CHOICES
The magazine of food, farm and resource issues
Fall 2004
A publication of the American Agricultural Economics Association

The Climate-Change Squeeze Facing the United States and US Agriculture

Brent Sohngen and Bruce A. McCarl

Is US agriculture caught in a climate-change squeeze? International scientific bodies, such as the Intergovernmental Panel on Climate Change (IPCC), project that the climate will warm by as much as 10°F over the next 100 years and assert that it has already warmed by about 1°F since 1900. The scientific community, for the most part, asserts that such climate change has been caused by increases in greenhouse gas (GHG) emissions, such as carbon dioxide, ozone-depleting substances (i.e., CFCs), methane, and nitrogen oxide, to name a few. Currently, most human emissions arise from electricity generation and petroleum consumption, although globally approximately 25% are purported to arise from forest clearing and burning in the tropics. Within the United States, electricity generation and petroleum use are the source of approximately 84% of total emissions.

In recent years, there has been widespread discussion about implementing policies to reduce or offset such GHG emissions, starting with ratification of the United Nations Framework Convention on Climate Change (UNFCC) in the early 1990s. Although the UNFCC was purely voluntary, the 1997 Kyoto Protocol—which achieved prominent recognition because it was signed by President Clinton (over an overwhelming rejection in advance by the US Senate) and subsequently "unsigned" by President Bush—may yet turn early voluntary measures into treaty obligations for a number of US trading partners.

The United States has opted out of the Kyoto Protocol for the time being, but policy makers are clearly mulling options. Most recently (2003), Senators John McCain and Joe Lieberman introduced a bill that would cap GHG emissions from the US energy and transportation sectors, while the President announced the Clear Skies Initiative that contains targets for GHG emission intensity reductions to be met through voluntary action.

Potential climate change and policy options to avoid it define the potential squeeze faced by agriculture and forestry in the United States. Climate change is a slow-moving force likely to influence future production conditions, potentially shifting optimal production regions north and causing impacts through wider variability in annual weather conditions. At the other end of the spectrum, policies adopted to reduce GHG emissions could influence the availability or desirability of a number of current management practices. Both the impacts and the potential mitigation options favored by policy makers will exert pressure on the

Articles in this Theme:

agriculture and forestry sectors in the near and long term.

The collection of papers in this edition of *Choices* is intended to cover a number of principally economically oriented aspects of the climate-change issue that are of potential interest to policy makers and agriculture and forestry sector participants. The potential agricultural and forestry impacts of climate change are addressed in two sector-specific papers based on the recent US National Assessment of climate change impacts (US National Assessment, 2002). The article by John Reilly covers the implications of climatic change for agriculture. The results of the research presented in that paper suggest that yields for many crops in the United States could increase with climatic change, with projected economic benefits ranging from \$0.8 to 7.8 billion in 2030 and from \$3.2 to 12.3 billion in 2100. The article by Alig, Adams, Joyce, and Sohngen focuses on the forestry sector, where yields of most timber species in the United States are expected to increase, leading to additional economic benefits for consumers. In both sectors, most benefits are experienced by consumers, whereas producers appear to be vulnerable to lower prices induced by climatic change.

Four additional papers cover issues surrounding agriculture and forestry participation in mitigating the GHG problem by reducing emissions or sequestering carbon. The paper by Murray reviews research exploring how land-use change and crop and livestock management in the United States could affect future net GHG emissions. The results presented in that paper suggest that agricultural and forest land could play a fairly important role in US carbon policy, potentially sequestering three billion tonnes of CO_2 equivalents per year—or 40% of all US GHG emissions—for fairly high carbon prices (\$50–80/tonne CO_2 equivalents). Feng, Kling, and Gassman cover the additional environmental benefits, such as water quality, that might arise if we pursue active greenhouse gas mitigation in the land using sectors. Although traditional farm programs like the Conservation Reserve Program have sequestered carbon over the years, they have not been undertaken specifically for carbon sequestration. Shifting program incentives to increase carbon would have implications for other programmatic goals, such as soil erosion and nutrient emissions. As the authors point out, it is important to account for these trade-offs when designing policies to achieve carbon sequestration.

Elbakidze and McCarl raise an issue of environmental tradeoffs across energy and land use activities. Given that there are also co-benefits associated with reducing fossil fuel emissions, they suggest that policies that allow energy emissions and land use activities to be “traded” must carefully account for the benefits and co-benefits in both sectors to design socially efficient markets. Finally, Butt and McCarl discuss current prospects for emergence of GHG mitigation as an income source for landowners. They point out that although there are several efforts underway nationally and in several regions within the United States to sequester carbon, carbon prices are fairly low at this point and likely not high enough to induce substantial sequestration efforts among landowners.

Collectively, the papers show that although a climate change squeeze may be coming, adjustments can be made through economic processes, and they may even benefit society, in particular consumers. Producers could be susceptible to climate change itself, but could benefit from policies designed to help mitigate climate change impacts. A little squeeze may not be all bad.

Choices guest editor Brent Sohngen is an associate professor in the Department of Agricultural, Environmental, and Development Economics at Ohio State University, Columbus, Ohio. Bruce McCarl is Regents Professor of Agricultural Economics at Texas A&M University and a Choices co-editor.

CHOICES
The magazine of food, farm and resource issues
Fall 2004
A publication of the American Agricultural Economics Association

US Agriculture and Climate Change: Perspectives from Recent Research

John Reilly

Both weather and climate affect virtually every aspect of agriculture, from the production of crops and livestock to the transportation of agricultural products to market. Agricultural crop production is likely to be affected by both climate change and the associated increase in atmospheric CO_2. The projected changes in temperature and precipitation have the potential to affect crop yields either positively or negatively; elevated CO_2 levels increase plant photosynthesis and thus crop yields. Changes in climatic conditions are also likely to alter livestock performance and growth, grazing availability, irrigation water supply and demand, pest populations, and incidence of extreme events (floods, droughts, hail, etc.).

Economists in association with other disciplines have done many studies investigating the effects of projected climate change on US agriculture. Here I review results from the 1999–2000 US National Assessment conducted by a team of scientists (Reilly et al., 2002, USGCRP). In addition to considering the effects of climate change on markets, this assessment also examined the potential implications of climate change on environmental outcomes.

Note that the results in this section focus only on agricultural sector impacts. The National Assessment included analyses of the impacts of climate variability and change for regions in the United States and crosscutting sectoral analyses of agriculture, forestry, water, health, and coastal and marine resources. (For details, see National Assessment Synthesis Team, 2000.)

Climate Context

The US National Assessment of climate change is based on climate scenarios derived from world climate simulation models developed at the Canadian Centre for Climate Modelling and Analysis and the Hadley Centre in the United Kingdom. Although the physical principles driving these models are similar, they differ in representation of important processes and paint different views of the future. By using these two scenarios, a range of future climate conditions is captured. For example, the Canadian scenario projects a greater temperature increase (10°F, on average) over the next 100 years than does the Hadley scenario (7°F), whereas the Hadley model projects a much wetter climate than does the Canadian model. Both models project much wetter conditions, compared to present, over many agricultural areas in the United States.

Currently, climate scientists have less confidence in climate model projections about precipitation changes. For the next 100 years, the Canadian model projects the increase in precipitation to be largest in the Southwest and California, whereas the southern half of the nation east of the Rocky Mountains is projected to experience less precipitation. The percentage decreases are projected to be particularly large in eastern Colorado and western Kansas and across an arc running from Louisiana to Virginia. Projected decreases in precipitation are most evident in the Great Plains during the summer and in the East during both winter and summer. In the Hadley scenario, the largest increases in precipitation are also projected to be in the Southwest and Southern California, but the increases are smaller than those projected by the Canadian model. Overall, however, annual precipitation is projected to increase over the entire United States, with the exception of small areas along the Gulf Coast and in the Pacific Northwest.

Agriculture-Climate-Environment Interactions

Broader agriculture-climate-environment interactions are particularly important for understanding the impacts of climate change on agriculture. Several of these interactions were explored in the US National Assessment and are discussed below.

Land and Water Use. The overall increase in productivity meant that less crop, pasture, and grazing land was needed. The results of the economic modeling assessment also showed a 5–35% reduction in irrigated acres and in water demand for irrigation, due to the differential effects of climate change on productivity of irrigated versus non-irrigated crops and reductions in the use of most resources.

Pesticide Use. Empirical analysis of the relationship between pesticide use and climate was developed using historical observations across regions and time periods. The derived relationship was used to simulate future use of pesticides in the economic model. The modeling results suggest increased expenditures on pesticides for most major field crops in most states (corn, +10 to +20%; potatoes, +5 to +15%; cotton and soybeans, +2 to +5%; wheat, –15 to +15%). Although the increases were substantial, including this impact in the economic model only reduced the benefits of climate change by about $100 million, because pesticide expenditures are only 3–5% of the total cost of production on average.

Regional Climate-Environmental Quality Interactions. Within the National Assessment, more specific studies of the Edwards aquifer region (around San Antonio, Texas) and the Chesapeake Bay were conducted. In both regions, climate change could increase the threat to the environment, at least given the nature of the two climate scenarios used in the analysis. The climate models projected less precipitation in the Edwards aquifer region, thus increasing the demand for irrigation water from both urban and agricultural users. Resultant increased pumping of groundwater from the aquifer, combined with reduced rainfall, would threaten surface spring flows supported by the aquifer that are habitat of protected endangered species. Estimates were that the regional welfare loss was between $2.2–6.8 million per year due to climate change. This estimated loss did not include an estimate of the value of the nonmarket effects on endangered species habitat. If spring flows are to be maintained at the currently protected level, pumping must be reduced by 10–20% below the limit currently set, at an additional cost of $0.5–2 million per year.

Findings for the Chesapeake Bay region showed that nitrogen loadings to the Bay could increase by 25–50% under climate change. Corn acreage and fertilization levels were estimated to increase, thereby expanding nitrogen use. Increased precipitation led to greater runoff. Collectively, these results suggest that climate change may make attaining some environmental goals somewhat more difficult.

The most important implications of these precipitation changes are realized in estimates of soil moisture—a critical issue for agriculture. Soil moisture levels are determined by an intricate interplay among precipitation, evaporation, runoff, and soil drainage. By itself, an increase in precipitation would increase soil moisture. However, higher air temperatures also increase the rate of evaporation. The differences in the climate projections are accentuated in the soil moisture projections. For example, in the Canadian model, soil moisture decreases above 50% are common in the Central Plains, while in the Hadley model, this same region experiences soil moisture increases.

