U.S. Agriculture's Role in a Greenhouse Gas Emission Mitigation World:

An Economic Perspective

Bruce A. McCarl

Uwe A. Schneider

Bruce A. McCarl and Uwe A. Schneider are Professor and Research Associate, respectively, Department of Agricultural Economics, Texas A&M University. Seniority of Authorship is shared. This research was supported by the Texas Agricultural Experiment Station through the IMPAC project.

Abstract

International agreements are likely to stimulate greenhouse gas mitigation efforts. Agriculture can participate either as a source of emission reductions or as a sink for gas emission storage. Emission trading markets are likely to emerge where agriculture could sell emission offsets. Several agricultural opportunities are available at a cost of $10-25 per ton carbon dioxide. Abatement costs for non-agricultural industries have been estimated to be as much as $200-250 per ton carbon dioxide In the longer run, agriculture's role may diminish because many agricultural strategies offer only one-time gains and non-agricultural emitters may lower costs through technical change.

Key Words

Agricultural Sinks, Emissions Trading, Greenhouse Gas Emission Reductions, Kyoto Protocol

Executive Summary

International agreements such as the Kyoto protocol are likely to cause the United States and other countries to reduce net greenhouse gas emissions. Agriculture is both a source of emission reductions and a potential sink which can offset the greenhouse gas emissions through storage. In an effort to efficiently reduce emissions, a market is likely to emerge where agricultural interests could sell emission offsets.

The paper examines agriculture's role in greenhouse gas emission reduction efforts and reviews the literature on the potential costs of such a role. Specifically it addresses: How might agriculture participate in or be influenced by greenhouse gas emission reduction efforts? How might an agricultural greenhouse gas emission reduction role be implemented? What characteristics of agriculture might be relevant in formulating greenhouse gas emission reduction policy?

There are a number of agricultural strategies available which are likely to exhibit lower costs than current opportunities in non-agricultural industries. Several agricultural sink strategies, i.e. planting trees on agricultural land, may be time limited and may offset less and less emissions as time goes on. However, these strategies could be used as bridge to the future for non-agricultural strategies. There are also potential positive externalities from adoption of strategies to promote greenhouse gas emission reduction. Property rights of land owners need to be considered in policy formation.

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Greenhouse gas emissions (GHGE) constitute a global production externality which is likely to adversely affect climate. The United Nations Framework Convention on Climate Change (UNFCCC) was established to negotiate net GHGE reduction. Actions under that convention yielded the Kyoto Protocol which represents the first significant international agreement towards GHGE reduction. This paper addresses how agriculture may be affected by dealing with four questions.

- What is the reason society might be involved in GHGE reduction?
- How might agriculture participate in or be influenced by GHGE reduction efforts?
- How might an agricultural GHGE reduction role be implemented?
- What characteristics of agriculture might be relevant in formulating GHGE reduction policy?

1 What is the Reason Society Might be Involved in GHGE Reduction?

Greenhouse gas (GHG) emissions pose a global environmental problem. Their atmospheric concentrations have increased significantly and are projected to continue to do so. According to the Intergovernmental Panel on Climate Change (IPCC), increasing GHG concentrations will cause global mean temperatures to rise by about 0.3 degree Celsius per decade (Houghton, Jenkins, and Ephramus). Global warming in turn is predicted to rise the sea level, to change the habitat boundaries for many plants and animals, and to induce other changes of the complex climate system (IPCC). Major agricultural impacts of increased GHGE may include changes of the species composition in a given area, changes in crop yields, changes in irrigation water requirements and supply, and changes in cost of production. Many scientists believe the risks of negative impacts across society outweigh potential benefits (Bruce, Lee, and Haites) and suggest that society reduce net GHGE to insure that future problems do not arise. Currently, many countries are considering policy actions regarding net GHGE emission reductions.

1.1 The Kyoto Protocol

In 1992, the UNFCCC was established with the "ultimate objective ... to achieve ... stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (p. 9). As of October 1998, 176 countries had signed the convention. However, the convention does not specify either GHG concentration targets or emission reduction levels. The Geneva conference in 1996, the Kyoto conference in 1997, the Buenos Aires conference in 1998, and the Bonn conference in 1999 were intended to create more specific targets.

In Kyoto, a first agreement was reached (Bolin). Thirty-eight countries, mainly developed nations in North America, Europe, Asia, and Australia, agreed to reduce emissions of six greenhouse gases [carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydro-fluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6)] to five to eight percent below 1990 levels. U.S. negotiators agreed to reduce emissions by seven percent. The resultant, commonly called, Kyoto protocol requires each participating party to “have made demonstrable progress in its commitments“ (p.9) by 2005 and to achieve the emission reductions within the period 2008 to 2012. In addition to emission reductions, the treaty approves offsets through enhancement of sinks which absorb greenhouse gases.

Agriculture (using a definition including forestry) is mentioned as both an emitter and a sink in the protocol. Annex A of the Protocol lists agriculture as an emission sources from enteric fermentation[1], manure management, rice cultivation, soil management, field burning, and deforestation. The protocol also lists agriculturally related sinks of afforestation and reforestation. Additional sources and sinks are under consideration.

2 How Might Agriculture Participate in or be Influenced by GHGE Reduction Efforts?

There are at least four ways agriculture may participate in or be influenced by greenhouse gas mitigation efforts.

- ! Agriculture may need to reduce emissions because it releases substantial amounts of methane, nitrous oxide, and carbon dioxide.
- ! Agriculture may enhance its absorption of GHGE by creating or expanding sinks.
- ! Agriculture may provide products which substitute for GHGE intensive products displacing emissions.
- ! Agriculture may find itself operating in a world where commodity and input prices have been altered by GHGE related policies.

We deal with each of these ways providing cost estimates and literature citations where available. Our treatment of the literature is as global as possible but is undoubtably biased toward U.S. sources.

2.1 Agriculture - A Source of Greenhouse Gases

Agriculture's global share of anthropogenic emissions has been estimated to be about fifty percent of methane, seventy percent of nitrous oxide, and twenty percent of carbon dioxide (see Cole et al., Isermann). Contributions across countries vary with large differences existing between developing and developed countries. Developing country agriculturally based emissions largely arise from deforestation and land degradation. Developed country agriculturally based emissions are largely caused by fossil fuel based emissions through energy use; reductions in soil carbon through intensive tillage; nitrous oxide emissions through fertilizer applications, livestock feeding, residue management, and tillage (Watson et al.); methane emissions from livestock raising and rice production (Hayhoe). Within livestock production about two thirds of methane emissions stem from enteric fermentation of ruminant animals, mainly cattle with the rest from animal waste. Costs of agricultural GHGE reduction strategies have been examined by a number of authors (see Tables 1 and 2 for a summary).

2.1.1 Methane

Gerbens reviewed manure management alternatives and dietary changes for enteric fermentation management. The combined additive effect of all enteric fermentation strategies is shown in Figure 1. Gibbs estimated the costs of liquid manure management improvements (Figure 2) and Adams et al. (1992) examined the effect of reduced high-energy feed rations, and tax induced demand shifts for beef. Gerbens asserts that almost all treatments aimed to reduce methane from enteric fermentation would be more profitable than currently used technologies. The studies also indicate that the total reduction potential from enteric fermentation strategies is significantly lower than for livestock manure management.

Seven percent of current methane emissions (the U.S. target level under Kyoto) amounts to 1.5 million metric tons methane. Both Gerbens and Gibbs estimated that liquid manure treatment has the potential to reduce methane emissions by that amount at costs ranging between $100 and $200 per ton carbon equivalent. Adams et al. (1992), at a one million ton reduction level, calculated average costs for methane emission reductions ranging from about $100 (rice) to $700 (beef tax) per ton carbon equivalent.

