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 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 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 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_2O emissions, though total emissions can vary depending on water management practices.

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 (for neutralizing acidic soil conditions) 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 (SIT) software and the methods provided in the Emission Inventory Improvement Program (EIIP) guidance document for the sector.[1] 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.[2]

Data on crop production and livestock in Arkansas from 1990 to 2005 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.[3] The default SIT manure management system assumptions for each livestock category were used for this inventory. SIT data on fertilizer usage came from the Arkansas Feed & Fertilizer Division of the Arkansas Agriculture State Plant Board, which provided the amount of fertilizer sold in the state[4]. These numbers were then used to approximate the amount of nitrogen applied to the soil for the years 1990-2005.

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).

There is some agricultural residue burning conducted in Arkansas. Emissions are estimated to be relatively small, approximately 0.11 $MMtCO_2e$ in 2005. The default SIT method was used to

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[1] 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.
[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/Arkansas/index.asp).
[4] From Jamey Johnson, Feed & Fertilizer Division, Arkansas State Plant Board. *Total Fertilizer Summary* chart out of the "Arkansas Distribution of Fertilizer Sales by County," 1990-2006.

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).[5] Swine populations were projected to remain constant between 2005-2025, so as to avoid negative population projections. Projections for all other livestock categories were estimated based on linear forecasts of the historical 1990-2005 populations. Livestock population growth rates are shown in Table F1.

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

Livestock Category	2005-2025 Annual Growth
Dairy Cattle	-8.24%
Beef Cattle	0.62%
Swine	0.00%
Sheep	1.80%
Goats	0.25%
Horses	1.29%
Turkeys	-0.81%
Layers	-0.16%
Broilers	1.39%

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. In the case of Liming of Soils, the historic default data are available from 1990 through 2004. Therefore, projections for this category begin with the year 2005, rather than 2006.

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.

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

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

Agricultural Category	2005-2025 Growth Rate
Agricultural Burning	2.00%
Liming of Agricultural Soils	1.36%
Agricultural Soils – Direct Emissions	
Fertilizers	-1.05%
Crop Residues	-0.57%
Nitrogen-Fixing Crops	-1.57%
Livestock	-1.09%
Agricultural Soils – Indirect Emissions	
Fertilizers	-0.99%
Livestock	-2.36%
Leaching/Runoff	-1.42%

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[6] 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 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. The inventory also reports national estimates of CO_2 emissions from limestone and dolomite applications from the United States Geological Survey (USGS).[7] Currently, these are the best available data at the state-level for this category.

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 Arkansas, Table F3 shows a summary of the latest estimates available from the USDA, which are for 1997.[8] The data show that changes in agricultural practices are estimated to result in net reduction of 1.8 million metric tons (MMt) of CO_2 equivalent (CO_2e) per year in Arkansas; this reduction comes largely from manure applications and the cultivation of other cropland. Since data are not yet available from

[6] 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.

[7] 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/.

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

USDA to make a determination of whether the emissions are increasing or decreasing in the subsequent years, emissions of -1.8 $MMtCO_2e$ per year are assumed to remain constant throughout all historical and projected analysis years.

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
0.81	(0.22)	(0.81)	(0.11)	0.04	(0.37)	(0.11)	(0.15)	(0.88)	0.00	(1.80)

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.

Results

Figure F1 and Table F4 show gross GHG emissions associated with the agricultural sector from 1990 through 2025. Table F4 also shows the net emissions associated with the agricultural sector after the sequestration from soil carbon changes due to cultivation practices is accounted for. In 1990, enteric fermentation accounted for about 19% (2.02 $MMtCO_2e$) of gross agricultural emissions. Enteric fermentation emissions increased slightly to 2.08 $MMtCO_2e$ between 1990 and 2005 due to the increase in beef cattle populations over this period. Due to this increase in the beef cattle population, enteric fermentation emissions are estimated to rise to 2.30 $MMtCO_2e$ by 2025. There is a projected increase in the beef cattle population, and enteric fermentation emissions are estimated to increase to 2.30 $MMtCO_2e$ in 2025.

The manure management category accounted for 16% (1.68 $MMtCO_2e$) of gross agricultural emissions in 1990 and decreased significantly by 2005, accounting for 11% (1.31 $MMtCO_2e$) of Arkansas's gross agricultural emissions. Manure management is projected to increase slightly by 2025, to account for 13% (1.55 $MMtCO_2e$) of gross agricultural emissions at that time.

The largest 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 emissions are projected to decrease from 1990 to 2025, with 1990 emissions accounting for 45% (4.76 $MMtCO_2e$) of gross agricultural emissions and 2025 emissions estimated to be about 35% (4.15 $MMtCO_2e$) of gross agricultural emissions.

