

## Appendix A. Agriculture

### Overview

The emissions discussed in this appendix refer to non-energy methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) 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 break down food and emit CH<sub>4</sub> as a by-product. More CH<sub>4</sub> is produced in ruminant livestock because of digestive activity in the large fore-stomach. Methane and N<sub>2</sub>O 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<sub>4</sub> is produced because decomposition is aided by CH<sub>4</sub> producing bacteria that thrive in oxygen-limited conditions. Under aerobic conditions, N<sub>2</sub>O 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<sub>2</sub>O emissions and net fluxes of carbon dioxide (CO<sub>2</sub>) causing emissions or sinks. In general, soil amendments that add nitrogen to soils can also result in N<sub>2</sub>O emissions. Nitrogen additions drive underlying soil nitrification and denitrification cycles, which produce N<sub>2</sub>O as a by-product. The emissions estimation methodologies used in this inventory account for several sources of N<sub>2</sub>O 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<sub>2</sub>O 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<sub>2</sub>O emissions also result when crop residues are burned and during rice cultivation. Rice fields must remain flooded, which means that decomposition occurs in a low-oxygen environment, resulting in anaerobic decomposition. This decomposition results in methane and N<sub>2</sub>O emissions, though total emissions can vary depending on water management practices.

The net flux of CO<sub>2</sub> 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<sub>2</sub> 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 (for neutralizing acidic soil conditions) results in CO<sub>2</sub> 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 (SIT) software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector.<sup>1</sup> In general, the SIT 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.<sup>2</sup>

Data on crop production in Florida 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 SIT.<sup>3</sup> The default SIT manure management system assumptions for each livestock category were used for this inventory.

Fertilizer data for the years 1998-2005 comes from the Florida Department of Agriculture and Consumer Services, Division of Agriculture Environmental Services.<sup>4</sup> This has data on the total nitrogen sold in the state of Florida. SIT Fertilizer data was used for 1990-1997. SIT 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<sub>2</sub>O emissions from crop residues and crops that use nitrogen (i.e., nitrogen fixation) and N<sub>2</sub>O and CH<sub>4</sub> emissions from agricultural residue burning were calculated through 2005. Emissions for the

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<sup>1</sup> GHG emissions were calculated using SIT, 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.

<sup>2</sup> Revised 1996 Intergovernmental 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/>).

<sup>3</sup> USDA, NASS ([http://www.nass.usda.gov/Statistics\\_by\\_State/florida/index.asp](http://www.nass.usda.gov/Statistics_by_State/florida/index.asp)).

<sup>4</sup> <http://www.flaes.org/complimonitoring/reports.html> Data from growing years factored together to represent calendar years, 1998-2005.

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<sub>2</sub> emissions in Florida (see below), N<sub>2</sub>O emissions are also probably occurring.

There is some agricultural residue burning conducted in Florida; however, emissions are estimated to be very small (~0.01 MMtCO<sub>2</sub>e). The default SIT method was used to calculate emissions. The SIT 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.

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).<sup>5</sup> Projections for all other livestock categories were estimated based on linear forecasts of the historical 1990-2005 populations. In the case of Swine and Broiler populations, significant population decreases occurred between 1990 and 2005, but both of these decreases seemed to level off in 2004-2005 range. To avoid the estimates of these animal populations going negative, the 2005 figure was used throughout 2006-2025. Population growth rates are shown in Table F1.

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

<b>Livestock Category</b>	<b>2005-2025 Annual Growth</b>
Dairy Cattle	-2.24%
Beef Cattle	-0.90%
Swine	0.00%
Sheep	1.80%
Goats	1.86%
Horses	-0.45%
Layers	0.33%
Broilers	0.00%

Projections for agricultural burning and agricultural soils were based on linear extrapolation of the 1990-2005 historical data. Table F2 shows the 2005-2025 annual growth rates estimated for each category. Crop residue values after 2005 were held at 2005 levels to prevent a forecast of negative emissions.

<sup>5</sup> FAPRI Agricultural Outlook 2006, Food and Agricultural Policy Research Institute, <http://www.fapri.iastate.edu/outlook2006>.

