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Greenhouse Gas Mitigation through Agriculture

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Greenhouse gas (GHG) emissions can be reduced or atmospheric GHGs sequestered to help reduce the future extent of climate change. Options to do this through agriculture have received increasing attention during the last decade. Some see agriculture as a potential low-cost provider of emission reductions in the near future with additional environmental and income distributional cobenefits. Others express concerns about agricultural mitigation efforts because of possible emission leakage and other environmental drawbacks. This article will not and cannot cover what is known about the whole gamut of the topic. Instead, it draws heavily on our experience and our role in the 2007 Intergovernmental Panel on Climate Change report on agriculture and mitigation (Smith et al. 2007). We focus on responses in the domain of technologies, economics, and subsequent impacts of agricultural mitigation covering mitigation strategies, mitigation potential, and possible externalities.

Mitigation Strategies

Agriculture produces primarily food and to a lesser extent fiber and other products. Emissions of GHG and sequestration[1] of carbon dioxide from agriculture are influenced by supply and demand for agricultural products, and farming technologies. Consequently, possible GHG emission mitigation options involve changes in these three aspects. However, given a growing and in part undernourished human population, global decreases in food supply are not desirable. Similarly, reductions in global fiber production would imply increased use of petroleum based, nonrenewable fiber sources and possibly increase emissions. The demand aspect for food relates to changes in human diets. Greenhouse gas emissions could be reduced by dietary shifts involving more local, more seasonal, less processed, and more vegetarian food. These options decrease emissions because they save energy used for transportation, processing, storage, and the metabolism of animals. To put the energy requirement of animal production in perspective, we computed land requirements per calorie by combining land requirements per kg food (Gerbens-Leenes et al. 2002) and nutritional energy contents in calories per kg food (FAO 2004). Results show that one thousand calories from beef, pork, wheat flour, and potatoes require about 9, 4, 0.4, and 0.3 square meters of land, respectively. However, these values should be interpreted with care because certain grasslands are only suitable for livestock and because proper human diets require more than carbohydrates. Diet changes could make a substantial contribution to greenhouse gas mitigation, especially in developed countries. In developing countries, such emission reductions are very unlikely because demand for livestock products grows as these countries become richer. And this trend might continue till 2050.

Most assessments of agricultural mitigation possibilities relate to changes in farming methods including a conversion from food production to alternative enterprises. The associated emission mitigation strategies are numerous and complex. Available direct options have been grouped into a) sinks or sequestration enhancements, b) emission reductions, and c) avoided emissions via replacement products or land use change prevention. Sinks can be interpreted as reversals of past agricultural emissions. They include carbon sequestration in soils and biomass achieved by changes in management or land use changes. Agricultural emission reductions comprise methane reductions from ruminant animals, manure, and rice fields; nitrous oxide emission reductions from fertilizer use and manure; and carbon diox-

1. *For more information on sequestration, see "A Perspective on Carbon Sequestration as a Strategy for Mitigating Climate Change" by G. Cornelis van Kooten in this issue.*

ide emission reductions from reduced fossil fuel combustion. Avoided emissions in other sectors include prevention of deforestation, substitution of biomass based energy for fossil fuel based energy or use of biomaterials to replace other emission intensive products. Energy replacement strategies generally distinguish biomass for direct combustion to generate electricity or heat and biofuel production replacing gasoline, diesel, and other transportation fuels. Biomaterial strategies comprise biopolymers, industrial plant oils, and plant based building materials. Biopolymers are substitutes for petrochemical polymers and can be processed into a wide range of plastic and packaging materials. Similarly, industrial plant oils can replace petroleum based lubricants. When used in non-confined outdoor settings, for example as chain saw lubricants, these biodegradable oils also reduce water pollution.

The societal desirability of possible agricultural options is strongly related to land scarcity and agricultural production intensities. Mitigation could be accomplished through intensification and extensification. Mitigation through intensification may increase emissions per hectare but could decrease total land requirements and therefore total agricultural emissions, although secondary environmental outcomes need to be considered. In addition, the released land can be used for greenhouse gas emission saving nonfood options. Mitigation through extensification involves a reduction in emissions per hectare. Total land requirements may increase slightly while still achieving a reduction in total greenhouse gas emissions.

