A Retrospective Look at Agricultural Soil N_2O Emissions Estimates in the *Inventory of U.S. GHG Emissions and Sinks*

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Introduction

U.S. EPA develops and submits the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (U.S. Inventory) to the United Nations each year in accordance with the United Nations Framework Convention on Climate Change (UNFCCC), which the United States signed and ratified in 1992. Parties to the Convention are required to "develop, periodically update, publish and make available…national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies…." The U.S. GHG Inventory is developed using methods that are consistent with the guidance specified by the IPCC, which provides a common and consistent mechanism through which Parties to the UNFCCC can estimate greenhouse gas (GHG) emissions and compare the relative contribution of individual sources, gases, and nations to climate change.

The U.S. has developed GHG inventories annually since 1994. Each year, the inventory covers a time series starting with 1990 and continuing through the "base year" (BY)—typically two years prior to the publication of the Inventory to allow data to be compiled and analyzed.

This poster provides a retrospective look at trends in the Agriculture section of the U.S. Inventory. It explores how estimates for N_2O emissions from the Agricultural Soil Management source category varied across Inventory base years and discusses the data and methodological improvements behind these variations.

Estimating N_2O Emissions from Agricultural Soil Management

Since the first Inventory submission in 1994, the U.S. Inventory has strived to improve the estimation methodologies used to calculate GHG emissions and sinks. This effort involves continual revisions and refinements to models and Inventory methodologies, including efforts to comply with the evolving IPCC guidance to ensure consistency with other national inventories.

Table 1 below compares Agricultural Soil N_2O sources and associated N inputs that have been included in past Inventory estimates. Only direct emissions from synthetic fertilizer use were covered in the first three years the Inventory was developed. Indirect emissions were first included in the 1996 BY Inventory as well as the emissions from other N inputs to soils, histosol (organic soil) cultivation, and manure deposition on pasture, range, and paddock (PRP). BY 2004 split out, for the first time, emissions originating on cropland from emissions originating on grassland.

Table 1. Agricultural Soil N_2O Sources and N Inputs Covered in the Inventory of U.S. GHG Emissions and Sinks

	Inventory Base Year		
	1993 BY–1995 BY	1996 BY–2003 BY	2004 BY
Direct Emissions			
Synthetic Fertilizer	•		
Cropping Practices[1]/Agricultural Soils[2]/ Managed Soils[3] *Includes emissions from N applications and histosol cultivation*		•	
Animal Production[1]/Grazing Animals[2]/PRP Livestock[3] *Includes emissions from manure deposited on pasture, range, & paddock*		•	
Cropland *Includes emissions from all N applications to cropland soils*			•
Grassland *Includes emissions from N applications to grassland soils*			•
Indirect Emissions		•	•

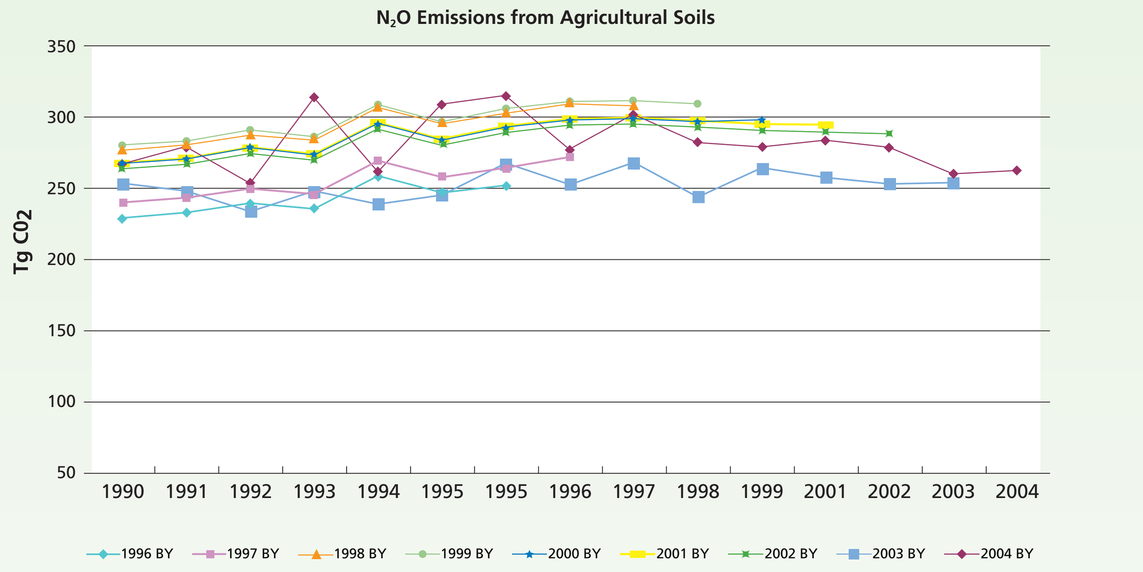
The names used for identical subcategories in the Inventory varied from year to year between 1996 and 2003, as follows: [1] Inventory base year 1996, [2] Inventory base years 1997–1998, [3] Inventory base years 1999–2003