SIT defaults for rice cultivation are derived from the US Agriculture and Forestry Greenhouse Gas Inventory.<sup>6</sup> Projections for rice cultivation were also held at 2005 levels to prevent a forecast of negative emissions.

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

<b>Agricultural Category</b>	<b>2005-2025 Growth Rate</b>
Agricultural Burning	1.02%
Liming of Agricultural Soils	0.00%
<b>Agricultural Soils – Direct Emissions</b>	
Fertilizers	-5.02%
Crop Residues	0.00%
Nitrogen-Fixing Crops	-4%
Histosols	0%
Livestock	-3.49%
<b>Agricultural Soils – Indirect Emissions</b>	
Fertilizers	-2.89%
Livestock	-8.99%
Leaching/Runoff	-4.25%

### *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<sup>7</sup> and the US Agriculture and Forestry Greenhouse Gas Inventory.<sup>8</sup> 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 CO<sub>2</sub> fluxes from mineral soils and emissions from the cultivation of organic soils were reported in the US Agriculture and Forestry Greenhouse Gas Inventory. The inventory also reports national estimates of CO<sub>2</sub> emissions from limestone and dolomite applications from the United States Geological Survey (USGS).<sup>9</sup> Currently, these are the best available data at the state-level for this category. Liming values were held at 2005 levels to prevent a forecast of negative emissions.

<sup>6</sup> USDA, published March 2004. Accessed at [http://www.usda.gov/oce/global\\_change/gg\\_inventory.htm](http://www.usda.gov/oce/global_change/gg_inventory.htm), Feb, 2008. See Appendix B, Table B-6.

<sup>7</sup> 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>.

<sup>8</sup> USDA, published March 2004.

<sup>9</sup> State-level annual application rates of limestone and dolomite to agricultural purposes were provided from the Minerals Yearbook “Crushed Stone” from the USGS website: [http://minerals.er.usgs.gov/minerals/pubs/commodity/stone\\_crushed/](http://minerals.er.usgs.gov/minerals/pubs/commodity/stone_crushed/).

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 Florida, Table F3 summarizes the latest estimates available from the USDA, which are for 1997,<sup>10</sup> except for the cultivation of organic soils, which is based on a University of Florida report on soil carbon.<sup>11</sup> These data show that changes in agricultural practices are estimated to result in net emissions of 9.63 million metric tons (MMt) of CO<sub>2</sub> equivalent (CO<sub>2</sub>e) per year in Florida; this is driven largely by the cultivation of organic soils in Florida. Since updated data are not yet available from USDA to make a determination of whether the emissions are increasing or decreasing, emissions of 9.63 MMtCO<sub>2</sub>e per year are assumed to remain constant.

Note that emissions from agricultural soils estimated using the SIT were multiplied by a national adjustment factor to reconcile differences between methodologies used in the National Inventory of Greenhouse Gas Emissions and the SIT.

**Table F3. GHG Emissions from Soil Carbon Changes Due to Cultivation Practices (MMtCO<sub>2</sub>e)**

Changes in cropland			Changes in Hayland				Other			Total <sup>5</sup>
Plowout of grassland to annual cropland <sup>1</sup>	Cropland management	Other cropland <sup>2</sup>	Cropland converted to hayland <sup>3</sup>	Hayland management	Cropland converted to grazing land <sup>3</sup>	Grazing land management	CRP	Manure application	Cultivation of organic soils <sup>4</sup>	Net soil carbon emissions
0.33	(0.04)	(0.22)	(0.07)	0.00	(0.48)	0.11	(0.07)	(0.23)	10.30	9.63

Based on USDA 1997 estimates, except where noted. Parentheses indicate net sequestration.

<sup>1</sup> 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).

<sup>2</sup> Perennial/horticultural cropland and rice cultivation.

<sup>3</sup> Gains in soil carbon sequestration due to land conversions from annual cropland into hay or grazing land.