2.1.2 Nitrous Oxide

Cost estimates for nitrous oxide emission reductions have been developed assuming relevant strategies are: a) reduced nitrogen fertilizer applications, b) use of nitrification inhibitors, c) improved nitrogen nutrient management, and d) reduced nitrogen content of animal feeds. The cost estimates vary widely in part due to the uncertainty in the magnitudes of emission levels. Battye, Werner, and Hallberg found reduced nitrogen content poultry feed to cost $1,300 per ton carbon equivalent while potential low protein amino acid supplements to swine feed could reduce feeding costs by $1,400 per ton carbon equivalent saved. In addition, Battye, Werner, and Hallberg argue improved nitrogen nutrient management can reduce emissions at cost savings. Average costs for nitrous oxide emissions from reducing anhydrous and total nitrogen fertilizer use were estimated in the neighborhood of $50 per ton carbon (Adams et al. 1992, Harnisch). About 0.13 million metric tons of N_2O emissions need to be reduced in order to meet the Kyoto requirements[2].

2.1.3 Carbon Dioxide

The volume of CO_2 emission reductions from agriculture is relatively low and thus will receive only brief mention here. Agricultural sources of carbon dioxide emissions from fuel use are minor relative to total societal emissions. U.S. EPA estimated agricultural emissions in 1996 from fossil fuel use to be less than one percent of the U.S. total emissions of 4,900 million metric tons of CO_2.

Soil carbon dioxide emissions have been larger in the past. In the first half of this century, Donigian et al. argue that for the central U.S. land conversion to agriculture decreased soil organic matter (SOM) to about fifty percent of its native level but the land base is not now expanding. While SOM remained relatively stable through 1970 (Allison), it then increased reflecting increased rates of reduced tillage systems (Flach, Barnwell, and Crosson). Similarly, total forest lands in the U.S. have been slightly increasing during the last decade (U.S. Forest Service). In countries with significant rates of deforestation emissions are significant. Houghton estimates that between twenty-five and thirty-one percent of global carbon emissions come from tropical deforestation and subsequent land degradation.

2.2 Agriculture - A Carbon and GHG Sequestering Sink

Another way to reduce net emissions is to increase absorption of GHG into the ecosystem through use of for example the soil or forests as a sink. This strategy is also commonly called carbon sequestration.

2.2.1 Soil Sequestration

Currently, U.S. agricultural soils hold about seven billion metric tons of carbon (Kern). Management practices such as land retirement (conversion to native vegetation), residue management, less disruptive tillage systems, increased use of winter cover crops and perennials, altered forest harvest practices, land use conversion to pasture or forest, and restoration of degraded soils can increase carbon retention. Kern argues that an increase in SOM could absorb 1 to 1.7 billion metric tons. Lal et al. estimate the fifty year potential at about five billion metric tons. Babcock and Pautsch analyzed the costs of carbon sequestration on cropland through reduced tillage generating estimates ranging from $0 to about $400 per ton of carbon depending on level sequestered (Table 3).

Soils also provide a sink for other gases, but much less is known. Estimates indicate that soils take up between ten and twenty percent of methane emissions (Reeburgh, Whalen, and Alperin). The soil sink of nitrous oxide is not well understood at the present time (Watson et al.). Studies (Mosier et al.) on grasslands indicate that conversion of grasslands to croplands tends to increase net emissions of nitrous oxide and methane. The net increase of methane emissions is due to a diminished soil sink capacity of cultivated land for methane.

2.2.2 Forest Sequestration

One management alternative that has been repeatedly examined involves conversion of agricultural lands to tree plantations (Table 3). Carbon is subsequently stored in the forest soil, the growing tree and any products which take up long term residence in buildings etc. Recent estimates of the average costs of sequestering carbon by tree plantations have been developed by Adams et al. (1999). Four selected carbon-fixing goals yielded undiscounted average annual costs between $13 and $26 per ton carbon. Their results were consistent with those of a number of previous studies (Winjum et al.; Dudek and Leblanc; Moulton and Richards; Adams et al.,1992; McCarl).

Tweeten, Sohngen, and Hopkins list further studies on carbon sequestration in forest ecosystems and tree plantations. Estimates have not been done for the costs via such possible strategies as Conservation Reserve Program (CRP) expansion[3], zero tillage, and forest harvest practice alterations.

2.3 Agriculture - A Way of Offsetting Net Greenhouse Gas Emissions

Agriculture could also be involved in providing substitutes for products whose use causes substantial greenhouse gas emissions. In particular, this could occur through use of agricultural commodities as biofuels replacing fossil fuels or through substitution of wood products for more GHGE intensive building materials.

2.3.1 Biomass for Power Plants

Substitution for fossil fuels generally involves using agricultural products as feedstock for electrical power plants or inputs to liquid fuel production. The power plant alternative involves burning agricultural biomass in the form of switch grass or short rotation woody crops to offset fossil fuel use for electricity generation. Burning biomass instead of fossil fuel would reduce net CO_2 concentration into the atmosphere because the photosynthetic process involved with biomass growth removes about ninety-five percent of CO_2 emitted when burning the biomass (Kline, Hargrove and Vanderlan) causing a recycling of the emissions. Fossil fuel combustion, however, releases the contained CO_2 without compensation.

A number of studies have examined the costs of biomass fuel substitution (recent ones are summarized in Table 4). The cost of CO_2 offsets with biomass-fueled electrical power plants can be computed from the results in McCarl, Adams, and Alig. Dividing their estimates of the extra costs of using biomass as opposed to coal by the difference in carbon dioxide emissions[4] yields an estimate of average abatement costs. McCarl Adams, and Alig estimates indicate that a million BTUs from biomass will cost $1.45 to $2.16 as opposed to a coal cost of $0.80 (U.S. DOE,1998a). The corresponding average costs of reducing carbon emissions by one metric ton are between $25 and $55 (Figure 4).

2.3.2 Liquid Fuel Production – Ethanol

Carbon emissions can also be offset by converting corn or other cellulose laden products into ethanol substituting for petroleum. Again this would recycle the majority of the GHGE from fuel use. The economics of ethanol has been investigated for more than 20 years with almost all results indicating a substantial subsidy is required to make it competitive with petroleum. Tyner et al. investigated the question in the late 70s. More recently Jerko derived ethanol production costs between $1.20 and $1.35 per gallon. Production of fossil fuel based gasoline costs only about $0.60 per gallon. Using the difference between Jerko's price and the gasoline price and an average carbon content of 0.616 kg carbon per gallon of gasoline (U.S. DOE, 1998b), average abatement costs range between $250 and $330 per ton carbon. Figure 5 shows ethanol based carbon emission reduction costs derived using the data in Jerko.

2.3.3 Building Products Substitution

Marland and Schlamadinger argue that increased use of wood in construction, while increasing carbon emissions from the forest products industry, reduces net emissions since it creates larger savings through reduced use of fossil fuels in the concrete block or steel industries. The authors, however, do not provide estimates of carbon equivalent costs.

2.4 Agriculture - Operating in a Mitigating World

Agriculture could be affected by greenhouse gas reduction policies which are largely directed toward other sectors. In particular, efforts to reduce emissions are likely to rise fossil fuel prices. For example, sellers of diesel fuel might have to purchase an emissions permit which would increase fuel prices. Similarly, fuel taxes might be imposed. Such increases would not only influence the cost of petro-based agricultural chemicals and fuel inputs but also alter off-farm commodities prices.

