178.1	278.5	312.6	327.4
GHG externality	%		76.8	12.7	5.0	-0.8	0.8	5.3	7.0	7.2
Other environmental impacts from traditional crop land										
Erosion	Δ%/acre		2.8	4.1	5.7	1.0	-4.0	-12.8	-25.4	-26.0
N percolation	Δ%/acre		-4.9	-7.5	-15.0	-12.9	-14.3	-8.9	-4.1	-3.6
N subsurface flow	Δ%/acre		-11.1	-13.1	-13.1	-9.9	-11.3	-12.3	-10.2	-9.5
N surface runoff loss	Δ%/acre		-0.6	-3.1	-5.0	-12.5	-14.5	-14.1	-17.7	-17.9
P loss with sediment	Δ%/acre		-0.3	0.6	3.9	-0.5	-2.5	-10.9	-22.2	-24.1

switchgrass and the low soil disturbance of all three portrayed perennial energy crops suggest further erosion reductions on lands diverted to these perennial crops.

Concluding Comments

Agriculture may find itself operating under higher energy prices due to domestic or international greenhouse gas emission reduction efforts. Farm interest groups fear that farm income will be negatively affected. Previous studies using restrictive assumptions about market and farm management adjustments have partially confirmed this concern. Our results do not support such a conclusion.

Our model suggests only small losses to agricultural producers when carbon taxes are modest, but show benefits to farmers when carbon taxes induce substantial energy price increases, with consumers bearing the main burden of these taxes. Two factors drive these conclusions. First, as agricultural production becomes more costly, supply cutbacks cause agricultural commodity prices to rise. Thus, higher revenues will offset a large portion of the farm cost increases. Second, when production of biofuel feedstocks becomes a profitable business opportunity, additional revenues are created in the farm sector. Moreover, the diversion of resources to bioenergy feedstocks lowers traditional production, which further increases traditional crop prices.

The results of our analysis provide insights into how farmers might adjust their management practices in response to higher energy prices if for example the high prices first seen in the fall of 2004 persist. The net response is driven by two opposite incentive developments. On the one hand, higher energy prices yield a competitive advantage for energy-friendly crop management practices including reduced tillage, reduced irrigation, and reduced nitrogen fertilization. On the other hand, as energy prices increase, agricultural commodity prices increase as well. Higher commodity prices promote yield-intensive crop management strategies, which commonly implies energy-intensive management. Depending on the net effect of these two incentives, farmers will pursue either energy-intensive or energy-friendly management. Our model suggests that the adoption of energy-friendly management prevails as long as biofuel production is not profitable. As the biofuel acreage increases, management for traditional crops gradually shifts back to yield and energy-intensive management.

Modifications in agricultural management have implications for many environmental qualities including greenhouse gas emissions, soil erosion, and nutrient emissions. Our results show that energy taxes do not automatically lead to environmental co-benefits in U.S. agriculture. For moderate carbon tax levels, i.e., levels below $100 per tce, our analysis suggests environmental gains in some unregulated greenhouse gas and nutrient emission accounts, but slight losses with respect to soil erosion and soil carbon. If a large area is diverted to biomass feedstock production, incentives for more intensive management can worsen environmental impacts from traditional crops. Environmental co-effects should therefore be carefully considered when judging the desirability and scope of an energy or climate policy.

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