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METHODS FOR ESTIMATING GREENHOUSE GAS EMISSIONS FROM AGRICULTURAL SOIL MANAGEMENT

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Prepared by:
ICF Consulting

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1

INTRODUCTION

The EIIP guidelines are designed to describe emission estimation techniques for greenhouse gas sources in a clear and unambiguous manner and to facilitate preparation of inventories at the state level. This chapter presents the methodology for estimating nitrous oxide emissions from the management of agricultural soils. The methodology presented in this chapter has been revised to reflect new activity data, emission factors, and methods pertaining to this source category. Where possible, the methodology has been updated to be consistent with the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002*.

Section 2 of this chapter contains a general description of this source category. Section 3 provides a listing of the steps involved in estimating nitrous oxide emissions from agricultural soil management. Section 4 presents the preferred estimation method. Section 5 is a placeholder for alternative estimation methods that may be added in the future. A summary of uncertainty for this source category is provided in Section 6. References used in developing this chapter are identified in Section 7.

In addition to these guidelines, there are a series of user friendly spreadsheet tools available to assist in the development of emission inventories at the state level. Please consult the Agriculture Module of the State Inventory Tool[1] to calculate emissions from this source category using the preferred emission estimation method.

[1] Note: The spreadsheet tool may have a different order of calculations, and may not show all calculations to the user.

2

SOURCE CATEGORY DESCRIPTION

2.1 EMISSION SOURCES

Various agricultural soil management practices contribute to greenhouse gas emissions. The use of synthetic and organic fertilizers adds nitrogen to soils, resulting in emissions of nitrous oxide (N_2O). Other agricultural soil management practices, such as irrigation, tillage practices, or the fallowing of land, can also affect fluxes of greenhouse gases to and from the soil. This chapter presents methods to estimate N_2O emissions from agricultural soils. Many other activities in the agricultural and forestry sectors are associated with greenhouse gas emissions as well. Table 10.2-1 summarizes the activities with potentially significant emissions of carbon dioxide, methane, and N_2O, and provides a roadmap indicating the chapter in which each activity is addressed.

N_2O is produced naturally in soils through the microbial processes of denitrification and nitrification.[2] A number of anthropogenic activities add nitrogen to soils, thereby increasing the amount of nitrogen available for nitrification and denitrification, and ultimately the amount of N_2O emitted. These activities include application of fertilizers, animal production, cultivation of nitrogen-fixing crops, and incorporation of crop residues. Another agricultural activity that leads to N_2O emissions, through the mineralization of old nitrogen-rich organic matter, is the cultivation of histosols (highly organic soils). In addition, applied nitrogen (i.e., from animal wastes or fertilizer) contributes indirectly to emissions from agricultural soils through volatilization, leaching, and runoff. The sources of N_2O described here are divided into three categories: (1) direct emissions from agricultural soils due to cropping practices; (2) direct emissions from agricultural soils due to animal production; and (3) emissions from soils indirectly induced by agricultural applications of nitrogen. The methodologies presented for all three components follow the methodologies in the Intergovernmental Panel on Climate Change (IPCC) *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997), the *IPCC Good Practice Guidance* (IPCC 2000), and the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (U.S. EPA 2004). A summary of the sources included in each of the IPCC categories is provided below:

- Direct emissions from agricultural soils due to cropping practices. N_2O is emitted from agricultural soils due to synthetic fertilizer use, organic fertilizer use, application of animal waste through daily spread operations, eventual application of managed animal wastes, crop

[2] Denitrification, the process by which nitrates or nitrites are reduced by bacteria, results in the release of nitrogen into the air. Nitrification is the process by which bacteria and other microorganisms oxidize ammonium salts to nitrites, and further oxidize nitrites to nitrates.

residues remaining on agricultural fields, biological nitrogen fixation by certain crops, histosol cultivation, and land application of sewage sludge.

- Direct emissions from agricultural soils due to animal production. Estimates of N_2O from this source category are based on animal wastes that are not used as commercial fertilizer, applied in daily spread applications, or managed in manure management systems, but instead are deposited directly on soils by animals in pastures, ranges, and paddocks.

- Emissions from soils indirectly induced by agricultural applications of nitrogen. N_2O is emitted indirectly from nitrogen applied as fertilizer and excreted by livestock. Indirect N_2O emissions follow one of two pathways: (1) volatilization of nitrogen as ammonia and nitrogen oxides, leading to atmospheric deposition and subsequent emissions of N_2O from the soil; or (2) fertilizer and animal waste nitrogen leaching and runoff, which enters groundwater and surface water systems, from which a portion is emitted as N_2O.

Methodologies for estimating N_2O emissions from these source categories are included in this chapter.

Table 10.2-1: Greenhouse Gas Emissions and Sinks from the Agricultural and Forest Sectors

A check indicates emissions or sinks may be significant

Activity	Associated Greenhouse Gas Emissions or Sinks and Chapter where these Emissions or Sinks are Addressed					
	CO_2	Chapter	CH_4	Chapter	N_2O	Chapter
Energy (Farm Equipment)	✓	1	✓	3	✓	3
Animal Production: Enteric Fermentation			✓	7		
Animal Production: Manure Management						
Solid Storage			✓	8	✓	8
Drylot			✓	8	✓	8
Deep Pit Stacks			✓	8	✓	8
Litter			✓	8	✓	8
Liquids/Slurry			✓	8	✓	8
Anaerobic Lagoon			✓	8	✓	8
Pit Storage			✓	8	✓	8
Periodic land application of solids from above management practices					✓	10
Pasture/Range (deposited on soil)			✓	8	✓	10
Paddock (deposited on soil)			✓	8	✓	10
Daily Spread (applied to soil)			✓	8	✓	10
Animal Production: Nitrogen Excretion (indirect emissions)					✓	10
Cropping Practices						
Rice Cultivation			✓	9		
Commercial Synthetic Fertilizer Application					✓	10
Commercial Organic Fertilizer Application					✓	10
Incorporation of Crop Residues into the Soil					✓	10
Production of Nitrogen-fixing Crops					✓	10
Liming of Soils	✓	12				
Cultivation of High Organic Content Soils (histosols)	✓	10			✓	10
Cultivation of Mineral Soils	✓	Not included[a]				
Changes in Agricultural Management Practices (e.g., tillage, erosion control)	✓	Not included[a]				
Forest and Land Use Change						
Forest and Grassland Conversion	✓	12				
Abandonment of Managed Lands	✓	12				
Changes in Forests and Woody Biomass Stocks	✓	12				
Agricultural Residue Burning			✓	11	✓	11

[a] Emissions may be significant, but methods for estimating greenhouse gas emissions from these sources are not included in the EIIP chapters.

2.2 FACTORS INFLUENCING GREENHOUSE GAS EMISSIONS FROM AGRICULTURAL SOIL MANAGEMENT

A number of conditions can affect nitrification rates in soils, including water content, which regulates oxygen supply; temperature, which controls rates of microbial activity; nitrate or ammonium concentrations, which regulate reaction rates; available organic carbon, which is required for microbial activity; and soil pH, which is a controller of both nitrification and denitrification rates and the ratio of N_2O to nitrogen from denitrification. These conditions vary greatly by soil type, climate, cropping system, and soil management regime. Moreover, the amount of added nitrogen from each source (e.g., fertilizers, livestock wastes, incorporation of crop residues, nitrogen fixing crops, atmospheric deposition, or leaching and runoff) that is not absorbed by crops or wild vegetation, but remains in the soil and is available for production of N_2O, is uncertain. Therefore, it is not yet possible to develop statistically valid estimates of emission factors for all possible combinations of soil, climate, and management conditions. The emission factors presented throughout this chapter are midpoint estimates based on measurements described in the scientific literature, and as such, are representative of current scientific understanding.

Nitrogen flux from animal production is dependent on the waste management system employed (if any) and the amount of waste excreted. The methodology presented here does not account for site-specific conditions that could affect the amount of nitrogen excreted, or the emission factor for N_2O emissions resulting from nitrogen excretion. These conditions could include temperature, humidity, and others.

N_2O is indirectly emitted following the deposition of volatilized ammonia and nitrogen oxides and through leaching and runoff. Nitrogen that leaches or runs off enters groundwater, riparian areas, wetlands, rivers, and eventually the coastal ocean.

3

OVERVIEW OF AVAILABLE METHODS

3.1 OVERVIEW OF PREFERRED METHOD

The preferred method provided in Section 4 is based on methods taken from the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997), the IPCC *Good Practice Guidance* (IPCC 2000), and the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (U.S. EPA 2004).