There have been a few economic examinations done[5]. McCarl, Gowen, and Yeats report an analysis where they show that, for example, a $100 per ton carbon tax would result in a 0.5 percent reduction in agricultural induced welfare. Collins and USDA Global Change Program Office studied the same magnitude of tax coming up with essentially the same conclusions. Antle et al. simulated economic effects of energy prices on Northern Plain grain producers. For a $110 carbon tax they estimate variable costs to rise between three and thirteen percent. Farm Bureau also did an analysis of the question (Francl; Francl, Nadler, and Bast) where they concluded that a $110 carbon tax would cause at least a twenty-three percent loss in net farm income for Midwest corn farms. As the estimated effects on farm income differ so does the scope of the analyses. While McCarl, Gowen, and Yeats treat both agricultural prices and crop acres endogenously, Antle et al. only allow for acreage substitution, holding prices constant. Farm Bureau did not use a complete cost benefit analysis rather based their analysis on simple budgeting, holding both prices and acreage constant. Generally, the results of the more complete studies reveal energy taxes are likely to have little agricultural sector impact.

3 How Might a Country Implement GHGE Reductions?

A system of incentives or regulations will be needed to secure participation in GHGE mitigation. The Kyoto Protocol establishes country-specific GHGE reduction targets, but provides flexibility in meeting these targets. It emphasizes "application of market instruments" to achieve the "quantified emission limitations" on a national level. Limits are not placed on individual emitters but rather on the whole country, and it is anticipated that domestic trading systems will be established. However, individual emitters are obligated to annually account, report, and verify their emissions. No provisions have been made yet for emissions trading between time periods, commonly called banking.

3.1 Markets for Emissions Trading

Markets for emissions trading should be at the top list of policy options to cost-effectively manage emissions (Sandor and Skees). Several emissions trading programs have been implemented. Examples in the U.S. are the Emissions Credit Trading (1977), the U.S. Lead Phase down (1982), and the Acid Rain Program (1995). Current policy debate on GHGE reduction implementation suggests that an emissions trading system much like the one used for the U.S. acid deposition program will be put in place. This system uses a cap and trade approach and has been successful in bringing down SO_2 emissions (Tietenberg et al.). It permits emitters who bear high costs from emission reductions to buy emission rights from lower cost emitters. The sum of all tradable emission rights equals the emission volume targeted. High penalties for violations and monitoring ensure compliance.

Fischer, Kerr, and Toman highlight features of potential GHGE trading systems. First, they assert that unlike SO_2 emissions, GHGE will have to be controlled upstream because control of GHGE at the point of billions of emission sources is too expensive. Fortunately, fossil fuel use is almost perfectly related to CO_2 emissions and much cheaper to account for. Also, Post et al. argue that keeping track of land management can provide reasonable estimates of agricultural sinks, as well as, methane and nitrous oxide emissions.

Second, Fischer, Kerr, and Toman assert that permits should be auctioned arguing that auctioning would substantially raise governmental revenue compared to gratis allocations such as grandfathering. The revenue then could be used to alleviate adverse effects, finance technological research and adaption to climate change, and benefit taxpayers through reductions in other taxes. With grandfathering, permits are allocated to emission sources according to their relative historical share on total. Thus, two additional weaknesses of grandfathering are that the system may be biased against new sources and that the beneficiaries of the initial allocation may not be the same who face the most adverse economic effects from emission control policies.

Third, credits for early emission reductions (commonly called emissions banking) would significantly lower compliance cost to the Kyoto Protocol. Burtraw, Palmer, and Paul estimate mitigation costs in the U.S. electricity sector in order to yield reductions equivalent to a full years obligation during the commitment period from 2008 to 2012. Their study shows average costs in the neighborhood of $25 per metric ton of carbon if emission credits were applicable over the next decade, i.e. from 2000 to 2009. According to a similar EIA study (US DOE, 1998b), the same emission reduction volume enforced in 2010 alone would cost on average $350 per metric ton of carbon.

3.2 Taxation or Subsidization

In addition to emissions trading, the Kyoto Protocol leaves open the possibility of taxes and subsidies. The nonpoint source nature of greenhouse gas emissions would again likely make it necessary to tax or subsidize inputs rather than emissions. Fossil fuel taxes may be employed because they have low transaction costs and yield revenues that can be used to finance other mitigation policies. Increased fossil fuel prices can also create a considerable economic incentive for emission saving technologies.

3.3 Trading Across Gases

Trading may be allowed across the spectrum of greenhouse gases. To place the gases on an equal footing, the IPCC developed the concept of global warming potential (GWP) which compares greenhouse gas ability to trap heat in the atmosphere. The IPCC uses carbon dioxide as a reference gas and calculates GWPs for three reference time horizons: 20, 100, and 500 years. For example, over a 100-year time horizon, one metric ton of methane and 21 metric tons of carbon dioxide trap an equal amount of heat in the atmosphere so the GWP of methane is 21. Equivalently, the GWP of nitrous oxide is 310. The other gases HFCs, PFCs, and SF_6 have GWPs of several thousand.

Implementation of trading systems across gases is likely to involve some type of uncertainty discounting. As argued above, emission reductions will have to be estimated upstream, hence uncertainties arise. The degree of these uncertainties, however, seems to differ widely between different GHG mitigation strategies. Nitrous oxide emissions savings from improved fertilizer management, for example, vary to a much higher degree, than do carbon dioxide emissions savings from reduced fossil fuel use. Thus, in a risk adverse society, the value of emission credits from fairly uncertain nitrous oxide reductions should be discounted relative to the value of emission credits from almost perfectly predictable carbon dioxide emission reductions. For example, Canada has proposed that carbon credits be determined in terms of a confidence interval.

3.4 Trading Across Countries

Four international implementation mechanisms are authorized. These include bubbles, emission trades, joint implementation, and the Clean Development Mechanism (CDM). The bubble approach permits groups of Annex B[6] countries of the Kyoto Protocol to merge their emissions compliance, setting few restrictions on trading within those country groups. The U.S. has reached a conceptual agreement with Australia, Canada, Japan, New Zealand, Russia and Ukraine to pursue a bubble group (U.S. DOS). Bubbles reduce the incentive for non-compliance through the joint responsibility of both the individual members and the regional organization. However, bubbles may result in efficiency losses compared to emissions trading for they restrict permit trading within the bubble member countries.

Emissions trading would allow Annex B countries to purchase or sell emission rights to any other such country. Each international transaction must be reported to and approved by the UNFCCC secretariat. The relevant modalities, rules and guidelines for these transactions still need to be defined. In principle, emissions trading could be authorized at the governmental level or at a sub-national entity level. The latter would increase trade efficiency.

Joint implementation (JI) refers to multi-national projects within Annex B countries, where involved parties can receive emission reduction units (ERUs). JI can be viewed as supplemental option to emissions trading. Instead of buying emissions allowances from another eligible party, a country can also directly finance and supervise emission reduction projects in that country. This can be more efficient than emissions trading, particularly, when significant technological differences exist between countries. The importance of JI, however, may be small with respect to the agricultural sector.

Through the Clean Development Mechanism, Annex B countries can secure certified emission reductions (CERs) in non-Annex B developing countries which are not subjected to emission reduction targets. The Clean Development Mechanism is especially favored by countries like the U.S. who are likely to buy additional emission allowances from outside to meet their national commitment. By integrating low cost emission reduction options in developing countries, this mechanism would result in a lower market price for emission permits.

3.5 Monitoring and Verification

A recurring theme in the Kyoto Protocol is the monitoring and verification of carbon emissions and sinks. To have a viable market in credits there needs to be a commodity that can be clearly identified and reliably and consistently measured. Marland, McCarl and Schneider note the possibility that GHG credits could depend on the uncertainty in their measurement. For example, Canada has proposed that credits could be claimed only to the extent that there was ninety-five percent certainty in the amount of carbon sequestered.

4. What Characteristics of Agriculture Might be Relevant in Formulating GHGE Mitigation Policy?

Agricultural policies have always been subject to controversial debates. Features of recent U.S. farm programs have been shown to induce changes in agricultural management and resource use. For example, the deficiency payment scheme motivated farmers to produce more. In this section, we will discuss characteristics of agriculture that should be considered in formulating GHGE mitigation policies.