Historically, the estimates for N_2O emissions from agricultural soils provided in the annual U.S. Inventory have varied considerably, as shown in the accompanying graphs and table. The major factors influencing this variability can be categorized, for the most part, as data or methodological improvements. The cumulative effects of these data and methodological changes over time are shown in Table 2 and Figure 1. Table 2 shows N_2O emissions for each Inventory base year from 1993 onwards. Figure 1 is a comparative illustration of variation in the N_2O emission trend lines over the historical time series across a sampling of Inventory base years. Note that the year-to-year variability in the 2004 BY line in this figure is mostly caused by DAYCENT's modeling of climatic effects, rather than by variability in N inputs.

Table 2. Total agricultural soil N_2O emissions across Inventory years ($Tg\ CO_2$ Eq.)

Base Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
1993 BY	57	58	59	59											
1994 BY	57	58	59	61	62										
1995 BY	110	112	114	113	126	117									
1996 BY	229	233	239	235	258	246	252	258							
1997 BY	239	243	249	246	269	257	264	272							
1998 BY	276	280	287	283	306	295	302	309	307						
1999 BY	280	283	291	286	308	296	306	311	311	309					
2000 BY	267	270	278	273	295	283	293	297	298	296	298				
2001 BY	268	271	278	274	296	284	293	298	299	297	295	294			
2002 BY	263	266	273	269	291	279	288	293	294	292	290	289	287		
2003 BY	253	248	233	248	238	245	267	252	268	243	264	257	253	254	
2004 BY	266	278	252	313	262	308	314	277	301	281	278	283	278	259	261

Figure 1. Variation in the Agricultural Soil N_2O trend lines over the historical time series across a sample of U.S. Inventory base years.



Inventory base years 1993, 94, and 95 not shown.

Methodological Improvements

The most significant improvement in methodology was the switch to DAYCENT, a Tier 3 process-based model run by Colorado State University's Natural Resource Ecology Laboratory, in the 2003 BY Inventory. N_2O emissions from agricultural soil management had previously been calculated using an IPCC Tier 1 methodology, which involved multiplying activity data (e.g., amount of fertilizer applied) by a default IPCC emission factor. Similarly, the expansion of sources covered in Inventory estimates has made the estimates more comprehensive in more recent years. The table below traces several of the most important improvements in methodology; Figure 2 shows emissions estimates for the years 1990-1992 from several Inventory base years.