Climate Change Impacts on US Agriculture in 2030 and 2090

The US National Assessment used site-specific crop models to project yield alterations and an economic model to simulate trade and market effects. Crop modeling studies were conducted at 45 sites in the United States for wheat, maize, soybean, potato, citrus, tomato, sorghum, rice, and hay under dryland and irrigated conditions. Yields were simulated assuming current varieties and planting schedules, as well as assuming varieties and planting schedules changed to adapt to the changed climate conditions. Yield results and changes in water demand for irrigated crops from the crop models were used in an economic model to simulate national-level changes in production, resource use, and economic impact on farmers and consumers. Additional crops simulated in the economic model were barley, oats, sugar cane, sugar beet, and cotton. Yield reductions were quite large for some sites (particularly in the South and Plains States) and for the Canadian Climate model scenario that projected declines in precipitation and substantial warming in these regions.

In addition to the yield inputs, three additional adjustments in input levels were incorporated into the economic model used for the US National Assessment. Water supply forecasts from the national water assessment were used to change water available for irrigation. A positive relationship between input use (i.e., fertilizers) and yield and a generally negative relationship between livestock productivity and temperature were included based on previous work. Additional empirical analysis was conducted to find the relationship between climate and pesticide use for major crops. This work showed increased pesticide expenditures occurred with higher temperatures and greater precipitation (see box).

The net effects on sectoral economic welfare (income-equivalent measures of damages for consumers and producers) was found to be positive for the United States as a whole. Economic welfare benefits ranged from $0.8 to 7.8 billion in 2030 and from $3.2 to 12.3 billion in 2100 (2000 US$), as the production benefits in the heat-limited Northern US outweighed the losses in the South. These gains were distributed unevenly among domestic consumers, foreign consumers, and US producers. Producers generally suffered income losses, due to lower commodity prices, while consumers gained.

Substantial regional differences were found. Net production in some regions, for instance, was projected to decline in some scenarios, even though the production effect for the country as a whole was positive. Agricultural production in the Corn Belt and Lake States increased by 40–80% in the Canadian scenario but fell as much as 60% in the Southeast. In the Hadley scenario, all regions showed increased crop production, with a more than 100% increase in the Lake States. The Canadian scenario was much warmer and much drier, particularly in the 2030 period, thus projecting less positive effects on crop production overall and negative effects in the Southern and Plains areas of the United States.

Future Climate and Crop Variability

One of the implications of climate change may be an increase in weather variability. To address this issue, the US National Assessment examined two questions: (1) Is there evidence that changes in the mean climate conditions, as predicted by the two climate scenarios, could change the variability of crop yields? and (2) What would be the economic impact on the United States if El Nino-Southern Oscillation (ENSO) intensity and frequency increased, as projected by a recent climate model (Timmerman et al., 1999)? In statistical analysis of historical yield patterns and climate conditions, increased precipitation was found to reduce yield variability. Thus, when these statistical results were used to simulate the effects of climate change, yield variability declined for corn and cotton, because the climate scenarios generally showed greater precipitation for where these crops were grown. Results were somewhat mixed for other crops. Wheat yield variability tends to decrease under the Hadley Center climate and increase under the Canadian climate model, following the precipitation projections for the wheat-producing Great Plains regions. Soybean yield variability shows a uniform increase with the Hadley Climate Change Scenario.

Increased frequency of El Nino events was found to cause an average annual loss of economic welfare of $323 million. When both increased frequency and strength of ENSO were considered, the total welfare (consumers and producers) loss increased to $1,008 million, or about 5% of typical US agricultural net income. We also considered whether better forecasts of ENSO prior to the growing season could help farmers avoid these losses through changes in practices. Under current ENSO conditions, the value of improved forecasts was estimated at $453 million average annually. This rose to $544 million under changed frequency of ENSO and to $556 million with changes in frequency and intensity. The relationship between GHG-induced warming and ENSO are highly uncertain (and remain controversial), but these results do show extreme events to be a potential area of concern.

Concluding Comments

The results from the recent US National Assessment showed productivity benefits to northern areas with possible losses in warmer growing areas—particularly if precipitation does not increase. The overall results are similar to previous studies but are more positive in general. The range of crops studied was larger than before; this may have allowed more varied and positive effects, but the most likely explanation for these effects were that the newer climate scenarios showed larger increases in precipitation than previously forecast.

Precipitation predictions of climate models remain highly uncertain. Thus, confidence in these results awaits more study with a wider range of climate model scenarios. Even with these overall productivity gains, some areas of concern are suggested. If variability of climate were to increase, reduced productivity could result and lead to losses that could not be offset even with better interannual forecasts. In addition, regional environmental goals, often affected by a complex interaction of land use, climate, cropping practice, and competing demands for resources, could become more difficult to achieve.

For More Information

National Assessment Synthesis Team. (2000). *Climate change impacts on the United States: The potential consequences of climate variability and change*. Cambridge, UK: Cambridge University Press.

Reilly, J., Tubiello, F., McCarl, B., Abler, D., Darwin, R., Fuglie, K., Hollinger, S., Izaurralde, C., Jagtap, S., Jones, J., Mearns, L., Ojima, D., Paul, E., Paustian, K., Riha, S., Rosenberg, N., & Rosenzweig, C. (2002). *Agriculture: The potential consequences of climate variability and change*. Cambridge, UK: Cambridge University Press.

Timmermann, A., Oberhuber, J., Bacher, A., Each, M., Latif, M., & Roeckner, E. (1999). ENSO response to greenhouse warming. *Nature*, 694-97.

John Reilly is Associate Director for Research, Joint Program on the Science and Policy of Global Change, Massachusetts Institute of Technology, Cambridge, MA. jreilly@mit.edu

CHOICES
The magazine of food, farm and resource issues
Fall 2004
A publication of the American Agricultural Economics Association

Climate Change Impacts and Adaptation in Forestry: Responses by Trees and Markets

Ralph Alig, Darius Adams, Linda Joyce, and Brent Sohngen

The forest sector—forestry and forest industries—plays an important role in the global climate change debate. The sector influences the global carbon cycle through the sequestration of atmospheric carbon in forests and is in turn influenced by global climate change through its impacts on the rates of forest growth and climate-induced changes in natural disturbances such as fire. Similar to agriculture, the effects of climate variability and change on forests and forest industries were examined in the US National Assessment (Joyce et al., 2001). Climate change may alter the productivity of forests, shifting resource management, economic processes of adaptation, and ultimately forest product harvests both nationally and regionally. In regions where climate change reduces timber growth, smaller timber volumes will be available for harvest in both existing forest stands and in those regenerated in the future. The reverse would be true in regions experiencing increased timber growth. In addition, differential impacts of climate change in forestry and agriculture could lead to land use shifts as one possible adaptation strategy. For example, if climate change results in relatively higher agricultural productivity per acre, some acres may be converted from forests to agricultural use.

Such changes would alter the supply of products to national and international markets, changing the prices of forest products and the economic well-being of both consumers and producers. Consumers, in turn, would shift their patterns of consumption between forest and nonforest products. Producers would change both the types of management they practice (planting, thinning, and other cultural treatments) and the ages at which they harvest trees, depending on the type of owner (private or public). This paper reviews key results for the forest sector highlighted in the US National Assessment (Joyce et al., 2001). The analysis described in this paper was conducted with the same model as was used in the agricultural analysis described in the Reilly article in this issue of *Choices*. During the National Assessment, a joint forestry and agriculture climate impact scenario was conducted; in this paper, we focus on the forestry results from that scenario. The results for the agricultural sector are qualitatively similar to those reported in the Reilly article.

Climate Change in the Woods

One difficult aspect associated with modeling climate change impacts on forests is that climate change effects will likely differ between existing trees and trees regenerated in the future (naturally or planted). Native forests are adapted to the local climate and the variability of that climate. Changes in the climate will affect these existing trees by changing growth rates, tree mortality, and seed production for the next generation of forests. For existing trees, other climate change impacts could include increased risk of forest fire and mortality associated with increased insects and diseases. Our understanding of the relationships between the existing trees and climate is the basis for modeling the future impact of climate. Trees planted in the

Impacts of Climate Change on the Forest Sector

- **Land uses may change.** Compared to the baseline for the Assessment, less cropland is projected to be converted to forests under the climate change scenarios.
- **Forest composition and carbon sequestration could shift.** The type of forests found in some regions might change, altering the amount of carbon stored in forests and the type of wood products produced.
- **Patterns of natural disturbances such as fire, insects, and disease may change.** The National Assessment indicated the possibility of a 10% increase in the seasonal severity of fire hazard over much of the United States under both climate scenarios.
- **Producers and consumers could be impacted.** In the aggregate, where climate change was projected to induce yield increases, consumers were found to benefit but not producers. Projections of yield decreases had the opposite effect.
- **Adaptation in the sector could limit effects.** Options include land market adjustments, interregional migration of production (e.g., northerly migration of productive capacity), substitution in consumption between wood and nonwood products (reflected in overall growth in wood products use) and between sawtimber and pulpwood, and alteration of stand management.

future, however, will grow entirely in an environment with altered climate; their response to these climate changes could include surprises in terms of the volume growth, product yield, and product quality.

Impacts on forests arise from increases in atmospheric CO_2 concentration, changes in temperature regimes, and variations in annual rainfall patterns. Such shifts could alter basic physiological processes in trees and soils, influencing growth and the yield of commercial products over time. The actual time pattern of change will be complex, owing to lags between atmospheric changes, climate effects, and biological responses. Economic impacts resulting from growth changes will be further delayed due to the length of forestry rotations (generally two or more decades). Any examination of the effects of climate change on forests needs to consider forest rotation decisions as well as lags between the onset of climate change and the resulting biological impacts.

Given considerable uncertainty about the biological impact of global change on forests, the US National Assessment Forest Sector Team (Joyce et al., 2001) examined four alternative scenarios of the biological response of forests to climate change (reflected by changes in forest growth rates). Climate projections were obtained from the same two global circulation models (GCMs produced by the Canadian Climate Center and the Hadley Center) used in the agricultural assessment. These climate scenarios were used to model potential ecological changes in forests in two ecological process models—Century and the Terrestrial Ecosystem Model (Vegetation-Ecosystem Modeling and Analysis Project, 1995)—that simulate the impacts of climate on forest productivity, considering the influence of environmental factors such as temperature, precipitation, and soil texture on the cycles of carbon, nutrients, and water in forest ecosystems. The two climate scenarios and two ecological models generate four estimates of changes in vegetation production in US forests by region.

As noted in the Reilly article, the two climate scenarios suggest a generally more productive forest environment in the future due to a warmer and wetter climate for the United States. As a result, the ecological process models project increases in total vegetation carbon storage over the century; timber growth in hardwoods and softwoods generally increases under all four cases. Some interesting regional differences are projected during the century. The largest change among forest types modeled is in the Northeast region, where forest growth in the oak-hickory type increases about 0.3% annually by 2100. In contrast, forest growth declines in the South in some decades. Compared to the Hadley scenario, the Canadian scenario is much warmer and generally drier, particularly in the Southern United States. Thus, under the Canadian scenario, some currently forested area is projected to experience a drought-induced loss of carbon. Forest growth is consequently projected to decline in the Southern US between 2010 and 2040 under the Canadian scenario, although by 2100, forest growth in this region is projected to rebound and increase relative to the baseline.