The method currently available includes four steps: (1) estimate direct emissions of N_2O from agricultural soils due to cropping practices; (2) estimate direct emissions of N_2O from animal production; (3) estimate indirect emissions from nitrogen in manure and nitrogen used as fertilizer; and (4) sum the emissions of N_2O from all of these sources and convert to units of metric tons of carbon equivalent (MTCE).

4

PREFERRED METHOD FOR ESTIMATING EMISSIONS

This section presents the preferred method for estimating emissions of nitrous oxide (N_2O) from agricultural soil management. The sources of nitrous oxide described here are divided into three categories: (1) direct emissions from agricultural cropping practices; (2) direct N_2O emissions from animal production; and (3) indirect emissions from nitrogen (N) applied to agricultural soils. Once emissions from each source are calculated, they are summed to yield total N_2O emissions from agricultural soil management and are then converted to units of metric tons of carbon equivalent (MTCE).

4.1 DIRECT EMISSIONS FROM AGRICULTURAL CROPPING PRACTICES

This section provides methods for estimating direct N_2O emissions from agricultural soils from the following sources:[3]

- commercial synthetic fertilizer application;
- commercial organic fertilizer application;
- manure applied to soils;
- incorporation of crop residues into the soil;
- production of N-fixing crops;
- cultivation of high organic content soils; and
- land application of sewage sludge.

As in the IPCC guidelines, emissions from the first five sources in this section should be estimated using a common emission factor to determine the portion of N applied to the soil that is subsequently emitted as N_2O. The emission factor used to estimate emissions from cultivation of high organic content soils is different from the direct emission factor used for other sources of direct N_2O emissions from agricultural cropping practices.

[3] The first two source categories listed in this section apply specifically to commercially available fertilizer. Because of the difficulty of obtaining data on non-commercial fertilizer use, the N applied from non-commercial fertilizer use is accounted for in the third category, manure applied to soils.

4.1.1 Commercial Synthetic Fertilizer Application

N_2O is emitted from synthetic fertilizer application. To estimate state emissions of N_2O from the application of commercially sold synthetic fertilizer, four steps should be performed: (1) obtain data on synthetic fertilizer application in the state; (2) calculate unvolatilized applied N from synthetic fertilizer use; (3) calculate direct emissions from synthetic fertilizer application in N_2O-N/yr; and (4) convert the emissions to units of N_2O.

Step (1): Obtain Required Data

- *Required Data*. In order to estimate N_2O emissions from synthetic fertilizer, data on the total use of synthetic fertilizer in the state are needed.

- *Data Sources*. Consult the state Fertilizer Control Official for county-level information or for total state fertilizer consumption in kg of N. In the cases of Hawaii and Alaska, which do not have such an official, contact the U.S. Department of Agriculture. Additionally, state fertilizer consumption can be found in *Commercial Fertilizers*, an annual report published by the Tennessee Valley Authority (TVA) for 1990-1994 and by the Association of American Plant Food Control Officials (AAPFCO) for 1995-present. These reports can be obtained directly from the Fertilizer Institute in Washington, D.C. by calling (202) 962-0490.[4] Additionally, the annual U.S. EPA *Inventory of U.S. Greenhouse Gas Emissions and Sinks* may soon be revised to include fertilizer estimates by state, so states should check future national inventories for that change.

  If data are obtained from *Commercial Fertilizers* or another source that reports fertilizer consumption by growing year (i.e., July through June) as opposed to calendar year (i.e., January through December), an adjustment must be made to convert from the former to the latter. This calculation is performed based on the assumption that 35 percent of fertilizer consumption occurs in the first half of each calendar year (i.e., January through June), while the remaining 65 percent of fertilizer consumption occurs in the second half of the year (i.e., July through December). For example, if fertilizer consumption from July 1989 through June 1990 equals 10 billion kg of N, and consumption from July 1990 through June 1991 equals 12 billion kg of N, the total for the calendar year 1990 should be 65 percent of 10 billion plus 35 percent of 12 billion, or 10.7 billion kg of N.

Step (2): Calculate Unvolatilized Applied Nitrogen From Synthetic Fertilizer

The IPCC specifies different emission factors for direct and indirect N_2O emissions (IPCC/UNEP/OECD/IEA 1997); therefore, direct emissions from synthetic fertilizer application must exclude the fraction of synthetic fertilizer N that is indirectly emitted through volatilization as ammonia (NH_3) and nitrogen oxides (NO_x). Indirect emissions from this source are covered in Section 4.3.

The fraction of synthetic fertilizer expected to volatilize is provided below.

[4] This report provides consumption in tons of N. Convert to kg by multiplying tons of N by 907.2 kg/ton.

Fraction of total synthetic fertilizer N that is emitted as NO_x and NH_3 = 0.1 kg (NH_3-N + NO_x-N)/kg N

The fraction of unvolatilized N from synthetic fertilizer is thus (1 - 0.1), or 0.9, kg unvolatilized N per kg total synthetic fertilizer N.

This factor is used in the equation below to calculate unvolatilized applied N from synthetic fertilizer.

Unvolatilized N from Synthetic Fertilizer (kg N/yr) = Synthetic Fertilizer Used in State (kg N/yr) x (1 – 0.1)

Step (3): Calculate Direct Emissions from Synthetic Fertilizer Application

Multiply the amount of unvolatilized N by the emission factor for direct emissions of N_2O to obtain the amount of emissions in N_2O-N/yr. The IPCC default emission factor is 1.25 percent.

Synthetic Fertilizer Direct Emissions (kg N_2O-N/yr) = Unvolatilized N from Synthetic Fertilizer (kg N/yr) x 0.0125 (N_2O-N)/N

Step (4): Convert Emissions to Units of Nitrous Oxide

Convert from kg N_2O-N to kg N_2O by multiplying the amount of emissions from synthetic fertilizer application by the molecular weight ratio of N_2O/N_2O-N. The ratio is 44/28.

Synthetic Fertilizer Direct Emissions (kg N_2O) = Synthetic Fertilizer Direct Emissions (kg N_2O-N) x 44/28

Example:	To calculate direct N_2O emissions from synthetic fertilizer application in New Jersey in 2000 follow these steps, as described above.
	New Jersey consumed 28,573,029 kg N as synthetic fertilizer during the calendar year 2000.
	28,573,029 kg N x (1 – 0.1) = 25,715,726 kg unvolatilized N/yr
	Convert emissions to N_2O-N using the 0.0125 emission factor, and then to units of N_2O using the molecular weight ratio, 44/28.
	25,715,726 kg N/yr x 0.0125 N_2O-N/N x 44/28 = **505,130 kg N_2O**

4.1.2 Commercial Organic Fertilizer Application[5]

N_2O is emitted from commercial organic fertilizers applied to the soil. To estimate emissions from this source, five steps must be performed: (1) obtain data on commercial organic fertilizer application in the state; (2) subtract out manure from the quantity of organic fertilizers applied in the state; (3) calculate unvolatilized applied N from organic fertilizers; (4) calculate direct emissions from organic fertilizers in N_2O-N/yr; and (5) convert the emissions to units of N_2O.

[5] Typical organic fertilizers include dried manure, dried blood, compost, sewage sludge, and tankage.

Step (1): Obtain Required Data

- *Required Data*. The information needed to estimate N from organics is the amount of these substances used as fertilizer, the N content of these substances, and the percent that volatilizes. Default data for organic fertilizer N content and volatilization fraction are given in Step 3.

- *Data Sources*. Departments within each state responsible for agricultural research should be consulted first. If state officials are not able to provide data on the amount of manure and other organics used as fertilizer, states should use the data provided in *Commercial Fertilizers.* As mentioned above, this report may be obtained directly from the Fertilizer Institute by calling (202) 962-0490. *Commercial Fertilizers* provides the total amount of organics (both manure and other organics used as fertilizer) used on a state by state basis. Information on other organics (dried blood, compost, dried manure, activated sewage sludge, other sewage sludge, tankage, etc.) is provided on a regional basis. Thus, a state can calculate the percentage on a regional basis of the use of manure as a fertilizer (dried manure) and the use of other organics as fertilizer. These percentages may then be applied to the state total for organics to estimate the amount of organics used in a state. An example of this calculation as well as the calculation for estimating total N from organics used as fertilizer follows Step 5.