Mitigation Potentials

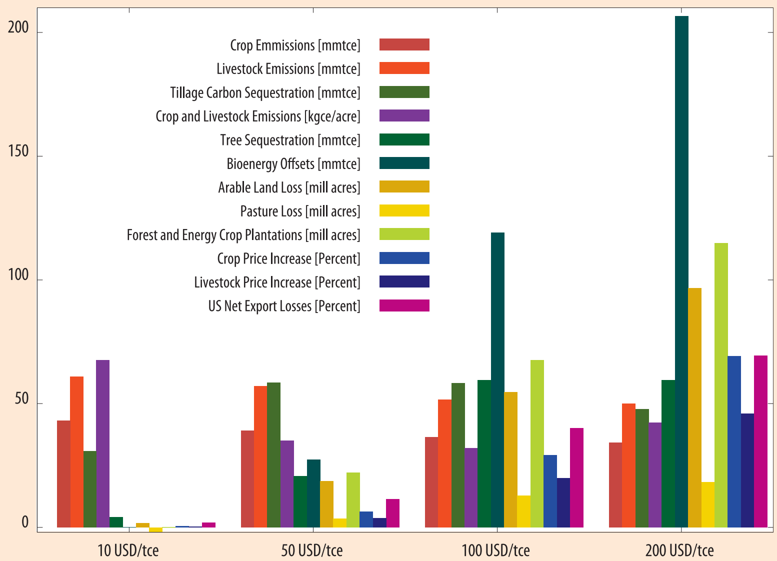
Now the question is what difference can agriculture make? Answers to this question usually involve measures of potential. The correct interpretation of such potentials, however, requires careful examination of the underlying data and methods. McCarl and Schneider (2001) found substantial differences between technical and economic potentials. Technical mitigation potentials give the greenhouse gas emission benefits from an exogenously specified change in technology. For example, one could assume that all cereal growers in the United States adopt zero tillage and compute the resulting carbon sequestration benefits as a measure of technical potential. Economic potentials specify the fraction of technical potentials that can be achieved at a certain economic incentive. For example, one could compute the likely carbon sequestration benefits in a scenario, where all U.S. cereal growers were offered a 20 USD per acre reward for using zero tillage. The resulting economic potential would then only include sequestration benefits from farms, where reduced tillage adoption would cost 20 USD per acre or less.

In examining agricultural greenhouse gas mitigation potentials in the face of the thousands of existing estimates, we will briefly cover general principals since differences in regional conditions and the scopes of assessments will always occur. First, since the greenhouse gas concentration concern is global, so should be the estimate of mitigation potential. This is discussed in more detail in the next section under leakage. Second, emission reductions should consider food production implications. If current or higher levels of food quantity and quality are to be sustained, fewer emissions can be mitigated than if quantity and quality decline. Third, emission reduction potentials of different individual mitigation options are interdependent. Many –especially land based– mitigation options are mutually exclusive. If individual strategy assessments are added up, the total mitigation potential may be substantially overstated (Schneider and McCarl 2006). Fourth, the heterogeneity of agricultural mitigation options implies that different strategies may be preferred in different regions. Fifth, agricultural mitigation estimates should take into account the whole spectrum of greenhouse gases. This is especially true because some available strategies, while giving huge benefits with respect to one greenhouse gas, may increase emissions of another. Wetland restoration may sequester large amounts of carbon dioxide but at the same time increase methane emissions. Similarly, while energy crops have beneficial carbon offsets they can lead to undesirable increases in nitrous oxide emissions (Crutzen et al. 2008).

The above principals imply that realistic mitigation option assessments need to take into account a diverse range of implementation costs including a) direct strategy costs pertaining to changes in input use and maintenance costs, b) opportunity costs from the use of scarce resources, c) transaction costs for policy implementation, and d) external social costs and benefits. These costs may change over the amount of mitigation effort. If a large cultivated area would be afforested, agricultural commodity production would decrease and prices for associated commodities would go up making additional afforestation more expensive. Transaction costs need to be considered and relate to monitoring, verification, and enforcement. The costs of verification include the impacts of uncertainties and vulnerabilities. Uncertainties are particularly high for methane and nitrous oxide emissions. Sequestered carbon, on the other hand, is vulnerable because wildfires or management changes can rapidly release the amount that has been stored. Risk averse preferences imply that uncertain and vulnerable emission reductions have a lower value than certain and permanent emission reductions.

Figure 1 shows policy simulation results from the U.S. Agricultural Sector and Mitigation of Greenhouse Gas Model (ASMGHG, Schneider and McCarl 2006) to illustrate the

Figure 1. Summary of Mitigation Incentives Impacts on U.S. Agriculture



complexity of agricultural GHG mitigation potentials. For relatively low emission mitigation incentives in U.S. agriculture, tillage based carbon sequestration dominates other mitigation strategies. Above incentive levels of 100 USD per ton of carbon equivalent (tce), the largest contributions come from exclusive mitigation strategies such as afforestation and bioenergy production. When traditional crop and pasture areas decrease, prices for crop and livestock commodities go up. As a consequence, emission intensities of traditional crop and pasture areas may increase as observed between incentive levels of 100 and 200 USD per tce. Decreasing net exports of agricultural commodities imply increasing production and associated emissions outside the United States unless foreign regions are subject to similar or higher GHG mitigation incentives.

Mitigation Externalities

Policies that encourage agricultural mitigation efforts result in intended and unintended external effects. There are several categories of unintended effects, which are briefly described below.

Offsite unintended greenhouse gas emission - also called emission leakage. When a climate policy regulates emissions in some countries, emission intensive production and accompanying emissions may shift to other countries, thereby increasing their emissions (Searchinger et al. 2008). More generally, emission leakage can span across geography, time, greenhouse gases, or technologies. The magnitude of emission leakage depends both on the scope of a climate policy and on characteristics of the chosen mitigation strategies. In principal, if mitigation strategies are neutral to agricultural commodity supply, leakage is negligible. Examples of relatively neutral strategies include carbon sequestration via reduced tillage, moderate crop residue use for bio-energy generation, livestock manure management, use of low-emission fertilizers, and crop-demand based fertilization. Land intensive mitigation strategies, on the other hand, have a high leakage potential because these strategies decrease traditional agricultural commodity supply and provide incentives to expand agriculture elsewhere. Thus, high leakage potentials exist for afforestation of agricultural land, dedicated energy crop plantations and wetland restoration.