<sup>4</sup> Based on University of Florida report *Opportunities for Greenhouse Gas Reduction Through Forestry and Agriculture in Florida* as mentioned in text.

<sup>5</sup> 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.

## Results

Cultivation of soils is estimated to be the largest source of net emissions source in Florida. The emissions for this category are estimated to account for 59% of total agricultural emissions in

<sup>10</sup> 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](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.

<sup>11</sup> “Opportunities for Greenhouse Gas Reduction Through Forestry and Agriculture in Florida”,

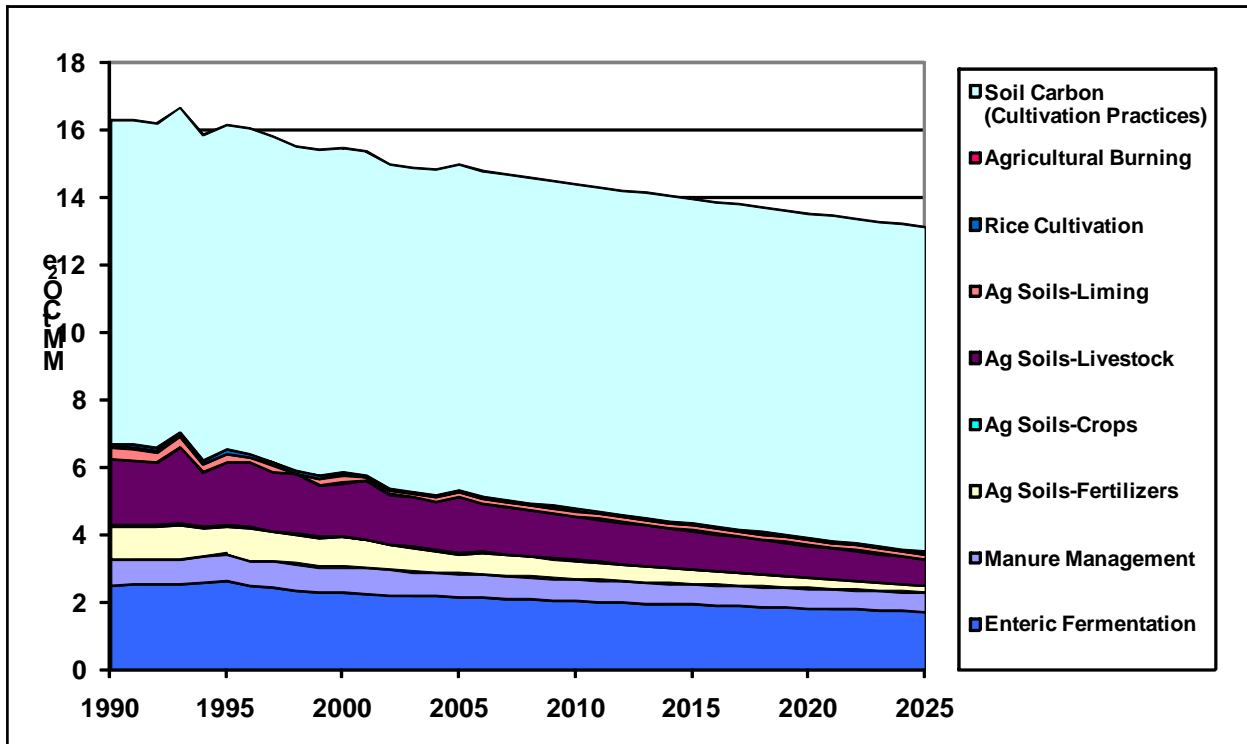
<http://snre.ufl.edu/pubsevents/source/summer08/climatereport.htm>

1990 and about 73% of total emissions in 2025. Since data are not yet available from USDA to determine if emissions are increasing or decreasing, emissions of 9.63 MMtCO<sub>2</sub>e per year are assumed to remain constant throughout the inventory and forecast period. The percentage of emissions from cultivation of soils is increasing because other agricultural emissions sources are estimated to decrease between 1990 and 2025.

