Economic Potential of Greenhouse Gas Emission Reductions:

Comparative Role for Soil Sequestration in Agriculture and Forestry

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Seniority of authorship is shared by the first two authors.
Paper prepared for presentation at DOE First National Conference on Carbon Sequestration, May 14-17, 2001, Washington D.C.

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Introduction

Society today stands at an important crossroads in terms of decision making. Increasingly, concerns are being expressed about the potential implications of the build-up in atmospheric concentrations of greenhouse gases. Alterations in agricultural and forestry (AF) land use and/or management provide a prospective way of mitigating net greenhouse gas (GHG) emissions. A number of AF practices are known to stimulate the absorption of atmospheric carbon or reduce GHG emissions at relatively modest cost with generally positive economic and environmental effects. Thus, an investigation of the comparative role for AF mitigation based practices in terms of economic implications appears in order.

AF practices partially involve sequestration and merit special consideration from that viewpoint. Sequestration involves capture of GHGs biologically or through industrial processes (e.g. by separating GHGs from fuels), then biological fixation or industrial injection into soils, aquifers, oceans or geological formations. AF sequestration generally refers to the absorption of carbon dioxide from the atmosphere through photosynthetic processes by plants or trees and subsequent fixation into soils, plants or trees. Thus, sequestration involves absorption of previously emitted gases and subsequent storage. Sequestration activities exhibit saturation where storage reservoirs fill up due to physical or biological capacity. They also generally store carbon in a potentially volatile state. For example, cutting down a forest and plowing the soil up for intensive farming quickly releases much of the sequestered carbon. Program costs involve development costs and operation costs as well as a maintenance cost to keep the carbon sequestered possibly even after saturation has been achieved. Comparison of the relevant role of sequestration considering these characteristics is another research need.

Objective

This paper examines the relative contribution of AF activities in an emission reduction program, focusing in part on the relative desirability of sequestration in forests and agricultural soils. The analysis will consider the effects of competition for land and other resources between AF activities and traditional production. In addition, analysis is done on the influence of saturation and volatility.

Approach

A two-pronged approach will be taken to the analysis of this question. First, following a paper by McCarl and Schneider (2001) we will use AF sector modeling to develop information on the marginal abatement cost curve describing the volume of GHG emission offsets at different farmer received carbon prices (i.e. market prices less brokerage fees and other transactions costs) ignoring saturation and volatility. That analysis will be done in the context of the total spectrum of U.S based AF responses to a net greenhouse gas mitigation effort. In particular, the role of AF sequestration efforts in the total portfolio of potential agricultural responses will be examined at alternative carbon price levels. The strategies considered are identified in Table 1. Definitions of those strategies and the characteristics of the underlying model are briefly summarized in the project description section below.

Second, following a paper by McCarl and Murray (2001), we will use a dynamic net present value framework to investigate the question of how a firm having to buy emission credits for the foreseeable future might factor in sequestration saturation and volatility to the prices it would be willing to pay for sequestration offsets. In turn, we will use the sector modeling methodology to investigate the implications for the role of soil carbon sequestration in a total AF mitigation effort.

Project Description -- Sector Modeling

The basic approach used for comparing the relative desirability of alternative mitigation strategies involves estimation of the amount of GHG net emission reduction supplied in the U.S. AF sectors and the choice of strategies under alternative carbon prices. The analytical framework employed had to be capable of looking at the induced adoption of the mitigation strategies listed in Table 1 as well as the complex interrelated nature of activities in the AF sectors. For example, use of a mitigation strategy could alter corn production and corn prices which in turn may impact exports, livestock diets, livestock herd size, and manure production as well as land allocation to biofuels and forests. The sector model captures these and other interactions. That model is a mathematical programming based, price endogenous sector model of the agricultural sector (ASM - McCarl et al., 2000b, Chang et al(1992), modified to include GHG emissions accounting by Schneider, 2000, and hereafter called ASMGHG) that is also expanded to include data from a forestry sector model (FASOM-Adams et al., 1996, Alig et al .,1998). ASMGHG depicts production, consumption and international trade in 63 U.S. regions of 22 traditional and 3 biofuel crops, 29 animal products, and more than 60 processed agricultural products. Environmental impacts include levels of greenhouse gas emission or absorption for carbon dioxide, methane, and nitrous oxide; surface, subsurface, and ground water pollution for nitrogen and phosphorous; and soil erosion.

