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Agriculture and Global Warming: Their Interaction and Other Problems of Sustainability

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Agriculture is a major source of greenhouse gas emissions. Reduction of greenhouse gas emissions from agriculture would contribute substantially to the mitigation of global warming. Conversely, the progression of global warming influences agriculture. Farmers need to adapt to the changing climate according to their particular agricultural situation.

Sustainability of the global environment is essential for agriculture and human life, but there remain several problems regarding the time scale of sustainability. To solve these problems, we must estimate the adaptive capacity of the Earth for irreversible impacts of global warming. Gaining an understanding of the "big picture", which will allow quantitative objectives for coping with global warming to be established, is currently the top-priority task of the natural sciences.

Key words: agriculture, global warming, greenhouse gas, sustainability, time scale

Impacts of Agriculture on Global Warming and Vice Versa

Agriculture accounts for about 15% of the global emissions of greenhouse gases (GHGs) (World Bank, 2007), making it the second largest source after the energy sector (~63%). Because of this large contribution, continued GHG emissions from agriculture will exacerbate global warming. Agriculture is responsible for emissions of all three major GHGs: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) (Table 1). In particular, its CH_4 and N_2O emissions account for about 50% and about 60%, respectively, of global anthropogenic emissions of those GHGs (Smith *et al.,* 2007). Moreover, although the CO_2 budget is almost in balance, CO_2 fluxes between agricultural lands and the atmosphere are large in both directions (~120 Pg C yr^{-1}) (Denman *et al.,* 2007). Part of the CO_2 efflux derives from decomposition of soil organic matter. Carbon storage in soils has been estimated to be 1500 Pg C, which is double that in the atmosphere (730 Pg C) (Prentice *et al.,* 2001). To sustain soil carbon storage is quantitatively important to reduce CO_2 emissions from agricultural soils.

Soils can also absorb atmospheric CO_2. "Soil carbon sequestration" occurs when the amount of carbon input into the land is larger than that emitted to the atmosphere. Soil carbon sequestration has been estimated to account for 89% of the total mitigation potential of agricultural GHG emissions, followed by reduction of CH_4 (9%) and N_2O (2%) emissions from soils (Smith *et al.,* 2007). Therefore, we should develop and practice effective mitigation options that both enhance soil carbon sequestration and reduce soil CH_4 and N_2O emissions.

Global warming affects the environment, and thus agriculture, in various ways. Global mean temperature increases of more than 4℃ are expected to lead to major increases in their vulnerability, exceeding the adaptive capacity of many systems (Schneider *et al.,* 2007). Crop productivity is projected to increase slightly at mid- to high latitudes with temperature increases of up to 3℃, depending on the

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Table 1. Lifetimes and global warming potential (GWP) of the three major GHGs

Gas	Lifetime (years)	GWP for given time horizons		
		20-yr	100-yr	500-yr
CO_2	—	1	1	1
CH_4	12	72	25	7.6
N_2O	114	289	298	153

Source: Forster *et al.* (2007)

crop, and then to decrease by more than the initial increase in some regions (Intergovernmental Panel on Climate Change, 2007a). At lower latitudes, even moderate temperature increases (1–2℃) are likely to reduce major cereal yields (Easterling *et al.*, 2007).

Negative impacts of increased temperatures on agriculture have already been reported. Temperatures above ~35℃ at the flowering stage of rice disturb anther dehiscence and pollen shedding (Matsui *et al.*, 2001), resulting in pollination failure (i.e., sterility). Rice sterility increases by 16% with each 1℃ increase in air temperature above ~35℃ during the growing period (Kim *et al.*, 1996). In Japan, a model simulation study has projected that the region suitable for the production of apples and mandarins will move gradually northward from now to the 2060s (Sugiura and Yokozawa, 2004). These findings indicate that farmers must adapt now to the currently changing climate. Agricultural practices can be adapted to global warming in several ways, such as by using cultivars with heat tolerance, changing crops, and shifting the cropping period. However, further warming (4–5℃) will have increasingly negative impacts in all regions of the world (Easterling *et al.*, 2007). Therefore, we must both mitigate GHG emissions from agriculture and adapt to the changing climate.

Time Scales of Global Warming

Anthropogenic GHG emissions are the most important driver of global warming. The warming effect (i.e., radiative forcing) of emissions of the three major GHGs account for 70% of the total warming effect caused by all drivers, including other GHGs, ozone, and surface albedo (Forster *et al.*, 2007). Each GHG has its own life time in the atmosphere, depending on removal processes, from less than 1 year to over 10000 years (Forster *et al.*, 2007).

To evaluate the total simultaneous GHG emissions from an agro-ecosystem, we must deal with several kinds of GHGs with different life times and different greenhouse effects. The IPCC has developed a useful index, the global warming potential (GWP), for comparing the warming effect of a unit mass of each GHG relative to that of CO_2 within a specified time horizon. The IPCC uses time horizons of 20, 100, and 500 years (Table 1). However, there is no particular scientific basis for using these three time horizons, which were chosen arbitrarily. Researchers investigating GHG emissions from agriculture conventionally use GWP values within a 100-year time horizon, and this criterion has been adopted by the Kyoto Protocol (United Nations, 1998). This raises the question of whether 100 years is long enough to evaluate the effects of global warming. The World Commission on Environment and Development (WCED) has defined "sustainable development" as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). This definition is ambiguous with regard to the time scale of sustainability. What time horizon is appropriate for evaluating the effects of development carried out by the present generation? Global model simulation studies have projected that current global warming effects will continue for several centuries, even if atmospheric GHG concentrations were stabilized (IPCC, 2007b), which suggests that 100 years is not a long enough time horizon for determining the sustainability of the global environment.

Other Problems of Sustainability

The above discussion raises several hierarchical problems regarding the sustainability of the global environment. A principal problem is that with current scientific knowledge, we cannot accurately estimate the adaptive capacity of the Earth for human activities. Solving this problem will provide crucial limits for various environmental problems. In the context of global warming, determining the time limit for irreversible effects, such as disintegration of the West Antarctic ice sheet and the shutdown of the North Atlantic thermohaline circulation, is a critical problem. Although the timing of these effects (i.e., in the near or distant future) and the speed with which they occur (i.e., gradually or suddenly) have been briefly discussed (Schneider *et al.,* 2007), no concrete projections have been made, because they depend mainly on future anthropogenic GHG emissions.

Solutions to the above hierarchical problems must be found by the present generation. What time horizon should we use when considering the effects of global warming? How much do we need to mitigate GHG emissions? How we answer these questions depends on future human activities. Gaining an understanding of the "big picture" is the top-priority problem for today's natural scientists if they are to ensure sustainability of the environment.

Conclusions

This paper briefly reviews the interaction between agriculture and global warming, indicating the importance of both mitigation and adaptation. Current scientific knowledge is insufficient to clearly project future world conditions. Time limits for the irreversible effects of global warming depend mainly on human choices. Within the adaptive capacity of the Earth, though not clarified at present, we have choices regarding the size of the human population and the magnitude of human activity. If we are to make wise choices, we must accelerate the progress of the natural sciences.

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