Estimates of changes in forest production for each climate change and ecological scenario were incorporated into an economic model of land use and management. The overall results suggest that consumers gain and producers lose, although the changes are not large. Net market welfare increases from 0.05% to 0.18% over this century. Pulpwood prices are estimated to rise approximately 3.1–3.8% during the period 2020–2050, while sawtimber prices are projected to decline 3.7–6.4%. Pulpwood price increases result from reduced growth over large areas of young forests projected during the near term, particularly in the Canadian scenario.

Forest Producers, Consumers, and Choices

Understanding the role of adaptation in forestry is important for assessing the overall impact on markets. One general conclusion from the US National Assessment, which is consistent with earlier studies, is that timber and wood product markets and forest landowners will adjust and adapt to climate change in ways that act to limit economic effects. Among choices for the millions of private landowners affecting adaptation are options to shift land uses. These shifts are occasioned by differences between the forest and agriculture sectors in lead times required to shift production from one crop or cropping method to another. Agricultural rotations are typically one to several years, compared to one to several decades in forestry. This affects the likely mix of afforestation, reforestation, and deforestation under different global climate change scenarios for forest industry and nonindustrial private owners—groups that tend to have notably different land management objectives.

Several findings related to adaptation from the US National Assessment on forestry impacts include:

Land Use Choice. Compared to the baseline for the assessment, less cropland is projected to be converted to forests under the climate change and ecological scenarios investigated in the US National Assessment. Although climate change is likely to affect the margin between agriculture and forestry in specific locations, aggregate productivity changes in forestry appear to outstrip aggregate productivity changes in agriculture.

Forest Composition and Sequestration. Economic models suggest that the overall area of forests in the United States is projected to expand less than the baseline under climate-change scenarios. Biogeographical models (although they do not account for price effects) suggest that the composition of forests is also likely to change. In particular, potential habitats for trees favored by cool environments are very likely to shift north. Eastern land area associated with aspen, sugar maple, and birch, for example, is likely to decline, whereas oak/hickory and oak/pine forests could possibly expand. As a result, the type of forests that individuals see on the landscape may change, altering the amount of carbon stored in forests and the type of wood products produced across these landscapes.

Changes in Natural Disturbances such as Fire, Insects, and Disease. Natural disturbances such as fire, insects, and disease have a large impact on forests across the United States, and climate has a large impact on the occurrence, frequency, and intensity of these natural disturbances. It is difficult to estimate the precise impact of climate change on these disturbances. However, analyses in the National Assessment indicated the possibility of a 10% increase in the seasonal severity of fire hazard over much of the United States under both of the climate scenarios. Warmer temperatures in the western United States have already enhanced the opportunities for insect spread across the landscape (Crozier, 2002). It is very likely that these natural disturbances will be altered by climate and will have an impact on US forests and forestry.

Producer and Consumer Impacts. In the aggregate, where climate change was projected to induce yield increases, consumers were found to benefit but not producers. Projections of yield decreases had the opposite effect. Producers' income from forestry activities, therefore, appears to be most at risk from climate change.

Adaptation Alternatives. The forest sector was found to have adaptation or adjustment mechanisms that may help to mitigate climate change impacts, including land-market adjustments, interregional migration of production (e.g., northerly migration of productive capacity), substitution in consumption between wood and nonwood products (reflected in overall growth in wood product use) and between sawtimber and pulpwood, and alteration of stand management. Stand-management options include types of site preparation and planting stock, fertilization, thinning, salvage of dead or dying trees, rotation age, and harvesting patterns among owners and regions.

Complications in a Complex World

For decision makers, the long time periods between germination of a tree seed and maturation of a forest crop mean that adaptation may take place at multiple times during a forestry rotation. The adjustment dynamics will be complex, in part, because better information on climate change and its effects will emerge over the course of a rotation. In forestry, longer rotation lengths complicate the development of data on actual biological responses of trees and forests to global change. Those rare long-term studies of tree growth have provided insights into relationships between trees and climate (particularly drought impacts). However, the uncertain effect of increased carbon dioxide on trees is only now being studied in comprehensive long-term experiments on how trees behave when exposed to alternative CO_2 levels and other stresses (such as ozone). Little is known about how these experimental results on individual trees generalize to stand, forest, and regional levels or to other tree species.

In addition to lengthy rotations for forest crops, the impacts resulting from climate change are unclear because of uncertain future changes in population, land use, trade in wood products, consumption of wood products, recreation patterns, and human values. For example, if human needs from forests increase over the next 100 years and imports are limited, the socioeconomic impacts from climate change would be greater than if needs were low or products could be imported from areas where climate might increase forest growth. These uncertainties increase the value of using scenario analysis in planning policy interventions in the forest sector. Projecting impacts of global climate change on the US forest sector helps to place in context concerns about economic shifts and the importance of human actions in adaptation and mitigation.

Based on the magnitude of changes in forest yields due to climate change as estimated by ecological models, we are led to expect relatively small *aggregate* welfare and economic impacts at a national level (Joyce et al., 1995, McCarl et al., 2000, Shugart, Sedjo, & Sohngen, 2003). At present, however, these yield-impact estimates have a wide range of uncertainty. Short-term impacts could become large, if climate change were to involve significant shifts in regional weather patterns or dieback in existing stands with large losses in timber stocks.

This paper has not addressed the impact of climate change on nonwood forest products and services, such as biodiversity, recreation, edible fruits, and other nonwood products. In general, the influences of climate change on these goods and services are more difficult to assess, because our understanding of the demand for these products is incomplete globally and because of high uncertainty regarding ecological effects of climate change. It is likely, however, that the impacts on nonwood forest products will vary from place to place, depending on the nature of climate change. Impacts on forest recreation, for example, will probably vary by the type and location of activity. Some activities, such as beach recreation at mountain lakes, might benefit as a result of extended seasons. Other uses that are sensitive to average temperatures and climatic variability, such as coldwater fishing in streams and snow skiing, may lose. Industrial wood products, in contrast, may be less susceptible to climate change due to global market systems that allow wood trade from region to region. There are fewer such established links for nonwood forest products, however, so that they are likely to exhibit more vulnerability to climate change. Impacts on some nonwood products, however, would be global regardless of whether or not they are traded across regions. For example, biodiversity is a global public good, with potentially high public value in all regions.

For More Information

Alig, R., Adams, D., & McCarl, B. (2002). Projecting impacts of global climate change on the U.S. forest and agriculture sectors and carbon budgets. *Forest Ecology and Management, 169*, 3-14.

Crozier, L. (2002) Climate change and its effect on species range boundaries: A case study of the Sachem Skipper butterfly, *Atalopedes campestris*. In T.L. Root & S.H. Schneider (Eds.), *Wildlife responses to climate change* (pp. 57-91). Washington, DC: Island Press.

Irland, L., Adams, D., Alig, R., Betz, C., Chen, C., Hutchins, M., McCarl, B., Skog, K., & Sohngen, B. (2001). Assessing socioeconomic impacts of climate change on US forests, wood-product markets, and forest recreation. *BioScience*, *51*(9), 753-764.

Joyce, L.A., Mills, J.R., Heath, L.S., McGuire, A.D., Haynes, R.W., & Birdsey, R.A. (1995). Forest sector impacts from changes in forest productivity under climate change. *Journal of Biogeography*, *22*, 703-713.

Joyce, L.A., Aber, J., McNulty, S., Dale, V., Hansen, A., Irland, L., Neilson, R., & Skog, K. (2001). Potential consequences of climate variability and change for the forests of the United States. In National Assessment Synthesis Team (Ed.), *Climate change impacts on the United States: The potential consequences of climate variability and change* (chapter 17). Cambridge, UK: Cambridge University Press.

National Assessment Synthesis Team. (2001). *National assessment of the potential consequences of climate variability and change*. Washington, DC: US Global Change Research Program. Available on the World Wide Web: http://www.usgcrp.gov/usgcrp/nacc.

McCarl, B.A., Burton, D.M., Adams, D.M., Alig, R.J., & Chen, C.C. (2000). Forestry effects of global climate change. *Climate Research*, *15*(3), 195-205.

Shugart, H., Sedjo, R., & Sohngen, B. (2003). *Forests and global climate change: Potential impacts on U.S. forest resources*. Arlington, VA: Pew Center on Global Climate Change.

Vegetation-Ecosystem Modeling and Analysis Project. (1995). Vegetation/ecosystem modeling and analysis project: Comparing biogeography and biogeochemistry models in a continental-scale study of terrestrial ecosystem responses to climate change and CO_2 doubling. *Global Biogeochemical Cycles*, *9*, 407-437.

Ralph Alig is a research forester with the USDA Forest Service, Pacific Northwest Research Station, Corvallis, Oregon. Darius Adams is a professor in the Department of Forest Resources at Oregon State University, Corvallis, Oregon. Linda Joyce is Project Leader, USDA Forest Service Rocky Mountain Research Station, Fort Collins, Colorado. Brent Sohngen is an associate professor in the Department of Agricultural, Environmental, and Development Economics at Ohio State University, Columbus, Ohio.

CHOICES
The magazine of food, farm and resource issues
Fall 2004
A publication of the
American Agricultural
Economics Association

Overview of Agricultural and Forestry GHG Offsets on the US Landscape

Brian C. Murray

The articles in this issue by Reilly and Alig et al. have focused primarily on the potential impacts of climate change in the agriculture and forest sectors, respectively. However, as discussed in the introductory article by Sohngen and McCarl, agriculture and forestry could also play a role in actions to mitigate greenhouse gases (GHGs) and forestall the threat of climate change. This article provides a brief overview of the types of agricultural and forestry activities that could be undertaken to sequester or reduce GHG emissions as well as their technical and economic potential to offset emissions from other sectors of the economy. The co-effects of these mitigation actions on other (nonclimate) environmental outcomes are discussed in the article by Feng, Kling, and Gassman.

How Much GHG can be Mitigated in Agriculture and Forestry, and at What Price?

US agriculture and forestry operate on an extensive land base; thus, the biophysical potential for GHG mitigation in these sectors is quite large. Under current conditions, US agricultural soils and forests sequester about 700 million tonnes (metric tons) of CO_2 equivalent per year (EPA, 2004), over 90% of which is from forest carbon sequestration. Although this amount alone offsets about one tenth of national GHG emissions, various actions can be taken to enhance sequestration above these baseline levels. Estimates of the biophysical carbon sequestration potential from changing management practices on the nation's cropland alone range from 300 to 550 million tonnes of CO_2 equivalent per year (Paustian et al., 2001). That is equal to the amount of CO_2 emitted annually by about 25–45 million cars. There is also ample potential to enhance carbon sequestration through afforestation, which can store up to 5–10 tonnes CO_2 per acre per year over a timber rotation (20–50 years in the most productive forests of the Southern and Pacific Northwestern U.S.). Given the amount of land available for conversion from agriculture to forest, this could amount to tens or hundreds of millions of tonnes CO_2 of additional annual carbon sequestration. Moreover, long-term storage of carbon in harvested wood products is possible for several decades at least, though not all accounting frameworks would necessary include this as a creditable form of sequestration (e.g., Kyoto).