ASMGHG simulates the market and trade equilibrium in agricultural markets of the U.S. and 28 major foreign trading partners. Domestic and foreign supply and demand conditions are considered, as are regional production conditions and resource endowments. The market equilibrium reveals commodity and factor prices, levels of domestic production, export and import quantities, GHG emissions management strategy adoption, resource usage, and environmental impact indicators. ASMGHG was then repeatedly solved for carbon prices ranging from $0 to $500 per ton of carbon equivalent. The 100-year global warming potentials of 1 for carbon dioxide, 21 for methane, and 310 for nitrous oxide were used to convert methane and nitrous oxide emissions to carbon dioxide equivalency. In turn the estimates were multiplied by 12/44 to convert from a carbon dioxide equivalent to a ton carbon equivalent basis.

Mitigation Strategy Overview

Readers are likely to be interested in the nature of the mitigation strategies and assumptions therein. A brief discussion of each item in Table 1 follows.

Afforestation and Timberland Management:

Forest based carbon sequestration can be stimulated by afforestation of agricultural lands, increasing rotation length, or changing management intensity through improved silvicultural practices. The data for the forest sequestration increase were developed using the Forest and Agricultural Sector Optimization Model (FASOM, Adams et al., 1996 , Alig et al .,1998). FASOM was repeatedly solved under alternative prices ranging from $0 to $400 per ton of carbon equivalents. For each FASOM solution, we computed and exported into ASMGHG the average annual sequestration rate over the first 30 years of the program (2000-2030) and the associated net land transfer from agriculture to forestry. The underlying data reflect regionally specific conversion of crop and pasture lands to and from trees as well as rotation and management changes.

Biofuel Production:

Offsets of GHG emissions from fossil fuel usage were examined by considering substitution of biofuels for fossil fuels. In particular, we incorporated poplar, switchgrass, and willow for fueling electrical power plants and cornstarch for conversion into ethanol. Information on the production and conversion alternatives were drawn from a joint U.S. EPA/DOE/USDA/OSTP study of biofuels as elaborated on in McCarl et al., 2000a. The emission savings were computed on a BTU basis assuming biomass substitution for coal in power plants and ethanol substitution for gasoline. In estimating emissions offsets the emissions accounting was the savings from not using traditional fossil fuels less the emissions from the energy involved in raising, hauling and processing the biofuels.

Crop Fertilization Alteration:

Nitrous oxide emissions are a byproduct of nitrogen fertilization. In turn, nitrogen fertilization also influences carbon sequestration rates. Altered fertilization practices were examined using data on crop yield response and resultant carbon sequestration rates. These data were developed via a crop simulation model as described under the tillage section below. The Intergovernmental Panel on Climate Change (IPCC) good practice inventory guidelines were used to estimate nitrous oxide emissions per unit fertilizer applied. These formulas basically had about 1.25 percent of applied nitrogen being released as nitrous oxide.

Crop Input Substitution:

A number of the inputs used in crop production are fossil fuel based or embody substantial GHG emissions in their manufacture. Carbon content estimates including upstream manufacturing carbon emissions were incorporated in the analysis for diesel, gasoline, natural gas, electricity, and fertilizers using the IPCC good practice guidelines. Thus, changes in crop mix, crop management, livestock numbers, etc. alter input use and resultant emissions patterns.

Crop Mix Alteration:

Not all crops emit equally because of differences in fertilizer applied, tillage practices, chemical inputs, harvest requirements, irrigation intensities, and post harvest processing among other factors. In this study, we included both direct emissions from these activities and indirect emissions from the involved inputs. As a result, carbon dioxide, nitrous oxide, and methane emissions are affected by crop mix choices.

Crop Tillage Alteration:

Energy intensity and soil carbon content are sensitive to choice of tillage method. The analysis considered implications of using conventional tillage, minimum tillage, and no tillage. Emission estimates for soil carbon increments were derived from a 63 region, 10 crop, 5 soil type crop simulation study using the EPIC crop growth simulator (Williams et al., 1989). The carbon sequestration rates pertaining to tillage changes were average results for the first 30 years of the program (2000-2030) adjusted to be consistent to an annual 75 million metric tons (MMT) from treating all U.S. croplands for sequestration as developed in Lal et al. (1998 who actually developed a range from 75 to 200+ MMT). Estimates were also developed on emissions from fossil fuels used to carry out the alternative tillage systems as well as applying an altered mix of chemical inputs based on USDA Natural Resource Conservation Service production budgets.

Grassland Conversion:

Reversion of cropland back to grassland is another mitigation strategy considered. Such a reversion generally increases soil carbon and, in addition, affects nitrous oxide emissions by displacing fertilizer used in crop production.