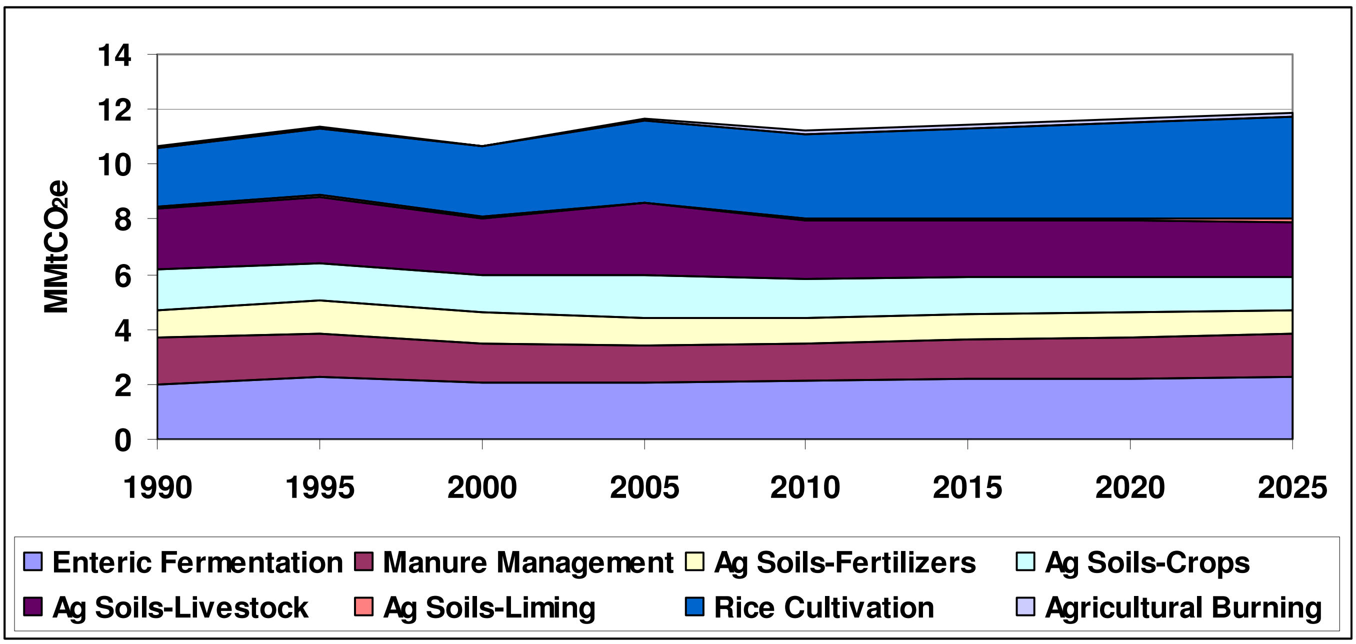
Rice cultivation is another significant contributor of GHG emissions in Arkansas. Emissions from rice cultivation made up 20% (2.14 $MMtCO_2e$) of gross agricultural emissions in 1990. This number is projected to increase to 31% (3.70 $MMtCO_2e$) of agricultural emissions in 2025.

Growth of emissions from rice cultivation between 1990 and 2025 was greater than the total growth predicted for all the remaining agricultural sectors.

Soil carbon changes due to cultivation practices are a net sink of carbon in the state of Arkansas. Since data are not yet available from USDA to determine if emissions are increasing or decreasing, emissions of -1.80 $MMtCO_2e$ per year are assumed to remain constant throughout the inventory and forecast period. This net sequestration is shown in Table F3. Since soil carbon changes due to cultivation practices are not a source of emissions in Arkansas, they are not shown in figure F1, which shows only gross (rather than net) emissions in the state.

The only standard IPCC source category missing from this report is N_2O emissions from the cultivation of histosols; there were no activity data available for Arkansas.

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



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.

Table F4. GHG Emissions from Agriculture in Arkansas ($MMtCO_2e$)

Source	1990	1995	2000	2005	2010	2015	2020	2025
Enteric Fermentation	2.02	2.24	2.05	2.08	2.10	2.17	2.24	2.30
Manure Management	1.68	1.61	1.45	1.31	1.37	1.43	1.49	1.55
Ag Soils-Fertilizers	0.97	1.18	1.16	1.02	0.96	0.92	0.87	0.83
Ag Soils-Crops	1.52	1.36	1.29	1.57	1.41	1.36	1.31	1.25
Ag Soils-Livestock	2.22	2.43	2.09	2.58	2.12	2.08	2.03	1.98
Ag Soils-Liming	0.05	0.07	0.08	0.07	0.07	0.07	0.08	0.09
Rice Cultivation	2.14	2.39	2.52	2.92	3.06	3.27	3.49	3.70
Agricultural Burning	0.05	0.05	0.06	0.11	0.11	0.13	0.14	0.16
Total Gross Emissions	***10.65***	***11.35***	***10.69***	***11.66***	***11.20***	***11.42***	***11.64***	***11.86***
Soil Carbon (Cultivation Practices)	-1.80	-1.80	-1.80	-1.80	-1.80	-1.80	-1.80	-1.80
Total Net Emissions	***8.85***	***9.55***	***8.89***	***9.86***	***9.40***	***9.62***	***9.84***	***10.06***

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 2025, the emissions could be appreciably affected.

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_2 – and what portion reacts with carbonic acid (H_2CO_3), resulting in the uptake of CO_2. 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.

There is also uncertainty in the nitrogen applied to soils through fertilizers. The information we have available from the state of Arkansas is measured in tons of fertilizer sold. We made assumptions that the amount of fertilizer sold is equal to the amount of fertilizer applied, and that we could correctly estimate the amount of nitrogen in each fertilizer type. Both of these estimates add a level of uncertainty calculations of the amount of nitrogen applied to soils.

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.