As a major emitter of CH_4 and N_2O, approximately 470 million tonnes CO_2 equivalent per year (EPA, 2004) or 7% of the total of all GHG emissions, substantial opportunity may exist to reduce these gases through changes in crop and livestock management if the economic incentives are strong enough.

Agricultural producers operate in competitive markets, often global in scale; the practices they currently employ are likely to be fairly efficient in producing as much saleable output as possible for a given level of inputs. Therefore, changes in agricultural land use and forest practices may involve opportunity costs in the form of higher production costs, lower or more variable yields, lower quality products, or some combination of the above. Farmers, then, may need some sort of economic inducement in order to engage in alternative practices that lower GHG emissions or sequester carbon. However, even if farmers are not directly paid to mitigate GHGs, they may do so as an economic response to GHG constraints put on other sectors of the economy, which could drive up prices of

What Activities in Agriculture and Forestry Can Help Reduce GHG Concentrations?

Agricultural and forestry activities can reduce and avoid the atmospheric buildup of GHGs, such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), in three basic ways: *sequestration, emissions reduction,* and *fossil fuel substitution*.

- **Sequestration**. CO_2 can be removed from the atmosphere and sequestered in soils, biomass, and harvested products, which can act as carbon sinks. Carbon sequestered in soils and biomass can be protected and preserved to avoid CO_2 releases to the atmosphere (i.e., remain sequestered instead of emitted).
- **Emissions reduction.** Agricultural CH_4 and N_2O emissions can be directly reduced by modifying livestock management and fertilizer applications. Emissions of CO_2 can be avoided indirectly by reducing the use of energy-intensive inputs in agriculture.
- **Fossil fuel substitution.** Net CO_2 concentrations can be lowered by using biofuels produced in the agricultural sector instead of fossil fuels to produce electricity. When biofuels are used, CO_2 is essentially recycled in the atmosphere, as carbon is sequestered in biomass throughout its growth stage and released during energy production. In contrast, fossil fuel combustion releases energy that would otherwise be stored permanently below ground in coal, gas, and petroleum deposits.

A list of specific GHG mitigation activities and the GHGs they most directly affect is provided in Table 1.

energy and energy-intensive goods (such as fertilizers) and thereby indirectly reduce input usage and corresponding emissions.

Several recent studies have examined the size of incentives necessary to generate GHG mitigation in the agriculture and forest sectors. Ongoing work by various researchers uses a model of the US forest and agricultural sectors (FASOMGHG) to estimate responses to a price incentive for GHG mitigation across these sectors. Results for the United States from one study using FASOMGHG (Lee, McCarl, Gillig, & Murray, in press) show the response from GHG price incentives ranging from $5 to $80 per tonne of CO_2 offered for all GHG mitigation options within the sectors (Figure 1). Some specific results include:

- Agricultural soil carbon sequestration and forest management are fairly low-cost options, each producing more than 100 million tonnes of CO_2 eq. mitigation per year at a GHG price of $5/tonne.

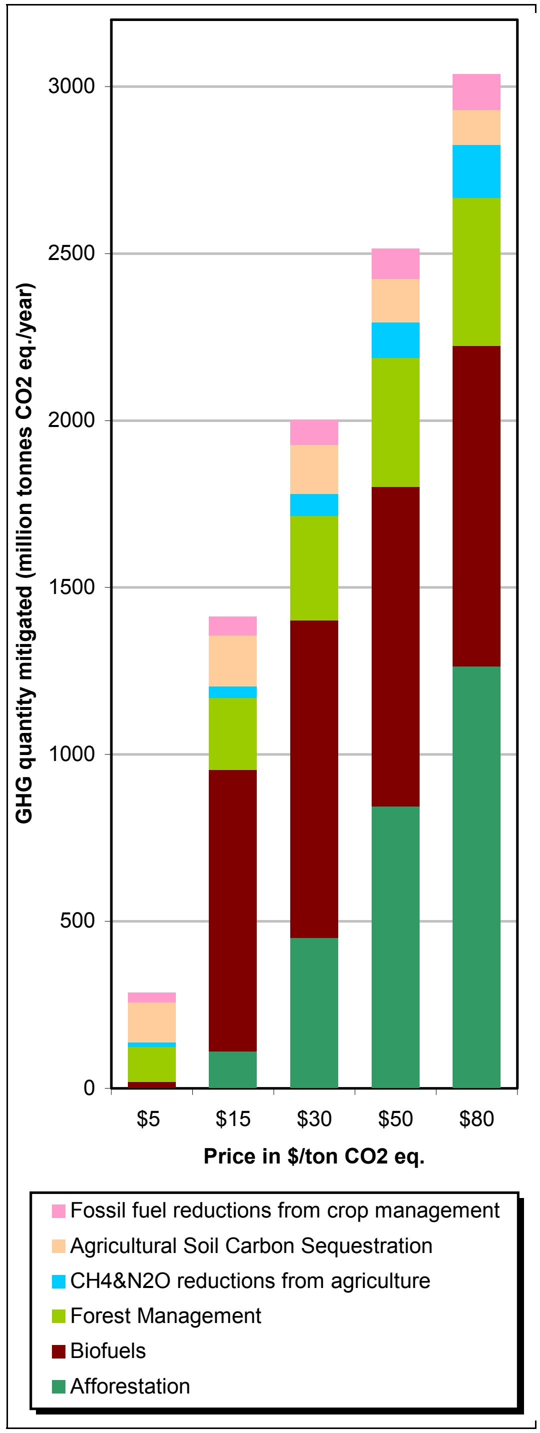

Figure 1. GHG mitigation by activity: US agriculture and forestry.

Note. Data from Lee et al (in press).

- Afforestation and biofuels become the dominant mitigation options at GHG prices above $15–30/tonne.[1]

Table 1. Key mitigation strategies in agriculture and forestry.

Mitigation strategy	Strategy nature	Greenhouse gas affected CO_2	CH_4	N_2O
Afforestation	Sequestration	X		
Rotation length	Sequestration	X		
Timberland management	Sequestration	X		
Deforestation (avoided)	Sequestration	X		
Biofuel production	Fossil fuel substitution	X	X	X
Crop mix alteration	Emission reduction, sequestration	X		X
Rice acreage reduction	Emission reduction		X	
Crop fertilizer rate reduction	Emission reduction	X		X
Other crop input alteration	Emission reduction	X		
Crop tillage alteration	Sequestration	X		
Grassland conversion	Sequestration	X		
Irrigated /dry land conversion	Emission reduction	X		X
Livestock management	Emission reduction		X	
Livestock herd size alteration	Emission reduction		X	X
Livestock system change	Emission reduction		X	X
Liquid manure management	Emission reduction		X	X

- Mitigation of CH_4 and N_2O from agriculture has a fairly small but steady scope for mitigation.

The results shown in Figure 1 are within the range of those found in other recent studies of mitigation potential in US agriculture and forestry. The USDA Economic Research Service recently completed a report (Lewandrowski et al., 2004) that found carbon sequestration potential in US agriculture to be up to 600 million tonnes of CO_2 per year at a cost of up to $35/tonne. Those numbers are lower than the totals in Figure 1, but the USDA study evaluated afforestation and agricultural soil management only, not forest management, biofuels, or non-CO_2 gas mitigation. The USDA's afforestation and agricultural soil carbon estimates are within the price-quantity range for those activities shown in Figure 1. A review of forest carbon sequestration studies over the last 10–15 years (Richards & Stokes, 2004) found a wide range of estimates of economic potential in the United States, ranging from 100 to 2,800 million tonnes CO_2 eq. per year of carbon sequestration at costs ranging from $1/tonne to $40/tonne.

These results suggest that US agriculture and forestry together have a rather sizeable potential to mitigate the buildup of greenhouse gases. The highest estimates, in the range of 3 billion tonnes of CO_2 eq. per year, would offset approximately 40% of all US GHG emissions—an amount larger than the GHG contribution of all motor vehicles in the United States. However, such a large potential can only be realized at very high incentive levels ($50–80/tonne CO_2 eq.). In contrast, GHG trades in the European Union are now being realized at prices of approximately $10/tonne CO_2 eq. and at much lower prices in informal markets emerging in the United States (see Butt & McCarl, this issue).

Agricultural and Forestry as GHG "Offsets"

The notion of agriculture and forestry activities serving as an offset to emissions in other sectors of the economy is rooted in the policy and institutional environment surrounding climate change mitigation. Most efforts to mitigate GHGs focus

1. *In this model simulation, biofuel potential is capped at just under one gigaton CO_2 equivalent per year, because of underlying assumptions about biofuel use capacity constraints in the US electricity generation sector. Without such a capacity constraint, biofuel potential would substantially outpace the other mitigation options at the higher prices evaluated.*

heavily on the CO_2 emissions from the energy, transportation, and industrial sectors, where a vast majority of developed countries' emissions originate. In the United States, for instance, CO_2 emissions from these sectors comprise about 80% of gross aggregate US GHG emissions (EPA, 2004). Much of the remaining GHG balance, however, can be attributable to agriculture and forestry activity, so there remains a substantial scope for US agriculture and forestry to offset the emissions from these other sectors.The institutions that have formed to implement GHG mitigation policy internationally and domestically in the United States have taken a mixed-bag approach to the role of the agriculture and forest sector in mitigation efforts. The Kyoto Protocol of the UN Framework Convention on Climate Change includes agriculture sector GHG emissions of CO_2, CH_4, and N_2O as part of each country's compliance commitment, but carbon sinks from agricultural soils and forestry activities have a more limited role, at least in the initial commitment period of 2008–2012. Of course, the United States has decided not to abide by the Kyoto Protocol commitments at this time, so the Kyoto provisions have fairly limited relevance for US domestic policy on the role of agriculture and forestry in GHG mitigation. However, the US Senate recently considered an alternative to Kyoto—the Climate Stewardship Act (S.139), introduced by Senators John McCain and Joseph Lieberman—which proposed binding GHG limits for some sectors of the US economy. The McCain-Lieberman bill was defeated in the Senate, but by a narrow enough margin (53–45) that follow-up proposals are now being considered. Under McCain-Lieberman, agricultural emissions were not to be capped, but mitigation projects in agriculture and forestry (and any other sector not covered in the cap) could be used to develop credits that are tradable to offset emissions in sectors covered by the caps (e.g., electric utilities, transportation, and manufacturing).

The following section and the article in this issue by Butt and McCarl provide more detail on project-based approaches to GHG offsets.