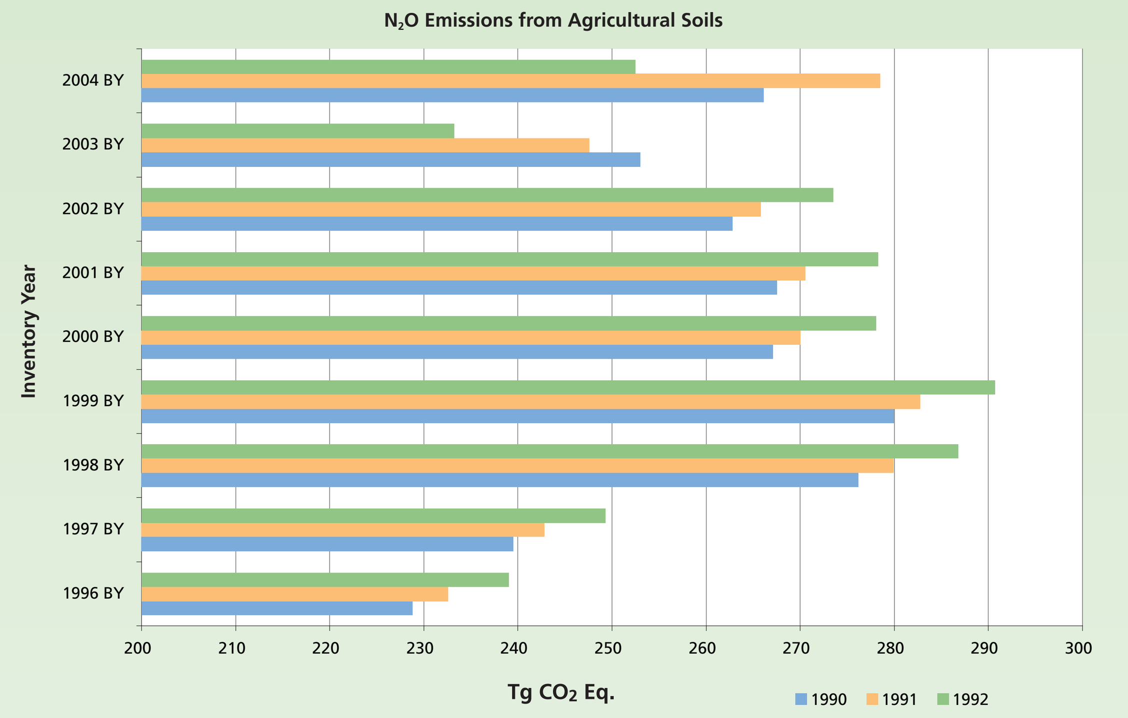
Table 3. Methodological Improvements to Estimates of N_2O emissions from Agricultural Soil Management

1996 BY	In accordance with the *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997), the 1996 BY Inventory report included for the first time direct and indirect emissions from: • Organic fertilizers, • N fixation by crops, • Crop residue inputs, • Histosol cultivation, • Livestock manure management, and • Manure deposition on PRP. These changes resulted in emissions estimates that were approximately 300 percent higher than previous estimates.
1998 BY	• Sewage sludge and non-alfalfa forage legumes were included as sources of N for the first time. • A draft IPCC *Good Practice Guidance* report (IPCC 1999) was published, revising the emission factor for histosol cultivation. • The methodology for indirect N_2O emissions was revised. The new IPCC methodology assumed that most volatilized nitrogen is redeposited, so the leaching/runoff emission factor was used for all applied N, rather than only a portion of applied N, as previously. These various improvements resulted in approximately a 15 percent increase in estimated emissions relative to the previous year.
2000 BY	• The emission factors for histosol cultivation were revised to account for climate (e.g., temperate or subtropical). • The calculation of indirect emissions from leaching/runoff of manure N was corrected to not include manure not applied/deposited to soils (i.e., poultry manure going to feed). These changes resulted in a decrease in estimated emissions of less than 1 percent.

