Agricultural N_2O Models and Estimates

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Background/Objectives

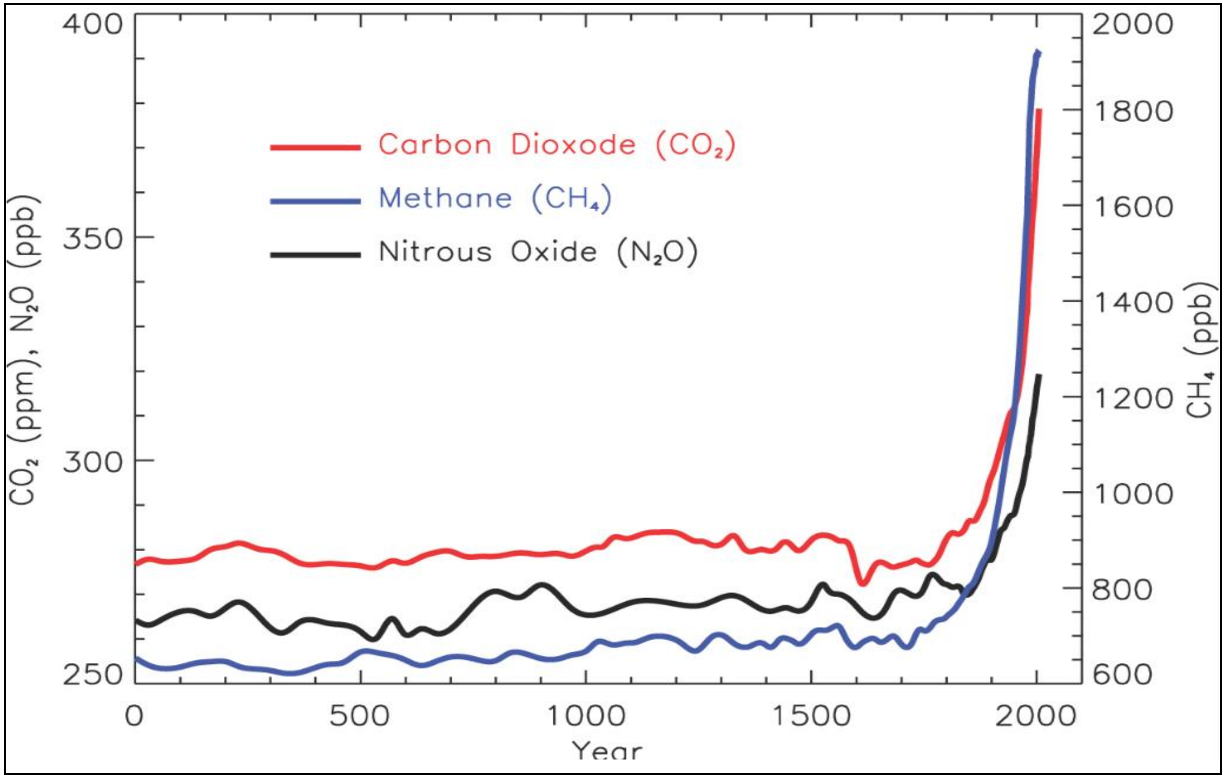
This assessment of agricultural N_2O is part of a broader CRC Project E-88-2: "Follow-on Study of Transportation Fuel LCA"

- Final report expected in 2-3 months
- Objectives of N_2O Component of Report:
  - Assess importance of agricultural, non-CO_2 GHG emissions in LCA of biofuels
  - Summarize N_2O inventories
  - Assess factors affecting N_2O formation and emissions
  - Summarize modeling methods to estimate N_2O emissions