Irrigated/Dry Land Conversion:

Alterations in the allocation of land between irrigated and dry land usages affects soil carbon, nitrous oxide emissions, and fossil fuel use needed for water delivery and other crop production and requirements.

Livestock Management:

Methane emissions per unit product produced may be influenced by giving growth hormones to animals or by increasing the use of grain relative to forage in feeding. Growth hormone based alternatives were incorporated based on EPA data. Feed substitution was also embodied in livestock production system choice as discussed below.

Livestock Herd Size Alteration:

Livestock produce methane and nitrous oxide generally as a function of the total size of the livestock herd through manure and ruminant enteric fermentation. Thus a simple mitigation alternative is to cut the size of the total herd.

Livestock Production System Substitution:

Mitigation may be pursued through the substitution of livestock production systems for one another. In the case of beef cattle, slaughter animals can be produced using either stocker or feedlot operations. The relative GHG emission rate varies across these alternatives, i.e., feedlot production has lower per unit emissions.

Manure Management:

Manure is a source of methane and nitrous oxide. The manure handling system can influence emissions. For example methane emissions are greater the more water is involved in the system but methane recovery systems can also be employed. For this analysis, we incorporated data on methane emissions from liquid manure handling alternatives by region and livestock type based on EPA data.

Rice Acreage:

Decomposition of plant material in flooded rice fields leads to methane emissions. While alternative management systems may affect the amount of methane released, no consistent data were available at this point. Thus, the only rice related mitigation alternative examined here involves reductions in acreage.

Results -- Sector Modeling

Scientific evidence and the number of inquiries regarding AF GHG mitigation are growing rapidly. The data underlying this study, while the best available to us as at this point in time will be old and obsolete tomorrow and could even be improved by substantial efforts today. Consequently, we will not concentrate on specific empirical results. Rather we will highlight a set of general findings, that we believe are highly relevant to consideration of the appropriate role for AF sequestration and to the extent possible, that rise above the flaws in the underlying data.

AF Provides Cost Effective Emissions Offsets Particularly Through Sequestration.

Figure 1 shows the amount of carbon offsets gained at carbon prices ranging from $0 to $100 by broad category of strategy. Note in those results that up to 326 MMT carbon equivalent can be offset by AF means (Table 2). Low cost strategies involve foremost soil carbon sequestration and to some extent afforestation, fertilization, and manure management. To place these costs in perspective one should note Weyant and Hill's (1999) report of a multi model study of non-agricultural Kyoto compliance costs sponsored by the Energy Modeling Forum (EMF). Across that EMF set of studies, abatement costs vary with assumptions on emissions trading and because of different baseline emissions scenarios across models. For the case of the United States with carbon emissions trading among Annex I regions, primarily the developed industrial countries along with eastern Europe and the former Soviet Union, abatement costs were generally in the range of $50 to $100 per metric ton of carbon but ranged as high as $227. See MacCracken et al. (1999) for an example of the range of abatement costs that can be derived within one model. Marginal abatement costs are much higher without international trade in carbon emissions rights.

A Portfolio of AF Strategies Seems to be Desirable.

Today many different GHG emission (GHGE) mitigating agricultural strategies are being considered and often individually advocated. Our results show that a portfolio solution appears to be appropriate. Figure 2 shows the total response of mitigation over the total range of carbon prices. The results show a role for biofuels, forests, agricultural soils, methane, and nitrous oxide based strategies. The figure also shows that different strategies take on different degrees of relative importance depending on price level. While soil carbon sequestration peaks at around $50 per ton, biofuel offsets are not competitive for prices below $60 per ton. Reliance on individual strategies appears to be cost increasing. For example reliance solely on agricultural soil carbon (Figure 3 – economic potential line) means it would cost $30 to achieve 60 MMT while consideration of the total portfolio leads to a cost below $15 per ton (from table 2).

Difference Between Technical, Economic, and Competitive Economic Potential

Many of the estimates for the potential of selected strategies ignore cost and resource competition. Lal et al., 1998, for example compute a total agricultural soil carbon (ASC) potential, but do not specify the cost of achieving such a potential level of sequestration. Figure 3 displays ASC technical, economic, and competitive economic potential. The total technical potential in this case is 75 MMT annually but under reliance only on ASC this does not occur even for prices as high as $500 per ton. At lower prices substantially less carbon is sequestered. Furthermore, when ASC strategies are considered simultaneously with other strategies, the carbon price ($500 per ton) stimulates at most 64 MMT or 87% of maximum potential while sequestration falls to 50 MMT (67%) at a $200 price because other strategies are more efficient at that payment level.

Concentration on Single Strategies Can Cause Leakages in Other Categories.

