MITIGATING NET GLOBAL WARMING POTENTIAL (CO_2, CH_4 and N_2O) IN UPLAND CROP PRODUCTION

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ABSTRACT

When appraising the impact of food and fiber production systems on composition of earth=s atmosphere, the entire suite of greenhouse gases [carbon dioxide (CO_2) methane (CH_4) and nitrous oxide (N_2O)] needs to be considered. Storage of atmospheric CO_2 into stable organic fractions in the soil can sequester CO_2 while normal crop production practices generate N_2O and decrease the soil sink for atmospheric CH_4 in upland soils. The overall balance between the net exchange of these gases constitutes the net global warming potential (GWP) of a crop production system. In upland cropping systems changes in soil organic matter content, the CO_2 emitted from fertilizer production, transport and application, and N_2O emissions are the major components of net GWP.

Managing upland agricultural systems to optimize soil C storage and minimize N_2O can have a significant impact on the future atmospheric radiative forcing resulting from CO_2 and N_2O in the atmosphere as well as sustainable intensive crop production. Soil C levels have been increased by reducing tillage intensity, increasing intensity of crop rotations, and with N fertilization. Nitrogen fertilization is essential to maintaining crop yields and economic sustainability, but excessive N application increases N_2O emissions which can more than offset gains in C storage. If we are to develop crop management systems that will decrease net GWP in the future, these systems will also need to maintain crop production and improve soil quality. The effect of management options that are currently available, such as tillage, control release fertilizers and nitrification inhibitors on N_2O emissions and net GWP are discussed.

INTRODUCTION

In the context of this conference on mitigating CH_4 and N_2O emissions, we need to keep in mind that the purpose of mitigating greenhouse gas emissions is to minimize the increase in atmospheric radiative forcing. Our goal is to mitigate radiative forcing in agricultural systems through increasing soil C storage, decreasing CH_4 emissions or increasing soil CH_4 oxidation and decreasing N_2O emissions. Production of food and fiber is the primary human-induced contributor to the emissions of these gases to the atmosphere. When we are appraising the impact of agricultural production on composition of earth's atmosphere, the entire suite of greenhouse gases, CO_2, CH_4 and N_2O needs to be considered. Storage of atmospheric CO_2 into stable organic fractions in the soil can sequester CO_2, while normal crop production practices generates N_2O and decreases the soil sink for atmospheric CH_4. The overall balance between the net exchange of these gases constitutes the net global warming potential (GWP) of a crop or livestock production system. Methane is produced mainly through enteric fermentation in livestock and through the handling of livestock and poultry manure in anaerobic lagoon systems. Typical agricultural soils are minor emitters of CH_4 and generally small sinks for atmospheric CH_4 and, because of space limitations, will not be discussed in detail. Nitrous oxide, the principal non-

CO_2 greenhouse gas concerned with soils, is produced naturally in the soil through microbial processes. Nitrogen fertilizer input to facilitate crop production augments this production. It is the relationship of soil C changes to N_2O emissions that typically regulate net GWP (Robertson et al. 2000).

The past and current increases in atmospheric N_2O can be directly related to increased N-fixation in synthetic fertilizer and legume crops. It has been directly demonstrated that any strategy which increases the efficiency of use of fertilizer N will reduce emissions of N_2O, ammonia (NH_3) and nitric oxide (NO). (Kroeze et al. 1999). In general, gaseous emissions can be decreased by management practices which optimize the crop's natural ability to compete with processes whereby plant-available N is lost from the soil-plant system. If fertilizer N is used more efficiently by the crop, then less N will need to be supplied to meet the demand for food, less N will be lost, and less N_2O will be produced and CO_2 fixation will be optimized. The undesirable effects of fertilizer use on increased N_2O production can be mitigated by agricultural management without decreasing production, and probably reducing rather than increasing costs. Net GWP will decrease as long as crop production is not appreciably affected.

Taking into consideration, in terms of CO_2 equivalents, the CO_2 emitted from farming, the N_2O emitted in crop and livestock production and the CH_4 emitted from livestock production, and estimates of increased soil C storage, U.S. agriculture is a net emitter of approximately 450 Tg of CO_2 equivalents annually (Fig. 1).

