Appendix F. Agriculture

Overview

The emissions discussed in this appendix refer to non-energy methane (CH_4) and nitrous oxide (N_2O) emissions from enteric fermentation, manure management, and agricultural soils. Emissions and sinks of carbon in agricultural soils are also covered. Energy emissions (combustion of fossil fuels in agricultural equipment) are included in the residential, commercial, and industrial (RCI) sector estimates.

There are two livestock sources of greenhouse gas (GHG) emissions: enteric fermentation and manure management. Methane emissions from enteric fermentation are the result of normal digestive processes in ruminant and non-ruminant livestock. Microbes in the animal digestive system break down food and emit CH_4 as a by-product. More CH_4 is produced in ruminant livestock because of digestive activity in the large fore-stomach. Methane and N_2O emissions from the storage and treatment of livestock manure (e.g., in compost piles or anaerobic treatment lagoons) occur as a result of manure decomposition. The environmental conditions of decomposition drive the relative magnitude of emissions. In general, the more anaerobic the conditions are, the more CH_4 is produced because decomposition is aided by CH_4-producing bacteria that thrive in oxygen-limited aerobic conditions. Under aerobic conditions, N_2O emissions are dominant. Emissions estimates from manure management are based on manure that is stored and treated at livestock operations. Emissions from manure that is applied to agricultural soils as an amendment or deposited directly to pasture and grazing land by grazing animals are accounted for in the agricultural soils emissions.

The management of agricultural soils can result in N_2O emissions and net fluxes of carbon dioxide (CO_2) causing emissions or sinks. In general, soil amendments that add nitrogen to soils can also result in N_2O emissions. Nitrogen additions drive underlying soil nitrification and de-nitrification cycles, which produce N_2O as a by-product. The emissions estimation methodologies used in this inventory account for several sources of N_2O emissions from agricultural soils, including decomposition of crop residues, synthetic and organic fertilizer application, manure application, sewage sludge, nitrogen fixation, and histosols (high organic soils, such as wetlands or peatlands) cultivation. Both direct and indirect emissions of N_2O occur from the application of manure, fertilizer, and sewage sludge to agricultural soils. Direct emissions occur at the site of application and indirect emissions occur when nitrogen leaches to groundwater or in surface runoff or volatilizes and is transported off-site before entering the nitrification/denitrification cycle.

The net flux of CO_2 in agricultural soils depends on the balance of carbon losses from management practices and gains from organic matter inputs to the soil. Carbon dioxide is absorbed by plants through photosynthesis and ultimately becomes the carbon source for organic matter inputs to agricultural soils. When inputs are greater than losses, the soil accumulates carbon and there is a net sink of CO_2 into agricultural soils. In addition, soil disturbance from the cultivation of histosols releases large stores of carbon from the soil to the atmosphere.

Other agricultural soils emissions include CH_4 and N_2O from crop residue burning. Also, CH_4 emissions occur during rice cultivation. Finally, the practice of adding limestone and dolomite to agricultural soils results in CO_2 emissions.

Emissions Inventory and Reference Case Projection Methods

Methane and Nitrous Oxide

GHG emissions for 1990 through 2005 were estimated by MPCA using EPA methods and emission factors as provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector and the national GHG inventory.[1,2] These methods apply emission factors developed for the US to activity data for the agriculture sector. Activity data include livestock population statistics, crop production statistics, amounts of fertilizer applied to crops, and trends in manure management practices. This methodology is based on international guidelines developed by sector experts for preparing GHG emissions inventories.[3]

Data on crop production in Minnesota from 1990 to 2005 and the number of animals in the state from 1990 to 2002 were obtained by MPCA.[4] The distribution of manure management systems for each livestock category, fertilizer usage data and data on acres of cultivated histosols (high organic content soils) were obtained by MPCA.[5]

Agricultural residue burning was not estimated in the MPCA inventory; therefore, emissions were estimated using the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SGIT) software. The SGIT methodology calculates emissions by multiplying the amount (e.g., bushels or tons) of each crop produced by a series of factors to calculate the amount of crop residue produced, the resultant dry matter, the carbon/nitrogen content of the dry matter, and the fraction of residue burned.