Figure 4 shows the relationship between the increase in forest based offsets and emissions in the rest of the AF sector. The results indicate for an afforestation accounting only case that the anticipated gains in forestry are in some cases augmented and in other cases offset by emissions in the rest of the AF sectors. This more complex relationship occurs because land moving out of agriculture into forests places pressure on the remaining cropland, stimulating production intensification in terms of irrigation, tillage and fertilization. Thus, we find more emission intensive technologies on fewer acres of agricultural cropland. Leakage also occurs in forestry, where the underlying FASOM results show up to a 50 percent offset, largely from traditional forestland moving into agriculture or reducing management intensity (McCarl (1998) shows such results).

Mitigation Based Offsets are Competitive With Food and Fiber Production.

Achieving net GHGE offsets requires that AF operations change. Many of the strategies divert land or inputs away from crop or possibly timber production. On the agricultural side, Table 2 shows that crop prices generally rise the more mitigation is undertaken while production falls. Exports are also strongly affected. On the forestry side, afforestation can cause price declines if the rotation of harvested stands lengthens. At higher carbon prices, increasing land competition among strategies leads to increased afforestation and biofuel usages of croplands but reduced agricultural soil sequestration.

Adopting Mitigation Strategies Impacts Environmental Quality

Many of the proposed agricultural mitigation actions (tillage intensity reduction, manure management, land retirement etc.) have long been discussed as strategies which simultaneously improve environmental quality. Consequently, one may expect benefits in terms of erosion control, runoff etc. which are created simultaneously with emissions abatement. Table 2 shows changes in a few selected environmental parameters as carbon equivalent prices increase. For the most part, these results confirm declining rates of nitrogen and phosphorous runoff as well as reduced erosion. However, reliance on biofuels causes the environmental co-benefits largely stabilize at prices around $200 per ton.

Project Description -- Saturation and Volatility

Yet another question regarding sequestration involves the way a decision maker might view AF sequestration relative to say an emissions reduction given the opportunity to buy one or the other. To investigate this question we use net present value analysis to find the breakeven carbon price one would be willing to pay for nominally equal cost and carbon potential sequestration and emission offset opportunities. In doing this we will follow the work of McCarl and Murray (2001).

The basic procedure we will use involves the evaluation of the price for carbon that renders the net present value of a stream of carbon equivalent offsets equal to program costs. Specifically, we solve the following equation for the breakeven carbon price p:

$$\sum_{t=0}^{T}(1+r)^{-t}\,p\;E_t=\sum_{t=0}^{T}(1+r)^{-t}C_t\,,$$

where r is the discount rate -- assumed to be 4%, T the number of years in the planning horizon - assumed to be 100, p a constant real price of emission offsets, E_t the emissions offset in year t, and C_t the cost of the emissions offset program in year t. Then by comparing prices for different possibilities we can determine the effect of saturation and volatility.

Results -- Saturation and Volatility

For illustrative purposes we will consider three hypothetical cases that allow comparison of relative carbon prices by opportunity. McCarl and Murray (2001) consider many more.

Case A: Emissions offset - Suppose an emission offset can be obtained which annually offsets one unit of carbon for the full 100 years at a cost of 1 monetary unit (e.g. one dollar) per year. The breakeven price for this is one unit ($1 per unit carbon).

Case B: Saturating Agricultural Soil Carbon - Consider an agricultural soil carbon case that sequesters an average amount of one carbon unit per year but then saturates after 20 years consistent with the findings in West et al. If payments stop after 20 years, the carbon preserving practice ceases, releasing (volatilizing) the carbon into the atmosphere over the next 3 years. Given these characteristics we find a breakeven price of 2.64 units. Alternatively, if the practice is subsidized for the remaining 80 years, this price amounts to 1.80. This implies that the saturating/volatile soil carbon is worth between 36 percent and 55 percent of the emissions offset.

Case C: Forest carbon - Carbon in forests will saturate after trees reach maturity in about 80 years. The sequestered carbon is volatile because the trees may be harvested releasing soil and standing tree carbon, but also placing carbon into products that provide longer term storage or fuel offsets. A forest reserve that sequesters a unit for 80 years costing one monetary unit has a break-even price of 1.02 or just a 2 percent discount. A 20-year harvest pattern for pulpwood stands with fuel credits counted leads to prices in the range of 65-70% of emissions while a 50 year saw timber stand comes out at 85-87%. Other cases in McCarl and Murray (2001) range as low as 51%.