2003 BY	Estimates were developed using DAYCENT, a Tier 3 process-based ecosystem model. The Tier 3 approach is more refined than the Tier 1 method, since it accounts for more of the environmental and management influences on soil N_2O emissions.
	• DAYCENT simulates crop and pasture growth, soil organic matter decomposition, GHG fluxes, and key biogeochemical processes affecting N_2O emissions. The simulations are driven by model input data generated from daily weather records, land management surveys, and soil physical properties determined from national soil surveys.
	• Simulations are conducted at the county scale, because soil and weather data are available for every county with more than 100 acres of agricultural land. However, land management data (e.g., timing of planting, harvesting, intensity of cultivation) are only available at the level of the 63 U.S. agricultural regions. Consequently, the results best represent emissions at the regional and national levels.
	• Emissions that could not be simulated by DAYCENT were accounted for using a Tier 1 methodology based on IPCC/UNEP/OECD/IEA (1997) and IPCC (2000, 2003). These include:
	  • Non-major crops on mineral soils (DAYCENT only simulates emissions from major crops (corn, soybean, wheat, alfalfa hay, other hay, sorghum, and cotton)).
	  • Drainage and cultivation of histosols.
	  • A portion of PRP manure not accounted for by DAYCENT.
	  • Sewage sludge applied to croplands and grasslands.
	  • Indirect emissions stemming from the above sources.

2004 BY	Estimates were split into emissions from croplands and emissions from grasslands, rather than the previous division of managed soils vs. livestock PRP. This was done to distinguish croplands and grasslands from other managed lands types, and because PRP manure is not the only influence on emissions from grasslands. • Emissions from grasslands are based on: PRP manure, managed manure, legume seeding, synthetic fertilizer, and sewage sludge as N inputs. • Emissions from croplands are based on all synthetic and organic fertilizer applied to croplands, managed manure, N-fixing crops, and crop residues as N inputs. • Soils data were derived from the STATSGO map unit that intersects the largest patch of agricultural land in each county instead of using the 0.5° VEMAP cell that intersects the geographical center of each county. • Instead of NASS, the NRI was used for county-level pasture and rangeland area data. • Sewage sludge was assumed to be applied only to pastures, instead of to crops and pastures. • DAYCENT was refined to simulate the grain filling period (anthesis) for some crops, and region-specific cultivars were simulated for corn and soybeans.

Figure 2. Variation in emissions estimates for years 1990-1992



Data Improvements

The data sources used to calculate N_2O emissions from agricultural soil management have undergone yearly improvements since the Inventory was first calculated. Soils and weather data used to drive DAYCENT have gradually increased in spatial resolution to more realistically represent the land areas in each county that are used primarily for cropping and grazing. Input files representing land management practices have also been improved continually to represent more accurately the common practices in different regions of the country.

Future Improvements

2006 IPCC Guidelines for National Greenhouse Gas Inventories

Nearly 140 scientists and national experts from more than thirty countries collaborated in the creation of the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories to ensure that the emission inventories submitted to the UNFCCC are consistent and comparable between nations. These guidelines were updated and revised to produce the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. The Agriculture and LULUCF chapters will be combined into a single Agriculture, Forestry, and Other Land Uses (AFOLU) chapter covering six land-use categories (Forest Land, Cropland, Grassland, Wetlands, Settlements, and Other Land). Some of the changes in IPCC (2006) (such as improved emission factors) have already been included in the 2005 BY Inventory report currently in review. Others, such as the structural change to a single AFOLU category, will not be implemented fully until the 2006 BY.

Changes driven by the 2006 Guidelines will include:

- Reporting on all emissions from managed lands, which are considered to be anthropogenic, while emissions and removals for unmanaged lands are not reported.
- Improvements of default emissions factors, as well as development of an Emission Factor Database (EFDB) that is a supplementary tool to the 2006 IPCC Guidelines, providing alternative emission factors with associated documentation.
- Greater consistency in land area classification for selecting appropriate emission factors and activity data.
- Emission factors for direct N additions and leaching/runoff N have changed.
- No double counting of fixed N in residues.

Source-specific planned improvements

EPA also updates and revises figures and methodologies for emissions estimates in the Inventory as new information and capabilities become available. Every year, EPA anticipates source-specific improvements that will increase accuracy and precision of emissions estimates in the subsequent year. Anticipated improvements are described below.