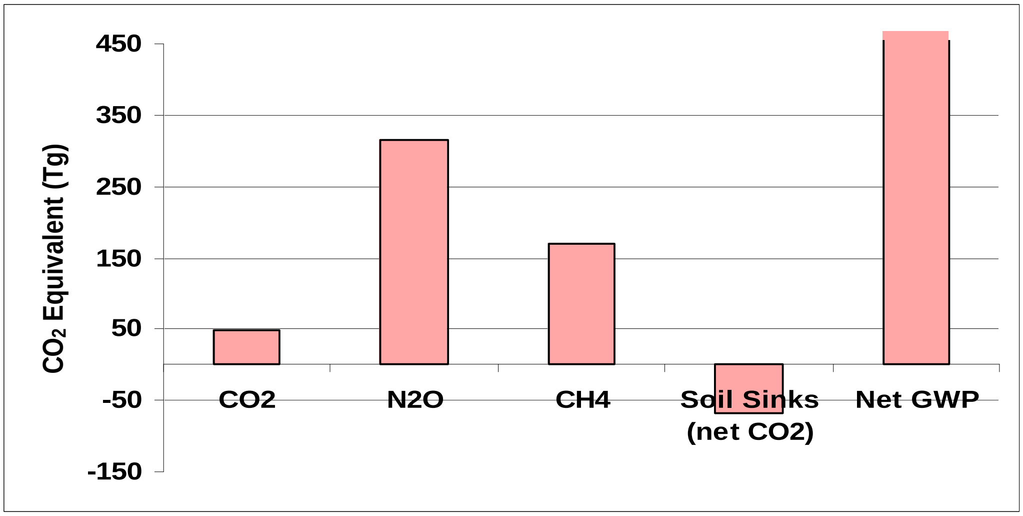

Figure 1. Estimate of U.S. greenhouse gas emissions and sinks for 2000 (USEPA, 2002).

Agricultural soils have the potential to greatly reduce amount by changing management to increase soil organic matter content (Follett, 2001) and decrease N_2O emissions (Kroeze et al. 1999). A goal of this paper is to address the issue of net radiative forcing and to consider the potential tradeoffs and/or synergisms between practices aimed at C sequestration and mitigation of N_2O and CH_4 emissions, in order to understand the net effect of all three gases (CO_2, N_2O and CH_4), which can be expressed as CO_2 equivalents.

MITIGATION OF CO_2 FLUXES THROUGH C SEQUESTRATION

Carbon dioxide is exchanged continuously between soils and the atmosphere, primarily through the processes of photosynthesis and incorporation of plant-derived organic matter into soils (CO_2 influx), and the decomposition of that organic matter by soil organisms (CO_2 outflux). The amount of C (C) stored in soils depends primarily on the balance between C inputs from plant (and animal) residues and C emissions from decomposition. Thus, increasing soil C stocks requires increasing C inputs and/or decreasing the decomposition. Both inputs and decomposition rates are affected by natural factors such as climate (temperature and rainfall) and soil physical factors (soil texture, clay mineralogy, profile development), as well as agricultural management practices; thus rates will vary, geographically, and between different management systems. In general, C sequestration will be favored under management systems that (1) minimize soil disturbance and erosion, (2) maximize the amount of crop-residue return, and (3) maximize water- and nutrient-use efficiency of crop production (Paustian et al. 1998).

Decreasing tillage intensity, especially by using no-tillage practices, has been found to promote C sequestration (Allmaras, et al. 2000). In semi-arid regions, no-till adoption provides increased water storage, enabling more continuous crop rotations with elimination or decreased frequency of bare fallowing (Peterson et al. 1998). The effects of no-till systems under these conditions are synergistic in that adoption of no-till enables higher crop inputs through more intensified rotations, lower decomposition rates accompanying (bare) summer-fallowing, greater water-use efficiency, and less soil disturbance (Peterson et al. 1998).

Most cropland soils show a clear response to increasing amounts of C return such that soil organic C levels, over time, are often directly proportional to the amount of C added to soil under different management treatments (Paustian et al. 1998). Eventually, for any given level of input, soil C levels tend toward equilibrium, limiting the amount and duration of additional C storage. In addition, energy costs associated with manufacture and distribution of fertilizer, energy for irrigation pumping, as well as potential increased emissions of N_2O and CH_4 must be considered, for these costs may offset part or all the gains in C storage. However, use of these inputs usually will be determined primarily as a means of achieving the objective of food production and not as a means of mitigating GHG emissions. Practices promoting optimally efficient water and nutrient use, however, will likely have the greatest benefits in terms of decreased CO_2 and N_2O.