For illustrative purposes we then reran the sector-modeling framework but multiplied the price applied to carbon from tillage changes on agricultural soils by 0.50

and that from forests by 0.75. In turn the total portfolio of options (Figure 5) chosen shifted with agricultural soil and forestry shares declining. The agricultural soil maximum fell by about 10 percent while the forestry adjusted down by almost one third. Further it took higher prices to achieve equivalent sequestration levels

Application

Agricultural and forest carbon sequestration are important components of a possible total societal response to a greenhouse gas emission reduction initiative. Our analysis shows that determination of their appropriate role depends upon the carbon price. At low prices, agricultural soil sequestration appears highly competitive but saturation and volatility will likely lead to price discounts. Forest based sequestration and biomass offsets gain in importance at higher carbon prices.

Future Activities

More work is planned along these directions to bolster the data underlying the sector model and further investigate the role of sequestration in a world where carbon prices change over time.

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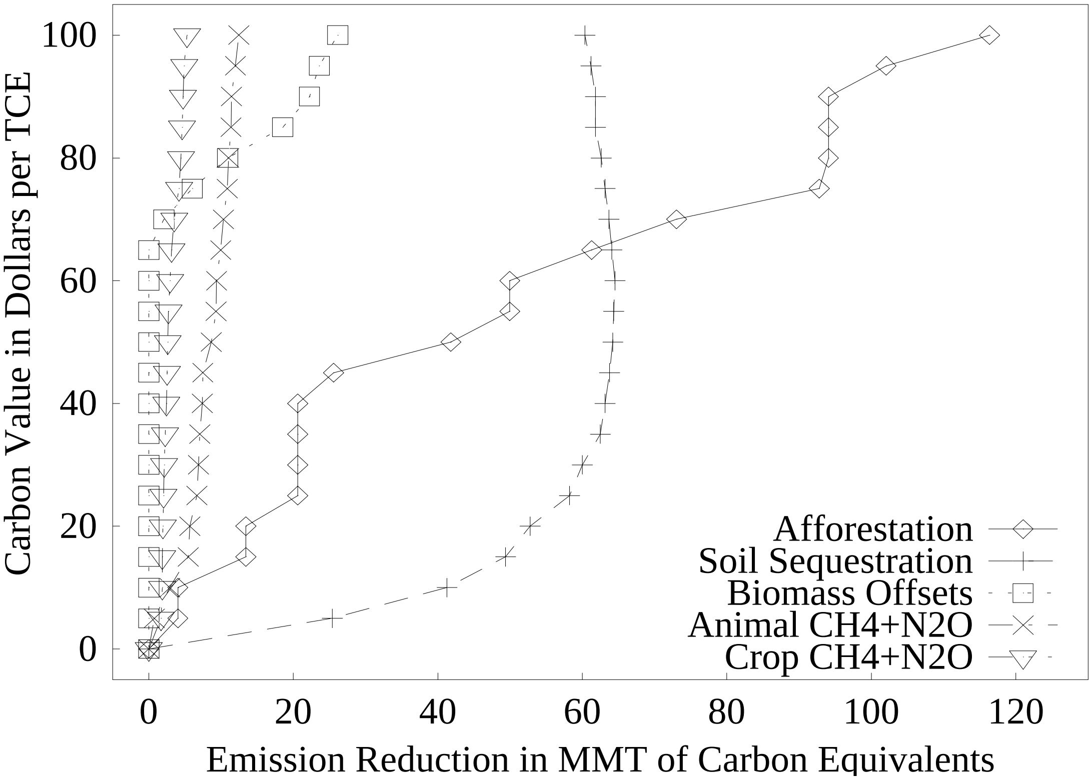

Figure 1 **Agricultural Mitigation Potential at $0 to $100 per Ton Carbon Equivalent Prices**