Emissions from enteric fermentation and manure management were projected based on forecasted animal populations. Dairy cattle forecasts were based on state-level projections of dairy cows from the Food and Agricultural Policy Research Institute (FAPRI).[6] Projections for all other livestock categories, except sheep, were estimated based on linear forecasts of the historical 1990-2004 populations. The sheep population dropped by almost 50% between 2003

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[1] GHG emissions were calculated using SGIT, with reference to EIIP, Volume VIII: Chapter 8. "Methods for Estimating Greenhouse Gas Emissions from Livestock Manure Management", August 2004; Chapter 10. "Methods for Estimating Greenhouse Gas Emissions from Agricultural Soil Management", August 2004; and Chapter 11. "Methods for Estimating Greenhouse Gas Emissions from Field Burning of Agricultural Residues", August 2004.

[2] Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004, U.S. Environmental Protection Agency, April 2006, http://epa.gov/climatechange/emissions/usinventoryreport.html.

[3] Revised 1996 1ntergovermental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories, published by the National Greenhouse Gas Inventory Program of the IPCC, available at (http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm; and Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, published in 2000 by the National Greenhouse Gas Inventory Program of the IPCC, available at: (http://www.ipcc-nggip.iges.or.jp/public/gp/english/).

[4] MPCA

[5] MPCA

[6] FAPRI Agricultural Outlook 2006, Food and Agricultural Policy Research Institute, http://www.fapri.iastate.edu/outlook2006.

and 2004, and forecasting the 1990-2004 historical sheep populations resulted in negative populations before 2030. Therefore, no growth from the 2004 population was assumed for this category. Livestock population growth rates are shown in Table F1.

Table F1. Growth Rates Applied for the Enteric Fermentation and Manure Management Categories

Livestock Category	2005-2030 Annual Growth
Dairy Cattle	-2.4%
Beef Cattle on Feed	-1.4%
Beef Cattle not on Feed	-0.4%
Swine	1.6%
Sheep	0.0%
Goats	3.0%
Horses and Mules	2.8%
Turkeys	1.9%
Broilers	-2.5%

Projections for agricultural burning and agricultural soils were based on linear extrapolation of the 1990-2004 historical data. Table F2 shows the 2005-2030 annual growth rates estimated for each category.

Table F2. Growth Rates Applied for the Agricultural Soils and Burning

Agricultural Category	2005-2030 Annual Growth
Mineral Fertilizer	1.7%
Manure Soil Applications	-0.2%
Legumes	1.6%
Crop Residues	2.1%
Atmospheric Deposition	0.6%
Cultivated Histosols	0.7%
Leaching and Runoff	1.4%
Rice Cultivation	3.7%
Residential Fertilizer	1.6%
Agricultural Burning	1.9%

Soil Carbon

Net carbon fluxes from agricultural soils have been estimated by researchers at the Natural Resources Ecology Laboratory at Colorado State University and are reported in the US Inventory of Greenhouse Gas Emissions and Sinks[7] and the US Agriculture and Forestry Greenhouse Gas Inventory. The estimates are based on the Intergovernmental Panel on Climate Change (IPCC) methodology for soil carbon adapted to conditions in the US. Preliminary state-level estimates of

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[7] US Inventory of Greenhouse Gas Emissions and Sinks: 1990-2004 (and earlier editions), US Environmental Protection Agency, Report # 430-R-06-002, April 2006. Available at: http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

CO_2 fluxes from mineral soils and emissions from the cultivation of organic soils were reported in the US Agriculture and Forestry Greenhouse Gas Inventory.[7] Currently, these are the best available data at the state-level for this category. The inventory did not report state-level estimates of CO_2 emissions from limestone and dolomite applications; hence, this source is not included in this inventory.

Carbon dioxide fluxes resulting from specific management practices were reported. These practices include: conversions of cropland resulting in either higher or lower soil carbon levels; additions of manure; participation in the Federal Conservation Reserve Program (CRP); and cultivation of organic soils (with high organic carbon levels). For Minnesota, Table F3 shows a summary of the latest estimates available from the United States Department of Agriculture (USDA), which are for 1997.[8] These data show that changes in agricultural practices are estimated to result in emissions of 4.1 million metric tons (MMt) of CO_2 equivalent (CO_2e) per year (yr) in Minnesota. This flux is driven largely by the amount of cultivated organic (i.e., histosol) soils and plowout of grassland to annual cropland. Since data are not yet available from USDA to make a determination of whether the emissions are increasing or decreasing, emissions of 4.1 MMtCO_2e/yr are assumed to remain constant in the emissions forecast.

