14.1 Emissions From Soils—Greenhouse Gases

14.1.1 General

A good deal of research has been done to estimate emissions of nitrogen oxides (NO_x) from soils. Although numerous measurements have been made, emissions from soils show variability based on a number of factors. Differences in soil type, moisture, temperature, season, crop type, fertilization, and other agricultural practices apparently all play a part in emissions from soils.

Soils emit NO_x through biological and abiological pathways, and emission rates can be categorized either by fertilizer application or land use. Agricultural lands and grasslands are the most significant emission sources within this category. The quantity of NO_x emitted from agricultural land is dependant on fertilizer application and the subsequent microbial denitrification of the soil. Microbial denitrification is a natural process in soil, but denitrification is higher when soil has been fertilized with chemical fertilizers. Both nitrous oxide (N_2O) and nitric oxide (NO) are emitted from this source. Emissions of NO_x from soils are estimated to be as much as 16 percent of the global budget of NO_x in the troposphere, and as much as 8 percent of the NO_x in North America.[1] This section discusses only emissions of N_2O from soils. Refer to reference 2 for information on estimating total NO_x from soils using the EPA's Biogenic Emissions Inventory System (BEIS).

14.1.2 Agricultural Soils

The description of the source and the methodology for estimating emissions and emission factors presented in this section are taken directly from the State Workbook: *Methodologies for Estimating Greenhouse Gas Emissions* and the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1994*, prepared by the U.S. Environmental Protection Agency's Office of Policy, Planning and Evaluation (OPPE). A more detailed discussion of the processes and variables affecting N_2O generation from this source can be found in those volumes.[3,4]

Various agricultural soil management practices contribute to greenhouse gas emissions. The use of synthetic and organic fertilizers adds nitrogen to soils, thereby increasing natural emissions of N_2O. Other agricultural soil management practices such as irrigation, tillage, or the fallowing of land can also affect trace gas fluxes to and from the soil since soils are both a source and a sink for carbon dioxide (CO_2) and carbon monoxide (CO), a sink for methane (CH_4), and a source of N_2O. However, there is much uncertainty about the direction and magnitude of the effects of these other practices, so only the emissions from fertilizer use are included in the method presented here.

Nitrous oxide emissions from commercial fertilizer use can be estimated using the following equation:

$$N_2O \text{ Emissions} = (FC * EC * 44/28)^a$$

[a] EMISSION FACTOR RATING: D.

where:

FC = Fertilizer Consumption (tons N-applied);[b]
EC = Emission Coefficient = 0.0117 tons N_2O-N/ton N applied; and
44/28 = The molecular weight ratio of N_2O to N_2O as N (N_2O/N_2O-N).

The emission coefficient of 0.0117 tons N/ton N-applied represents the percent of nitrogen applied as fertilizer that is released into the atmosphere as nitrous oxide. This emission coefficient was obtained from the Agricultural Research Service of the U.S. Department of Agriculture (USDA), which estimated that 1.84 kg N_2O was emitted per 100 kg of nitrogen applied as fertilizer. After applying the appropriate conversion, this is equivalent to 0.0117 tons N_2O-N/ton N-applied.

The total amount of commercial fertilizer consumed in a given state or region is the sum of all synthetic nitrogen, multiple-nutrient, and organic fertilizer applied (measured in mass units of nitrogen). Fertilizer data by type and state can be obtained from the Tennessee Valley Authority's National Fertilizer and Environmental Research Center. In the case of organic fertilizers, such as manure from livestock operations, data may be available from state or local Agricultural Extension offices. There may be instances in which fertilizer consumption is given as the total mass of fertilizer consumed rather than as nitrogen content. In such cases, total mass by fertilizer type may be converted to nitrogen content using the percentages in Table 14.1-1.

Because agricultural activities fluctuate from year to year as a result of economic, climatic, and other variables, it is recommended that an average of 3 years of fertilizer consumption be used to account for extraordinary circumstances.

Example:

For County A, a 3-year average of 16 tons of monoammonium phosphate is applied. As shown in Table 14.1-1, monoammonium phosphate is 11 percent N.

$$\begin{aligned} FC &= 16 \text{ tons fertilizer} * 11\% \text{ N/ton fertilizer} \\ &= 1.76 \text{ tons N} \end{aligned}$$

where:

FC = Fertilizer consumption

Emissions are calculated by:

$$N_2O \text{ Emissions} = (1.76 \text{ tons N applied}) * (0.0117 \text{ tons } N_2O) * \frac{44}{28}$$

$$= 0.032 \text{ tons } N_2O$$

[b] In some instances, state fertilizer consumption data may only be provided by fertilizer type and not aggregated across all types by total N consumed. If this is the case, then analysts must first determine the amount of N consumed for each fertilizer type (using the percentages in Table 14.1-1) and then follow the method presented. To obtain total emissions by state, sum across all types.