Project GHG Accounting Issues

In the context of GHG mitigation policy, a *project* refers to a purposeful activity in a specific location and sector to reduce GHGs below some baseline level in order to demonstrate a net emissions reduction. In principle, a project's mitigation quantity can be used to offset emissions in a capped sector. Project-based offsets introduce several important phenomena that would need to be incorporated into the project GHG accounting system in order to maintain the integrity of the trade between an emission unit allowed by one party (the buyer of the offset) and an emission unit reduced by another party (the project developer or seller of the offset). There is currently an effort underway by the World Resources Institute (WRI) and World Business Council on Sustainable Development (WBCSD) to develop consensus standards for project-level accounting across sectors and countries to enable more accurate comparisons across GHG projects. Key project accounting issues are discussed below.

Additionality and Project Baselines

The net GHG benefit of a mitigation project is the additional GHG emission reductions (sequestration) that occur relative to emissions (sequestration) levels in the project's absence. This is the concept of *additionality*. To determine additionality, project managers need to establish a project *baseline*, which is an estimate of the emissions or sequestration that would occur under business as usual. Setting an accurate project baseline can be difficult, because it involves quantifying a hypothetical outcome, rather than the world as it exists with the project. A number of analyses and GHG mitigation programs have focused on the complexity of setting a baseline case to estimate GHG mitigation benefits (e.g., WRI/WBCSD, 2003).

"Permanence" and the Risk of Sequestration Reversal

The accumulated carbon from forestry and agricultural sequestration practices can be re-released back to the atmosphere through either natural or intentional disturbances, such as fires, management changes, or logging. The climate benefits of carbon sequestration activities are therefore potentially reversible. One way to deal with this problem is to design project contracts that assign liability for carbon reversal if it occurs. However, a project may last for a finite time period, in which case the threat of reversal occurs after the project ends. One way to address this problem is to set up the transaction as a carbon lease or rental contract for a set period of time—say, five years (Marland, Fruit, & Sedjo, 2001). At the end of the lease, the credit expires and the buyer needs to replace the carbon with another set of verifiable sequestration (or emission reduction) units. Yet another way is to discount the amount of offset credit given in the first place to account for the possibility of future reversal.

Leakage

Project-based mitigation approaches run the risk that some of the direct GHG benefits of these efforts will be undercut by leakage of emissions outside the boundaries of the project. For instance, a tree-planting project in one place may displace tree planting that would have occurred elsewhere, a so-called "investment crowding" effect. Or, the adoption of zero-tillage in some locations may cause other producers to intensify their cultivation practices elsewhere (also called "slippage"). Therefore, it may be important to recognize the potential for leakage in agriculture and forestry projects and to develop methods to target or design projects to minimize leakage, monitor leakage after projects are implemented, quantify the magnitude of leakage when it exists, and take leakage into consideration when estimating net GHG benefits of activities.

Transaction Costs

In addition to the direct production costs from adopting changes in management practices, there are also costs associated with actually getting the mitigation project up, running, and operational. These transaction costs include those for

- initial project planning;
- measuring, monitoring, and verifying the project's GHG effects;
- market brokering and assembly; and
- insuring risks.

These transaction costs may be paid by the offset buyer, seller, or both, but in any case, they impose real costs that diminish the net value of the offsets generated. Transaction costs tend to have a large fixed-cost component to them and are therefore more burdensome for small projects than for large ones.

Table 2. Activity portfolio at different cost levels and time frames.

	Near term	Long term
Low cost	Agricultural soil carbon management Forest management	Reduction of non-CO_2 emissions from changes in crop and livestock practices
High cost	Afforestation Biofuels	Biofuels

Conclusions

Due to the effects of land use on the carbon cycle and the dominance of agriculture and forests as a land use in the United States, the scope for agriculture and forestry practices on GHG flows can be substantial. A number of actions within the sectors can be taken. Table 2 identifies candidate activities within the sectors at high and low prices and in the near term and long term. Some activities, such as changes in crop tillage practices and forest management, can be accomplished at a fairly low opportunity cost and in the near term. However, sequestration options tend to have a saturating effect over time as the new (postpractice) equilibrium for soil or biomass carbon is reached and may even experience reversal if harvesting or natural disturbances intervene. Therefore, emission reduction or fossil fuel substitution projects, such as biofuels, may have a more permanent impact on mitigation efforts in the long run.

For More Information

Lewandrowski, J., Peters, M., Jones, C., House, R., Sperow, M., Eve, M., & Paustian, K. (2004). *Economics of sequestering carbon in the U.S. agricultural sector* (technical bulletin no. 1909). Washington, DC: US Department of Agriculture Economic Research Service.

Lee, H-C, McCarl, B.A., Gillig, D., & Murray, B. (in press). U.S. agriculture and forestry greenhouse mitigation over time. In F. Brouwer & B.A. McCarl (Eds.), *Rural lands, agriculture and climate beyond 2015: Usage and management responses.* Dordrecht, The Netherlands: Kluwer Academic Publishers.

Marland, G., Fruit, K., & Sedjo, R. (2001). Accounting for sequestered carbon: The question of permanence. *Environmental Science and Policy, 4*, 259-268.

Paustian, K., Babcock, B., Kling, C., Hatfield, J.L., Lal, R., McCarl, B., Post, W., Mosier, A.R., Rice, C., & Robertson, G. (2001). *Agricultural mitigation of greenhouse gases: Science and policy options*. National Conference On Carbon Sequestration. Available on the World Wide Web: http://www.netl.doe.gov/publications/proceedings/01/carbon_seq/4C2.pdf.

Richards K.R., & Stokes, C. (2004). A review of forest carbon sequestration cost studies: A dozen years of research. *Climatic Change*, *68*, 1-48.

United States Environmental Protection Agency. (2004). *Inventory of U.S. greenhouse gas emissions and sinks: 1990–2002*. Washington, DC: EPA.

World Resources Institute and World Business Council on Sustainable Development (WRI/WBCSD). (2003). *The Greenhouse gas protocol: Project quantification standard*. Road Test Draft.

Brian C. Murray is director of the Environmental and Natural Resource Economics Program, Research Triangle Institute International, Raleigh, NC.

CHOICES
The magazine of food, farm and resource issues
Fall 2004
A publication of the American Agricultural Economics Association

Carbon Sequestration, Co-Benefits, and Conservation Programs

Hongli Feng, Catherine L. Kling, and Philip W. Gassman

Capturing and storing carbon in biomass and soils in the agriculture and forest sector has gained widespread acceptance as a potential greenhouse gas mitigation strategy. Scientists increasingly understand the mechanisms by which various land-use practices can sequester carbon. Such practices include the introduction of cover crops on fallow land, the conversion of conventional tillage to conservation tillage, and the retirement of land from active production to a grass cover or trees. However, the policy design for implementing carbon sequestration activities is still being developed, and significant uncertainties remain concerning the cost effectiveness of carbon sequestration relative to other climate-change mitigation strategies.

A potentially important plus in the cost-effectiveness ledger is the fact that the storage of carbon in agricultural soils is likely to come with a number of "co-benefits." In particular, carbon sequestration is not separable from other environmental effects of a given land-use practice. For example, the introduction of cover crops or the conversion to conservation tillage from conventional tillage also reduces soil erosion, in addition to sequestering carbon. The list of potential co-benefits is large, including wildlife habitat, water quality, and landscape aesthetics.[1]

A second key feature of carbon sequestration is its nonpoint source characteristic. The amount of carbon sequestered in a field or region is costly to measure and monitor, and protocols for doing so are still being developed, making it difficult to base any policies directly on environmental performance. (See Mooney, Antle, Capalbo & Paustian, 2004, for a discussion on the costs of measuring soil carbon credits.) In the near term, carbon sequestration policies are likely to base payments on land-use practices or other easy indicators of carbon sequestering activities.

The issue of co-benefits from sequestration activity has received relatively little attention, with some important exceptions. Plantinga and Wu (2003) estimated the reductions in agricultural externalities from an afforestation program encouraging the conversion of agricultural land to forest in Wisconsin. Using existing benefit estimates, they showed that the value of reduced soil erosion and some benefits from enhanced wildlife habitat are on the same order of magnitude as the costs of the carbon sequestration policy. Matthews, O'Connor, and Plantinga (2002) also found that carbon sequestration through afforestation has significant impacts on biodiversity and that impacts can differ by region. McCarl and Schneider (2001) found reduced levels of erosion and phosphorous and nitrogen pollution from traditional cropland as carbon prices increase. Greenhalgh and Sauer (2003) and Pattanayak et al. (2002) both showed that the water quality co-benefit of carbon sequestration is very significant.

Policy Design Issues When Co-Benefits are Considered

The co-benefit aspect of carbon sequestration and its nonpoint source nature have important implications for policy design. Two policy environments

1. *There may also be "dis-benefits" including increased pesticide use with some carbon sequestering practices.*

have been discussed by economists: (a) carbon trading in a well-functioning carbon market or (b) some type of green payment program akin to the Conservation Reserve Program (CRP) or the newly initiated Conservation Security Program (CSP). Explicit consideration of the co-benefits of carbon sequestration in the agricultural and forest sector will need to be treated differently, depending on whether carbon markets are the primary driver of sequestration activities or whether a green payment policy is pursued. In the context of carbon markets, co-benefits are externalities. To achieve socially efficient trades, we need to determine who will be responsible for (or benefit from) the noncarbon effects associated with sequestration activities. On the other hand, if we place carbon sequestration in the context of agri-environmental policies and consider it as just one of the multiple benefits from conservation practices, then a different set of issues arises, including determining which benefits are most important, which management practices should be encouraged, which geographical areas should be targeted, and whether costs, benefits, or some other criteria should be used to direct the allocation of funding.

A situation in which both green payment programs and carbon markets operate simultaneously adds complications. A green payment program would need to be designed to consider interactions between its payments and potential payments from a carbon market. For instance, if recipients of green payments were also eligible to sell carbon credits in a market, then practices that yield high levels of carbon sequestration relative to other environmental benefits would be particularly attractive to land owners (all else equal), potentially resulting in inefficient land-use decisions. If not, the carbon market would act as competition for land in the green payment program, with implications for the cost of the program. The issue of coordination between these two policy approaches is already on the horizon, as some conservation programs have been sequestering carbon for many years, and nascent carbon markets are emerging (see Butt & McCarl, this issue). The CRP program, with its annual budget of $1.6 billion, has been shown to have large carbon-sequestering potential. This is so despite the fact that carbon sequestration was added only in recent signups as an environmental benefit in the evaluation of the applications to the program.

Table 1. Total acres and annual change for some environmental indicators as a result of land retirement in the UMRB.

Policy scenarios	Carbon sequestration (tons)	Erosion reduction (tons)	N Runoff reduction (pounds)	Acres enrolled (acres)
Actual CRP	1,054,000	15,293,000	4,654,000	3,122,000
Targeting carbon	4,141,000	4,699,000	6,365,000	3,926,000
Targeting erosion	988,000	43,744,000	9,399,000	3,972,000

Co-benefits in the Upper Mississippi River Basin (UMRB)

Given the present existence of green payment programs (e.g., the CRP as well as the new CSP), the remainder of this paper explores the co-benefits of carbon sequestration in the context of subsidy policies. The example developed here compares carbon sequestration, erosion reduction, and nutrient reduction benefits across several different methods that could be used to implement the CRP program in the Upper Mississippi River Basin (UMRB). Similar methodologies are used in Kurkalova, Kling, and Zhao (2004), although that study explores the adoption of conservation tillage in the region.