In addition to C sequestration, increasing soil organic matter levels generally carries with it substantial benefits to soil biological, chemical and physical attributes, which translate into improved fertility and soil sustainability. These improvements include enhanced water storage capacity, increased water infiltration, reduced runoff (and erosion), increased soil buffering capacity, and increased storage of essential plant nutrients.

MITIGATION OF N_2O FLUXES

Agriculture contributes approximately 35% of total global annual emissions of N_2O emissions to the atmosphere (Kroeze et al. 1999). The major sources include emissions from soils due to microbial metabolism of nitrogen, through the processes of nitrification and denitrification. The same processes act on animal wastes, resulting in emissions both in storage and when applied to the field. Emissions occur both directly on agricultural lands and from nitrogen transported to non-agricultural lands, through gaseous and leaching/runoff losses from agricultural soils.

Kroeze and Mosier (2000) estimated that improved crop N-use efficiency could decrease soil derived N_2O emissions from agriculture by as much as 35% globally, with even greater savings in the input-intensive systems of North America, Europe, and the former Soviet Union. Such savings could be achieved by the application of existing technology, largely by better matching crop N-needs with soil N-availability Both reducing the amount of off-site N loss and managing the non-cropland areas offer options for N_2O mitigation and increasing soil C. Typical practices which can decrease net GWP include:

MINIMIZE FALLOW PERIODS AND CONSERVE RESIDUES. Agricultural systems that provide continuous plant cover should be utilized whenever feasible to minimize leaching and denitrification of nitrate associated with bare soil fallow. Nitrate accumulates in the soil during fallow periods between cropping seasons as a result of mineralization of soil organic matter and nitrification of the ammonium so formed. The nitrate accumulated during fallow is more susceptible to loss by denitrification than that which is produced when plants are present. The amount of fertilizer N used and the timing of application should have a goal of leaving as little residual N as possible in the soil during the non-cropped periods of the year. Using interseasonal cover crops is one means of minimizing the accumulation of nitrate and its loss by denitrification.

Reduced or no-till farming systems, in which plant residues are retained, and soil disturbance is minimized encourage reduced rates of N mineralization. However, there is evidence which indicates that no-till soils suffer from greater gaseous losses through denitrification than those under conventional cultivation (Aulakh et al. 1984). This may be because in no-till soils there is a greater bulk density resulting in reduced diffusion of air in the surface layers, larger and more anaerobic aggregates, increased water content due to greater water conservation, greater concentrations of organic matter near the surface that increase C availability for denitrification, a more favorable environment for denitrifying microorganisms. Since maximum denitrification rates are commonly observed when soil water filled pore space is >90 percent, minimizing the time a soil is saturated should limit denitrification. It has been shown that less N_2O was emitted from less frequently irrigated soils.

SPLIT APPLICATIONS/CONTROLLED RELEASE FERTILIZERS. More efficient use of fertilizer N will result when application of fertilizer coincides with the period of rapid plant uptake. Therefore, several applications of small amounts of fertilizer N during the growing season would be a more effective means of supplying N for plant growth, than one large dose at the beginning of the season. Unfortunately, multiple applications of fertilizer are not always practical in many agricultural situations and application may increase fuel consumption, thus control release fertilizers should be useful in such conditions (Shoji 1999)

Control release fertilizer formulations should limit N_2O emissions by controlling the nitrate supply to limit denitrification. By using specific fertilizer formulations to release N in synchrony with plant growth it should be possible to provide sufficient N in a single application to satisfy plant requirements yet maintain very low concentrations of mineral N in the soil throughout the growing season. With this concept, any gaseous loss event would be small because of the limited substrate. Delgado and Mosier (1996) found that CRF decreased N_2O emissions from irrigated barley (Table 1).