Nongreenhouse gas environmental side effects include impacts on soil, water, ecosystems and ecosystem services. Impacts may be beneficial or detrimental. Because soil quality correlates positively with humus levels, soil organic carbon enhancing mitigation strategies are typically beneficial. Restoration of degraded lands and wetlands are examples. On the other hand, if mitigation measures reduce the amount of organic or mineral fertilizer input, soil quality will decrease. Such measures include crop residue removal for bioenergy generation and manure digestion. Water quality can also be impacted. Higher soil organic carbon levels improve moisture and nutrient holding capacities and thus, decrease nutrient emissions into surface, sub-surface, and ground water along with irrigation requirements. Fertilizer based mitigation options, which aim at minimizing excess fertilizer, are likely to reduce water pollution. On the other hand, if tillage reductions increase herbicide applications, water quality will decrease. Finally, mitigation efforts through intensification could lead to soil salinity, water-logging and biodiversity suppressing mono cropping as has been experienced in many parts of the developing world with the green revolution. Collectively these undesirable ecological outcomes undermine agricultural sustainability and societal well being.

Synergies and trade-offs with ecosystems and their services. Mitigation impacts the condition and resilience of cultivated and downstream ecosystems which in turn decide the flow of the ecosystem services critical for agricultural inputs and outputs (Millennium Ecosystem Assessment 2005). Overall, whether ecosystem coeffects are positive or negative depends foremost on how mitigation influences the size of nature reserves. The establishment of permanent native forests or restorations of wetlands are beneficial. But replacement of rainforest with homogeneous energy crop or tree plantations is generally not desirable. If mitigation efforts reduce agricultural intensities on grasslands, pastures, and croplands, some on-site ecological benefits are possible. However, intensity reductions can increase land scarcity and thus increase pressure on nature reserves elsewhere.

Social welfare externalities related to food, water, energy, health, employment, extreme events, and landscape. Food security deceases if agricultural mitigation efforts a) consume land suitable for food production, i.e. via dedicated energy crop plantations, wetland restoration, or afforestation; or b) lead to a reduction in land productivity, i.e. via crop residue removal or livestock manure digestion thereby decreasing organic fertilizers. Synergies between mitigation and food supply are possible through soil carbon sequestration on degraded farmland or nutrient increasing fish production on waste or degraded lands. Changes in global food production patterns are also likely to affect food supply and prices in turn altering malnutrition and obesity with attendant health implications

Water availability. Land intensive mitigation strategies lead to increases in irrigation intensities for traditional crops (McCarl and Schneider 2001). In addition, negative water impacts are expected from large-scale energy crop plantations (Berndes 2002).

Broader societal side effects. Land use change may alter recreational opportunities and civil protection. For example, restored wetlands may increase flood protection. Increased nutrients may degrade water quality. Provision of water storage facilities in arid and semi arid areas can contribute towards bioremediation.

Important Issues

Society can reap benefits from agricultural GHG mitigation options but there are several important issues that arise such as: Which of the complex array of alternatives should be used given regional variations, and uncertainties? Alternatively, what mitigation strategies should not be adopted by agriculture? For those considering these questions, we offer general remarks.

1) The best mitigation strategy mix would minimize the social costs of emission mitigation per unit GHG reduction. In achieving this note that inefficiencies arise if a) technologies are regulated instead of emissions, b) noncarbon greenhouse gas effects are excluded, c) environmental and societal side effects are ignored, and d) uncertainties, vulnerabilities, and irreversibilities are not properly integrated.
2) The complexity of land use impacts on food, water, energy, climate, and ecosystems calls for integrated assessments. Otherwise, today's solution may become tomorrow's problem.
3) Agriculture has a limited potential to provide low cost emission reductions. Higher emission mitigation targets are land intensive and due to land scarcity lead to substantial increases of marginal mitigation costs.
4) Emission leakage leading to increased deforestation of native forests or destruction of wetlands or other valuable ecosystems could become a serious drawback to agricultural mitigation efforts particularly those involving land use change and commodity production reduction. Irreversible biodiversity losses coupled with positive overall net emissions of greenhouse gases would essentially imply an environmental loss-loss strategy. Such situations could arise with unconditional promotion of dedicated energy crops or large-scale afforestation programs replacing croplands. Similarly, on-site greenhouse gas emission reductions from low input cropping systems may be more than offset through emission leakage.
5) Measures, which relax land scarcity, decrease the potential for emission leakage and negative environmental side effects. Such measures include supply side restorations of degraded lands and emission friendly yield improvements, along with demand side promotion of energy friendly diets.
6) Cost must be considered as often technical potential is much higher than cost effective potential particularly when considering transactions (implementation) and externality costs.

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