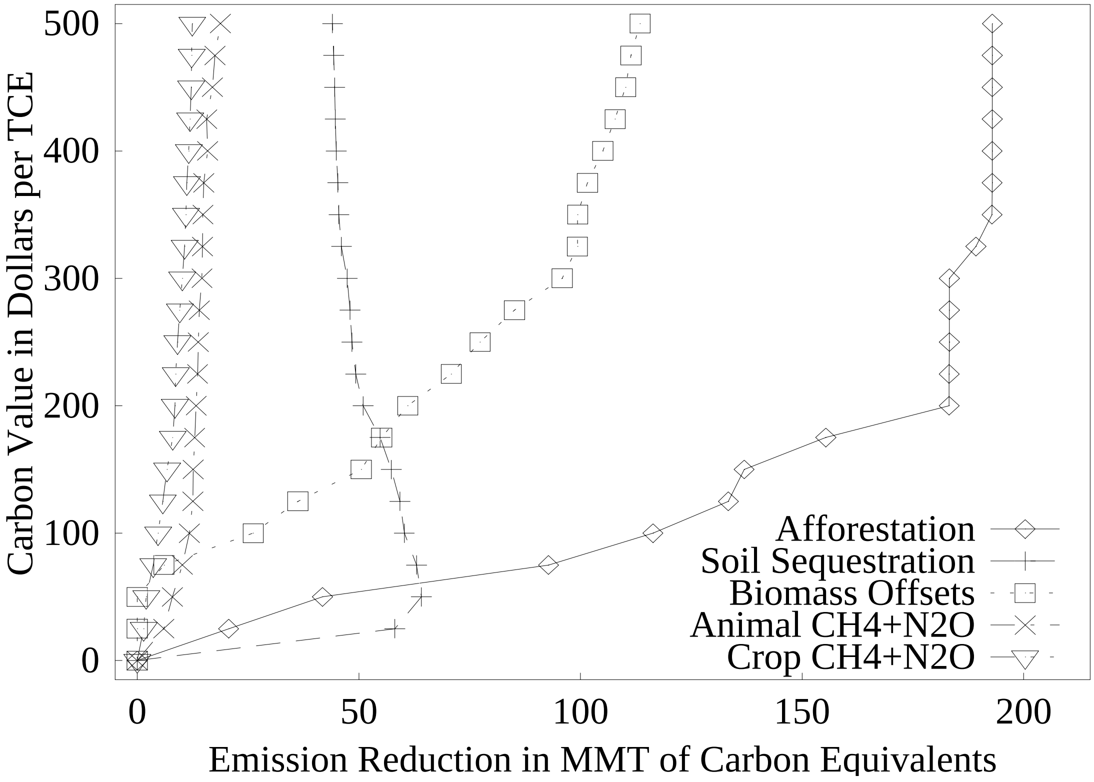

Figure 2 Agricultural Mitigation Potential at $0 to $500 per Ton Carbon Equivalent Prices

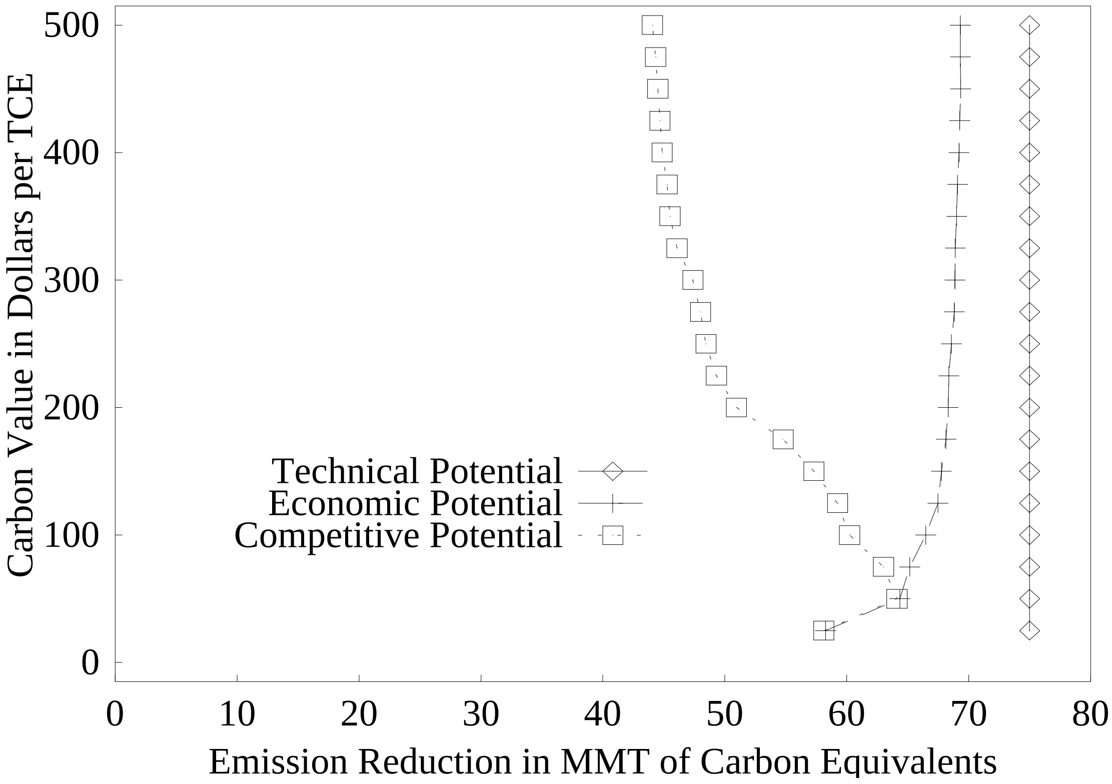

Figure 3 **Agricultural Soil Carbon, Technical, Sole Source Economic and Competitive Economic Response**

