

Appendix F. Agriculture

Overview

The emissions covered in this appendix refer to non-energy methane (CH₄) and nitrous oxide (N₂O) emissions from livestock and crop production. Emissions and sinks of carbon in agricultural soils due to changes in cultivation practices 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). The primary GHG sources and sinks - livestock production, agricultural soils, and crop residue burning are further subdivided as follows:

- *Livestock production – enteric fermentation:* CH₄ 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 CH₄ as a by-product. More CH₄ is produced in ruminant livestock because of digestive activity in the large fore-stomach.
- *Livestock production – manure management:* CH₄ and N₂O 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 CH₄ is produced because decomposition is aided by CH₄-producing bacteria that thrive in oxygen-limited conditions. In contrast, N₂O emissions are increased under aerobic conditions. Emission estimates from manure management are based on manure that is stored and treated on livestock operations (e.g. dairies, feedlots, swine 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 under agricultural soils emissions.
- *Agricultural soils – fertilizers:* The management of agricultural soils can result in N₂O emissions and net fluxes of carbon dioxide (CO₂) causing emissions or sinks. In general, soil amendments that add nitrogen to soils can also result in N₂O emissions. Nitrogen additions drive underlying soil nitrification and de-nitrification cycles, which produce N₂O as a by-product. The emissions estimation methodologies used in this inventory account for several sources of N₂O emissions from agricultural soils, including decomposition of crop residues, synthetic and organic fertilizer application, manure application, sewage sludge application, nitrogen fixation, and histosols (high organic soils, such as wetlands or peatlands) cultivation (see additional agricultural soils subsectors below). Both direct and indirect emissions of N₂O 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 enters the nitrification/denitrification cycle.
- *Agricultural soils – crops:* this source sector covers N₂O emissions from decomposition of crop residues, production of nitrogen fixing crops, and the cultivation of histosols.
- *Agricultural soils – livestock:* this source sector covers N₂O emissions resulting from animal excretions left on agricultural soils (e.g. pasture or range).
- *Agricultural soils – liming:* the practice of adding limestone and dolomite to agricultural soils (for neutralizing acidic soil conditions) results in CO₂ emissions.
- *Agricultural soils – rice cultivation:* CH₄ emissions occur during rice cultivation; however, rice is not grown in Iowa.

- *Agricultural soils – soil carbon:* the net flux of CO₂ 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 CO₂ into agricultural soils. In addition, soil disturbance from the cultivation of histosols releases large stores of carbon from the soil to the atmosphere in the form of CO₂ (Note: N₂O emissions from cultivation of histosols are covered under the *Agricultural soils - crops* sector above).
- *Crop residue burning:* CH₄ and N₂O emissions are produced when crop residues are burned.

Emissions and Reference Case Projections

Inventory Data

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 in Iowa 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.³ The default SIT manure management system assumptions for each livestock category were used for this inventory. SIT data on fertilizer usage came from *Commercial Fertilizers*, a report from the Fertilizer Institute. Details for each of the livestock and crop production subsectors are provided below.

Livestock production – enteric fermentation. SIT default data on livestock populations are taken from the USDA NASS and are available from 1990-2005. Methane emission factors specific to each type of animal by region (e.g. dairy cattle, beef cattle, sheep, goats, swine, and horses) are provided in SIT.

Livestock production – manure management. The same population data used above for enteric fermentation are also used as input to estimate CH₄ and N₂O emissions from manure management. Population estimates are multiplied by an estimate for typical animal mass and a

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 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/>).

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

volatile solids (VS) production rate to estimate the total VS produced. The VS estimate for each animal type is then multiplied by a maximum potential CH₄ emissions factor and a weighted methane conversion factor to derive total CH₄ emissions. The methane conversion factor adjusts the maximum potential methane emissions based on the types of manure management systems employed in Iowa.

Nitrous oxide emissions are derived using the same animal population estimates above multiplied by the typical animal mass and a total Kjeldahl nitrogen (K-nitrogen) production factor. The total K-nitrogen is multiplied by a non-volatilization factor to determine the fraction that is managed in manure management systems. The unvolatilized portion is then divided into fractions that get processed in either liquid (e.g. lagoons) or solid waste management systems (e.g. storage piles, composting). Each of these fractions is then multiplied by an N₂O emission factor, and the results summed, to estimate total N₂O emissions.