The UMRB covers 189,000 square miles in seven states in the central United States and is a highly fertile agricultural region, with 67% of the area being either cropland or pasture land. The potential for significant co-benefits from carbon sequestration in the region is large, given that it contains more than 1,200 stream segments and lakes that appear on the US Environmental Protection Agency's listing of impaired waterways. The region contained 3,363,000 acres of CRP in 1997 with a total annual payment of about $277,500,000 (estimated with the rental payment information of the 18th signup of the CRP). Average CRP rental rates in Iowa and Illinois are above $120/acre, whereas Missouri and Wisconsin have the lowest rental rates with an average of about $60/acre. The average rental rate in Minnesota, $86/acre, falls in the middle.

To estimate the environmental benefits of converting land to CRP, we use the Environmental Policy Integrated Climate (EPIC) model version 3060.[2] EPIC simulations were run for each point in the Natural Resource Inventory database in the

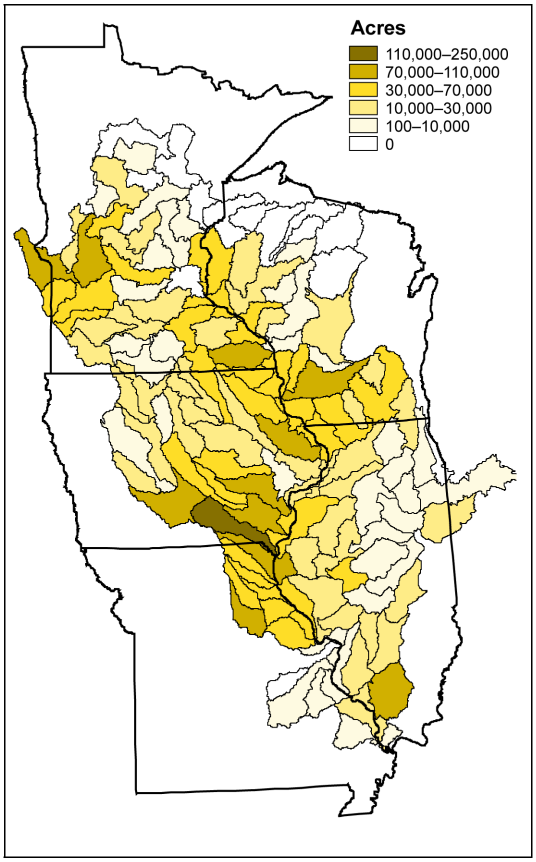

Figure 1. Area selected—the actual CRP program.

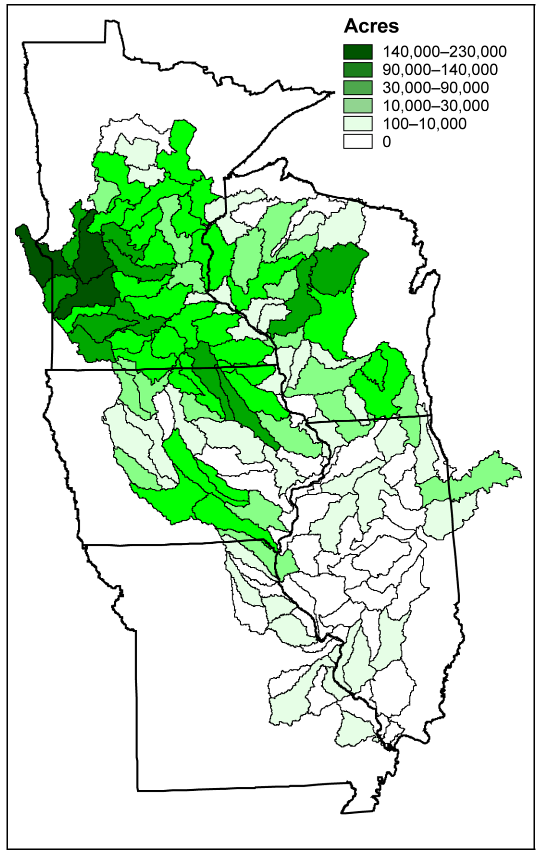

Figure 2. Area selected—target carbon.

region (more than 40,000 points in total) for ten years, the duration for most CRP contracts. Carbon sequestration is measured as the annual average of the total accumulated carbon (i.e., the difference of the total soil carbon pool at the beginning and the end of the simulation period). Other environmental benefits (reduction of water erosion and nitrogen runoff) are the average of the annual measurement, where CRP land is compared to intensive farming practices typical for the region. For the whole UMRB, the annual average carbon-sequestration rate for land converted to CRP is 0.487 tons/acre. The first row of Table 1 provides an estimate of three environmental benefits that result from the existing CRP program.

We next examine how sensitive these environmental results are to different ways of implementing the policy. Specifically, we consider how much carbon would have been sequestered by the CRP had the program been implemented primarily as (a) a carbon sequestration policy or (b) an erosion reduction policy. Information on rental rates is used to analyze two different scenarios with different targeting strategies, such that parcels with the highest targeted benefit are chosen until the program funding (the total expenditure for the actual CRP program) is exhausted.

Two results are evident in Table 1. First, if the CRP had been targeted at carbon specifically (row 2), then considerably more carbon would have been sequestered relative to the actual CRP (row 1). More reduction in nitrogen runoff would also have been achieved, although the erosion reduction benefit would have fallen relative to the existing program. Second, if the CRP had been targeted at erosion specifically (row 3), then significantly more erosion and runoff benefit would have been achieved, while carbon sequestration levels would have declined slightly. Different regions benefit from the program depending on which policies are used to implement the program. Figure 1 indicates

2. *Additional information concerning EPIC can be found in Gassman, et al. (2004). Details concerning model assumptions and data can be found in Feng, Kurkalova, Kling, and Gassman (2004).*

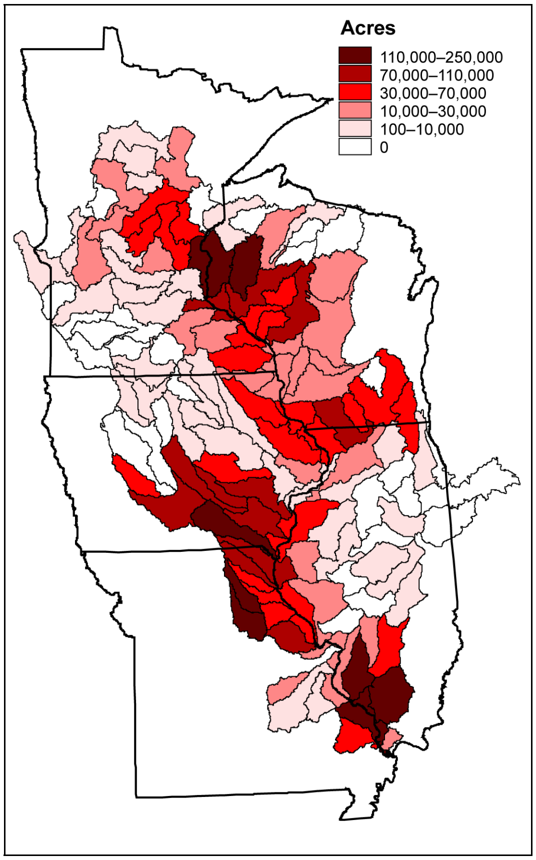

Figure 3. Area selected—target erosion.

that the actual CRP acres are about evenly spread around the region. When carbon is targeted, selected land concentrates in southern Minnesota, eastern Wisconsin, and parts of Iowa (Figure 2); when erosion is targeted, selected land concentrates along the Mississippi river (Figure 3).

To gain more perspective on the total amount of carbon sequestered, suppose there is a carbon market with various prices. At a carbon price of $10/ton—a relatively low value used in the literature—the value of the carbon sequestered by the actual CRP is about $10 million. This is far less than the actual program costs in the region, implying that at this price the carbon market would not be able to induce the land-use practice change the actual CRP program induced. On the other hand, if the carbon price were over $100/ton, the value of the carbon sequestered by the actual CRP would be about a third of the program's costs. However, if parcels with the best carbon potential participate in the market, as theory would predict, then the total value would be above $300 million, which exceeds the program's costs. In this case, the carbon market could replace the actual CRP in the sense of obtaining the same level of carbon sequestration. However, other environmental benefits might be reduced. This perspective illustrates the complication of policy design for carbon sequestration when both green payment programs and carbon markets coexist.

Conclusions

Given that carbon sequestration cannot be separated from many important co-benefits, policies focused on increasing carbon storage in agriculture and forest lands need to consider carefully the consequences of carbon sequestration programs on multiple environmental benefits. To demonstrate the importance of this point, this article presents results from an analysis of a large and potentially rich source of carbon sequestration as well as co-benefits—the Upper Mississippi River Basin. Our results suggest that had the CRP been designed to achieve the greatest carbon for the budget allocated, the land parcels chosen for inclusion would be significantly different from either the actual CRP or a different kind of program that targets soil erosion instead.

Numerous design challenges remain for conservation policies to elicit socially optimal levels of carbon sequestration, nutrient loads, soil erosion, biodiversity, and other landscape amenities. In addition to considering co-benefits, interactions among incentives from competing conservation programs (e.g., the CRP and the CSP) and the introduction of carbon markets will also present challenges to policy design. Finally, we note that the results presented here are based on field-level simulations for a large region and that there is ongoing development of EPIC, other environmental models, and economic models of costs. As the models evolve, the results of analyses such as the one undertaken here may change as well.

For More Information

Feng, H., Kurkalova, L.A., Kling, C.L., & Gassman, P.W. (2004). *Environmental conservation in agriculture: Land retirement versus changing practices on working land* (04-WP 365). Ames, IA: Iowa State University Center for Agricultural and Rural Development. Available on the

World Wide Web: http://www.card.iastate.edu/publications/DBS/PDFFiles/04wp365.pdf.

Gassman, P.W., Williams, J.R., Benson, V.R., Izaurralde, R.C., Hauck, L.M., Jones, C.A., Altwood, J.D., Kiniry, J.R., & Flowers, J.D. (2004). *Historical development and applications of the EPIC and APEX models* (ASAE paper no. 042097). PSt. Joseph, MI: American Society of Agricultural Engineers. Available on the World Wide Web: http://asae.frymulti.com.

Greenhalgh, S., & Sauer, A. (2003). *Awakening the dead zone: An investment for agriculture, water quality, and climate change*. Washington, DC: World Resources Institute. Available on the World Wide Web: http://pubs.wri.org/pubs_description.cfm?PubID=3803.