Step (2): Subtract out Manure from Organics Used as Commercial Fertilizer

It is assumed that all manure, except that used as animal feed, is eventually applied to soils. Therefore emissions from manure used as fertilizer are accounted for in Section 4.1.3, Application of Animal Waste Through Manure Applied to Soils. To avoid double-counting these emissions, fertilizer manure is subtracted out from the total organics used as commercial fertilizer.

Organics Used as Fertilizer (tons) = Total Organics (tons) – Manure Used as Fertilizer (tons)

Step (3): Calculate the Amount of Nitrogen from Organics Used as Commercial Fertilizer

It is assumed that (non-manure) organics used as fertilizer contain between 2 and 12 percent N (Terry 2002).[6] N input from application of organic fertilizers can be calculated using these factors:

- Aggregated fraction of N in other commercial organic fertilizers = 0.041 (Terry 2002);
- Fraction of N in organics that is emitted as NO_x and NH_3 = 0.20 (Mosier 1997).

The IPCC provides different emission factors for direct and indirect N_2O emissions from fertilizer and animal waste; therefore, the total amount of N from organic fertilizer application must be reported, excluding indirect N_2O emissions resulting from volatilization of NH_3 and

[6] Dr. David Terry compiles the statistics for the American Association of Plant Food Control Officials and the Fertilizer Institute's *Commercial Fertilizers* publication. He provided default grades of fertilizer to determine the N content of organics used as fertilizer.

NO_x. Of the N in manure used as fertilizer, 20 percent volatilizes as NH_3 and NO_x; this 20 percent figure should also be applied to the other organic fertilizers (Mosier 1997). The equation used to determine unvolatilized applied N from this source is provided below.

Unvolatilized N from Organic Fertilizers = Amt. Organics Used as Fertilizer (kg) x Fraction N Content x (1 – 0.20)

Step (4): Calculate Direct Emissions from Organics Used as Fertilizer

Multiply the amount of unvolatilized N by the emission factor for direct emissions of N_2O to obtain the amount of emissions in N_2O-N/yr. The IPCC default emission factor is 1.25 percent.

Direct Emissions from Organic Fertilizers (kg N_2O-N/yr) = Unvolatilized N from Organic Fertilizers (kg N/yr) x 0.0125 (N_2O-N)/N

Step (5): Convert Emissions to Units to of Nitrous Oxide

Convert from kg N_2O-N to kg N_2O by multiplying the amount of emissions from organics used as fertilizers by the molecular weight ratio of N_2O/N_2O-N. The ratio is 44/28.

Direct Emissions from Organic Fertilizer (kg N_2O) = Direct Emissions from Organic Fertilizer (kg N_2O-N) x 44/28

Example: To calculate direct N_2O emissions from the use of organics in New Jersey in 2000 the following steps should be followed:

New Jersey is located in the Middle Atlantic region. Organic fertilizer use in the Middle Atlantic region is broken out into the following categories:

13 tons of Dried Blood	11,751 tons of Other Sewage Sludge
7,559 tons of Compost	0 tons Tankage
13,188 tons of Dried Manure	15,967 tons of Other
10,048 tons of Activated Sewage Sludge	**TOTAL** 58,526 tons

The total dried manure used in the Middle Atlantic region is 13,188 tons. The amount of other organics used as fertilizer is equal to the total amount of organics, 58,526 tons, minus the total manure, 13,188 tons; thus, 45,338 tons of other organics are used as fertilizer. The percentages of organic fertilizer in the Middle Atlantic region may be calculated by dividing the amount of manure used as fertilizer by the total amount of organics used as fertilizer in this region: (13,188/58,526) = 23% of organic fertilizer is manure. Thus (100% - 23%), or 77%, is composed of other non-manure organics.

This percentage may then be applied to the total amount of organic fertilizer used in New Jersey, which, according to *Commercial Fertilizers 2001*, was 17,200 tons in 2000.

(100% - 23%) non-manure organics x 17,200 tons organic fertilizer in New Jersey = 13,244 tons of other organics used as fertilizer

Using these activity data, the unvolatilized applied N from this source can be calculated by converting the data to kg and assuming 20 percent volatilization of NH_3 and NO_x and 4.1 percent N content of other organics.

13,244 tons of organics x 907.2 kg/ton = 12,014,957 kg of organics

(12,014,957 kg of organics x 0.041) x (1 - 0.20)
= 394,091 kg unvolatilized N from Commercial Organic Fertilizers

Convert to units of N_2O-N and then to N_2O, using the 1.25% emission factor and 44/28 molecular weight ratio:

394,091 kg N/yr x 0.0125 (N_2O-N)/N x 44/28 = **7,741 kg N_2O** from Commercial Organic Fertilizers

4.1.3 Application of Animal Waste Through Manure Applied to Soils

Emissions from animal waste applied through manure applied to soils, including daily spread operations and the eventual application of managed animal wastes, are considered in this section because this waste is intentionally applied to the soil, as opposed to manure deposited on pastures, ranges, and paddocks (addressed in Section 4.2). This method reflects the assumption that all manure, except the small part used as animal feed, is eventually applied to agricultural soils as a mode of disposal. In order to estimate emissions from this source, follow these six steps: (1) obtain data on animal herd characteristics; (2) calculate the amount of N from animal waste applied as daily spread; (3) calculate N from animal waste eventually applied to soils; (4) add the N from animal waste applied as daily spread and the N from animal waste eventually applied to soils; (5) calculate direct emissions from animal manure applied to soils in N_2O-N/yr; and (6) convert the emissions to units of N_2O.

Step (1): Obtain Required Data

- *Required Data*. The information needed to estimate direct N_2O emissions from application of animal waste through manure applied to soils are: population of each type of animal, typical animal mass (TAM) for each type of animal, Kjeldahl N emitted per unit of animal mass for each type of animal, the percentage of manure applied through "daily spread" (i.e., spread daily on cropland and pasture), and the percentage of managed manure for each type of animal. TAM and Kjeldahl N default values are provided for each type of animal in Table 10.4-1 if more specific information is unavailable.

- *Data Sources*. Departments within each state responsible for conducting agricultural research and monitoring agricultural waste practices should be consulted for animal population data. Alternatively, animal population data are provided by the National Agriculture Statistics Service of the U.S. Department of Agriculture (USDA) and can be found at the following Internet URL: http://usda.mannlib.cornell.edu/. Animal population data may also be found in the *1997 Census of Agriculture, Volume 1: Geographic Area Series*, published by the USDA. Table 10.4-1 provides default average TAM and total Kjeldahl N excreted per unit mass for each of the major types of farm animals. The percent of manure for dairy cows and dairy heifers[7] managed as daily spread can be found in the Agriculture Module of the State Inventory Tool (hereafter referred to as the State Inventory Tool). Where state data are available, they may be used in place of these default values.

Step (2): Calculate Nitrogen from Animal Waste Applied as Daily Spread

For each animal type *i*, multiply population times (1) the percent of manure managed as daily spread (from the State Inventory Tool), (2) the TAM for animal type *i* (found in Table 10.4-1), and (3) the daily rate of N excreted by animal type *i* (also found in Table 10.4-1). Plug these constants into the equation below to determine N excretion for each type of animal.

$$\textit{N Excreted by Animal}_i \textit{ (kg/yr)} = \textit{Pop. of Animal}_i \times \textit{\% of Manure Managed as Daily Spread} \times \textit{TAM}_i \textit{ (kg)} \times \textit{Kjeldahl N (kg N/1000 kg Animal}_i\textit{/day)} \times \textit{365 days/yr}$$

Sum the results of this equation across animal types to yield total N input from animal waste applied as daily spread. Next, adjust the total Kjeldahl N excreted per year to account for the portion that volatilizes to NH_3 and NO_x, i.e., 20 percent (IPCC/UNEP/OECD/IEA 1997). To do so, multiply the product of the equation above times (1 - 0.20), or 0.80, as shown in the equation below.

$$\textit{Unvolatilized N from Daily Spread Operations (kg N)} = \textit{Total N Excreted in Manure Spread Daily (kg N)} \times (1 - 0.20)$$

[7] In the State Inventory Tool, only dairy cows and dairy heifers are assumed to have their manure managed in this way. Include information on other animals' daily spread manure when available.