NITRIFICATION INHIBITORS. Using nitrification inhibitors does not always result in increased crop yields, but a number of field studies indicate that nitrification inhibitors do limit N_2O emissions from ammonium based fertilizers (Peoples et al. 1995). Only a limited number of chemicals are available commercially for use as nitrification inhibitors in agriculture and these include nitrapyrin, sulfathiazole, dicyandiamide, terrazole and thiourea (McCarty, 1999). Unfortunately, most of these compounds have limitations to their usefulness. For example, the most commonly used nitrification inhibitor, nitrapyrin, is seldom effective because of sorption on soil colloids, hydrolysis, and loss by volatilization. Using calcium carbide coated with layers of wax and shellac to provide a slow-release source of acetylene has reduced nitrification and increased yield, or recovery of N, in irrigated wheat, maize and cotton, and flooded rice. Wax coated calcium carbide also inhibited N_2O emission from urea fertilized maize, wheat and flooded rice soils (Table 1). In these studies, calcium carbide limited nitrate accumulation in the soil following urea fertilization and limited N_2O emissions in all 3 crops. Dicyandiamide was equally effective in winter wheat while nitrapyrin provided moderate inhibition in corn (Table 1).

Table 1. Effect of nitrification inhibitors on nitrous oxide emission (g N ha^{-1} day^{-1}) from urea fertilized, cropped fields [a].

Treatment	Corn[b, c]	Rice	Wheat	Barley[d]
Urea	31 B	73 C	5.8 B	8.2A
Urea + dicyandiamide	-	-	2.5 A	5.2C
Urea + nitrapyrin	16 B	99 D	-	-
Urea + wax coated CaC_2	5.4 A	16 B	2.3 A	-
Urea + CRU	-	-	-	6.9B

[a] Modified from Mosier et al. 1994.

[b] Numbers in each column followed by the same letter are not significantly different (p=0.05). The periods over which mean rates were calculated were 97days for corn, 23 days for rice, and 292 days for wheat, and 90 days for barley.

[c] A dash indicates no measurement was made.

[d] Barley study from Delgado and Mosier, 1996, CRU=polyolefin coated urea, 90 kg urea N ha^{-1}.

All of these mitigation strategies have other environmental benefits. First, increasing on-farm N-use efficiency will lessen groundwater nitrate loading and eutrophication of surface and coastal waters. Tighter farm N cycles will help decrease NH_3 and NO_x emissions to the atmosphere, subsequently decreasing deposition-N inputs to nonagricultural ecosystems. Making crop N-use more efficient also will decrease the need for synthetic N-fertilizer, which produces CO_2 in its manufacture, so substituting excess manure for synthetic N will provide measurable CO_2 mitigation. Some N_2O mitigation practices also will mitigate CO_2 more directly. Riparian forests that can mitigate against indirect N_2O fluxes will store C in growing vegetation for a number of decades, and both riparian forests and cropping systems with cover crops accumulate C in soil.

USING CROPPING SYSTEM MANAGEMENT IN SEMI-ARID DRYLAND AGRICULTURE TO DECREASE GLOBAL WARMING POTENTIAL: A CASE STUDY

In May 2002 a study to quantify net GWP within an established dryland agricultural management project was begun in northeastern Colorado, USA. This project, “The Sustainable Dryland Agroecosystem Management” project was established in 1985 in a field that had been used for dryland winter wheat production using a wheat-fallow system for the previous 50 years. Located at an elevation of 1340 meters and longitude of 40°22’12” N and latitude of 103°7’48” W average annual rainfall is 420 mm. The study site was positioned in a catenary sequence of soils that are common to the geographic area. In 1985, crop rotations of wheat-corn-fallow, wheat-corn-soybeans, wheat-wheat-corn-soybeans, opportunity cropping and perennial grass. No-tillage cropping was used throughout. A mixture of native grasses was planted into the grass plots in 1986. Opportunity cropping, continuous cropping, (Sherrod et al. 2003) was an attempt to crop continuously without resorting to monoculture. This system was in a forage legume in 2000, wheat in 2001 and was cropped to corn in 2002. The 2002 corn in both continuous cropping and WCF was fertilized with 112 kg N ha^{-1} as a solution of urea and ammonium nitrate.

We selected wheat-corn-fallow (WCF), continuous cropping (CC), and perennial grass (Grass) for quantification of net GWP based on previous observation of the greatest differences in soil C storage. See Sherrod et al. (2003) and Peterson et al. (1993) for a complete site description. For trace gas measurements we selected the midslope and toeslope position of the catenary sequence. Midslope and toeslope soils both loam soils that are classified as Fine-loamy, mixed, mesic Aridic Argiustoll and Fine-loamy, mixed mesic Pachic Argiustolls, respectively.