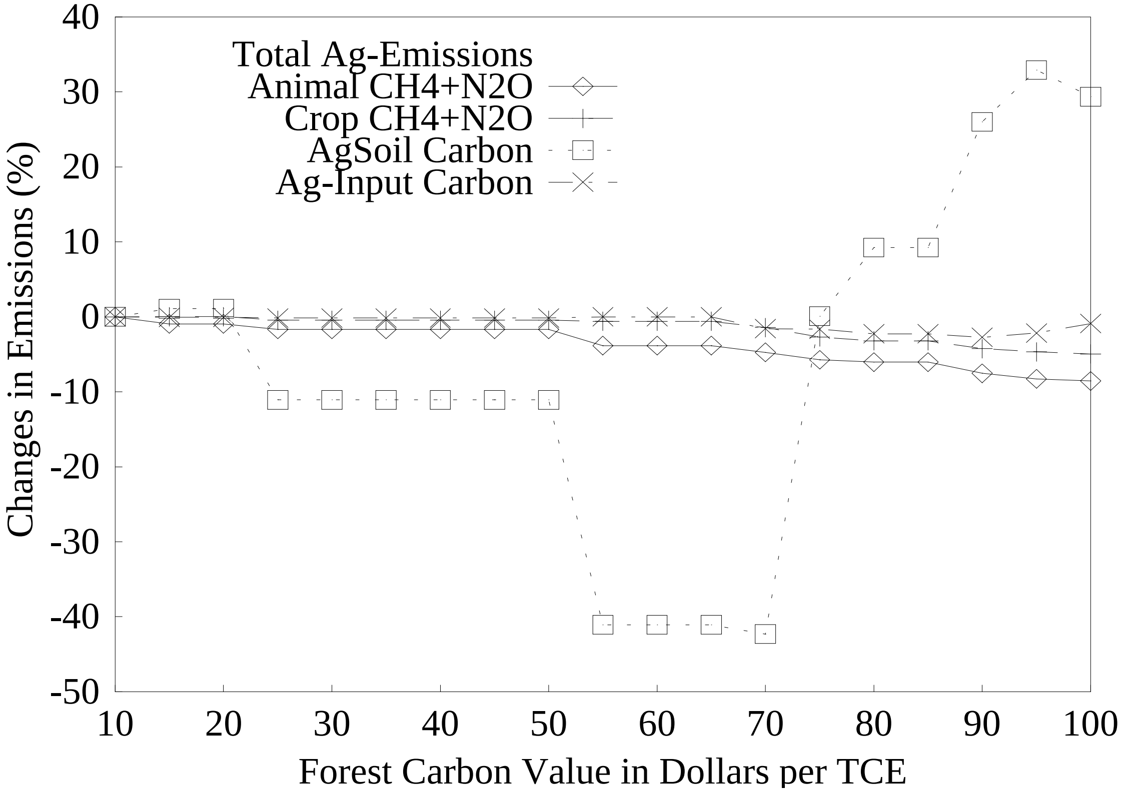

Figure 4 Gross and Net Mitigation of Sole Reliance on Forestry Related Strategies

