POLICY FORUM: CLIMATE CHANGE

Greenhouse Gas Mitigation in U.S. Agriculture and Forestry

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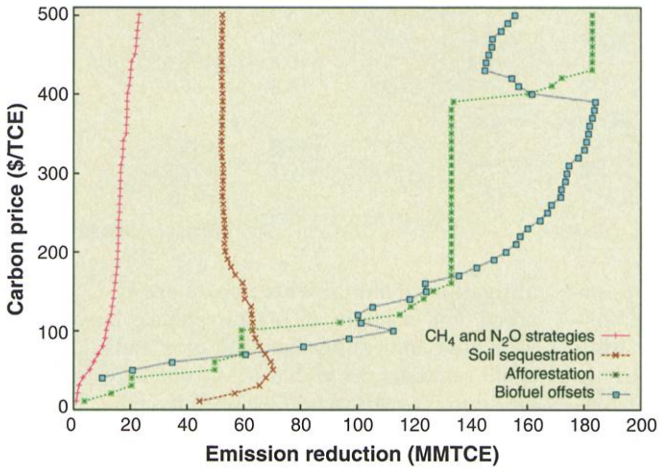
The Department of Energy estimated CO_2 emissions for the United States to equal 1562 million metric tons of carbon equivalents (MMTCE) in 2000, which is 305 MMTCE more than in 1990. With an estimated average annual emission increase of 1.5% per year, the Kyoto Protocol would require the United States to reduce CO_2 by about 524 MMTCE in 2008, 549 MMTCE in 2009, 578 MMTCE in 2010, 608 MMTCE in 2011, and 635 MMTCE in 2012. Agricultural and forestry (AF) activities may mitigate greenhouse gas (GHG) emissions through (i) direct emission reductions, (ii) terrestrial carbon sink expansions, and (iii) production of replacements for emission-intensive products (*1*). Uncertainty and controversy exist about AF's practical mitigation potential, partly because aggregate studies have been lacking (*1*).

The heterogeneity and management interdependencies in AF make it difficult to assess aggregate economic mitigation potential. Soil properties, climate conditions, and land management history are heterogeneous, and collectively, they result in unique GHG emissions mitigation potential for each field. For example, U.S. carbon concentrations in mineral soil surface layers range from less than 1% organic carbon for sandy soils in warm, dry climates to more than 4% for clay soils in cold, wet climates. Peat soils contain as much as 50% organic carbon. Carbon sequestration potential depends on carbon lost during previous cultivation. Highly degraded soils with low carbon-holding capacity may have greater sequestration potential than fairly undisturbed soils with high capacity.

Interdependencies of crop and livestock management affect the costs and potential for agricultural GHG emission mitigation in four principal ways. First, many agricultural mitigation strategies either compete with or enhance traditional agricultural production. For example, farmers who plant trees cease production of traditional crops on those lands. Thus, carbon sequestration must be worth enough to compensate for forgone revenues. In contrast, long-term soil carbon buildups enhance agricultural productivity. Second, agricultural mitigation strategies either compete with or complement one another. Fields cultivated with switchgrass for biomass electricity generation are unavailable for afforestation. Reduced tillage, however, increases soil carbon sequestration and reduces fossil fuel use and accompanying emissions. Third, interactions arise from multiple gas emissions associated with particular AF mitigation strategies. Increased nitrogen fertilization can increase nitrous oxide emissions, soil carbon sequestration, and GHG emissions during fertilizer manufacture. Fourth, GHG emission abatement strategies can impact other environmental properties such as soil erosion and nutrient leaching. Accounting for all these interdependencies is important to find the true costs of agricultural GHG emission mitigation strategies.



Competitive economic potentials for agricultural and forest GHG emission mitigation strategies in the United States. All strategies were simultaneously examined. Decreasing levels of emission reductions as prices increase reflect competition among strategies.

To appraise the total mitigation potential, we expanded an existing agricultural sector model (*2*) to include GHG treatment. The new model, hereafter called ASMGHG (*3*), portrays farmers' choices across regions among a broad set of crop and livestock management options including tillage, fertilization, irrigation, manure treatment, and feeding alternatives. ASMGHG depicts production and consumption in 63 U.S. regions for 22 traditional and 3, biofuel crops, 29 animal products, and more than 60 processed agricultural products. It also depicts eight crops being traded within 28 international regions. Emission coefficients, environmental effects, basic cost changes, and yield adjustments for each combination of management, soil category, and geographic location were derived by linking ASMGHG variables to a variety of economic and environmental simulation models from the agricultural, forestry, and energy sectors. A list of these models, important characteristics and assumptions, and the GHG accounts modeled is provided in supplemental data (*4*). ASMGHG equilibrates demand and supply in agricultural markets of the United States and major trading partners. The equilibrium solution reveals commodity and factor prices; levels of domestic production; export and import quantities; agricultural welfare distribution; adoption of specific management alternatives; resource usage; and a wide variety of environmental impact indicators.

To derive the multistrategy economic potential for AF GHG emission mitigation, alternative carbon prices were introduced in ASMGHG. The implied policy instrument is thus a combination of emission taxes and sequestration subsidies. Because policy transaction costs are excluded, our estimates represent a lower bound on marginal abatement cost. Methane and nitrous oxide emissions were jointly regulated with equivalency made on the basis of IPCC's 100-year global-warming potentials (*5*) as suggested in (*6*).