Agricultural soils - fertilizers, crops, and livestock. The fertilizers subsector covers direct and indirect N₂O emissions from the application of synthetic and organic fertilizers. The crops subsector covers N₂O emissions from nitrogen fixing crops, decomposition of crop residues, and cultivation of high organic content soils (histosols). The livestock category covers N₂O emissions from animal excretions directly onto the land area (rather than manure applied intentionally to farmland, which is captured under the *Agricultural soils – fertilizers* subsector).

Emissions of N₂O occur naturally as part of the nitrogen cycle. However, various soil management practices have significantly increased the amount of N₂O going into the atmosphere. There are three source categories of nitrous oxide emissions from soil management. The first is direct emissions from agricultural cropping practices, which occur primarily through applications of fertilizer or decomposition of crop residues, cultivation of histosols, and through the production of nitrogen fixing crops. Data inputs used to calculate the direct emissions from agricultural cropping practices include:

1. The amount of nitrogen applied to the soil through fertilizers (synthetic and organic);
2. Animal population, mass and N emitted per unit of animal mass;
3. Amount of manure intentionally applied to soils;
4. Amount of residue left on cropland and the N content of such residues; and
5. Acreage of histosols cultivated (these data were not available for Iowa).

A variety of factors can influence the amount of nitrous oxide produced through these agricultural cropping practices, such as temperature, water content, soil pH, etc.

Direct emissions from livestock is another source category of nitrous oxide emissions from agricultural soils, namely through animal excretions directly onto the land area. This requires data on animal population, mass and N emitted per unit of animal mass, as well as the amount of manure left on the soil.

The third source category is indirect emissions from nitrogen applied to soils. This can occur through the volatilization of ammonia and oxides of nitrogen (which can then be re-deposited, enter the nitrification/denitrification cycle, and be emitted as N₂O); or through leaching/runoff of

N, which can enter the nitrification/denitrification cycle on or off-site, and then be emitted as N₂O. To calculate these emissions, the data used above on nitrogen inputs from fertilizers and animals to crop soils are used again along with factors on the fraction of nitrogen volatilized (10% for synthetic fertilizers and 20% for organic fertilizer nitrogen), and an IPCC-based emission factor for N₂O emissions from the re-deposited nitrogen (0.01 kg N₂O-N/kg N re-deposited).

Crop production data from USDA NASS were available through 2005; therefore, N₂O emissions from crop residues and crops that fix nitrogen were 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 CO₂ emissions in Iowa (see soil carbon discussion below), N₂O emissions are also probably occurring. CCS was unable to obtain the state-level cultivation data for histosols which would have allowed for an estimate of N₂O emissions.

Crop production – liming. Additions of lime for pH adjustment and urea fertilizer to soils release carbon dioxide as these materials are degraded. Data on limestone and dolomite application from 1990-2004 were available from the Land-Use Change and Forestry Module of SIT. The SIT emission factor of 0.06 Mt C/Mt limestone/dolomite was used to estimate CO₂ emissions. Limestone/dolomite application data are not specific to land use; however, CCS assumed that the applications were all applied to agricultural soils. Data specific to urea application were not readily-available; hence, the emissions are not captured in this inventory. The data in SIT are provided in terms of total commercial fertilizer N applied.

Crop production – rice cultivation. Methane emissions occur during rice cultivation as a result of the anaerobic decomposition of organic materials in flooded fields. No rice cultivation occurs in Iowa.

Crop production – 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 Sinks⁴ 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 CO₂ 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 CO₂ emissions from agricultural limestone and dolomite applications from the United States Geological Survey (USGS).⁵ However, these are now included above under the *Agricultural soils – liming* subsector.

⁴ 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>.

⁵ 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/.

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 Iowa, Table F1 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 emissions of 1.48 million metric tons (MMt) of CO₂ equivalent (CO₂e) per year in Iowa; this is driven largely by the cultivation of organic soils and the plowout of grassland to annual cropland in Iowa. Since data are not yet available from USDA to make a determination of whether the emissions are increasing or decreasing, emissions of 1.48 MMtCO₂e per year are assumed to remain constant.

Table F1. GHG Emissions from Soil Carbon Changes Due to Cultivation Practices (MMtCO₂e)

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
4.44	(0.11)	(0.00)	(1.91)	(0.00)	(0.54)	0.04	(0.77)	(1.49)	1.87	1.48

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.

Note that emissions from agricultural soils estimated using the SIT were multiplied by a national adjustment factor to reconcile differences between methodologies used in EPA’s National Inventory of Greenhouse Gas Emissions and the SIT. The national adjustment factor varies substantially from year to year resulting in the introduction of noise into the agricultural soils categories.