Fluxes of CO_2, CH_4 and N_2O were measured one or two times per week, year-round, midmorning of each sampling day. Ten centimeter high vented (Hutchinson and Mosier, 1981) rectangular aluminum chambers were installed on permanently fixed anchors (78.6 cm X 39.3 cm X 10 cm) in a water channel at each sampling. Anchors were set perpendicular to the corn row so that the corn row and interrow were contained within each chamber. Gas samples from inside the chambers were collected by syringe at 0, 15 and 30 minutes after installation (Hutchinson and Mosier, 1981; Mosier and Mack, 1980; Mosier et al. 1991). Four anchors were established within each replicate treatment and slope position so that eight total observation points within each of the six treatment by slope position combinations were used. Gas samples were injected into 12-ml evacuated tubes that were sealed with butyl rubber septa and transported to the laboratory in Fort Collins for analysis by gas chromatography. The gas chromatograph used was a Varian 3800 that is equipped with thermoconductivity, flame ionization and electron capture detectors to quantify CO_2, CH_4 and N_2O, respectively (Mosier and Mack, 1980; Mosier et al. 1991). Soil temperature and volumetric soil water content of each sampling site was recorded at each gas flux measurement period.

The annual change in soil organic C content between 1986 and 1997 (Sherrod et al. 2003) was used as soil C input into the GWP calculation (Table 2. In addition to annual N_2O emission, CH_4 consumption and SOM change the CO_2 equivalents used for farm operations such as planting and herbicide production and application (Farm Operations) were estimated from information in West and Marland (2002). The energy used to produce the N-fertilizer (0.82 kg CO_2-C per kg N (Follett, 2001); and application 45.5 kg CO_2 ha^{-1} (West and Marland 2002).

Table 2. Estimate of net GWP in notill dryland agroecosystem cropping systems

Treatment	Annual Biomass	Farm Operations	N Fertilizer Production	N_2O	CH_4	SOM	Net GWP
	kg ha^{-1} yr^{-1}	--------------------------kg CO_2 equivalents ha^{-1} yr^{-1}-------------					
WCF-M	2060	85	383	353	-22.8	-476	322d
WCF-T	2705	85	383	314	-27.6	-590	164e
CC-M	2880	85	383	321	-20.9	-1100	-332d
CC-T	3790	85	383	386	-28.5	-1467	-642b
Grass-M	803	0	0	172	-11.3	-653	-492c
Grass-T	1569	0	0	157	-11.5	-968	-823a

WCF-M=wheat-corn-fallow midslope; WCF-T = wheat-corn-fallow toeslope; CC-M = continuous cropping midslope; CC-T = continuous cropping toeslope; Grass-M= grass midslope; Grass-T = grass toeslope. The IPCC (2001) conversion of N2O and CH4 to CO2 equivalents on a 100 year time frame is 296 and 23, respectively, estimates are based on average observed flux calculated for the year, May 2002-May 2003. Soil organic matter is based on average annual increase in soil organic C content for the 0-5 cm depth between 1985 and 1997. The new GWP values followed by the same letter are not significantly different at P-0.05.

Although we have only one year of trace gas flux data, and precipitation was unusually low for much of the cropping season, the data suggest that crop management can dramatically affect net GWP. Incorporating fallow into the cropping sequence maintains lower SOM content than continuous cropping. The difference would be even greater if a conventionally tilled wheat-fallow system had been available for comparison (Del Grosso, 2002). Soil C storage was directly related to above ground biomass production (Sherrod et al. 2003) and stabilization of soil C by eliminating the fallow part of the cropping sequence. Neither N_2O nor CH_4 fluxes differed by slope position or cropping system. The only difference observed was between grass where CH_4 uptake and N_2O efflux was lower than in either crop rotation. Studies within the shortgrass stepp indicate that it may take 50 years before grassland systems equilibrate following plowing (Mosier et al. 1997).

CONCLUSION

Soil C storage, energy use in fertilizer production, and field N_2O emissions are the main contributors to net GWP in cropping systems. Management techniques such as crop rotations and reduced tillage are available to increase soil organic C without increasing N_2O emissions while control release fertilizers and inhibitors can directly decrease N_2O emissions without decreasing soil C. Combinations of these techniques should be useful in decreasing net GWP while enhancing crop production in many agroecosystems.

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