Kurkalova, K., Kling, C., & Zhao, J. (2004). Multiple benefits of carbon-friendly agricultural practices: Empirical assessment of conservation tillage. Environmental Management, *33*(4), 519-527.

Matthews, S., O'Connor, R., & Plantinga, A.J. (2002). Quantifying the impacts on biodiversity of policies for carbon sequestration in forests. *Ecological Economics*, *40*(1), 71-87.

McCarl, B.A., & Schneider, U.A. (2001). Greenhouse gas mitigation in U.S. agriculture and forestry. *Science*, *294*(5551), 2481-82.

Mooney, S., Antle, J.M., Capalbo, S.M., & Paustian, K. (2004). Influence of project scale on the costs of measuring soil C sequestration. *Environmental Management*, *33*(S1), S252-S263.

Pattanayak, S.K., Sommer, A., Murray, B.C., Bondelid, T., McCarl, B.A., & Gillig, D. (2002). *Water quality co-benefits of greenhouse gas reduction incentives in U.S. agriculture* (final report). Washington, DC: Environmental Protection Agency. Available on the World Wide Web: http://foragforum.rti.org/documents/Pattanayak-paper.pdf.

Plantinga, A.J., & Wu, J. (2003). Co-benefits from carbon sequestration in forests: Evaluating reductions in agricultural externalities from an afforestation policy in Wisconsin. *Land Economics*, *79*(1), 74-85.

Catherine L. Kling is professor of economics in the Department of Economics at Iowa State University and head of the Resource and Environmental Policy Division at the Center for Agricultural and Rural Development (CARD), Iowa State University. Hongli Feng and Phillip W. Gassman are assistant scientists at CARD, Iowa State University. *We appreciate the significant and careful computational assistance of Todd Campbell and editorial suggestions of Brent Sohngen and an anonymous reviewer. All errors and lack of clarity are our responsibility. For more information on the carbon sequestration work on the Upper Mississippi River Basin discussed herein, see our web site http://www.card.iastate.edu/environment/carbon/.*

CHOICES
The magazine of food, farm and resource issues
Fall 2004
A publication of the American Agricultural Economics Association

Should We Consider the Co-benefits of Agricultural GHG Offsets?

Levan Elbakidze and Bruce A. McCarl

Feng, Kling, and Gassman (in this issue) argue that significant co-benefits can be realized when agricultural management strategies are utilized to offset or reduce greenhouse gas (GHG) emissions. Such benefits arise in the form of cleaner water, increased recreational land, and improved farm income, among other categories. However, their attention to such effects is limited to those arising in the agricultural sector; we wish to broaden the issue to consider effects arising outside of agriculture.

About 84% of US GHG emissions arise from the petroleum-related energy and electrical power sectors. Under most of the proposed approaches for implementing GHG emission reductions, permits to emit would be allocated to emitting and carbon sequestering parties. In turn, a market structure would be established that allowed trading of permits. Many agriculturalists feel that such trading will involve sales by agriculture and that the case for such sales is bolstered by accompanying co-benefits (identified by many advocates as a win-win situation). This suggests that agricultural permit sales will allow increases in emissions by those in the energy sectors. The question, then, is what happens in terms of co-effects.

Let us consider the commonly discussed case where a coal-fired electrical power plant, which is allocated fewer emission permits than it needs under its current practices to meet its anticipated business activities, finds it less expensive to purchase sequestration-based agricultural permits than to reduce its own emissions. In turn, the sequestration activity would stimulate agricultural co-benefits. However, purchasing sequestration permits allows both power generation and coal burning byproducts, including commonly discussed air pollutants like NO_X, SO_X, and mercury, to increase. Because these emissions are often associated with health and other environmental costs, there could be attendant increases in damages relative to a no-trading case.

A full accounting of co-benefits, therefore, would suggest balancing the agricultural benefits and the nonagricultural costs. Specifically, policy makers interested in considering co-benefits should consider the relative magnitude of the countervailing coeffects. (Elbakidze & McCarl, 2004, provide a more detailed discussion.)

Estimates have been constructed for the coeffects of reduced GHG emissions by power plants by Burtraw and colleagues at Resources for the Future (Burtraw et al., 1999, 2003). Their results indicate that increased power plant activity would generate additional environmental costs amounting to about 50% of the value of emission permits purchased. These costs arise from the consequences of worsened health and needed increased investments in air pollution abatement. In addition, increased power plant activity increases ozone damages, which negatively affects water quantity and quality, nutrient cycling, recreational opportunities, and terrestrial carbon uptake. Felzer et al. (2003) estimate that the co-costs of this are an additional 5–20%. Collectively, then, the co-costs are in the neighborhood of 60% of the value of a permit. This compares with agricultural co-benefits currently estimated to be in the neighborhood of 60–70%. Agricultural co-benefits therefore may be almost entirely offset by the nonagricultural co-costs.

What, then, do we do about co-benefits and co-costs in formulating GHG policy? The implicit argument in the consideration of agricultural co-benefits is that there be a government role in increasing the use of sequestration-based credits through some form of subsidy that lowers the costs. The use of subsidies is justified, because agricultural co-benefits are not reflected in the price of traded permits. However, the countervailing co-benefits suggest that any incorporation of co-benefits into agricultural policy be carefully approached with simultaneous consideration of the implications of increased nonagricultural emissions.

There is also an inherent difficulty in both estimating the magnitude of co-effects and then comparing them on an equal footing (i.e., comparing the incidence of cleaner water with increased ozone-induced health problems). Co-benefits and costs are likely highly dependent on the specific situation posed by the purchasing emitter and the entity creating the sequestration depending on proximity to population centers, regional water quality, and so on. Such difficulties coupled with the approximate offsetting nature of the co-effects suggest that policy and trading be based on direct costs for now without consideration of the co-benefits.

References

Burtraw, D., Krupnick, A., Palmer, K., Paul, A., Toman, M., & Bloyd, C. (1999). *Ancillary benefits of reduced air pollution in the U.S. from moderate greenhouse gas mitigation policies in the electricity sector* (discussion paper no. 99-51). Washington, DC: Resources for the Future. Available on the World Wide Web: http://www.rff.org/Documents/RFF-DP-01-61.pdf.

Burtraw, D., Krupnick, A., Palmer, K., Paul, A., Toman, M., & Bloyd, C. (2001). Ancillary benefits of reduced air pollution in the U.S. from moderate greenhouse gas mitigation policies in the electricity sector. *Journal of Environmental Economics and Management*, *45*(3), 650-673.

Felzer, B., Reilly, J., Melillo, J., Kicklighter, D., Wang, C., Prinn, R., Sarofim, M., & Zhuang, Q. (2004). *Past and future effects of ozone on net primary production and carbon sequestration using a global biogeochemical model* (report no. 90). Cambridge, MA: Massachusetts Institute of Technology Joint Program on Science and Policy of Global Change.

Levan Elbakidze is a research assistant in the Department of Agricultural Economics at Texas A&M University. Bruce McCarl is Regents Professor of Agricultural Economics at Texas A&M University and a Choices co-editor.

CHOICES
The magazine of food, farm and resource issues
Fall 2004
A publication of the American Agricultural Economics Association

Farm and Forest Carbon Sequestration: Can Producers Employ it to Make Some Money?

Tanveer A. Butt and Bruce A. McCarl

Carbon sequestration has attracted the interest of researchers, energy industry participants, policy makers, forest producers, and farmers. Forest and farm producers have a special interest in whether such actions will increase their income. This paper explores that prospect in the context of the current and near-term future in the United States. In particular, we address key issues relevant to the question: *Can farmers or forest owners make some money from carbon sequestration?* These issues include the policy options that could stimulate carbon sequestration, the types of participants in a greenhouse gas (GHG) offsets/carbon market, and the existing status of sequestration-based income prospects.

Potential Policy Toward GHG Emission Mitigation

Under the 1997 Kyoto Protocol, many countries (including the United States at the time) agreed to limit their GHG emissions to a level below 1990 emissions by the period 2008–2012. The particular target for the United States was to achieve emissions levels 7% below 1990 levels. However, after its formation, the Protocol needed to be ratified by the party countries. As of May 2004, 124 countries had ratified the Protocol.[1] In 2002, the US administration indicated that it would not ratify the Protocol and promised its own emission reduction plan for the United States.

In early 2002, the US administration announced the Clear Skies Initiative, saying that the "administration is committed to cutting our nation's greenhouse gas intensity—how much we emit per unit of economic activity—by 18% over the next 10 years. This will set America on a path to slow the growth of our greenhouse gas emissions and, as science justifies, to stop and then reverse the growth of emissions" (President Announces, 2002). Under this initiative, emissions per unit of gross domestic product would be reduced by 2012. This program is currently voluntary. If implemented, it has been estimated that by 2012 the program would generate GHG emission reductions of a size about one sixth of those that would have arisen under the Kyoto implementation.

There are also various emission-reduction-related legislative initiatives, the most prominent of which is the McCain-Lieberman Climate Stewardship Act,[2] which, if passed, would limit country-wide emissions and establish a market in which producers could sell GHG emission offsets and sequestration.

Beyond the federal and global emissions reduction plans, there are a large number of state initiatives, all aimed at reducing emissions. For example, officials from eight states, including New York, New Jersey, Iowa, and California, recently filed a lawsuit against utility companies, charging that

1. *See http://unfccc.int/resource/convkp.html for more information.*

2. *See http://www.rff.org/rff/News/Features/Understanding-the-McCain-Lieberman-Stewardship-Act.cfm for more information.*

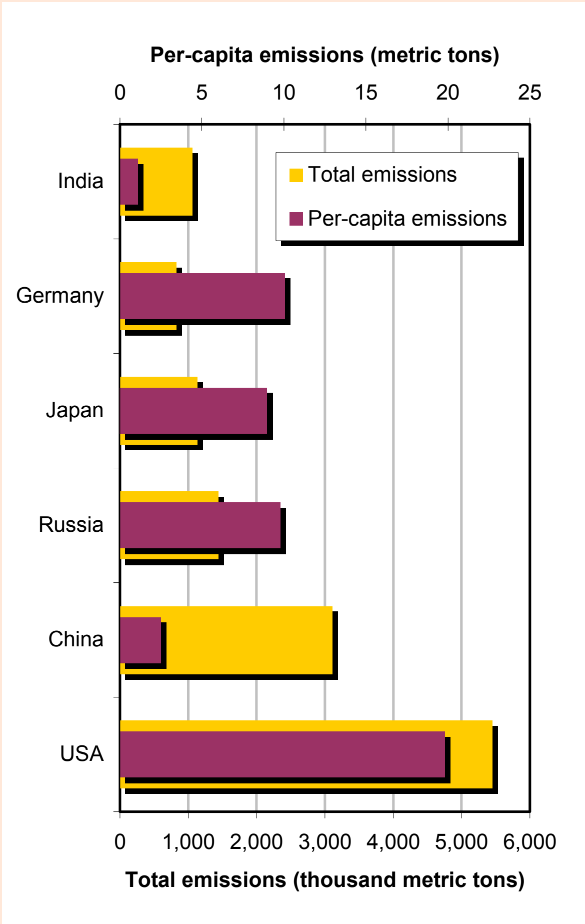

Figure 1. Total and per-capita CO_2 emissions.

they generate carbon dioxide emissions that harm human health and the environment. Other states have demanded emission-reducing technologies in power plants. Oregon has started the Forest Resource Trust program, which facilitates sequestration offsets by power plants.[3]

Who Might Buy and Sell in a GHG Offset/ Carbon Market?