Crop production – residue burning. There is some agricultural residue burning conducted in Iowa; however, emissions are estimated to be relatively small (<0.2 MMtCO₂e). Agricultural burning can result in emissions of both N₂O and CH₄. The default SIT method was used to calculate emissions along with NASS crop production data through 2005. 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, the resultant dry matter, the

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.

carbon/nitrogen content of the dry matter, the fraction of dry matter burned, the combustion efficiency, and emission factors for N₂O and CH₄.

Forecast Data

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).⁷ Projections for all other livestock categories except sheep and broilers were estimated based on linear forecasts of the historical 1990-2005 populations. Sheep populations were held at 2005 levels throughout the forecast period to prevent their population estimate from going negative. Broiler populations used only the last five years (2000-2005) to predict population growth between 2006 and 2025. This was done because rapid growth between 1990-2000 caused unrealistic population estimates if the full fifteen year range is used to predict future growth. Livestock population growth rates are shown in Table F2.

Projections for agricultural burning and the various agricultural soils categories were based on linear extrapolation of the 1990-2005 historical data. Table F3 shows the 2005-2025 annual growth rates estimated for each category. In the case of liming of soils, there is only default data available for 1990-2004. Projections for this category begin with the year 2005, rather than 2006. For agricultural soil carbon, the net flux was held at the 1997 levels shown in Table F1, since there was only one year of data available.

Table F2. Growth Rates Applied for the Enteric Fermentation and Manure Management Categories

Livestock Category	2005-2025 Annual Growth
Dairy Cattle	-1.25%
Beef Cattle	-2.43%
Swine	0.53%
Sheep	0.00%
Goats	0.65%
Horses	0.81%
Turkeys	-6.39%
Layers	3.69%
Broilers	-2.30%

Table F3. Growth Rates Applied for the Agricultural Soils and Burning

Agricultural Category	2005-2025 Growth Rate
Agricultural Burning	1.57%
Liming of Agricultural Soils	2.21%
Agricultural Soils – Direct Emissions	

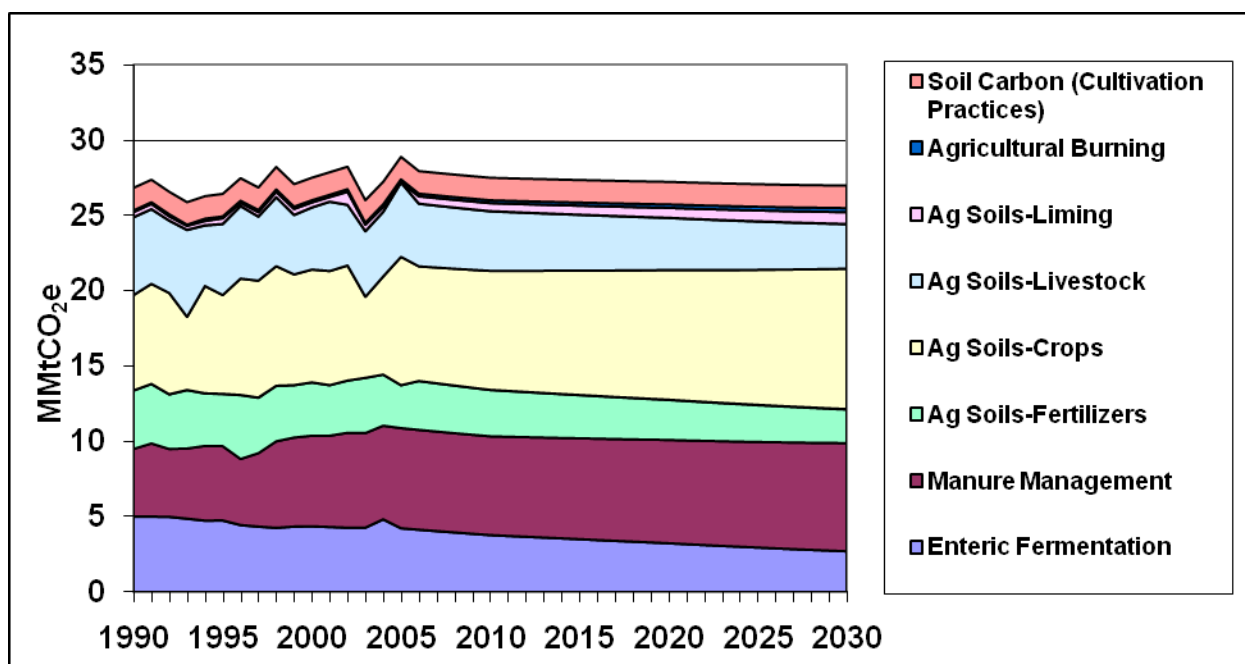
⁷ FAPRI Agricultural Outlook 2006, Food and Agricultural Policy Research Institute, <http://www.fapri.iastate.edu/outlook2006>.