Table 10.4-1: Constants Used to Estimate Nitrogen Excretion During Animal Production

Animal Type	TAM (kg)	Kjeldahl Nitrogen (kg/1000 kg animal mass/day)
Dairy Cattle		
Dairy Cows	604	0.440
Dairy Replacement Heifers	476	0.310
Beef Cattle		
Beef Cows	533	0.330
Beef Replacement Heifers	420	0.310
Calves	118	0.300
Steer Stockers	318	0.310
Heifers Stockers	420	0.310
Feedlot Steer	420	0.300
Feedlot Heifers	420	0.300
Bulls	750	0.310
Swine		
Breeding	198	0.235
Market <60 lbs	15.9	0.600
Market 60 – 119 lbs	40.6	0.420
Market 120 – 179 lbs	67.8	0.420
Market >180 lbs	90.8	0.420
Poultry		
Layers		
Hens > 1 yr	1.8	0.830
Pullets	1.8	0.620
Chickens	1.8	0.830
Broilers	0.9	1.100
Turkeys	6.8	0.740
Sheep		
On Feed	27	0.420
Not on Feed	27	0.420
Goats	64	0.450
Horses	450	0.300

Source: U.S. EPA 2004.

Step (3): Calculate Nitrogen from Animal Waste from Managed Systems Eventually Applied to Soils

For each animal type *i*, multiply population times (1) the percent of manure in managed systems (from the State Inventory Tool) (i.e., all animal waste not applied as daily spread or pasture, range, and paddock), (2) the TAM for animal type *i* (found in Table 10.4-1), and (3) the daily rate of N excreted by animal type *i* (also found in Table 10.4-1). Plug these constants into the equation below to determine N excretion for each type of animal.

Total N Excreted by Animal$_i$ (kg/yr) = Pop. Of Animal$_i$ (head) x % of Managed Manure for Animal$_i$ x TAM$_i$ (kg) x Kjeldahl N (kg)/1000 kg Animal$_i$/day x 365 days/yr

Next, an adjustment must be made for the small portion of animal waste used as animal feed. For all poultry categories (i.e., layers (hens, pullets, and chickens), broilers, and turkeys), multiply their total Kjeldahl N value by (1-0.042), or 0.958, as 4.2 percent of all poultry manure is used as animal feed and not applied to agricultural soils (Carpenter 1992). Then sum the results of the above equation (with the adjusted poultry values) across animal types to yield total N input from animal waste applied as daily spread. Next, adjust the total Kjeldahl N excreted per year to account for the portion that volatilizes to NH_3 and NO_x, i.e., 20 percent (IPCC/UNEP/OECD/IEA 1997). To do so, multiply the product of the equation above times (1 - 0.20), or 0.80, as shown in the equation below.

Unvolatilized N from Managed Systems that is Eventually Applied to Soils (kg N) = Total N Excreted in Manure Spread Daily (kg N) x (1 - 0.20)

Step (4): Sum the Nitrogen from Animal Waste Applied as Daily Spread and the Nitrogen from Animal Waste from Managed Systems Eventually Applied to Soils

To arrive at a total for direct emissions from manure applied to soils, add the unvolatilized applied N from daily spread operation to the unvolatilized N from managed systems, as shown in the equation below.

Total Unvolatilized N from Manure (kg N) = Unvolatilized N from Daily Spread Operations (kg N) + Unvolatilized N from Managed Systems (kg N)

Step (5): Calculate Direct Emissions from Manure Systems

Multiply the amount of unvolatilized N by the emission factor for direct emissions of N_2O to obtain the amount of emissions in N_2O-N/yr. The IPCC default emission factor is 1.25 percent.

Manure Systems Emissions (kg N2O-N/yr) = Unvolatilized N from Manure Systems (kg N/yr) x 0.0125 (N2O-N)/N

Step (6): Convert Emissions to Units of Nitrous Oxide

Convert from kg N_2O-N to kg N_2O by multiplying the amount of emissions from manure systems application by the molecular weight ratio of N_2O/N_2O-N. The ratio is 44/28.

Manure Systems Emissions (kg N_2O) = Manure Systems Emissions (kg N_2O-N) x 44/28

Example: This example shows calculations for direct N_2O emissions from dairy cows in New Jersey in 2000. These emissions are calculated in two parts: (1) emissions from animal waste applied as daily spread, and (2) animal waste from managed systems eventually applied to soils. In both cases emissions must be calculated for all relevant animal populations and summed to estimate total emissions from this source.

The number of dairy cows in New Jersey in 2000 was 16,052 head. According to the State Inventory Tool and Table 10.4-1, 17 percent of manure from dairy cows is managed in daily spread operations, 46 percent is kept in managed systems, the TAM for dairy cows is 604 kg, and the Kjeldahl N per 1000 kg mass for dairy cows is estimated to be 0.44 kg/day. Therefore, the amount of N produced by dairy cows in New Jersey that is used in either daily spread or managed systems during the year would be calculated as follows:

N from daily spread operations is calculated as follows:

16,052 head x 0.17 x (604 kg mass/head) x (0.440 kg Kjeldahl N/1000 kg mass/day) x (365 days/yr) = 264,704 kg per year of Kjeldahl N from manure managed as daily spread

Adjust for N that volatilizes to NH_3 and NO_x by multiplying by (1 - 0.20) to determine unvolatilized applied N from manure from dairy cows that is applied in daily spread operations.

264,704 kg/yr of Kjeldahl N x (1 - 0.20) = 211,763 kg/yr unvolatilized applied N from daily spread

N from animal waste from managed systems that is eventually applied to soils is calculated in the same manner as N from daily spread, substituting in the correct percentage of dairy cows kept in managed systems. The result here is 573,006 kg N applied to soils.

Sum the total N from application of animal waste through manure applied to soils:

211,763 kg N from daily spread + 573,006 kg N from managed systems = 784,769 kg N

Convert emissions to N_2O-N using the 0.0125 emission factor, and then to units of N_2O using the molecular weight ratio, 44/28.

784,769 kg N x 0.0125 N_2O-N/N x 44/28 = **15,415 kg N_2O**

According to State Inventory Tool, summing these results across animal types in New Jersey in 2000 yields **29,812 kg N_2O**

4.1.4 Incorporation of Crop Residue into the Soil

N_2O is also emitted from crop residue that is incorporated into the soil (i.e., the portion of the crop that has been neither removed from the field as crop nor burned). To estimate state emissions of N_2O from crop residues (for both N-fixing and non-N-fixing crops), four steps should be performed: (1) obtain data on crop production; (2) calculate the amount of N entering the crop residue pool; (3) calculate direct emissions from crop residue in soil in N_2O-N/yr and sum across crop types; and (4) convert the emissions to units of N_2O.

Step (1): Obtain Required Data

- *Required Data*. In order to estimate N_2O emissions from crop residue, data on state crop production of both N-fixing (e.g., beans and pulses) and non-N-fixing crops (e.g., wheat and corn) are needed. The residue dry matter fraction, retention fraction, and N content are also required, though default data for several crops are provided in Table 10.4-2 if more specific values are unavailable.

- *Data Sources*. Departments within each state responsible for agricultural research should be consulted first. Crop production information is provided by USDA and is available on the Internet at http://www.usda.gov/nass/pubs/histdata.htm. Table 10.4-2 provides default data for the mass ratio of crop residue to crop, dry matter fraction for residue, fraction burned, and N content of residue.

Step (2): Calculate the Amount of Nitrogen Entering the Crop Residue Pool

Little data exists on the amount of crop residue left on fields, because crop residue is not recorded as a commercial product. For example, during the harvest of corn grown for grain[8], typically only the kernels are taken from the field and other parts of the corn plant (i.e., stalks and cobs) are shredded and left on the field as crop residue. Following the methodology used in the U.S. Inventory (U.S. EPA 2004), it is assumed that all residues from corn (for grain), wheat, bean, and pulse production, except the fractions burned in the field after harvest, are left in the field (e.g., plowed under).

To estimate the total N in crop residues returned to the soil for each crop, multiply the production of each crop ($crop_i$) by (1) the mass ratio of $crop_i$ residue to $crop_i$ and (2) the dry matter fraction for residue. The resulting values are the amounts of $crop_i$ residue biomass, measured as dry matter. Next, multiply by (1) a factor of 1 minus the fraction burned and (2) the N content of the residue. These steps are shown in the equation below.

N in Crop$_i$ Residue (kg N/yr) = Crop$_i$ Production (kg/yr) x Mass Ratio of Crop$_i$ Residue to Crop$_i$ x Dry Matter Fraction for Residue$_i$ x Residue Retention Fraction x N Content of Residue$_i$ (kg N/ kg dry biomass)

Finally, sum the results for all crop types to provide total N for all crop residues.

