Greenhouse Gas Emission Mitigation through Agriculture

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Greenhouse gas emission mitigation options through agriculture have received increasing attention during the last decade. A relatively detailed topic search within the scientific journal database Current Content Connect for 'agriculture', 'climate' or 'global change', and 'mitigation' or 'emission reduction' yields 222 entries within the last 10 years, 151 entries within the last 5 years, and 45 entries in 2007. In Google Scholar, the same items match more than 25,000 document links. The 222 peer-reviewed studies, which capture only a fraction of the scientific work, include 139 articles ranging from Alig et al. (1997) to Rokityanskiy et al. (2007), 25 reviews ranging from Paustian et al. (1997) to Smith et al. (2007), and 4 editorials.

This article will not and cannot summarize the wealth of analysis contained in all of these studies. Instead, it draws heavily from the cumulative experience of the authors, who, over the last decade, have written and worked extensively on this topic and were also part of the latest Intergovernmental Panel on Climate Change report on agriculture. We will focus on technologies, economics, and impacts of agricultural mitigation but leave out many aspects of policy design. The paper is structured as follows. The first section hereafter provides an overview over possible mitigation strategies. The next section discusses agricultural mitigation potentials in qualitative terms. Following, we review environmental and societal side effects of agricultural mitigation. Finally, we draw several general conclusions about prospects and limitations of agricultural greenhouse gas emission mitigation efforts.

**Mitigation Strategies**

Agriculture primarily produces food. Emissions of greenhouse gases from agriculture are influenced by food supply, food type, and farming technologies. Consequently, possible 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. The second aspect relates to changes in human diets. Greenhouse gas emissions could be reduced by shifts to energy and land sparing diets involving more local, more seasonal, less processed, and more vegetarian food. To put this 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 kilocalorie from beef, pork, wheat flour, and potatoes require about 9, 4, 0.4, and 0.3 square meter of land, respectively. However, these values should be used with care because certain land qualities are only suitable
for livestock and because proper human diets require more than carbohydrates. Generally, changes in human diets are more relevant for richer countries but they are usually addressed in a human health context and not in a greenhouse gas mitigation context.

The majority of agricultural mitigation assessments relate to the third of the above mentioned aspects: changes in farming methods. These changes also include abandonment of food production in favor of forestry, energy crop plantations, or other non-food uses. The associated emission mitigation strategies are numerous and complex. Available direct options have been grouped into a) sinks, b) emission reductions, and c) avoided emissions in non-agricultural sectors including forestry. Sinks can be interpreted as reversals of past agricultural emissions. They include carbon sequestration in soils and biomass accomplishable through 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 dioxide emission reductions from reduced fossil fuel combustion for agricultural operations and connected businesses. Avoided emissions in other sectors include prevention of deforestation and substitution of fossil fuel by biomass as feedstock for energy and material. Bioenergy strategies generally distinguish biomass for direct combustion to generate electricity and heat and bio-fuel production for substitution of gasoline, diesel, and other transportation fuels. Biomaterial strategies comprise biopolymers, industrial plant oils, and plant based building materials.

The complexity of agricultural options is strongly related to land scarcity and agricultural production intensities. In principal, mitigation could be accomplished by both intensification and extensification. Mitigation through intensification of agricultural production may increase emissions per hectare but at the same time decrease total land requirements and total agricultural emissions. In addition, the spared land can be used for greenhouse gas emission saving non-food options. Mitigation through extensification involves a reduction in emissions per hectare. Total land requirements may moderately increase but total greenhouse gas emissions go down.

Mitigation Potentials

What difference can agriculture make in an emission intensive world heavily dependent on fossil energy sources? In analyzing this question, we will not review empirical emission mitigation estimates but rather provide some guidance for comparison and interpretation of
different existing assessments. First, since greenhouse gases constitute a global externality, the potential contribution of agriculture should be accounted at and judged on the global level. Emission mitigation measures, given as local emission savings per hectare, are incomplete and may be misleading. This is discussed in more detail in the next section under leakage. Second, emission reductions should be related to food production levels. If current or higher levels of food quantity and quality should be sustained, much less emissions can be mitigated through agriculture than otherwise. Third, the emission reduction potential of different individual mitigation options from agriculture should be accounted simultaneously. Many–especially land based–mitigation options are mutually exclusive. On the other hand, the heterogeneity of agricultural mitigation options implies that different strategies may be preferred in different regions. If individual strategy assessments are added up, the total mitigation potential may be substantially overstated (Schneider and McCarl). Fourth, agricultural mitigation accounts should comprise the whole spectrum of greenhouse gases. This is especially true for agriculture 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, some of the targeted energy crops are considered to increase greenhouse gas emissions, when considering beneficial carbon offsets together with undesirable increases in nitrous oxide emissions (Crutzen et al.).

