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 (see Appendix B).

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 breakdown 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 conditions. Under aerobic conditions, N_2O emissions are dominant. Emissions estimates from manure management are based on manure that is stored and treated on 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 and is transported off-site before entering the nitrification/denitrification cycle. Methane and N_2O emissions also result when crop residues are burned. Methane emissions occur during rice cultivation; however, rice is not grown in Maryland.

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. Finally, the practice of adding limestone and dolomite to agricultural soils results in CO_2 emissions.

Emissions and Reference Case Projections

Methane and Nitrous Oxide

GHG emissions for 1990 through 2005 were estimated using the United States Environmental Protection Agency's (US EPA) State Greenhouse Gas Inventory Tool (SGIT) software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector.[1] In general, the SGIT methodology applies 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.[2]

Data on crop production in Maryland from 1990 to 2005 and the number of animals in the state from 1990 to 2005 were obtained from the United States Department of Agriculture (USDA) National Agriculture Statistical Service (NASS) and incorporated as defaults in SGIT.[3] The default SGIT manure management system assumptions for each livestock category were used for this inventory. SGIT data on fertilizer usage came from *Commercial Fertilizers*, a report from the Fertilizer Institute. Activity data for fertilizer includes all potential uses in addition to agriculture, such as residential and commercial (e.g., golf courses). The estimates are reported in the agriculture sector but they represent emissions occurring on other land uses.

Crop production data from USDA NASS were available through 2005; therefore, N_2O emissions from crop residues and crops that use nitrogen (i.e., nitrogen fixation) and N_2O and CH_4 emissions from agricultural residue burning were calculated through 2005. Emissions for the other agricultural crop production categories (i.e., synthetic and organic fertilizers) were also calculated through 2005. Data were not available to estimate nitrogen released by the cultivation of histosols (i.e., the number of acres of high organic content soils). Given that cultivation of organic soils is a source of CO_2 emissions in Maryland (see below), N_2O emissions are also probably occurring.

There is some agricultural residue burning conducted in Maryland; however, emissions are estimated to be relatively small (<0.01 MMtCO$_2$e). The default SGIT method was used to calculate emissions. 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 and burned, the resultant dry matter, and the carbon/nitrogen content of the dry matter.

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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] 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/).

[3] USDA, NASS (http://www.nass.usda.gov/Statistics_by_State/Maryland/index.asp).

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).[4] Projections for all other livestock categories, except swine and sheep, were estimated based on linear forecasts of the historical 1990-2005 populations. The sheep population fluctuated greatly during the 1990-2005 period and linear projection result in negative population at year 2020. Therefore, sheep population was projected based on the 1995-2005 historical data. The swine population showed a sharp decline in the late 1990s and early 2000s, and linear projection of the 1990-2005 populations result in negative populations before 2020. As a result, no growth is projected for the swine population after 2005. Livestock population growth rates are shown in Table F1.

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

Livestock Category	**2005-2020 Annual Growth**
Dairy Cattle	-0.7%
Beef Cattle	0.3%
Swine	0%
Sheep	-9.2%
Goats	0.3%
Horses	-4.2%
Turkeys	2.9%
Layers	0.03%

Projections for agricultural burning and agricultural soils were based on linear extrapolation of the 1990-2005 historical data. Table F2 shows the 2005-2020 annual growth rates estimated for each category.

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

Agricultural Category	**2005-2020 Growth Rate**
Agricultural Burning	0.1%
Agricultural Soils – Direct Emissions	
Fertilizers	2.9%
Crop Residues	0.3%
Nitrogen-Fixing Crops	0%
Histosols	0%
Livestock	-3.3%
Agricultural Soils – Indirect Emissions	
Fertilizers	2.9%
Livestock	-1.3%
Leaching/Runoff	1.3%

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

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[5] and the US Agriculture and Forestry Greenhouse Gas Inventory. The estimates are based on the Intergovermental Panel on Climate Change (IPCC) methodology for soil carbon adapted to conditions in the US. Preliminary state-level estimates of 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. 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 at present.

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 Maryland, Table F3 shows a summary of the latest estimates available from the USDA, which are for 1997.[6] These data show that changes in agricultural practices are estimated to result in net sequestration of 0.15 million metric tons (MMt) of CO_2 equivalent (CO_2e) per year (yr) in Maryland; this is driven largely by the amount of land conversions from cropland to hay or grazing land in Maryland. Since data are not yet available from USDA to make a determination of whether the emissions are increasing or decreasing, emissions of -0.15 $MMtCO_2e$/yr are assumed to remain constant.

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 manage-ment	Other cropland[2]	Cropland converted to hayland[3]	Hayland manage-ment	Cropland converted to grazing land[3]	Grazing land manage-ment	CRP	Manure application	Cultivation of organic soils	Net soil carbon emissions
0.18	(0.04)	0.00	(0.15)	0.00	(0.07)	0.00	0.00	(0.08)	0.00	(0.15)

Based on USDA 1997 estimates. Parentheses 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.

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[5] US Inventory of Greenhouse Gas Emissions and Sinks: 1990-2005 (and earlier editions), US Environmental Protection Agency, Report # 430-R-07-002**,** April 2007. Available at: http://www.epa.gov/climatechange/emissions/usinventoryreport.html.

[6] 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 F3. The sum of the first nine columns is equivalent to the mineral soils category.