Step (3): Calculate Direct Emissions from Crop Residue in Soils

Multiply the total N in all crop residues by the emission factor for direct emissions of N_2O to obtain the amount of emissions in N_2O-N/yr. The IPCC default emission factor is 1.25 percent.

Direct Emissions from Crop Residue (kg N2O-N/yr) = Total N in all Crop Residue (kg N/yr) x 0.0125 kg N2O-N/kg N

Step (4): Convert Emissions to Units of Nitrous Oxide

Convert from kg N_2O-N to kg N_2O by multiplying the amount of emissions from crop residues by the molecular weight ratio of N_2O/N_2O-N. The ratio is 44/28.

Direct Emissions from Crop Residue (kg N_2O) = Direct Emissions from Crop Residue (kg N_2O-N) x 44/28

[8] The corn area harvested should only include corn for grain, not corn for silage. Corn for silage is not accounted for because it does not yield residues to be incorporated into the soil.

Table 10.4-2: Residue to Crop Mass Ratio, Residue Dry Matter Fraction, Fraction Residue Applied, and Residue Nitrogen Content for Selected Crops

Crop	Residue to Crop Mass Ratio	Residue Dry Matter Fraction	Residue Retention Fraction	N Content of Residue (kg N/kg dry biomass)
Alfalfa	0	0.85	0	NA
Corn for Grain	1	0.91	0.90	0.0058
All Wheat	1.3	0.93	0.90	0.0062
Barley	1.2	0.93	0.90	0.0077
Sorghum for Grain	1.4	0.91	0.90	0.0108
Oats	1.3	0.92	0.90	0.0070
Rye	1.6	0.90	0.90	0.0048
Millet	1.4	0.89	0.90	0.0070
Rice	1.4	0.91	1.00	0.0072
Soybeans for Beans	2.1	0.87	0.90	0.0230
Peanuts for Nuts	1	0.86	0.90	0.0106
Dry Edible Beans	1.55	0.87	0.90	0.0168
Dry Edible Peas	1.55	0.87	0.90	0.0168
Austrian Winter Peas	1.55	0.87	0.90	0.0168
Lentils	1.55	0.87	0.90	0.0168
Wrinkled Seed Peas	1.55	0.87	0.90	0.0168

Sources: Turn et al. 1997, Ketzis 1999, Karkosh 2000, Strehler and Stützle 1987, Barnard and Kristoferson 1985, and U.S. EPA 2004.

Example: This example shows calculations for direct N_2O emissions from soybean crop residue incorporated into the soil in New Jersey in 2000. The same steps should be applied for residues from all other crops in the state.

New Jersey produced 106,686 metric tons (3,920,000 bushels) of soybeans in 2000. According to the State Inventory Tool and Table 10.4-2, for soybeans the residue to crop mass ratio is 2.1, the residue dry matter fraction is 0.87, the residue retention fraction is 0.90, and the N content of the residue is 0.0230.

106,686 metric tons of soybeans x 1,000 kg/metric tons = 106,686,000 kg soybeans

106,686,000 kg/yr x 2.1 x 0.87 x 0.90 x 0.0230 kg N/kg dry biomass = 4,034,747 kg N

These results should be summed for all crop types to provide total N for all crop residues in New Jersey. According to the State Inventory Tool this total is 5,685,149 kg N for the year 2000. Convert emissions to N_2O-N using the 0.0125 emission factor, and then to units of N_2O using the molecular weight ratio, 44/28.

5,685,149 kg N x 0.0125 N_2O-N/N x 44/28 = **111,673 kg N_2O**

4.1.5 Production of Nitrogen-Fixing Crops

N_2O is emitted from the cultivation of N-fixing crops, also known as legumes. To estimate state emissions of N_2O from N-fixing crops, four steps should be performed: (1) obtain data on biomass production of N-fixing crops; (2) calculate total N input from N-fixing crops; (3) calculate direct emissions from N-fixing crops in N_2O-N/yr and sum across all crop types; and (4) convert the emissions to units of N_2O.

Step (1): Obtain Required Data

- *Required Data*. In order to estimate N_2O emissions from the cultivation of legumes, data on the amount of beans, pulses, and alfalfa produced in the state are needed. Default values for the residue to crop mass ratio, residue dry matter fraction, and residue N content are provided for these crops in Table 10.4-2.

  Data on production of non-alfalfa forage crops, such as red clover, white clover, birdsfoot trefoil, arrowleaf clover, and crimson clover are also desirable. The default values in Table 10.4-2 are not required to estimate emissions from forages because the methodology for these crops simply requires biomass of forage produced and the N content of the forage.

- *Data Sources*. Departments within each state responsible for agricultural research should be consulted first. Crop production information is provided by USDA and is available on the Internet at http://www.usda.gov/nass/pubs/histdata.htm. Crop types include soybeans, peanuts, dry edible beans and peas, Austrian Winter peas, lentils, alfalfa, and wrinkled seed peas. Since production data on non-alfalfa forage crops are not readily available, state forage experts should be consulted for this information. Data should be collected in kg dry biomass/yr.

Step (2): Calculate Total Nitrogen Input from Nitrogen-fixing Crops

In order to calculate the total N input from N-fixing crops, multiply (1) the production of each type of N fixing crop (pulses, soybeans, alfalfa, and non-alfalfa forage) in the state by (2) 1 plus the residue to crop mass ratio for each crop, by (3) the residue dry matter fraction, times (4) the fraction of N in each crop. The IPCC method uses the fraction of N in N-fixing crops as a proxy for the amount of N added to soil by N-fixing crops (IPCC 2000). The default value is shown below:

- Fraction of N in N-fixing crops = 0.03 kg N/kg of dry biomass (IPCC/UNEP/OECD/IEA 1997).

N input from N-fixing crops (such as soybeans, lentils, and peanuts) is calculated as follows:

N Input from N-fixing Crops (kg N/yr) = Production of N-fixing crops in State (kg dry biomass/yr) x (1+ Residue to Crop Mass Ratio) x Residue Dry Matter Fraction x (Fraction of N in N-fixing Crops (kg N/kg dry biomass)

N input from N-fixing forage crops (such as red clover, white clover, etc.) is calculated as follows:

N Input from N-fixing Forage Crops (kg N/yr) = Production of N-fixing crops in State (kg dry biomass/yr) x (Fraction of N in N-fixing Crops (kg N/kg dry biomass)

The values are then summed across all crops, to yield the total N input from N-fixing crops.

Step (3): Calculate Direct Emissions from Nitrogen-Fixing Crop Soils

Multiply the amount of N from N-fixing crops by the emission factor for direct emissions of N_2O to obtain the amount of emissions in N_2O-N/yr. The IPCC default emission factor is 1.25 percent.

Direct Emissions from N-fixing Crops (kg N_2O-N/yr) = N from N-fixing Crops (kg N/yr) x 0.0125 N_2O-N/N

Step (4): Convert Emissions to Units of Nitrous Oxide

Convert from kg N_2O-N to kg N_2O by multiplying the amount of emissions from N-fixing crops by the molecular weight ratio of N_2O/N_2O-N. The ratio is 44/28.

Direct Emissions from N-fixing Crops (N_2O) = Direct Emissions from N-fixing Crops (kg N_2O-N) x 44/28

Example:	This example shows calculations for direct N_2O emissions from soybeans, a N-fixing crop, in New Jersey in 2000. The same steps should be applied for other N-fixing crops, and then summed across crop types. New Jersey produced 106,686 metric tons (3,920,000 bushels) of soybeans in 2000, which is equivalent to 106,686,000 kg soybeans. According to the State Inventory Tool and Table 10.4-2, for soybeans the residue to crop mass ratio is 2.1 and the residue dry matter fraction is 0.87. 106,686,000 kg dry biomass/yr x (1 + 2.1) x 0.87 x 0.03 kg N/kg dry biomass = 8,631,964 kg N These results should be summed for all crop types to provide total N for all N-fixing crops in New Jersey. According to the State Inventory Tool this total is 10,713,949 kg N for the year 2000. Next convert emissions to N_2O-N using the 0.0125 emission factor, and then to units of N_2O using the molecular weight ratio, 44/28. 10,713,949 kg N x 0.0125 N_2O-N/N x 44/28 = **210,453 kg N_2O**

4.1.6 Cultivation of High Organic Content Soils

N_2O is also emitted from the cultivation of high organic content soils, or histosols. To estimate state emissions of N_2O from the cultivation of histosols, three steps should be performed: (1) obtain data on histosol cultivation area; (2) calculate direct emissions from histosols in N_2O-N/yr; and (3) convert the emissions to units of N_2O.