4.1 Positive and Negative Externalities

Pursuit of agriculturally based policies limited to carbon sequestration can have a number of possibly, unintended beneficial and detrimental external effects. A total weighing of the externalities may be key to policy formation.

4.1.1 Potential Positive Externalities

When McCarl, Gowen, and Yeats examined the effects of carbon permit prices, they found that the policy stimulated widespread expansion of conservation tillage and a large reduction in soil erosion. A country bears a number of costs due to erosion in terms of water quality, ecology, sedimentation, etc. that would be reduced by increased use of conservation tillage. Thus, a policy based on carbon emissions or sequestration might benefit a number of erosion-related areas not originally the target of the policy. Other types of positive externalities could occur including:

a) Reduced tillage could alter soil organic matter, increasing soil water-holding capacity and leading to the need for less irrigation water;

b) Expanded conversion of agricultural lands to grasslands or forests could stimulate wildlife populations ;

c) Diminished use of fertilizer could alter the chemical content of runoff from agricultural lands affecting water pollution, water quality and ecology of streams, rivers, lakes and aquifers. Such alterations might improve the characteristics of the waters in these regions for use by non-agricultural water consumers;

d) Diversion of agricultural lands into energy production to reduce CO_2 emissions might induce technological improvement in agricultural crops, permitting expanded electricity generation at lower cost.

Many other cases could be cited but the basic point has been made. There could be positive environmental and economic benefits (externalities) arising out of policies intended to reduce CO_2 accumulation in the atmosphere.

4.1.2 Potential Negative Externalities

Along with the possibility of unintended benefits, there is the possibility of unintended costs. Here is a short list of possible negative externalities:

a) Adams et al. (1992), and more recently McCarl, show that programs designed to move agricultural lands into forestry could have deleterious effects on the traditional forest sector, leading to either deforestation of traditional parcels or reduced incomes.

b) Reductions in intensity of tillage have in cases been found to require additional use of pesticides for weed, fungus, and insect management. This may have deleterious effects on ecological systems, runoff, and water quality.

c) Expanded use of agricultural lands for carbon sequestration increases the competition with traditional food and fiber production. The result might well be decreased food and fiber production; increased consumer prices for crops, meat and fiber; and decreased export earnings from agriculture.

Again, many other cases could be cited, but the basic point has been made. There could be negative environmental externalities arising out of policies intended to reduce emissions or increase carbon sequestration.

4.2 Political Will for Public Intervention and Farm Support

Historically, the agricultural sector in many countries has received substantial public subsidies in the form of price and income supports. Today, U.S. farm subsidies have been reduced. However, there is also increasing pressure from farm interests to get back into the farm program business, particularly given low current prices for agricultural commodities. GHGE reductions under the Kyoto Protocol raise new possibilities for income supports. Perhaps a new breed of farm programs could be justified with funding based on energy and GHGE savings.

Also the emergence of a carbon offset market could reduce the government role. Private agricultural and non agricultural interests contracting for carbon would provide a new source of private income to farmers.

4.3 Demand Characteristics

Most agricultural production is up against an inelastic demand curve. People do not eat a great deal more even if food costs less, so increased production is often matched by declining prices. However, producing biofuels for the energy market would probably place agriculture as a fairly small player producing against an elastic demand curve. The carbon market may have similar characteristics. Such a market would not yield such large price reductions when agricultural carbon credits are included and would yield producer benefits, as opposed to consumer gains as has been the prevalent recent case. Adding such a market would have income distribution implications.

4.4 Practical Sectoral Economics

From a practical standpoint when considering both how to garner agricultural participation and how such participation might influence the economics of the agricultural sector, there are a number of important economic questions.

4.4.1 Are the Comparative Costs of Agricultural Net GHGE Reductions Low Enough?

Are comparatively cheap emission reductions of sink enhancements available? Will non-agricultural interests buy carbon credits from agricultural interests? Anecdotal evidence seems to suggest that this is the case, but the demand by non-agricultural interests for carbon credits is not clear. The evidence above shows the cost of several agricultural opportunities to be well below $100 per ton of carbon. Recent studies by the President's Council of Economic Advisors (1998), the Energy Information Administration of DOE (1998b), and by economists such as Manne and Richels have produced a wide range of numbers for the cost of carbon emission reductions in other sectors. The range of costs depends very much on program timing and trading regime permitted, i.e. the extent to which emissions credits will be traded internationally and which countries will participate, and when the program is implemented. Many cost estimates exceed $100 per ton of carbon.

4.4.2 Will a Carbon Program Disrupt the Traditional Agricultural Sector?

The economic impacts on the traditional agricultural sector participants depend on the intensity of mitigation efforts. The more agriculture enters the GHGE business the less there will be conventional agricultural production. Some mitigation strategies may be competitive (biofuel, ethanol, forestation) and some may be complementary (management alterations) to existing land uses. Competitive strategies will decrease conventional agricultural production and cause prices for food commodities to rise. However, such rises may induce further innovation and resources into the sector. With inelastic demand curves as often encountered for food commodities, producers are likely to gain but consumers will probably lose. Land prices would likely rise as consequence of the competition between crops used for food and crops including trees used directly for mitigation strategies, such emission sequestration and biofuel generation. The total issue portends shifts in the distribution of income between agricultural producers and consumers. We also need to consider the costs and benefits of the negative and positive program externalities, including, ideally, the costs and benefits of a changing climate.

4.5 Will the Farmer Participate

Many physical scientists evaluate farmer mitigation strategies and conclude there are “win-win” possibilities available asserting that the farmer would make money, emissions would be lowered, and often there would be positive environmental externalities. However, the adoption of such strategies by farmers is not granted. Farmers do not choose a “winning” strategy from a social or scientific point of view, they choose the “best” winning strategy available to them. Thus the strategy chosen must dominate the other strategies available from farmers’ viewpoint. Farmers may not choose a profitable reduced tillage method if a more profitable intensive tillage method is available. In addition, a number of other factors will enter into their decisions. In particular:

a) Risk is a consideration. Farmers who switch practices may experience not only changes in net returns but also changes in operational risk. Studies on tillage intensity show that slightly increased net returns under reduced or no-tillage are offset by higher variation in net returns thus increased risk (Klemme; Mikesell, Williams, and Long; Williams, Llewelyn, and Barnaby; Epplin and Al-Sakkaf). This may imply that to stimulate adoption the development of insurance programs partially alleviating risk may be desirable.

b) Management requirements can be more demanding for mitigation related strategies, particularly less tillage-intensive practices. Farmers may be unwilling to adopt practices that require substantially more critical management activities and a long learning time. This may be particularly true of older farmers nearing retirement. Extension efforts and insurance may be needed to facilitate adoption.

c) Many farmers are motivated by a stewardship role in terms of the soil and the environment. In that context one may find that farmers would more easily adopt soil conserving techniques than would otherwise be the case.

d) A number of the mitigation practices, once adopted, have to remain in use for a long time if GHGE gains are to be captured and maintained. Farmers may be unwilling to take on such long-term commitments and it may be difficult to pass on the commitment and monitor continued performance when farm ownership changes. Leasing arrangements may also create obstacles.

4.6 Incentive Program Design

Incentive programs which capture gains through emission reductions need to be carefully designed with respect to four big issues: 1) preservation of gains over time, 2) discouragement of countervailing actions, 3) avoidance of unintended program expenses (hitting more than the target), and 4) diminution of nonpoint sink uncertainties.