Results

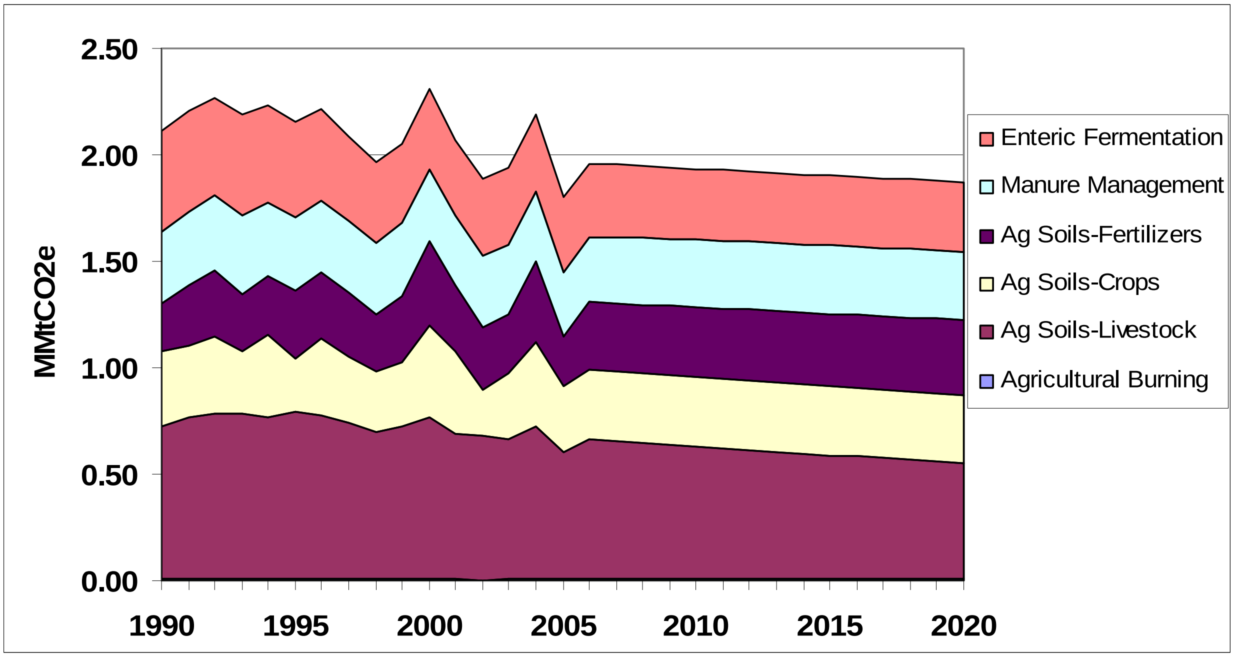
Figure F1 shows gross GHG emissions associated with the agricultural sector from 1990 through 2020. In 1990, enteric fermentation accounted for about 22.5% (0.47MMtCO$_2$e) of total agricultural emissions. Enteric fermentation emissions decreased to 0.35 MMtCO$_2$e (19.4% of total agricultural emissions) due to the decline in beef and dairy cattle populations between 1990 and 2005. While the beef cattle population is projected to increase slightly, this increase does not offset the decrease projected for the dairy cattle population, and enteric fermentation emissions are estimated to be 0.33 MMtCO$_2$e in 2020.

The manure management category accounted for 16% (0.34 MMtCO$_2$e) of total agricultural emissions in 1990 and remained relatively unchanged at 16.8% (0.3 MMtCO$_2$e) in 2005. Manure management is projected to remain constant at 0.32 MMtCO$_2$e in 2020. This is largely due to the projection that the swine population was to stay relatively unchanged between 2005 and 2020.

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 stay relatively constant from 1990 to 2020, with 1990 emissions accounting for 61% (1.3 MMtCO$_2$e) of total agricultural emissions and 2020 emissions estimated to be about 65% (1.2 MMtCO$_2$e) of total agricultural emissions.

Agricultural burning emissions were estimated to be very small based on the SGIT activity data (<0.01 MMtCO$_2$e/yr from 1990 to 2005). Emissions for this category account for about one-half of the national emissions included in the USDA Inventory which, relative to other agricultural categories, reports a low level of residue burning emissions (0.02 MMtCO$_2$e). Even though these initial emission estimates using the SGIT are low relative to emissions associated with the other agricultural categories in Maryland, the emission estimates for agricultural burning in Maryland using the SGIT methodology are inconsistent with other data and should be refined using actual activity data for Maryland, if available.

Figure F1. Gross GHG Emissions from Agriculture



Source: CCS calculations based on approach described in text.
Notes: Ag Soils – Crops category includes: incorporation of crop residues and nitrogen fixing crops (no cultivation of histosols estimated); emissions for agricultural residue burning are too small to be seen in this chart.

The only standard IPCC source categories missing from this report are CO_2 emissions from limestone and dolomite application and N_2O emissions from the cultivation of histosols. Estimates for limestone and dolomite application in Maryland were not available; however, the USDA's national estimate for soil liming is about 9 $MMtCO_2e$/yr.[7]

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, 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. 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 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

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[7] 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.

2020, the emissions could be appreciably affected. As mentioned above, emission estimates for soil liming have not been developed for Maryland.

Another contributor to the uncertainty in the emission estimates is the forecast assumptions. The growth rates for most categories are assumed to continue growing at historical 1990-2005 growth rates.