Step (1): Obtain Required Data

- *Required Data*. The emissions of N_2O from the cultivation of histosols can be estimated using the area of cultivated histosols in the state.

- *Data Sources*. State soil scientists and/or state NRCS representatives should be consulted first. Mausbach and Spivey (1993) compiled an estimate of the national area of cultivated histosols. This estimate does not provide a breakdown to the state level; therefore, states may have difficulty locating data on histosol cultivation. Additionally, U.S. Inventory calculations may soon be revised to include histosols estimates by state based on histosols data from the *1997 Natural Resources Inventory,*[9] so states should check future national inventories for that change. The area of cultivated histosols in the state should be reported in hectares.[10] The emission factor, where available, should be expressed in kg N_2O-N/ha/yr of cultivated histosol.

Step (2): Calculate Direct Emissions from Histosols

To calculate the direct emissions from histosols, add (1) the area of cultivated soils in temperate climates multiplied by the emission factor for direct emissions from histosols in temperate climates, and (2) the area of cultivated soils in sub-tropical climates multiplied by the emission factor for direct emissions from histosols in subtropical climates. The emission factors for direct emissions from histosols are listed below in Table 10.4.3. (IPCC 2000).

Table 10.4-3: Emission Factors for Histosols

Climate	Emission Factor (kg N_2O-N/ha-yr)
Temperate	8
Subtropical	12

Source: IPCC 2000

Direct N_2O Emissions from the Cultivation of Histosols (kg N_2O-N/yr)=[Area of Cultivated Histosols in Temperate Climates (ha) x Emission Factor for Direct Soil Emissions from Temperate Climates (kg N_2O-N/ha-yr)] + [Area of Cultivated Histosols in Subtropical Climates (ha) x Emission Factor for Direct Soils Emissions from Subtropical Climates (kg N_2O-N/ha-yr)]

Step (3): Convert Emissions to Units of Nitrous Oxide

Convert from kg N_2O-N to kg N_2O by multiplying the emissions from cultivation of histosols by the molecular weight ratio of N_2O/N_2O-N. The ratio is 44/28.

Direct Emissions from Histosols Cultivation (kg N_2O) = Emissions from Histosols Cultivation (kg N_2O-N) x 44/28

4.1.7 Land Application of Sewage Sludge

The preferred methodology does not include a detailed step-by-step approach to estimating emissions from land application of sewage sludge. There are three basic reasons for minimizing guidance on this source category in this chapter. First, the data necessary to estimate emissions are not likely to be available at the state level. Second, there is considerable uncertainty surrounding the method used to estimate these emissions at the national level. Third, emissions

[9] Available from USDA for $50. http://www.nrcs.usda.gov/technical/NRI/1997/obtain_data.html.

[10] To convert from acres to hectares, multiply acres by the conversion factor 0.4047 hectares per acre.

from sewage sludge are already captured in the methodology for estimating emissions from wastewater in Chapter 14. However, if states have data on sewage sludge applied to soils, they can calculate emissions by applying the general guidance provided below.

States with data on sewage sludge applied to soils can calculate emissions by multiplying (1) the dry weight of sewage sludge produced in the state by (2) the fraction of sewage sludge applied to soil and by (3) 3.3 percent to estimate the amount of N applied to soils in the form of sewage sludge.[11] This value should then be used to estimate direct emissions of N_2O (following the methodology used in Section 4.1.2, Section 4.3.1, and Section 4.3.2).

4.2 DIRECT NITROUS OXIDE EMISSIONS FROM ANIMAL PRODUCTION

This section provides a method for determining direct N_2O emissions from animal excretion deposited directly onto pastures, ranges, and paddocks. To estimate direct emissions from animal production, perform the following four steps: (1) obtain data on animal waste production; (2) calculate N from animal waste deposited directly on pastures, ranges, and paddocks; (3) calculate direct emissions from animal production in N_2O-N/yr; and (4) convert the emissions to units of N_2O.

Step (1): Obtain Required Data

- *Required Data*. The information needed to estimate direct N_2O emissions from animal waste deposited directly onto pasture, range, and paddock are data, for each type of animal, on (1) animal population, (2) TAM, (3) Kjeldahl N emitted per unit of animal mass, and (4) the percent of manure deposited on pasture, range, and paddock. TAM and Kjeldahl N default values are given in Table 10.4-1 in case more specific information is unavailable.

- *Data Sources*. Departments within each state responsible for conducting agricultural research and monitoring agricultural waste practices should be consulted for animal population data. Alternatively, animal population data are provided by the National Agriculture Statistics Service of the U.S. Department of Agriculture (USDA) and can be found at the following Internet URL: http://usda.mannlib.cornell.edu/, or in the State Inventory Tool. Animal population data may also be found in the *1997 Census of Agriculture, Volume 1: Geographic Area Series*, published by the USDA. Table 10.4-1 provides default average TAM and total Kjeldahl N excreted per unit mass for each of the animal types. The percent of manure for livestock deposited on pasture, range, and paddock can be found in the State Inventory Tool. Where state data are available, they may be used in place of these default values.

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[11] States choosing to estimate N_2O emissions from land application of sewage sludge should recalculate emissions from commercial organic fertilizer application to ensure that sewage sludge emissions are not being counted twice.

Step (2): Calculate Nitrogen from Animal Waste Deposited Directly on Pastures, Ranges, and Paddocks

For each animal type *i*, multiply population times (1) the percent of manure deposited on pastures, ranges, and paddocks (from the State Inventory Tool), (2) the TAM for animal type *i* (found in Table 10.4-1), and (3) the daily rate of N excreted by animal type *i* (also found in Table 10.4-1). Use these data to perform the calculation shown below, for each animal type. Then sum the results across all animal types to determine total N input from animal waste deposited on pastures, ranges, and paddocks.

Total N Excreted by Animal$_i$ (kg N/yr) = Pop. of Animal$_i$ x % of Manure Deposited on Pastures, Rages, and Paddocks x TAM (kg) x Kjeldahl N (kg N/1000 kg Animal$_i$/day) x 365 (days/yr)

Step (3): Calculate Direct Nitrous Oxide Emissions from Animal Production

The direct N_2O emissions from animal production can be calculated by multiplying the applied N from animal waste deposited on pastures, ranges, and paddocks by the IPCC default emission factor for direct emissions, 0.02 kg N_2O-N/kg N excreted (IPCC/UNEP/OECD/IEA 1997, U.S. EPA 2004). IPCC (2000) assumes that all manure deposited on pastures, ranges, and paddocks remains unvolatilized (therefore, no manure volatilization emission factor is applied here).

Direct N_2O Emissions from Animals (kg N_2O-N) = Applied N from Waste Deposited (kg N) x Emission Factor for Direct Emissions from Animal Production (kg N_2O-N/kg N)

Step (4): Convert Emissions to Units of Nitrous Oxide

Convert from units of N_2O-N to units of N_2O by multiplying the amount of emissions from animal production by the molecular weight ratio of N_2O/N_2O-N. The ratio is 44/28.

Direct N_2O Emissions from Animals (kg N_2O) = Direct N_2O Emissions from Animals (kg N_2O-N) x 44/28

Example:	This example shows calculations for direct N_2O emissions from dairy cows in New Jersey in 2000. The same steps should be applied for other livestock, and then summed across animal types. In 2000, there were 16,052 dairy cows in New Jersey. According to the State Inventory Tool and Table 10.4-1, for these dairy cows, 8 percent of manure is deposited on pasture, range and paddock, TAM is 604 kg, and Kjeldahl N is 0.440 kg/1000 kg animal mass/day. 16,052 dairy cows x 0.08 x 604 kg/dairy cow x 0.440 kg/1000 kg animal mass/day x 365 days/yr = 124,567 kg N/yr Assuming all manure deposited on pastures, ranges, and paddocks remains unvolatilized, the IPCC default emission factor can be used as follows: 124,567 kg N/yr x 0.02 kg N_2O-N/kg N = 2,491 kg N_2O-N Convert to units of N_2O: 2,491 kg N_2O-N x 44/28 = **3,914 kg N_2O** These emissions should be calculated for each type of livestock and then summed across animal types. The State Inventory Tool reports a total of **123,000 kg N_2O** from pasture, range, and paddock direct emissions for New Jersey in 2000.