4.6.1 Preservation of Gains over Time

Many mitigative strategies regarding sinks result in increased absorption of GHGs until a new equilibrium state is reached. Growth rates of both trees and soil carbon accelerate over the first few decades, but decline as trees reach maturity or soils approach a new carbon equilibrium (Sprugel). Tillage experiments have shown that the carbon content of agricultural soils changes up to 30-40 years after tillage alteration (Hendrix). Many sink strategies have three important features. First, they cannot be counted as a recurring annual sink for GHG. Initially, they offset emissions, but later their net emission reduction falls close to zero as the new equilibrium is approached. Second, if after some time the management of the sink changes to a less "friendly" basis such as plowing the land, harvesting the trees, or adopting conventional tillage, then the stored GHG's volatize rapidly. Thus, management alterations once began must be retained. Third, the holding ability of carbon in soils may diminish as the climate warms as there is a negative relationship between higher temperatures and the organic matter content of soils (Kutsch and Kappen).

4.6.2 Countervailing Actions

The adoption of certain emission reduction strategies in one economy segment may lead to a substantial offset by countervailing actions in other parts of the economy. For example, McCarl recently found that land converted to forest under a carbon-based subsidy program would revert back to agriculture after one forest rotation unless the program was somehow designed to not let the land be harvested or to make it stay within the forest sector. In addition, he discovered a substantial countervailing movement of land from the traditional forest sector back into the agricultural sector when a carbon subsidy caused large amounts of land to be afforested. A program with a semi permanent ban on harvesting and a non reversion to agriculture clause might be required to maintain the gain over the long term. This will raise program cost.

4.6.3 Hitting More than the Target

The design of an incentive scheme may pose challenging policy targeting questions and could encounter unintended expenses. Our history of targeting nonpoint source pollution phenomena in agriculture has been checkered (Malik, Larson, and Ribaudo). The conservation reserve program, for example, helped reducing soil erosion significantly. However, the program most likely incurred unwanted expenses by paying farmers for enrollment of land that was not intended to be cultivated anyway. In the carbon arena, incentives designed to keep land in forestry might end up paying land owners who had no real intention of ever moving land out of forestry.

4.6.4 Uncertainty of Nonpoint Sinks

Acceptance of agricultural sink strategies implies the establishment of a trading scheme involving land in many diverse areas of the country. Unfortunately, emission savings from some sink enhancements are not perfectly correlated to land management, thus uncertainties result. The wide spread nature of possible participants coupled with the uncertainties may dampen the enthusiasm for including such sinks in a national or international emissions trading scheme and may discourage nonagricultural interests from approaching agriculture for permit trades. Taff and Senjem find that trading schemes' success depends on the nonpoint sinks' ability to offer remedial practices that are at once visible and whose effectiveness can be predicted within acceptable degrees of certainty.

4.7 Property Rights

Programs which tax or regulate alterations of land-use, will cause private property rights issues to arise. Public discussion of such issues has been observed, for example, when land-use changes have been restricted in order to preserve endangered species whose habitat is dependent on private property. Consider the following questions

Will we allow existing forest owners, who are not being compensated in the program, to choose to deforest their lands and move them into agriculture?

Will harvested forests be taxed in proportion to any carbon released?

Will farmers who are currently using some form of reduced tillage be allowed to later reverse that decision and use more intensive tillage systems?

Will land owners who now have land in some form of grass or forested lands and develop that land into tilled agricultural lands have to pay for emissions?

Will land that is currently rather minimally disturbed in the agriculture or forest sectors but moves into subdivisions or other uses that diminish the carbon storage potential be requiring emission permits ?

All of these appear to be major property rights issues.

4.8 Trade and Program Participation by Trade Competitors

The concept that not all countries will be treated equally, largely because of their development status, is prominent in the Kyoto protocol with the Annex B etc. country discussion. The Farm Bureau has stated opposition to adoption of the protocol because certain key competitive agricultural countries such as Brazil and Argentina are not covered (Francl). The Bureau's analysts feel U.S. farmers will lose their comparative advantage if they need to obey GHGE regulations while key competitive agricultural producing countries do not. Such an issue may well have to be resolved before countries like the United States ratify the protocol.

4.9 Eligibility of Agricultural Sinks

There are a variety of agricultural land-management practices that might enhance sinks or limit emissions. However, only the forestry activities involving afforestation, reforestation and deforestation appear eligible under the current phrasing of the Kyoto Protocol. Article 3.4 leaves the way open to add other items in the list at some future time but as of yet this has not occurred.

5 Concluding Comments -- Agriculture as a Bridge to the Future

Agriculture with the near-term possibilities for changes in tillage and/or forest incidence offers a near-term way of reducing GHGE which may or may not persist at a future date. The essential question is whether agriculture provides a way of reducing current compliance costs before major nonagricultural technological breakthroughs are available which reduce dependency on fossil fuels and lower future GHGE, such as the long awaited fusion development. Many of the above cost estimates seem low enough that agricultural strategies may have a role at least as bridge to future nonagricultural technological fixes. In meeting such agreements as the Kyoto Protocol, agricultural participation may be highly desirable as there are cheap GHGE reductions or offsets. However, the 10 years until the commitment period are short. GHGE offset strategies will be cheapest when trees and soil carbon reach their maximum growth rates which in the case of trees will not uniformly happen by the critical Kyoto dates. Agriculture certainly will respond if proper incentives or markets are provided as the historic participation in such programs as the U.S. conservation reserve program, farm program and payment in kind programs indicate.

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Table 1. Cost estimates for methane emission reductions

Author	Strategy	Cost in \$ per ton carbon and potential in million metric tons CH_4: Low		High		Comments
		\$/ton	Potential tons	\$/ton	Potential tons	
Gerbens	Enteric Fermentation	-3,700	0.12	270	0	see Figure 1
	Liquid Manure Management	20	1	94	1	
Gibbs	Liquid Manure Management	0	0	200	2	see Figure 2
Adams et al. 1992	Rice Cultivation	103	0	116	1	Low: 50 % fertilization reduction High: 100% fertilization reduction
	Altered rations	204	1			Low: 5% yield decrease (supply shift)
	Herd reduction	730	1			High: 5% demand increase (beef tax)

Table 2. Cost estimates for nitrous oxide emission reductions

Authors	Strategy	Cost in $ per ton carbon	Reduction in million metric tons of N_2O	Comments
Battye, Werner, and Hallberg	Improved crop nutrient management	-158	0.16	
	Nitrification inhibitors	164	0.13	
	Low protein swine feed	-1,400	0.17	
	Nitrogen reduced poultry feed	1,300	0.67	
Harnisch	Nitrogen fertilizer tax	370	0.02	
	No anhydrous nitrogen fertilizer	46	0.06	
Trachtenberg and Ogg	Improved nutrient management			Total benefits of 473-624 Mill.$, Estimate excess N-application at 24-32%
Adams et al. 1992	Nitrogen fertilizer use reduction	56	0.14	

Table 3. Cost estimates for carbon emission reductions through sink enhancements

Authors	Strategy	Cost in $ per ton carbon	Reduction in million metric tons of carbon	Comments
Winjum et al.	Tree planting	5		Reforestation, only vegetation carbon
		2		Afforestation, only vegetation carbon
Moulton and Richards	Tree planting	12	127	Soil, litter, and vegetation carbon, see Figure 3
		16	255	
		18	382	
Adams et al. 1992	Tree planting	16 23 30 62	127 255 382 636	Soil, litter, and vegetation carbon and also include land rental costs and forgone costs of less agricultural production, see Figure 3
Adams et al. 1999	Tree planting	21 23 25 26	43 (annually) 53 (annually) 63 (annually) 73 (annually)	Above and below ground carbon, study analyzed annual carbon flux increase, cost estimates are undiscounted, see Figure 3
Dudek and Leblanc	Tree planting	3 to 12	35	
McCarl	Tree planting	wide range	wide range	Supply curve up to 40 billion metric tons -see Figure 3
Parks and Hardie	Tree planting	9 to 10	42 (annually)	
Sedjo and Solomon	Tree planting	13 to 21	2600	
Sedjo	Tree planting	3.5	2900	Temperate forests
Stavins	Tree planting	< 66	9	37 U.S. counties in the South
Newell and Stavins	Tree planting	0 to 145	0 to 14 annually	36 counties, econometric model -see Figure 3