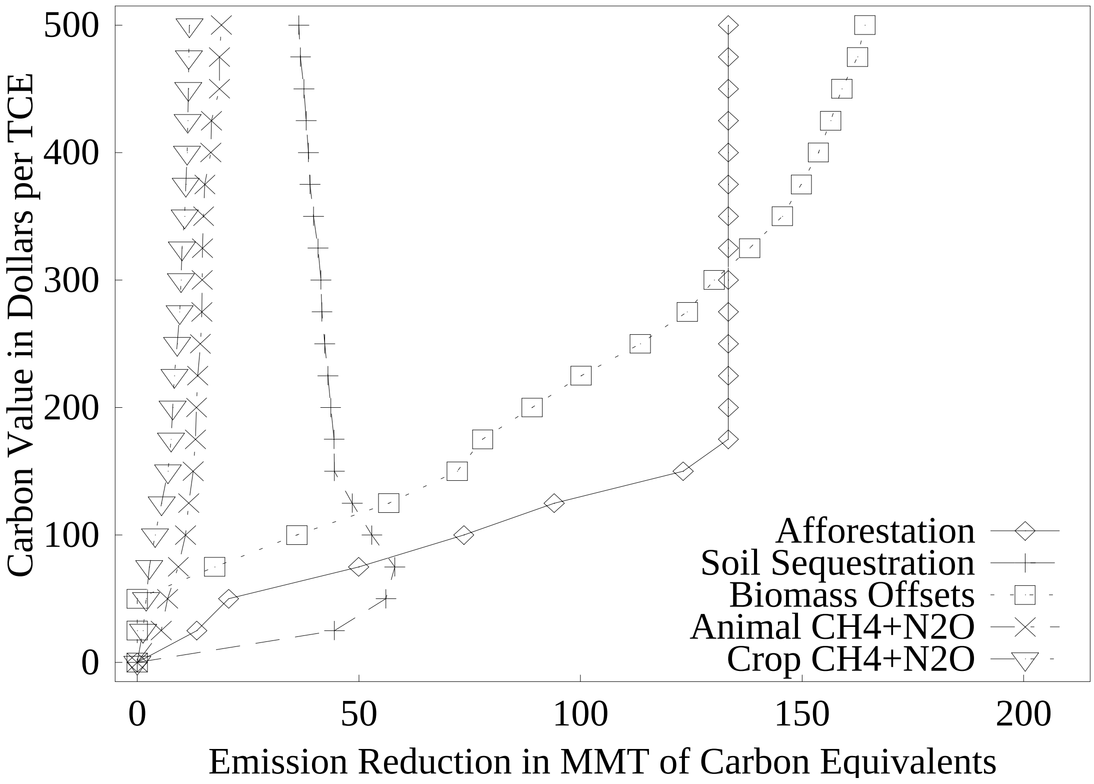

Figure 5 Agricultural Mitigation Potential at $0 to $500 per Ton Carbon Equivalent Prices When Saturation and Volatility are Accounted for by Price Discounts

Table 1 Mitigation Strategies Included in the Analysis

Strategy	Basic Nature	Greenhouse Gas Effected		
		CO2	CH4	N2O
Afforestation / Timberland Management	Sequestration	X		
Biofuel Production	Offset	X	X	X
Crop Mix Alteration	Emission, Sequestration	X		X
Crop Fertilization Alteration	Emission, Sequestration	X		X
Crop Input Alteration	Emission	X		X
Crop Tillage Alteration	Emission	X		X
Grassland Conversion	Sequestration	X		
Irrigated /Dry land Conversion	Emission	X		X
Livestock Management	Emission		X	
Livestock Herd Size Alteration	Emission		X	X
Livestock Production System Substitution	Emission		X	X
Manure Management	Emission		X	
Rice Acreage	Emission		X	

Table 2 **Results at Selected Carbon Price Scenarios**

Category Sub-Category	Unit	Carbon Equivalent price in $/metric ton C					
		10	20	50	100	200	500
Strategy							
Soil Carbon	1000 TCE	52,771	63,148	60,341	51,060	44,967	44,163
Afforestation	1000 TCE	13,445	20,619	116,361	183,191	192,893	192,947
Biomass	1000 TCE	0	0	26,154	61,020	105,045	113,456
Fossil Fuel Ag-Inputs	1000 TCE	4,285	6,696	10,156	12,433	14,971	15,807
Livestock Related	1000 TCE	5,674	7,390	12,462	13,989	16,547	19,443
Crop Non-Carbon	1000 TCE	1,959	2,427	5,304	9,081	12,239	13,003
GHGE Mitigation							
C	MMTC	71.26	91.81	216.14	309.3	356.7	364.61
CH4	MMTCH4	0.78	1.02	1.89	2.39	3.07	3.50
N2O	MMTN2O	0.04	0.05	0.09	0.14	0.18	0.20
CE	MMTCE	79.11	101.98	235.31	334.11	389.09	400.94
Market Effects							
Production	Fisher Index	99.81	98.74	91.20	77.77	67.73	65.37
Prices	Fisher Index	100.65	102.41	118.81	155.93	222.07	261.01
Ag-Sector Welfare	Billion $	-0.45	-0.90	-5.65	-15.33	-29.79	-35.05
Net Exports	Fisher Index	99.17	96.11	74.26	35.33	25.58	22.81
Other Externalities							
Nitrogen pollution	% Change	2.10	3.63	-6.26	-21.47	-34.65	-37.40
Phosphorous pollution	% Change	-43.35	-49.02	-52.93	-53.61	-58.15	-60.54
Erosion	% Change	-35.04	-41.28	-49.70	-55.62	-61.23	-63.27