4.3 INDIRECT NITROUS OXIDE EMISSIONS FROM NITROGEN APPLIED TO AGRICULTURAL SOILS

N_2O emissions can also result from agricultural activities via the following indirect pathways:

- NH_3 and NO_x volatilization; and
- Leaching and runoff of N from agricultural fields.

4.3.1 Volatilization of Ammonia and Oxides of Nitrogen

Some of the N applied to the soil as fertilizer and excreted by livestock volatilizes, enters the atmosphere as NO_x and NH_3, and subsequently returns to soils through atmospheric deposition, thereby enhancing N_2O production. The atmospheric deposition of NO_x and NH_3 can be calculated in five steps: (1) obtain data for applied synthetic and organic fertilizers and livestock N excretion; (2) calculate the amount of N applied to the soil as fertilizer that volatilizes;[12] (3) calculate total N excretion by livestock that volatilizes; (4) calculate indirect emissions from NO_x and NH_3 volatilization in N_2O-N/yr; and (5) convert the emissions to units of N_2O.

Step (1): Obtain Required Data

- *Required Data*. The estimates for indirect emissions through atmospheric deposition are based on the amount of N in fertilizer and total animal waste that is applied or deposited on

[12] The methodology for estimating nitrogen applied to the soil as fertilizer that volatilizes accounts for all commercially sold fertilizer (both synthetic and organic) minus the manure fraction of commercially sold fertilizer. All volatilization from animal wastes are accounted for in Step 3.

the soil. The activity data used in Sections 4.1.1, 4.1.2, 4.1.3, and 4.2 are required to determine the amount of N that volatilizes.

- *Data Sources*. Use activity data obtained for sections 4.1.1, 4.1.2, 4.1.3, and 4.2.[13]

Step (2): Calculate the Amount of Nitrogen Applied to the Soil as Fertilizer that Volatilizes

In order to calculate NH_3 and NO_x volatilization from fertilizer application, multiply the amount of N applied to the soil times the fraction of fertilizer N that volatilizes. The IPCC suggests default values of 10 and 20 percent for the fraction of synthetic and organic fertilizer N that volatilizes, respectively (IPCC/UNEP/OECD/IEA 1997). See the following equations:

Volatilized N from Synthetic Fertilizer (kg N/yr) = Total State Application of Synthetic Fertilizer (kg N/yr)[14] *x 0.10*

Volatilized N from Organic Fertilizer (kg N/yr) = Total State Application of Organic Fertilizer (kg N/yr)[15] *x 0.20*

Total Volatilized N from Fertilizer (kg N/yr) = Volatilized N from Synthetic Fertilizer Application (kg N/yr) + Volatilized N from Organic Fertilizer (kg N/yr)

Step (3): Calculate the Total Nitrogen Excretion by Livestock that Volatilizes

NH_3 and NO_x volatilization from animal wastes can be calculated using total N excretion by all livestock in the state. In order to calculate total N excretion, use the equation below, which is a variation on the equations provided in Sections 4.1.3 and 4.2.

Total N Excreted (kg N/yr) = Pop. Of Animal$_i$ *x TAM*$_i$ *(kg) x Kjeldahl N (kg N/1000 kg Animal*$_i$*/day) x 365 (days/yr)*

N excreted as calculated above must then be summed across animal types. The total N excretion by livestock should then be multiplied by 20 percent, the fraction of total manure N that volatilizes, as shown in the following equation (IPCC/UNEP/OECD/IEA 1997).

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[13] States interested in directly measured wet and dry atmospheric deposition data can access the National Atmospheric Deposition Program (NADP) on the Internet at http://nadp.sws.uiuc.edu/ for wet N deposition data, and the U.S. EPA Clean Air Status and Trends Network (CASTNet) Internet site at http://www.epa.gov/castnet/data.html for dry N deposition data. These resources report data collected at various monitoring stations across the United States. In addition, the USGS National Water Quality Assessment Program's report on *Nonpoint and Point Sources of Nitrogen in Major Watersheds of the United States* contains estimates of atmospheric deposition of N in regions of the United States, based on data collected at watersheds across the country.

[14] See Section 4.1.1, Step 2

[15] See Section 4.1.2, Step 2; this value should not include manure used as commercial fertilizer.

Total N Excretion by Livestock that Volatilizes (kg N/yr) = Total N Excretion by Livestock (kg N/yr) x 0.20

Step (4): Calculate Total Indirect Nitrous Oxide Emissions from Volatilization of NH_3 and NO_x

Using the totals calculated in Steps 2 and 3, calculate the indirect emissions from both sources of atmospheric deposition. Sum the amount of synthetic N applied to soil that volatilizes and the total N excretion by livestock that volatilizes, and multiply by 0.01 kg N_2O-N per kg NH_3-N and NO_x-N (where 0.01 is the emission factor for indirect emissions, from IPCC/UNEP/OECD/IEA 1997). This method accounts for the fraction of volatized N returned to the soils and then emitted as N_2O.

N_2O Emissions (kg N_2O-N/yr) = (Amount Volatilized N from Synthetic Fertilizer + Amount Volatilized N from Organic Fertilizer + Total N Excretion by Livestock that Volatilizes) (kg N/yr) x 0.01 kg N_2O-N/kg N

Step (5): Convert Emissions to Units of Nitrous Oxide

Convert from kg N_2O-N to kg N_2O by multiplying the amount of emissions from volatilization of NH_3 and NO_x by the molecular weight ratio of N_2O/N_2O-N. The ratio is 44/28.

Emissions from NH_3 and NO_x Volatilization (kg N_2O) = Emissions from NH_3 and NO_x Volatilization (kg N_2O-N) x 44/28

Example: To calculate indirect N_2O emissions from volatilization in New Jersey in 2000, perform the following calculations:

28,573,029 kg N (synthetic fertilizer) x 0.10 = 2,857,303 kg N

492,613 kg N (organic fertilizer – manure used as fertilizer) x 0.20 = 98,523 kg N

2,857,303 kg N + 98,523 kg N = 2,955,826 kg volatilized N from fertilizer

According to the State Inventory Tool total N excreted by livestock in New Jersey was 6,930,228 kg N in 2000.

6,930,228 kg N/yr x 0.20 = 1,386,046 kg volatilized N from livestock excretion

Total indirect N_2O emissions from volatilization are the sum of the volatilized N from fertilizer and animal excretion multiplied by 0.01, the emission factor for indirect emissions.

(2,955,826 kg N/yr + 1,386,046 kg N/yr) x 0.01 kg N_2O-N = 43,419 kg N_2O-N

Convert to units of N_2O:

43,419 kg N_2O-N x 44/28 = **68,230 kg N_2O** from volatilization

4.3.2 Leaching and Runoff of Nitrogen from Agricultural Fields

Estimates of N_2O emissions from agricultural leaching and runoff account for applied N that migrates into groundwater, rivers, and estuaries. Emissions of N_2O from leaching and runoff can be calculated using the following five steps: (1) obtain data on unvolatilized synthetic and organic N applications; (2) estimate leaching and runoff from fertilizer application; (3) estimate leaching and runoff from animal waste; (4) calculate indirect emissions from leaching and runoff in N_2O-N/yr; and (5) convert the emissions to units of N_2O

Step (1): Obtain Required Data

- *Required Data*. Estimates of N_2O emissions from leaching and runoff are based on the amount of N in synthetic and organic fertilizer and total animal waste that is applied or deposited on the soil. The amount of unvolatilized N from commercial synthetic and organic fertilizers calculated in Section 4.1.1, Step 2, and Section 4.1.2, Step 2 can be used here. The calculations in Sections 4.1.3 and 4.2 provide the animal waste values used in Step 3 of this section.

- *Data Sources*. Use activity data and results presented in Sections 4.1.1, 4.1.2, 4.1.3, and 4.2.[16]

Step (2): Estimate Leaching and Runoff from Fertilizer Application

Indirect N_2O emissions from leaching and runoff can be calculated by using the default ratio provided below.

- Percent of N that leaches or runs off = 30 percent of fertilizer or manure (IPCC/UNEP/OECD/IEA 1997).

The methodology for estimating leaching and runoff (L&R) from non-manure fertilizer application is shown in the equations below.

Synthetic Fertilizer L&R (kg N/yr) = Unvolatilized N from Synthetic Fertilizer (kg N/yr) x 0.30

Organic Fertilizer L&R (kg N/yr) = Unvolatilized N from Organic Fertilizer (kg N/yr) x 0.30

Total N from Fertilizer L&R (kg N/yr) = Synthetic Fertilizer L&R (kg N/yr) + Organic Fertilizer L&R (kg N/yr)

Step (3): Estimate Leaching and Runoff from Animal Waste

Animal waste also contributes to N_2O emissions from leaching and runoff. Use the following emission factor and the equation below to estimate N leaching from animal waste. Note that the input to this equation, “Total N Excretion by Livestock,” can be found in the equation under Step 3 of Section 4.3.1.