The first major planned improvement is to incorporate more land survey data from the National Resources Inventory (NRI) (USDA 2000) into the DAYCENT simulation analysis, replacing data from the National Agricultural Statistics Service (NASS) (USDA 2005) currently used.

- NASS land survey data have three major disadvantages, which can be corrected by using NRI:
  - Most crops are grown in rotation with other crops (e.g., corn-soybean), but NASS data provide no information regarding rotation histories.
  - NASS does not conduct a complete survey of cropland area each year, leading to gaps in the land base.
  - The current Inventory based on NASS does not quantify the influence of land-use change on emissions.
- NRI has a record of land-use activities since 1982 for all U.S. agricultural land, which is estimated at about 386 Mha. In contrast to NASS,
  - NRI is designed to track rotation histories, which is important because emissions from any particular year can be influenced by the crop that was grown the previous year.
  - NRI provides a complete history of cropland areas for 4 out of every 5 years, and is currently moving to an annualized inventory that will include a full record for each year.
  - NRI can be used to quantify the influence of land-use change on emissions.
  - NRI provides additional information on pasture land management that can be incorporated into the analysis (particularly the use of irrigation).
  - Using NRI data will also make the Agricultural Soil Management sector methods more consistent with the methods used to estimate C stock changes for agricultural soils.

The second planned improvement is to further refine the uncertainty analysis.

- New studies are being completed and published evaluating agricultural management impacts on soil N_2O emissions, and these studies can be incorporated into the empirical analysis, leading to a more robust assessment of structural uncertainty in DAYCENT.
- Structural uncertainty in DAYCENT is currently only evaluated for emission estimates in croplands, but the evaluation could likely be expanded to include grasslands.
- The DAYCENT Monte Carlo uncertainty analysis will be expanded to address uncertainties in activity data related to crop- and grassland areas, as well as irrigation and tillage histories, because NRI data include an uncertainty measure, while NASS data do not.
- Input data on managed manure N production, PRP manure N production, other organic fertilizer amendments, indirect losses of N in the DAYCENT simulations, and sewage sludge amendments to soils are currently treated as certain. Uncertainties in these quantities will be derived and included in future years.

Other more minor improvements include:

- Update DAYMET weather for more recent years.
- Revise manure N application data to not include poultry manure that is used for cattle feed. Currently, the analysis assumes approximately 5 percent of poultry manure is used for feed. Future inventories will create a time series of poultry manure going to feed, since initial research indicates that the percentage may have changed over time.
- Revise amount of fertilizer assumed applied to settlements. The current assumption that a constant 10 percent of total fertilizer used annually in the US is applied to settlements will be likely be changed to recognize that this value varies through time because of increasing urbanization.

Works Cited

DAYMET (No date) *Daily Surface Weather and Climatological Summaries*. Numerical Terradynamic Simulation Group (NTSG), University of Montana. Available online at <http://www.daymet.org>.

IPCC (2003) *Good Practice Guidance for Land Use, Land-Use Change, and Forestry*. J. Penman and others, editors. IPCC National Greenhouse Gas Inventories Programme. Available online at <http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.htm>, Accessed September 2005.

IPCC (2006) *Guidelines for National Greenhouse Gas Inventories*, Intergovernmental Panel on Climate Change, National Greenhouse Gas Inventories Programme, Montreal.

IPCC (1999) *Good Practice in Inventory Preparation. Agricultural Sources of Methane and Nitrous Oxide*. Draft Version.

IPCC/UNEP/OECD/IEA (1997) *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Paris: Intergovernmental Panel on Climate Change, United Nations Environment Programme, Organization for Economic Co-Operation and Development, International Energy Agency. Paris, France.

USDA (2005) 1992, 1997, and 2002 Census of Agriculture, U.S. Department of Agriculture, National Agriculture Statistics Service, Washington, DC. Data available from <http://www.nass.usda.gov/census/>.

USDA (2000) *1997 National Resources Inventory*. U.S. Department of Agriculture, Natural Resources Conservation Service, Washington, DC. Available online at <http://www.nrcs.usda.gov/technical/NRI/>.