The other significant source of emissions in the agricultural sector is the agricultural soils category, which includes crops (legumes and crop residues), fertilizer, manure application, application of limestone and dolomite, and indirect sources (leaching, runoff, and atmospheric deposition). Agricultural soils is projected to decrease between 1990 and 2025, with 1990 emissions accounting for 21% (3.36 MMtCO<sub>2</sub>e) of total agricultural emissions and 2025 emissions estimated to be about 9% (1.14 MMtCO<sub>2</sub>e) of total agricultural emissions.

Figure F1 and Table F4 show gross GHG emissions associated with the agricultural sector from 1990 through 2025. In 1990, enteric fermentation accounted for about 15% (2.51 MMtCO<sub>2</sub>e) of total agricultural emissions. Enteric fermentation emissions decreased slightly to 13% (1.75 MMtCO<sub>2</sub>e) between 1990 and 2025 due to the decline in dairy and beef cattle populations in this time period.

**Figure F1. Gross GHG Emissions from Agriculture, 1990-2025**



Source: 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 Burning, Rice Cultivation, and Ag Soils-Crops and are too small to be seen in this chart.

**Table F4. Gross GHG Emissions from Agriculture in Florida (MMtCO<sub>2e</sub>)**

Source	1990	1995	2000	2005	2010	2015	2020	2025
Enteric Fermentation	2.51	2.67	2.30	2.18	2.05	1.95	1.85	1.75
Manure Management	0.76	0.78	0.76	0.69	0.63	0.60	0.57	0.55
Ag Soils-Fertilizers	0.98	0.84	0.90	0.56	0.56	0.45	0.33	0.21
Ag Soils-Crops	0.06	0.04	0.03	0.05	0.04	0.03	0.03	0.03
Ag Soils-Livestock	1.97	1.85	1.57	1.67	1.28	1.10	0.93	0.75
Ag Soils-Liming	0.35	0.24	0.23	0.15	0.15	0.15	0.15	0.15
Rice Cultivation	0.06	0.12	0.09	0.06	0.06	0.06	0.06	0.06
Agricultural Burning	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Soil Carbon (Cultivation Practices)	9.63	9.63	9.63	9.63	9.63	9.63	9.63	9.63
<b>TOTAL</b>	<b>16.3</b>	<b>16.2</b>	<b>15.5</b>	<b>15.0</b>	<b>14.4</b>	<b>14.0</b>	<b>13.6</b>	<b>13.1</b>

The manure management category accounted for 5% (0.76 MMtCO<sub>2e</sub>) of total agricultural emissions in 1990 and decreased slightly over the next thirty five years, accounting for 4% (0.55 MMtCO<sub>2e</sub>) in 2025. This is largely due to the projection that the dairy cow population will decrease between 1990 and 2025.

Rice cultivation accounted for less than 1% (0.06 MMtCO<sub>2e</sub>) of agricultural emissions in 1990 and in 2005 and is projected to remain steady throughout the forecast period.

The only standard IPCC source category missing from this report is N<sub>2</sub>O emissions from the cultivation of histosols; there was no activity data available for Florida.

### 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<sub>4</sub> 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, the USDA estimates for emissions associated with changes in agricultural soil carbon levels are from 1997. Newer data are scheduled to be released by the USDA by August 2008. When released, the data 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 2025, the emissions could be appreciably affected. The data on cultivation of histosol soils will be compared to that reported by Dr. Sabine Grunwald in the University of Florida study.

Uncertainties in the estimates of emissions from liming result from both the emission factors and the activity data. It is uncertain what fraction of agricultural lime is dissolved by nitric acid – a

process that releases CO<sub>2</sub> – and what portion reacts with carbonic acid (H<sub>2</sub>CO<sub>3</sub>), resulting in the uptake of CO<sub>2</sub>. Also, there is uncertainty in the limestone and dolomite data (reported to USGS) as some producers do not distinguish between them, and report them both as limestone.

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. These historic trends may not reflect future projections. Other emissions are assumed to remain at 2004-2005 levels (as noted under Emissions and Reference Case Projections) to prevent a forecast of negative emissions for those categories.