Table F3. GHG Emissions from Soil Carbon Changes Due to Cultivation Practices (MMtCO_2e)

Changes in cropland			Changes in Hayland				Other			Total[4]
Plowout of grassland to annual cropland[1]	Cropland management	Other cropland[2]	Cropland converted to hayland[3]	Hayland management	Cropland converted to grazing land[3]	Grazing land management	CRP	Manure application	Cultivation of organic soils	Net soil carbon emissions
4.62	0	-0.04	-3.01	-0.11	-0.55	0.04	-0.95	-1.18	5.24	4.06

Based on USDA 1997 estimates. Negative values indicate net sequestration.

[1] Losses from annual cropping systems due to plow-out of pastures, rangeland, hayland, set-aside lands, and perennial/horticultural cropland (annual cropping systems on mineral soils, e.g., corn, soybean, cotton, and wheat).

[2] Perennial/horticultural cropland and rice cultivation.

[3] Gains in soil carbon sequestration due to land conversions from annual cropland into hay or grazing land.

[4] Total does not include change in soil organic carbon storage on federal lands, including those that were previously under private ownership, and does not include carbon storage due to sewage sludge applications.

The MPCA inventory included estimates of CO_2 emissions from pastured and cultivated peat, which range from 0.59 MMtCO_2e in 1990 to 0.66 MMtCO_2e in 2004.[9] However, CO_2 emissions for other types of cultivated high organic soils were not estimated.

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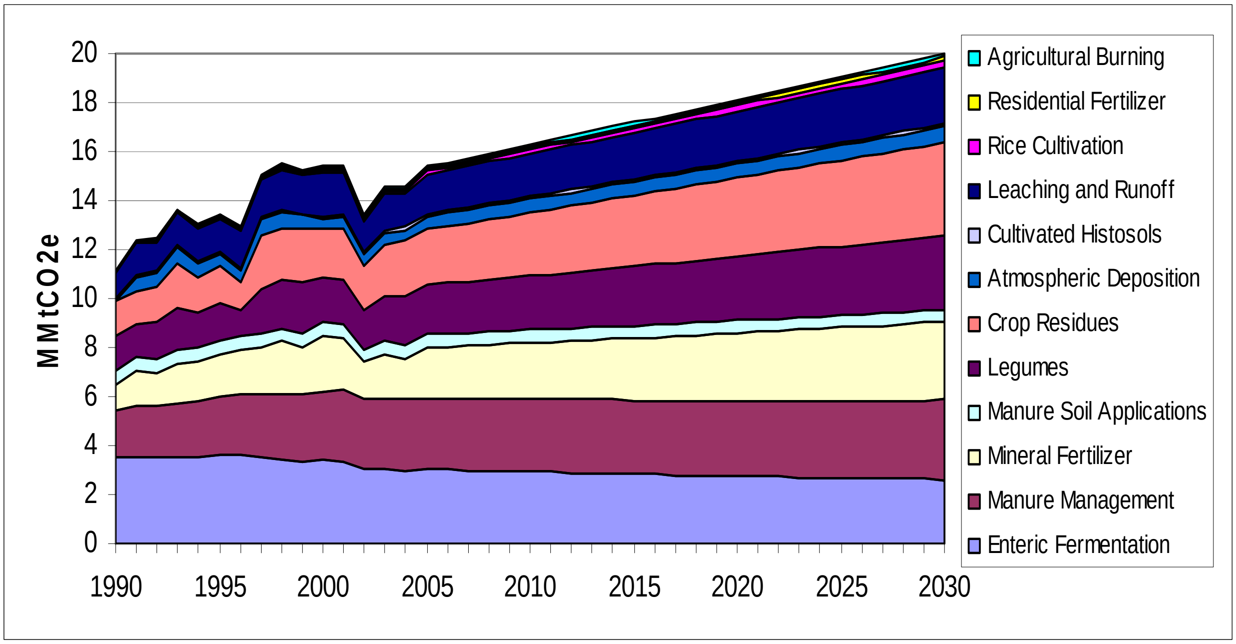
[8] US Agriculture and Forestry Greenhouse Gas Inventory: 1990-2001. Global Change Program Office, Office of the Chief Economist, US Department of Agriculture. Technical Bulletin No. 1907, 164 pp. March 2004. http://www.usda.gov/oce/global_change/gg_inventory.htm; the data are in Appendix B, Table B-11. The table contains two separate IPCC categories: "carbon stock fluxes in mineral soils" and "cultivation of organic soils." The latter is shown in the second to last column of Table F1. The sum of the first nine columns is equivalent to the mineral soils category.