Authors	Strategy	Cost in $ per ton carbon	Reduction in million metric tons of carbon	Comments
Plantinga, Mauldin, and Miller	Tree planting	0 to ~ 110 0 to ~ 45 0 to ~ 75	0 to ~ 5 0 to ~ 16 0 to ~ 60	Maine South Carolina Wisconsin
van Kooten et al.	Tree planting	0 to 50 0 to 70	0 to 30 0 to 30	Western Canada, hybrid poplar used for wood products, infinite time horizon, zero percent (upper row) and four percent (lower row) discounting
Babcock and Pautsch	Reduced tillage	0 200 400	11 19 22	

Table 4. Cost estimates of carbon emission reductions through fossil fuel offsets

Authors	Category	Cost in $ per ton carbon	Reduction in million metric tons of carbon	Comments
McCarl, Adams, and Alig	Bio-fuel for power plants	11 (26)	26	see Figure 4, numbers in parentheses are cost estimates if no research progress is assumed
		24 (42)	137	
		53 (73)	560	
Graham et al.	Bio-fuel for power plants	29 to 52	0 to 520	
Walsh et al.	Bio-fuel for power plants	58	23	
		96	110	
Jerko	Ethanol	290	110	see Figure 5
		324	800	
Kane and Reilly	Ethanol	180 (320)	8	Authors provided two estimates: in parentheses are high cost estimates
		250 (370)	20	
		275 (390)	160	
Jerko	Both ethanol and bio-fuel	255	200	Ag and forestry model
		290	800	
van Kooten et al.	Coal substitution	40 (50)	5	Infinite time horizon, Hybrid Poplar only, Western Canada, zero (four) percent discounting
		110 (100)	33	

Figure 1. Costs of GHGE reductions through enteric fermentation, based on Gerbens

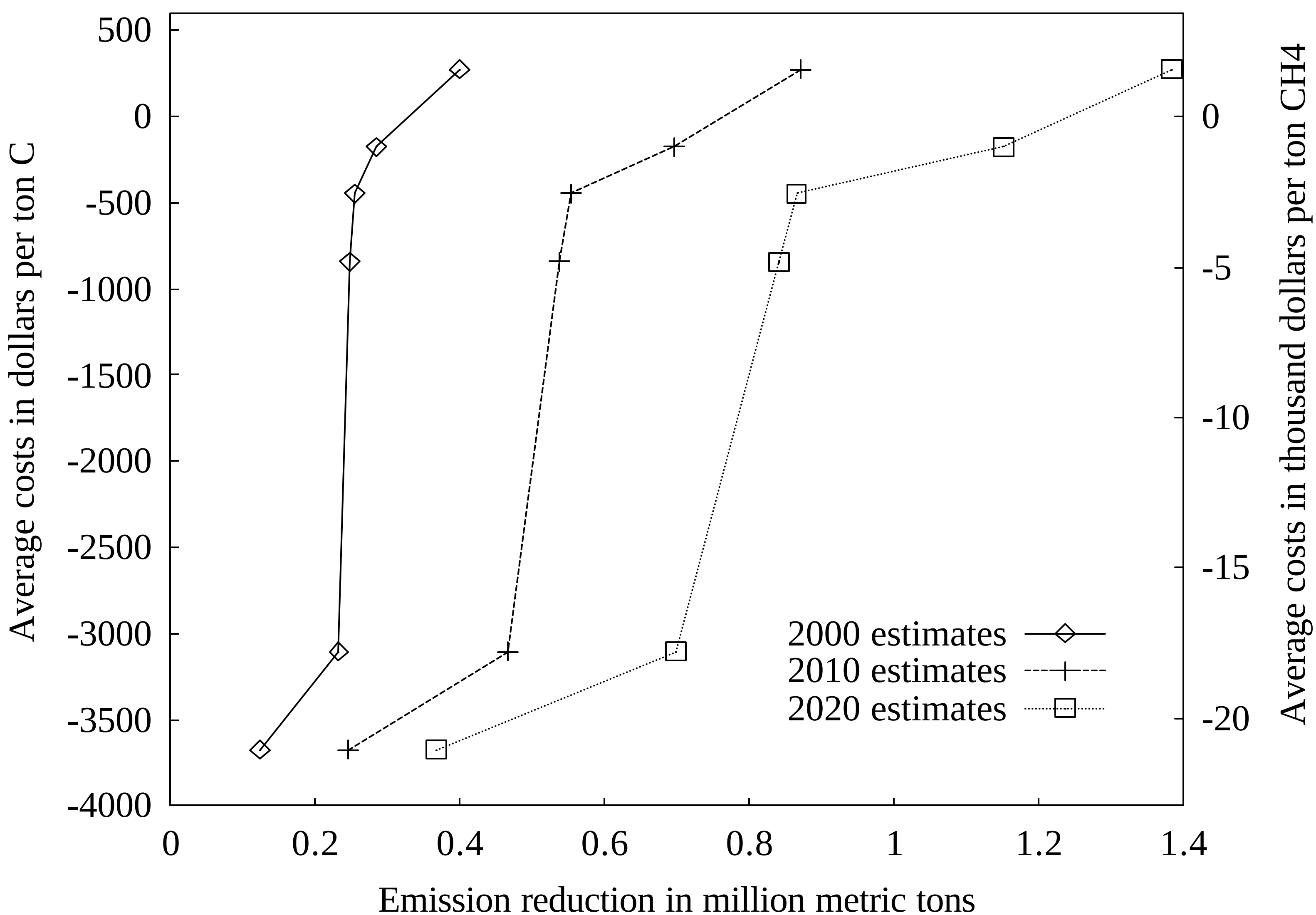


Figure 2. Costs of GHGE reductions through livestock manure management, based on Gibbs