Being the largest total and per-capita emitter (Figure 1), the United States has a fairly large role in the GHG mitigation arena. Emissions come largely from coal-fired power plants and petroleum-based energy use. If emissions were limited, entities in these industries (including transportation) would either need to cut back production (i.e., electricity generation, miles driven), alter technology or shift fuel sources to reduce emissions per unit of output, or (depending on whether a GHG trading program is implemented) buy emissions permits from others. If permit trades are incorporated as a policy, GHG emitters could potentially acquire offset credits at a lower cost than it would cost the emitting entities to alter operations so that emissions were reduced.

Emission offset credits can arise from various sources. GHG emitters may alter their practices to lower emissions, reduce fuel consumption, or switch to alternative fuels (for example, from coal to natural gas or biofuel). Alternatively, various agriculture- and forestry-based strategies can be pursued that involve soil or ecosystem sequestration through tillage change (i.e., adoption of conservation tillage), grassland expansion, afforestation, biofuel production, or longer forest rotations, among many alternatives (see McCarl & Schneider, 2001, for details).

As currently envisioned in the US policy process, the set of buyers and sellers of emissions credits is largely constrained to the large GHG-emitting industries (mainly power plants and other industrial power generators) and the land-using sectors. The land-using sectors traditionally have been considered to be sellers of credits, although this status clearly depends on an eventual distribution of property rights. For example, emissions from the land-using sectors could be capped at levels that would require cutbacks in those industries. At this time, it is less clear how other important GHG-emitting sectors, such as drivers of cars or other vehicles, would fit into a trading system.

The Current Prospects for Sequestration Producers' Making Money

The prospects for farmers and forest producers earning additional income through carbon sequestration depend on the eventual distribution of property rights for emissions, the status of the market, the competitiveness of land using sectors to produce GHG offsets, and the role of government. We briefly review these factors.

3. See http://www.pewclimate.org/what_s_being_done/in_the_states/ for a listing and more information.

Existing Status of the US GHG Market

The strength of the US GHG market, into which producers would sell, depends on the status of the GHG mitigation policy. Because federal policies currently do not mandate emission reductions, there is little stimulus in the United States for a broad carbon market to develop. However, it appears that many GHG-emitting industries believe that their assets could be at risk in a GHG-constrained world. There are several reasons for this. First, industry recognizes that GHG emissions are likely to be limited in the future, and these cuts could eventually be costly. For instance, various estimates indicate that Kyoto adherence would have required emissions by 2012 to be 30–40% smaller than they would have been without adherence. Second, many large emitters in the United States are international companies that do business in countries that will face emissions limits. They have already begun to limit emissions in their operations elsewhere in the world. Third, state programs in some regions of the country (as noted above) appear to be advancing more rapidly than federal policy and may require emissions reductions in particular places in the United States. Many US emitters are consequently already concerned about how they would operate under emission reductions, and as a result, they have started the quest to discover ways to reduce GHG emissions in an economically sound manner. Sequestration is one relatively large option on the table (see article by Murray, this issue).

Given the current policy arena, a *niche carbon market* has arisen. Emitters and offset producers already have signed limited-scope contracts for producing carbon offsets. The motivations of the participants in this niche market appear to be a mixture of:

- *environmental citizenship goals*, where firms wish to show themselves to be responsible environmental actors (possibly for advertising purposes);
- *business venture exploration*, where firms desire to see if they can develop future salable capabilities for GHG emission management; and
- *cost-reduction efforts*, where firms wish to tie up or discover low-cost alternatives that may be used to comply with future emission limitations.

On the supply side, participating farmers and forest producers either are in close proximity to the niche market or are venturing to explore new opportunities anticipating they will be low-cost producers of future offsets.

These niche markets generally are operating in one of two ways:

- *Direct contracts*. Some energy companies have directly approached producers to generate carbon offsets. For example, Reliant Energy, a Houston-based energy company, is funding planting of over 150,000 trees in an effort to capture an estimated 215,000 tons of carbon dioxide, generating "carbon credits" that will be retained by Reliant.
- *Market trading*. Commodity-market-like trading operations are emerging. In the United States, the Chicago Climate Exchange (CCEX) is based on a voluntary association of a number of emitters and offset suppliers. The CCEX has set up guidelines for participation. For example, in the case of soil sequestration, an entering group has to represent at least 10,000 metric tons of carbon, has to commit to four years of continuous conservation tillage, and must not plant soybeans for more than two years. No requirements are imposed on how that land was used in the past. Participating farms must have at least 250 acres. Farmers will be paid at the rate of 0.14 ton of carbon per acre. Carbon offsets generated from grassland also get credits at the rate of 0.2 ton of carbon per acre, provided grasses were planted after January 1, 1999. For forestry, the CCEX carbon allowance is based on a combination of age of the trees, planting densities, and tree species. A forester entering contract with CCEX must at least offer 3,400 tons of carbon for trees planted after January 1, 1990 on sites not forested before then. On average, an acre of trees provides approximately a ton of carbon (McCarl & Schneider, 2001). Under the CCEX, the auction prices as of early 2004 have ranged from \$1.84 to \$9.9 per ton of carbon, with a weighted average of \$3.6 per ton of carbon. Under the CCEX terms and these prices, farmers would get \$0.5/acre for tillage changes, \$0.74/acre for grass conversions, and about \$3.6/acre of forest.

Are Farmers Competitive Suppliers of Carbon Offsets?

The present buying and selling activities in the carbon market largely reflect exploratory behavior of buyers and sellers rather than widespread economic opportunities. If GHG emissions are capped or the GHG market otherwise develops more rapidly, the forces of supply and demand of sequestration will play a greater role. It is still unclear whether farmers and foresters are competitive suppliers of carbon offsets.

Paustian, Kurkalova, Babcock, and Kling (2001) show that sequestration cost under the tillage change may vary from $0 per ton of carbon to over $300 per ton of carbon for farmers in Iowa. McCarl and Schneider (2001) show that land management practices (mainly tillage change and converting cropland to grassland) are competitive at relatively low GHG offset prices but indicate the potential may be capped because offsets from forestry and bio-fuel production are competitive at higher GHG offset prices.

Under the current policy situation in the United States, which focuses on voluntary actions and goals rather than targets, GHG offset prices are likely to remain low, and forestry and agriculture have a small role to play. However, current research suggests that a combination of strong near-term targets for GHG emission reductions and a fully functioning GHG market could raise the willingness to pay for sequestration options substantially. For example, Edmonds, MacCracken, Sands, and Kim (1998) estimate per-ton costs of meeting the Kyoto Protocol target for the United States showing prices as high as $250/ton if all cuts were borne by the energy industry. They also show that with full international trading, prices fall to around $25 per ton of carbon—a price that is still substantially higher than prices currently observed in the United States.

Key Problems Influencing Carbon Sequestration

Although sequestration in land-use activities has been widely considered an option for reducing net GHG emissions, several key issues have been raised about the efficiency of potential trades. These efficiency issues will ultimately affect the scope of a trading market. However, because there has been no federal attempt to develop a GHG trading market in the United States, these issues have been treated in an ad-hoc fashion. For GHG trades occurring in other regions of the world that have adopted trading (e.g., Europe), they have been incorporated directly into the rules of the trading market. These issues are:

- *Additionality.* Only the additional carbon generated under a project will earn credit. For example, CCEX accepts forest projects only for trees were planted after January 1, 1990 on lands not grown before then since carbon growth thereon was preordained.[4]
- *Leakage.* Creditable emissions reduction on a project site may not lead to more emissions elsewhere.
- *Uncertainty and impermanence.* If the amount of emission reduction arising from a project is uncertain or is not permanent, the buyer of emission reduction credits might pay the sellers less than the market price of the credits (McCarl, Butt, & Kim, 2003).

In a marketplace, the competitiveness of agricultural projects will depend on how agriculture-based projects perform across these factors compared to nonagricultural projects.

Closing Remarks

The performance of the current carbon market reveals that the prospects for US farmers and forest producers to make money from sequestration are presently limited. The main determining factor currently is the lack of binding GHG emission limits. Despite this, we note that several activities are underway in the United States that attempt to induce GHG mitigation in the land-using sectors. Today, those who have participated in these programs are generally exploiting a small market niche. At the existing carbon offset prices (as reported by CCEX), in that narrow market, farmers' earning potential is modest: $0.49/acre for practicing conservation tillage and $0.74/acre for planting grasses. Participation is also limited—producers may place future income at risk, because the question of when a program will start is uncertain, and, in turn, what will count as preexisting activity is unknown.

4. *For details on additionality and leakage, see http://unfccc.int/issues/lulucf.html.*

The prospects for future producers earning additional income through carbon sequestration requires either US policy-level implementation of mandatory GHG emissions reductions or introduction of well-funded programs that subsidize carbon sequestration enhancing actions. Neither is present today.

For More Information

Edmonds, J.A., MacCracken, C.N., Sands, R.D., & Kim, S.H. (1998). *Unfinished business: The economics of the Kyoto Protocol*. Washington, DC: United States Department of Energy. Available on the World Wide Web: http://www.pnl.gov/globalchange/pubs/gtsp/kyoto_paper_98.pdf.

McCarl, B.A., & Schneider, U.A. (2001). The cost of greenhouse gas mitigation in US agriculture and forestry. *Science*, *294*, 2481-82.

McCarl, B.A., Butt, T.A., & Kim, M. How much would carbon cost a buyer? College Station, TX: Texas A&M University Department of Agricultural Economics. Available on the World Wide Web: http://agecon.tamu.edu/faculty/mccarl/1015.pdf.

Paustian, K.R., Kurkalova, L.A., Babcock, B.A., & Kling, C.L. (2001). The efficiency of sequestering carbon in agricultural soils. *Contemporary Economic Policy*, *19*, 123-124. Available on the World Wide Web: http://www.card.iastate.edu/publications/texts/00wp246.pdf.

President Announces Clear Skies & Global Climate Change Initiatives [press release]. (2002, Feb. 14). Available on the World Wide Web: http://www.whitehouse.gov/news/releases/2002/02/20020214-5.html.

The World Bank. (2003). *The Little Green Data Book – 2002*. Washington, DC: International Bank for Reconstruction and Development/The World Bank.

Tanveer A. Butt is a visiting assistant professor and Bruce McCarl is Regents Professor of Agricultural Economics at Texas A&M University.