Table 14.1-1. NITROGEN CONTENT OF PRINCIPAL FERTILIZER MATERIALS[a]

MATERIAL	% NITROGEN (by wt)
Nitrogen	
Ammonia, Anhydrous	82
Ammonia, Aqua	16-25
Ammonium nitrate	33.5
Ammonium nitrate-limestone mixtures	20.5
Ammonium sulfate	21
Ammonium sulfate-nitrate	26
Calcium cyanamide	21
Calcium nitrate	15
Nitrogen solutions	21-49
Sodium nitrate	16
Urea	46
Urea-form	38
Phosphate	
Basic slag, Open hearth	—[b]
Bone meal	2-4.5
Phosphoric acid	—[b]
Rock phosphate	—[b]
Superphosphate, Normal	—[b]
Superphosphate, Concentrated	—[b]
Superphosphoric acid	—[b]
Potash	—[b]
Potassium chloride (muriate)	—[b]
Potassium magnesium sulfate	—[b]
Potassium sulfate	—[b]
Multiple Nutrient	
Ammoniated superphosphate	3-6
Ammonium phosphate-nitrate	27
Ammonium phosphate-sulfate	13-16
Diammonium phosphate	16-21
Monoammonium phosphate	11
Nitric phosphates	14-22
Nitrate of soda-potash	15
Potassium nitrate	13
Wood ashes	—[b]
Blast furnace slag	—[b]
Dolomite	—[b]
Gypsum	—[b]
Kieserite (emjeo)	—[b]
Limestone	—[b]
Lime-sulfur solution	—[b]
Magnesium sulfate (Epsom salt)	—[b]
Sulfur	—[b]

[a] Reference 3.
[b] No, or a negligible amount of, nitrogen present.

14.1.3 Other Soils

The amount of N_2O emitted from non-agricultural soils is dependent on the soil's nutrient level and moisture content.[5] It is believed therefore that soils in tropical regions emit far more N_2O than soils in other terrestrial ecosystems.[5,6] Because of the variability of soil types and soil moisture levels, some tropical soils emit more N_2O than others.

Global soil N_2O flux measurements were compiled from various sources[5-8] and used to delineate soil N_2O emission factors.[9] Table 14.1-2 presents the mean emission factors developed for 6 ecological regions. These emission factors are based on test data from primarily undisturbed soils.[9]

14.1.4 Uncertainty[3]

Scientific knowledge regarding nitrous oxide production and emissions from fertilized soils is limited. Significant uncertainties exist regarding the agricultural practices, soil properties, climatic conditions, and biogenic processes that determine how much fertilizer nitrogen various crops absorb, how much remains in soils after fertilizer application, and in what ways the remaining nitrogen evolves into either nitrous oxide or gaseous nitrogen and other nitrogen compounds.

A major difficulty in estimating the magnitude of emissions from this source has been the relative lack of emissions measurement data across a suitably wide variety of controlled conditions, making it difficult to develop statistically valid estimates of emission factors. Previous attempts have been made to develop emission factors for different fertilizer and crop types for state and national emission inventories. However, the accuracy of these emission factors has been questioned. For example, while some studies indicate that N_2O emission rates are higher for ammonium-based fertilizers than for nitrate, other studies show no particular trend in N_2O emissions related to fertilizer types. Therefore, it is possible that fertilizer type is not the most important factor in determining emissions. One study suggests that N_2O emissions from the nitrification of fertilizers may be more closely related to soil properties than to the type of fertilizer applied.

There is consensus, however, as to the fact that numerous natural and management factors influence the biological processes of the soil microorganisms that determine N_2O emissions from nitrogen fertilizer use.

While it is relatively well known how the natural processes individually affect N_2O emissions, it is not well understood how the interaction of the processes affects N_2O emissions. Experiments have shown that in some cases increases in each of the following factors (individually) enhance N_2O emissions: pH, soil temperature, soil moisture, organic carbon content, and oxygen supply. However, the effects on N_2O emissions of soil moisture, organic carbon content, and microbial population together, for example, are not readily predictable.

Management practices may also affect N_2O emissions, although these relationships have not been well quantified. As mentioned, levels of N_2O emissions may be dependent on the type of fertilizer used, although the extent of the effect is not clear, as demonstrated by the wide range of emission coefficients for individual fertilizer types derived in experiments. Although high fertilizer application rates may cause higher N_2O emission rates, the relationship between fertilizer application rate and nitrous oxide emissions is not well understood. Deep placement of fertilizer as an application technique will result in lower N_2O emissions than broadcasting or hand placement. One study found that emissions from fertilizer applied in the fall were higher than emissions from the same fertilizer applied in the spring, indicating that the timing of fertilizer application can affect N_2O emissions. Tillage practices can also affect N_2O emissions. Tilling tends to decrease N_2O emissions; no-till and

Table 14.1-2. EMISSION FACTORS FOR N_2O FROM NON-AGRICULTURAL SOILS[a]

EMISSION FACTOR RATING: E

Ecosystem	Emission Factor (lbs N_2O/acre/yr)[b]
Tropical forest	3.692
Savanna	2.521
Temperate forest (coniferous)	1.404
Temperate forest (deciduous)	0.563
Grassland	1.503
Shrubs/Woodlands	2.456

[a] Reference 9.
[b] To convert lb N_2O/acre/yr to g N_2O/m^2/yr, multiply by 0.11208.

use of herbicides may increase N_2O emissions. However, limited research at unique sites under specific conditions has not been able to account for the complex interaction of the factors, making the effects of combinations of factors difficult to predict.

Emissions may also occur from the contamination of surface and ground water due to nutrient leaching and runoff from agricultural systems. However, methods to estimate emissions of N_2O from these sources are not included at this time due to a lack of data and emission coefficients for each contributing activity. Because of the potential relative importance of these N_2O emissions, they should be included in the future as data availability and scientific understanding permit.

References For Section 14.1

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