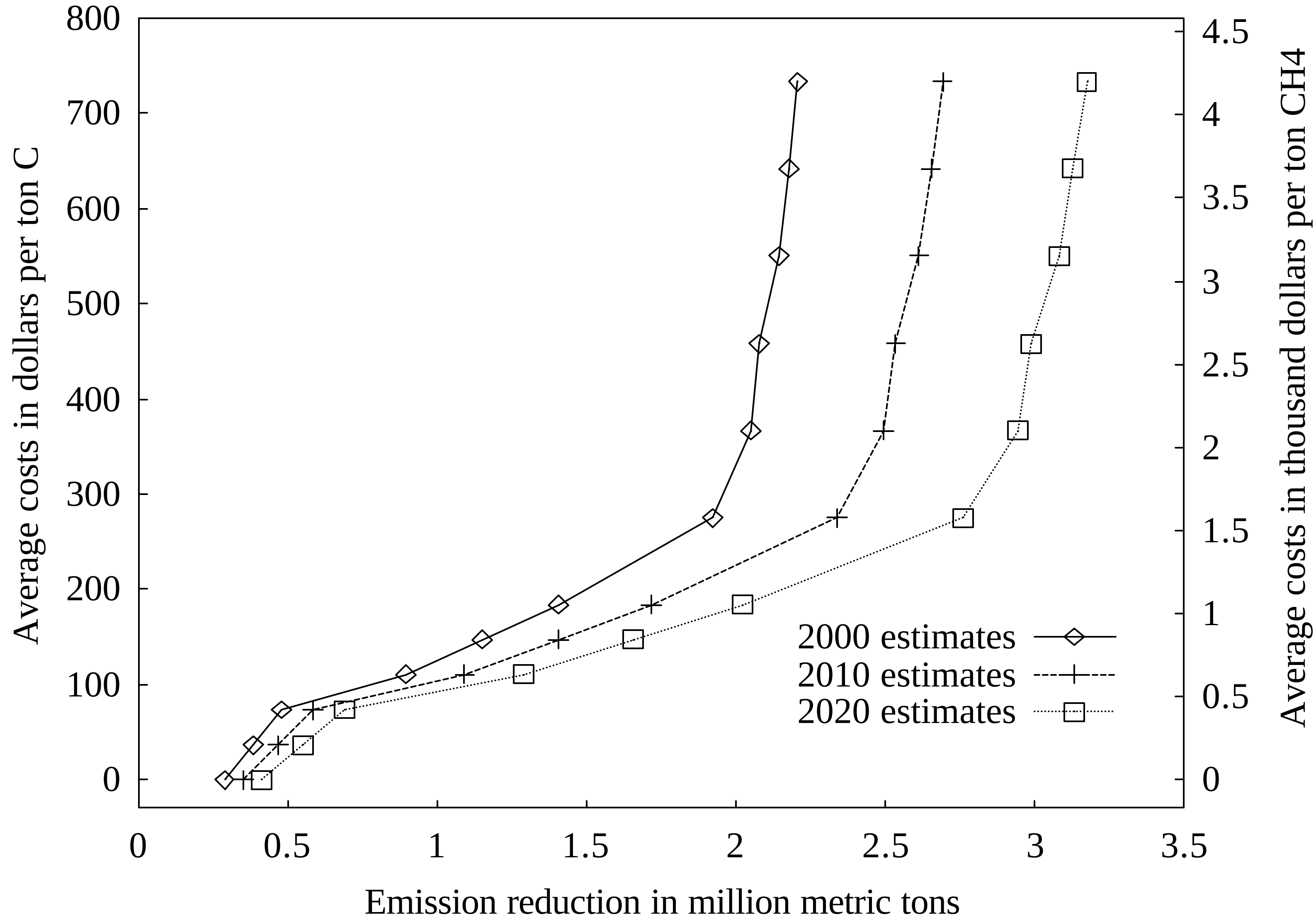


Figure 3. Costs of GHGE reductions through tree planting

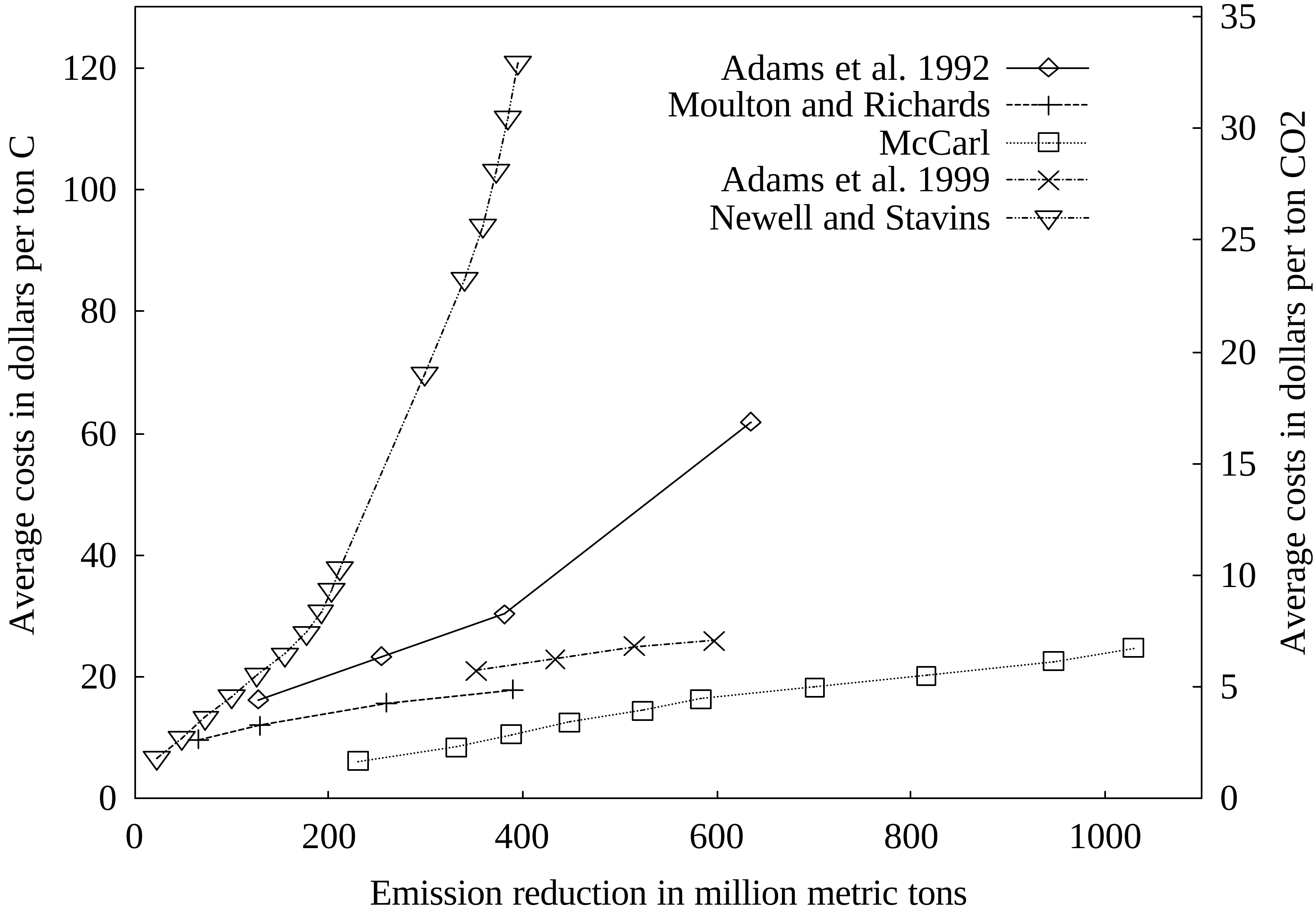


Figure 4. Costs of GHGE reductions through biofuel for power plants, based on McCarl, Adams, and Alig