The ASMGHG results for AF mitigation at selected carbon prices are summarized in the table [p. 2482 and (*4*)]. At the highest price level, AF annually removes slightly more than 425 MMTCE of combined GHGs. Total mitigation potential, however, is price-sensitive, and low incentives result in low abatement levels. Individual AF mitigation strategies exhibit different relative importance depending on price level (see the figure). Low-cost

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SUMMARY OF MITIGATION POLICY IMPACTS ON U.S. AGRICULTURAL SECTOR

Category	For carbon price ($/MTCE)				
	0	10	50	100	500
Total GHG emission abatement (MMTCE)					
Carbon dioxide	0.0	51.8	146.4	238.5	395.5
Methane	0.0	0.3	4.7	12.3	21.1
Nitrous oxide	0.0	1.7	3.0	4.9	9.3
Crop management					
Traditional crops (10^6 acres)	325.6	323.9	307.0	270.9	191.6
Perennial biofuel crops (10^6 acres)	0.0	0.0	9.6	53.9	76.0
Afforestation (10^6 acres)	0.0	0.0	12.5	13.6	65.0
Reduced tillage (%)	32.6	68.0	81.1	81.4	80.0
Irrigation (%)	18.7	18.3	18.3	20.3	31.0
Nitrogen fertilizer (1000 MT)	10,527	10,451	10,007	9240	7148.9
Alternative livestock management (% of population)					
Dairy, liquid manure treatment	5.6	5.6	8.2	10.3	17.1
Swine, liquid manure treatment	3.4	3.4	15.7	29.6	40.6
Dairy, growth hormone treatment	9.1	9.1	9.1	28.8	80.0
Agricultural markets (Fisher index)					
U.S. crop production	100.0	99.2	95.7	86.3	62.3
U.S. crop prices	100.0	100.8	108.1	129.1	288.6
U.S. crop exports	100.0	97.4	87.1	59.2	20.3
U.S. livestock production	100.0	100.3	97.4	92.9	77.9
U.S. livestock prices	100.0	100.1	104.8	119.1	207.6
Agricultural welfare impacts (10^9 $)					
U.S. farmers gross welfare	0	0.4	4.5	13.9	80.0
U.S. ag–consumers welfare	0	–0.4	–5.4	–19.2	–108.8
U.S. ag–sector welfare	0	–0.2	–2.1	–8.8	–36.5
Non-GHG environmental impacts (per acre change)					
Wind and water erosion	0	–24.0	–42.7	–44.9	–49.7
Nitrogen loss through percolation	0	–7.8	–16.2	–19.7	–12.9
Phosphorus loss in sediment	0	–32.6	–50.4	–49.6	–51.7

strategies include soil carbon sequestration, afforestation, and to some extent noncarbon emission mitigation. At high prices, emission abatements stem mainly from forestry and biofuels. The total contribution of noncarbon strategies is relatively small and does not exceed 30 MMTCE. By comparison, Weyant and Hill's (*7*) report of Energy Modeling Forum estimates for compliance with the Kyoto Protocol show a range of industrial cost estimates averaging from $44 to $89 per metric ton of carbon depending on the trading assumption and reaching as high as $227.

The composition of the strategy portfolio varies regionally. Soil-based strategies dominate in the corn belt, whereas biofuels dominate in the lake states and afforestation in the Mississippi Delta states (*4*). These differences suggest that a multistrategy program, which gives landowners greater flexibility to choose the strategy most suitable to regional characteristics, may facilitate AF GHG policy acceptance. In addition, unilateral reliance on individual strategies increases mitigation cost (*4*).

Experiments with ASMGHG also illustrate an important difference between economic and technical potential. Technical potential refers to the maximum physical mitigation potential where costs are ignored. For example, in (*8*) an estimate is presented, indicating that U.S. croplands could sequester 75 to 208 MMT annually for 20 to 50 years. ASMGHG results indicate that, with costs considered, the economic potential is smaller, with lower levels achieved even under extreme prices ($500 per metric ton), and that at lower carbon prices, substantially less is sequestered. Furthermore, when agricultural soil carbon strategies are considered simultaneously with other strategies such as afforestation and biofuels, resource competition decreases the maximum sequestration level.

National efforts to mitigate GHG emissions through AF operations impact traditional agriculture (see table). Adoption of strategies such as afforestation, biofuel generation, reduced fertilization, and smaller animal populations decrease overall agricultural production for traditional food, fiber, and livestock products but increase their prices. U.S. exports diminish and international production increases. Although not accounted for here, this would likely increase emissions in other countries, creating leakage (*9*). The costs of emission abatement are not shared equally among market segments. Higher operational costs to farmers are more than offset by higher revenues because of increased prices. U.S. consumers of agricultural commodities, however, lose substantially.

Many possible AF GHG emission mitigation strategies have additional environmental-quality attributes (tillage intensity reduction, manure management, land retirement, and so forth) ASMGHG results (see table) show reduced levels of erosion and phosphorus and nitrogen pollution on traditional cropland as carbon prices increase. The other environmental benefits tend to stabilize at higher prices. Increased afforestation and biofuel production create economic incentives to stop or even to reverse adoption of crop management strategies that limit production, such as rain-fed agriculture.

We do not find evidence that AF-directed GHG mitigation efforts may be sufficient to fulfill Kyoto Protocol–like emission-reduction obligations, which would be in the neighborhood of 550 million metric tons per year for the United States. Furthermore, as AF mitigation efforts increase in volume, per unit cost of emission reductions will rise, eventually exceeding those from other sectors, e.g., the abatement costs from the electricity sector as summarized by Weyant and Hill. However, AF mitigation programs may generate substantial side benefits. Higher market prices for agricultural commodities reduce the need for expensive income support currently paid to farmers. Correlations among AF-based environmental impacts suggest that a combined conservation program may be more efficient than targeting various environmental goals separately.

References and Notes

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9. Several issues remain to be explored in addition to empirical improvements of this analysis. Foremost is inclusion of discounts for permanence and leakage, along with addition of transactions costs estimates for practical program implementation.
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