Agricultural Category	2005-2025 Growth Rate
Fertilizers	-0.77%
Crop Residues	0.34%
Nitrogen-Fixing Crops	0.20%
Histosols	0.00%
Livestock	-3.89%
Agricultural Soils – Indirect Emissions	
Fertilizers	-0.73%
Livestock	-3.73%
Leaching/Runoff	-1.31%

Results

Figure F1 and Table F4 show gross GHG emissions associated with the agricultural sector from 1990 through 2020.

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.

In 1990, enteric fermentation accounted for about 19% (5.04 MMtCO₂e) of total agricultural emissions. Enteric fermentation emissions decreased slightly to 4.26 MMtCO₂e between 1990 and 2005 due to the decline in livestock populations in this time period. Both the dairy cattle and beef cattle populations are projected to decrease in the future, and enteric fermentation emissions are estimated to decrease to 2.98 MMtCO₂e in 2025, or about 11% of agricultural emissions.

Table F4. Gross GHG Emissions from Agriculture in Iowa (MMtCO₂e)

Source	1990	1995	2000	2005	2010	2015	2020	2025
Enteric Fermentation	5.04	4.78	4.39	4.26	3.81	3.54	3.27	2.98
Manure Management	4.49	4.93	6.02	6.64	6.55	6.70	6.86	7.01
Ag Soils-Fertilizers	3.83	3.42	3.49	2.81	3.04	2.83	2.62	2.41
Ag Soils-Crops	6.35	6.58	7.52	8.55	7.93	8.28	8.64	9.00
Ag Soils-Livestock	5.17	4.72	4.12	4.95	3.96	3.71	3.46	3.21
Ag Soils-Liming	0.34	0.39	0.33	0.47	0.54	0.60	0.67	0.73
Agricultural Burning	0.13	0.14	0.16	0.19	0.20	0.22	0.24	0.26
Soil Carbon (Cultivation Practices)	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48
TOTAL	26.8	26.4	27.5	29.3	27.5	27.4	27.2	27.1

The manure management category accounted for 17% (4.49 MMtCO₂e) of total agricultural emissions in 1990 and increased to 23% (6.64 MMtCO₂e) by 2005. Manure management emissions are projected to increase slightly by 2025, to account for 26% (7.01 MMtCO₂e) of total agricultural emissions at that time. This is largely due to the projection that the swine population will increase between 2005 and 2025.

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 hold steady from 1990 to 2025, accounting for 59% (15.7 MMtCO₂e) of total agricultural emissions in 1990 and 57% (15.4 MMtCO₂e) in 2025.

As noted previously, cultivation of soils is estimated to be a net emissions source in Iowa. The emissions for this category are estimated to account for 5.5% of total agricultural emissions in 1990 and 2025. Since data are not yet available from USDA to determine if emissions are increasing or decreasing, emissions of 1.48 MMtCO₂e per year are assumed to remain constant throughout the inventory and forecast period.

The only standard IPCC source category missing from this report is N₂O emissions from the cultivation of histosols; there were no activity data available for Iowa.

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 CH₄ 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. Also, one of the agricultural cultivation practices addressed by EPA in their national assessment is cultivation of organic soils and a state-level estimate of the resultant CO₂ emissions has been included in this inventory; however, the associated acreage of organic soils cultivation was not available such that CCS could estimate the N₂O emissions that also occur as a result of cultivation of these soils (histosols).

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 CO₂ – and what portion reacts with carbonic acid (H₂CO₃), resulting in the uptake of CO₂. 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.

Uncertainty in agricultural soils is introduced by the national emissions factor, which reconciles differences between methodologies used in the National Inventory of Greenhouse Gas Emissions and the SIT. The national adjustment factor varies substantially from year to year resulting in the introduction of noise into the agricultural soils categories.

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 (e.g. due to recent dramatic increases in the prices of agricultural commodities such as corn).