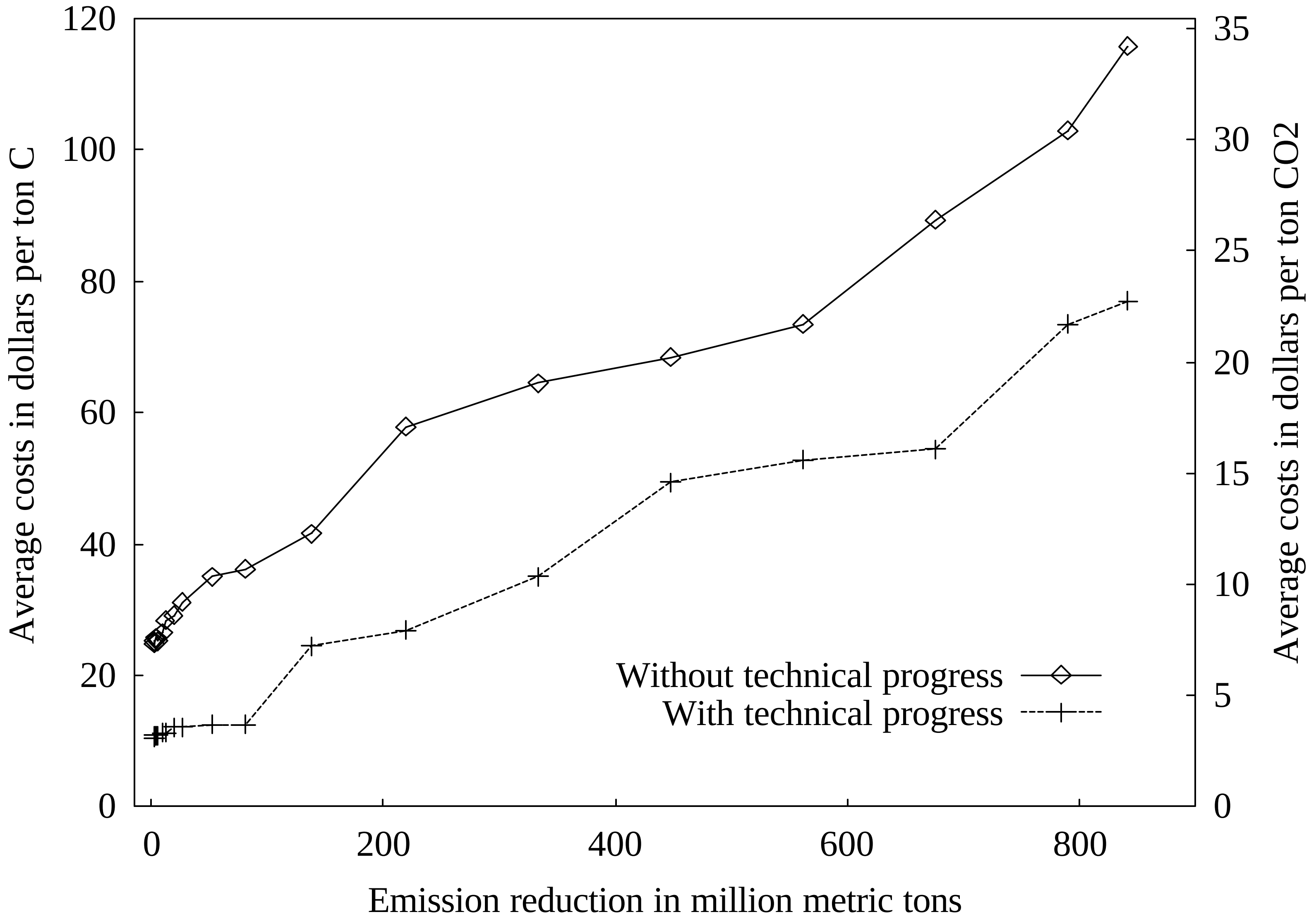
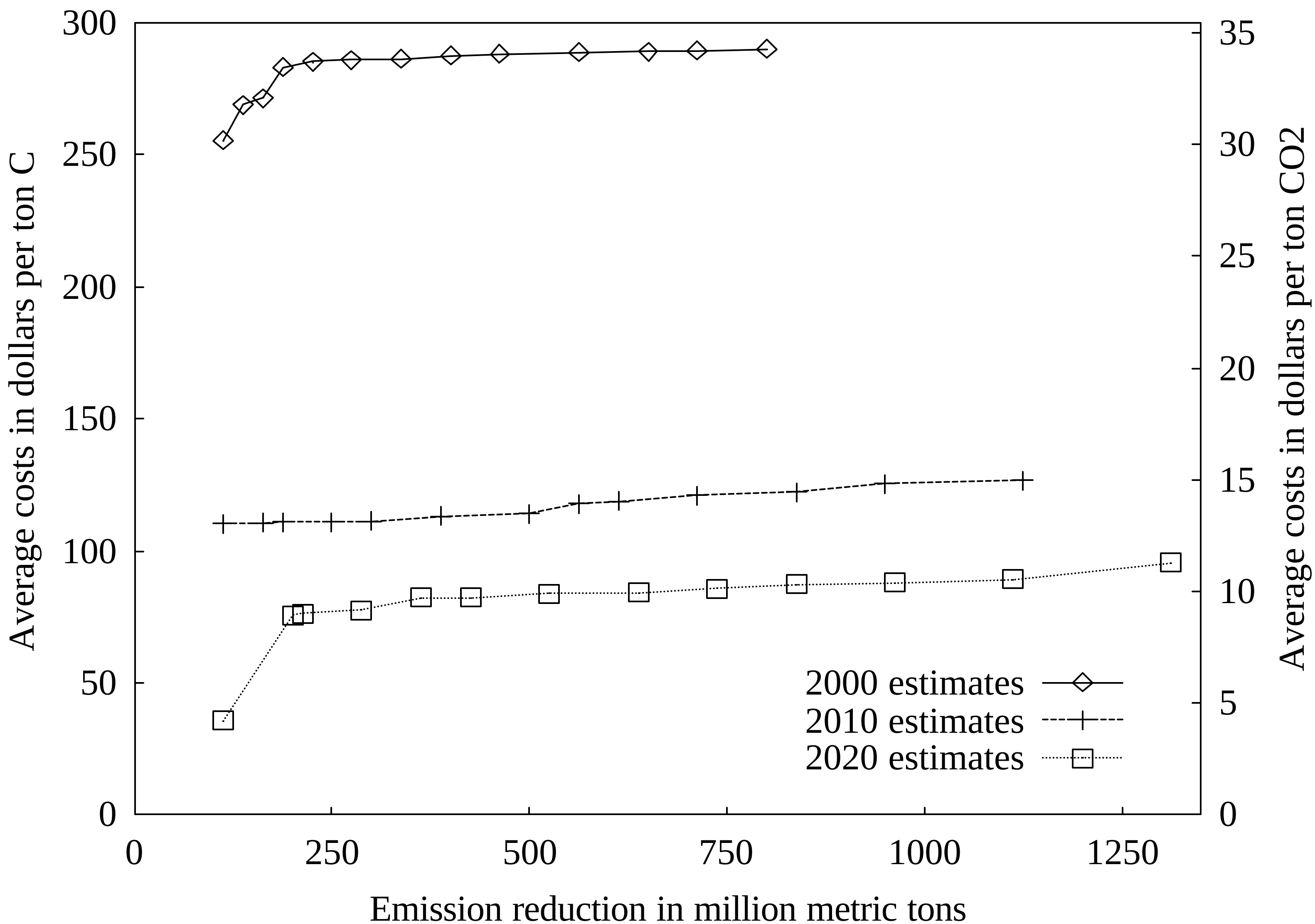


Figure 5. Costs of GHGE reductions through ethanol use, based on Jerko



Footnotes

1. Enteric fermentation relates to methane emissions through microbial fermentation in digestive systems of ruminant animals.

2. N_2O emissions in 1990: 0.4 million metric tons, current emissions: 0.5 million metric tons (U.S. EPA).

3. Note that the U.S. agricultural sector is currently experiencing a reduction in commodity programs and environmental incentive programs. Under the 1996 Farm Act, the CRP will spend twenty-two percent less than CRP historically and as of yet it will expire in 2002.

4. A weighted U.S. average of 210 pounds CO_2 per million BTU generated is used based on the CO_2 content of coal (U.S. DOE, 1998a) and biomass is assumed to displace 95 percent of that level of emissions.

5. Note that the tax levels examined in all studies reviewed here is substantially greater than any anticipated carbon tax. Current policy discussions seems to indicate carbon tax much more in the neighborhood of $10 per ton carbon.

6. Annex B countries comprise the developed countries including countries which are undergoing the transition to a market economy. The countries listed in Annex B are almost identical to the countries listed in Annex I to the UNFCCC with the exception of Croatia, Liechtenstein, Monaco, and Slovenia (included only in Annex B), and Turkey (included only in Annex I). The listing in Annex B to the Kyoto Protocol imposes specific emission reduction quantities on each contained country while the listing in Annex I or II of the convention only indicates the general agreement of contained countries to various emission control measures as qualified in the convention.