- Percent of N that leaches or runs off = 30 percent of fertilizer or manure (IPCC/UNEP/OECD/IEA 1997); and

[16] States interested in obtaining directly measured data on N in specific watersheds should refer to the USGS National Water Quality Assessment Program’s report on *Nonpoint and Point Sources of Nitrogen in Major Watersheds of the United States*.

- Percent of total manure N excreted that volatilizes = 20 percent (IPCC/UNEP/OECD/IEA 1997); therefore, 80 percent of manure N does not volatilize.

Livestock Excretion L&R (kg N/yr) = Livestock Excretion (kg N/yr) x 0.80 x 0.30

Step (4): Estimate Total Indirect Emissions from Leaching and Runoff

Emissions from leaching and runoff are comprised of leached N from fertilizers (synthetic and organic) and animal waste. The results of Steps 2 and 3 above must be multiplied by the emissions factor for indirect N_2O emissions, to yield total indirect N_2O emissions from leaching. These equations are diagramed below.

- Emission factor for emissions of N_2O through leaching/runoff = 0.025 kg N_2O-N/kg N leaching/runoff (IPCC/UNEP/OECD/IEA 1997).

Total N L&R (kg N/yr) = Fertilizer L&R (kg N/yr) + Livestock Excretion L&R (kg N/yr)

N_2O Emissions from L&R (kg N_2O-N/yr) = Total N L&R (kg N/yr) x 0.025 (kg N_2O-N/kg N)

Step (5): Convert Emissions Units to Nitrous Oxide

Convert from kg N_2O-N to kg N_2O by multiplying the amount of emissions from leaching and runoff by the molecular weight ratio of N_2O/N_2O-N. The ratio is 44/28.

Indirect N_2O Emissions from L&R (kg N_2O) = Indirect N_2O Emissions from L&R (kg N_2O-N) x 44/28

To calculate total N_2O emissions from agricultural soils in kg N_2O, simply add the N_2O emissions calculated in Sections 4.1 through 4.3. Table 10.4-3 presents a worksheet to aid in this calculation.

Example:	To estimate indirect N_2O emissions from leaching and runoff in New Jersey in 2000, perform the following calculations:
	25,715,726 kg N (unvolatilized, synthetic fertilizer) x 0.30 = 7,714,718 kg N L&R
	492,613 kg N (unvolatilized, organic fertilizer) x 0.30 = 147,784 kg N L&R
	(7,714,718 kg N + 147,784 kg N) = 7,862,502 kg N from fertilizer L&R
	As noted in 4.3.1, total N excretion by livestock in New Jersey in 2000 was 6,930,228 kg N. 0.80 of manure N does not volatilize; 0.30 leaches or runs off.
	6,930,228 kg N x 0.80 x 0.30 = 1,663,255 kg N from manure L&R
	The L&R emission factor is 0.025 kg N_2O-N/kg N; the molecular weight ratio of N_2O/N_2O-N is 44/28.
	(7,862,502 kg N + 1,663,255 kg N) x 0.025 kg N_2O-N/kg N = 238,144 kg N_2O-N
	238,144 kg N_2O-N x 44/28 = **374,226 kg N_2O** from L&R

4.4 CALCULATE TOTAL NITROUS OXIDE EMISSIONS FROM AGRICULTURAL SOIL MANAGEMENT

To calculate total N_2O emissions from agricultural soil management in kg N_2O, simply add the N_2O emissions calculated in Sections 4.1 through 4.3. Table 10.4-3 presents a worksheet to aid in this calculation.

Table 10.4-4: Worksheet to Calculate the Total Emissions of N_2O from Agricultural Soil Management

Emission Source	Emissions (N_2O)
Direct Emissions from Agricultural Cropping Practices	
Unvolatilized N from Synthetic Fertilizer	(see Section 4.1.1 Step 4)
Unvolatilized N from Commercial Organic Fertilizer	(see Section 4.1.2 Step 4)
Unvolatilized N from Commercial Animal Waste	(see Section 4.1.3 Step 6)
N in Crop Residues Returned to Soil	(see Section 4.1.4 Step 4)
N Fixation from N-Fixing Crops	(see Section 4.1.5 Step 4)
N from Histosol Cultivation	(see Section 4.1.6 Step 3)
N from Sewage Sludge Land Application	(see Section 4.1.7)
Direct Emissions from Animal Production	(see Section 4.2 Step 4)
Indirect Emissions from N Applied to Soils	
NO_x and NH_3 Volatilization	(see Section 4.3.1 Step 5)
Leaching and Runoff of N	(see Section 4.3.2 Step 5)
TOTAL	

To convert the estimate of total N_2O emissions in units of kg (as calculated in Table 10.4-3) to units of metric tons of carbon equivalent (MTCE), first convert kg to metric tons by multiplying the number of kg by 0.001. Then multiply the number of metric tons of N_2O times (1) the Global Warming Potential (GWP) for N_2O (310), and (2) the ratio of the atomic weight of carbon to the molecular weight of CO_2 (12/44). The resulting value represents N_2O emissions in MTCE.

Total Emissions N_2O (MTCE) = Total Emissions N_2O (kg N_2O) x 0.001 (metric tons/kg) x 310 x 12/44

Example: To calculate total N_2O emissions from agricultural soil management in New Jersey in 2000, sum up the emissions calculated in Sections 4.1–4.3. (Note that this example does not include emissions from cultivation of histosols or sewage sludge and that state totals not calculated earlier in this section were taken from the State Inventory Tool.)

505,130 kg N_2O (synthetic fertilizer) + 7,741 kg N_2O (organic fertilizer) + 29,812 kg N_2O (manure) + 111,673 kg N_2O (crop residues) + 210,453 kg N_2O (N-fixing crops) + 123,000 kg N_2O (animal production) + 68,230 kg N_2O (volatilization) + 374,226 kg N_2O (leaching/runoff) = 1,430,265 kg N_2O

Convert emissions to units of MTCE:

1,430,265 kg N_2O x 0.001 metric tons/kg x 310 x 12/44 = **120,922 MTCE**

5

ALTERNATIVE METHODS FOR ESTIMATING EMISSIONS

There are currently no alternative methods for estimating state-level emissions from agricultural soil management.

6

UNCERTAINTY SUMMARY

The amount of nitrous oxide (N_2O) emissions from managed soils is dependent on a large number of variables besides nitrogen (N) inputs, including soil moisture content, pH, soil temperature, organic carbon availability, oxygen (O_2) partial pressure, and soil amendment management practices. However, the effect of the combined interaction of these variables on N_2O flux is complex and highly uncertain. The IPCC default methodology that is followed here is based only on N inputs and does not incorporate other variables. As noted in the *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997), this is a generalized approach that treats all soils equally, with the exception of cultivated histosols" (U.S. EPA 2004). This methodology covers the following three sub-categories: direct emissions due to cropping practices, direct emissions due to animal production, and indirect emissions from agricultural applications of N. Uncertainties exist in both the emission factors and activity data used to derive emission estimates in each sub-category.

As noted in Section 2.2, scientific knowledge is limited regarding N_2O production and emissions from soils to which nitrogen is added. Thus it is not currently possible to develop statistically valid estimates of emission factors for all possible combinations of soil, climate, and management conditions. The emission factors presented throughout this chapter are midpoint estimates based on measurements described in the scientific literature. They are representative of current scientific understanding, but also possess a significant level of uncertainty.

Uncertainties also exist in the default activity data used to derive emission estimates in each sub-category. In particular, the fertilizer statistics do not include non-commercial fertilizers (except estimated manure and crop residues). Site-specific conditions are not taken into consideration when determining the amount of nitrogen excreted from animals. Limited research on nitrogen-fixing crops has resulted in the use of conversion factors that may not account for the variety of conditions in all states. Expert judgment, with its inherent uncertainty, was used to estimate the amount of crop residues left on soils as no data were available.

Additional uncertainty surrounds the emission sub-categories for which state-level data may not be available, i.e., land application of sewage sludge and cultivation of histosols. Emissions of N_2O due to leaching and runoff are also relatively uncertain at this time, due to the uncertainty of the volatilization rates and proportion of leached nitrogen.

7

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