Fifth, mitigation options are of little use if they are too costly. In particular, agricultural mitigation potentials have been estimated to be very cost sensitive (McCarl and Schneider). The competitive economic potential of agricultural mitigation strategies at low-costs can fall several magnitudes short of the corresponding technical potential. True mitigation costs include a) direct strategy costs including single adjustment and continuous maintenance costs, b) opportunity costs, c) transaction costs, and d) external social costs and benefits. All costs depend on certain prices and thus, may change over the amount of mitigation effort. If a large cultivated area would be afforested, traditional agricultural commodity production would decrease and prices for associated commodities would go up. Increasing prices for forgone commodity production increases the economic disincentive for additional afforestation. Transaction costs relate to monitoring, verification, and enforcement. The costs of verification include the impacts of uncertainties and vulnerabilities. Risk averse preferences imply that uncertain and vulnerable emission reductions have a lower value than certain and permanent emission reductions.
Mitigation Externalities

Mitigation policies which induce agricultural mitigation efforts yield intended and external effects. Intended or targeted effects include reduced greenhouse gas concentrations, which may slow down climate change, and increased energy security. The focus of this section is mitigation externalities related to agriculture. Particularly, we consider three types of unintended and usually unattended side effects: a) greenhouse gas emission impacts, b) other environmental impacts, and c) societal impacts. Unintended greenhouse gas emission impacts are also referred to as emission leakage. Emission leakage is often thought of as leakage over space. If a climate policy regulates emissions in some countries, emission intensive production may shift from these countries to unregulated countries, thereby increasing their emissions. More generally, emission leakage applies to any partially implemented climate policy if it is partial with respect to space, 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.

Non-greenhouse gas environmental side effects include impacts on soil, water, ecosystems and the flow of ecosystem services. Again, depending on the characteristics of the chosen mitigation strategies, impacts may be beneficial or detrimental. Because soil quality correlates positively with humus levels, soil organic carbon enhancing mitigation strategies are beneficial. Restoration of degraded lands and wetlands as well as tillage reducing systems is generally considered beneficial for soil quality. On the other hand, if mitigation measures reduce the amount of organic or mineral fertilizer input, soil quality will decrease. Such measures include extensive crop residue removal for bio-energy generation and manure digestion. The on-site impact of higher cropping intensities on soil quality is ambiguous because both nutrient inputs and nutrient removals are increased and the resultant of the two would determine the direction of
impact. Furthermore, agricultural intensification of agriculture could increase soil salinity, water-logging and mono cropping as has been experienced in many parts of the developing world, for example in India after the green revolution. Water quality impacts are linked to soil impacts. Higher soil organic carbon levels improve moisture and nutrient holding capacities and thus, decrease nutrient emissions into surface, sub-surface, and ground water. 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.

Mitigation efforts have synergies and trade-offs with ecosystems especially cultivated ecosystems. Mitigation impacts the condition and resilience of cultivated ecosystems which in turn decide the flow of the ecosystem services critical for agricultural inputs and outputs. Mitigation here works as driver of change for the cultivated ecosystems (MA 2005). Overall, whether ecosystem co-effects 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 for carbon sequestration are beneficial for ecosystems. Trade-offs exist, if homogeneous energy crop or tree plantations replace native forests. An environmental worst case scenario would be where subsidized energy crop plantations with a positive net emission balance across all greenhouse gases irreversibly replace species-rich rain forests. If mitigation efforts reduce agricultural intensities on grasslands, pastures, and croplands, some on-site ecological benefits are possible. However, intensity reductions increase land scarcity and thus increase pressure on nature reserves elsewhere.

The third category of side effects from agricultural mitigation involves social welfare externalities related to food, water, energy, health, employment, extreme events, and landscape. Food security decreases 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. Wasteland could also be used for fish production as demonstrated in Israel, Syria and other parts of Mediterranean Africa. Changes in global food production patterns are likely to affect malnutrition and obesity. Malnutrition increases if agricultural mitigation makes food relatively more expensive for poor
people. However, if higher food prices are coupled with beneficial changes in employment and income distribution, alleviations of malnutrition are possible. Furthermore, increasing land scarcity will shift the supply equilibrium from land intensive food commodities, i.e. livestock products, towards land friendly commodities, i.e. crop products. This may worsen some nutritional deficiencies in poor countries but reduce obesity in richer countries. However, these are tentative conjectures. The real direction of outcome is context specific and depends on the strength of the cause and effect relationship between the forces described earlier.

Water security impacts comprise changes in regional agricultural water use resulting from greenhouse gas emission mitigation efforts. Land intensive mitigation strategies lead to increases in irrigation intensities for traditional crops (McCarl and Schneider). In addition, negative water impacts are expected from large-scale energy crop plantations (Berndes). Finally, societal side effects may involve recreational and civil protection impacts through landscape restructuring. For example, restored wetlands may increase flood protection. It can also bring nutrients, provide water storage facilities especially in arid and semi arid areas and contribute towards bioremediation.

**Conclusions**

What benefits can society reap from agricultural mitigation options despite the described complexities, variations, and uncertainties? Which strategies should be pursued at which level? Alternatively, what mitigation strategies should agriculture not become engaged to? In answering these questions, we will draw several general conclusions.

1) The socially optimal mitigation strategy mix minimizes the social costs of emission mitigation per calorie. Inefficiencies arise if a) technologies are regulated instead of emissions, b) non-carbon 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. 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 in suitable cropland areas. 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, simultaneously decrease the potential for emission leakage and negative environmental side effects. Such measures include on the supply side restoration of degraded lands and emission friendly yield improvements, and on the demand side promotion of energy friendly diets.

6) Non-carbon emissions from crop and livestock production are important but very costly to measure and regulate.

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