[9] MPCA

Results

Figure F1 shows gross GHG emissions associated with the agricultural sector from 1990 through 2020. In 1990, enteric fermentation accounted for about 31% (3.49 MMtCO$_2$e) of total agricultural emissions. Enteric fermentation emissions decreased to 3.21 MMtCO$_2$e (22% of total agricultural emissions) in 2004 due to the decline in beef and dairy cattle populations. Enteric fermentation emissions are projected to continue declining to 2.58 MMtCO$_2$e by 2030.

Figure F1. Gross GHG Emissions from Agriculture



The manure management category accounted for 18% (1.96 MMtCO$_2$e) of total agricultural emissions in 1990 and increased to 20% (2.90 MMtCO$_2$e) in 2004. Manure management is projected to increase to 3.24 MMtCO$_2$e by 2030. This emissions growth is mainly due to historical and projected increases in the swine population.

The largest source of emissions in the agricultural sector is the agricultural soils category, which includes crops (legumes and crop residues), cultivated histosols, fertilizer, manure application, and indirect sources (leaching, runoff, and atmospheric deposition). Agricultural soils account for 50% (5.55 MMtCO$_2$e) of total agricultural emissions in 1990 and increase to 57% (8.41 MMtCO$_2$e) in 2004. Emissions from this category are projected to increase to 13.6 MMtCO$_2$e in 2030.

Agricultural burning emissions were estimated to be relatively small based on the SGIT activity data (0.10 MMtCO$_2$e in 2004). Emissions from rice cultivation and residential fertilizer are also estimated to be relatively small, 0.10 MMtCO$_2$e and 0.08 MMtCO$_2$e, respectively in 2004.

The only standard IPCC source category missing from this report is CO_2 emissions from limestone and dolomite application. Estimates for limestone and dolomite application in Minnesota were not available; however, the USDA's national estimate for soil liming is about 9 $MMtCO_2e$/yr.[10]

Key Uncertainties

Emissions from enteric fermentation and manure management are dependent on the estimates of animal populations and the various factors used to estimate emissions for each animal type and manure management system (i.e., emission factors which are derived from several variables including manure production levels, volatile solids content, and CH_4 formation potential). Each of these factors has some level of uncertainty. Also, application of these emission factors to the actual types of manure management systems employed in Minnesota produces uncertainty, since the distribution of manure management systems is based on survey data. Finally, animal populations fluctuate throughout the year, and thus using point estimates introduces uncertainty into the average annual estimates of these populations. In addition, there is uncertainty associated with the original population survey methods employed by USDA. CCS believes that the largest contributors to uncertainty in emissions from manure management are the emission factors, which are derived from limited data sets.

As mentioned above, for emissions associated with changes in agricultural soil carbon levels, the only data currently available are for 1997. When newer data are released by the USDA, these should be reviewed for incorporation to represent current conditions as well as to assess trends. In particular, given the potential for some CRP acreage to retire and possibly return to active cultivation prior to 2030 (given growing interest in biofuels production), the forecasted emissions could be appreciably affected. As mentioned above, emission estimates for soil liming have not been developed for Minnesota.

Another contributor to the uncertainty in the emission estimates is the projection assumptions. The growth rates for most categories are assumed to continue growing at historical 1990-2004 growth rates.

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[10] US Agriculture and Forestry Greenhouse Gas Inventory: 1990-2001. Global Change Program Office, Office of the Chief Economist, US Department of Agriculture. Technical Bulletin No. 1907. 164 pp. March 2004.