N_2O Occurrence and Inventories

N_2O is a very potent GHG: ~ 300 times GWP of CO_2

Atmospheric N_2O levels are increasing rapidly

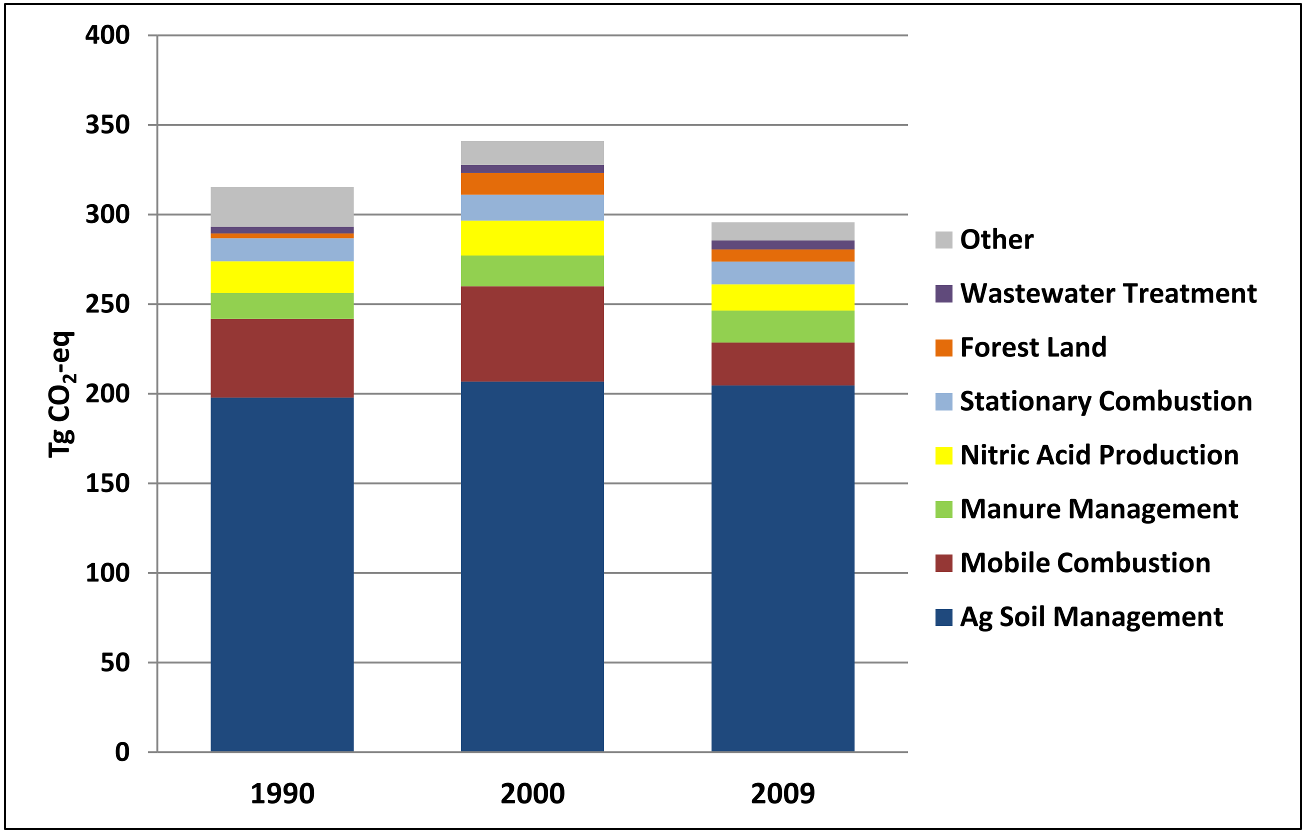


Concentrations of long-lived GHGs over the past 2000 years. (From IPCC-2007)

N_2O Occurrence and Inventories

Most N_2O originates from agricultural activities

N_2O constitutes 4-5% of total GHG inventory in the U.S.; 7-8% globally



U.S. Anthropogenic N_2O Inventory, Tg CO_2-eq (EPA, 2011)

N_2O Formation Mechanisms

- N_2O is formed by microbial processes involving nitrification and de-nitrification pathways:
  - Nitrification: $NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$
  - De-Nitrification: $NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$
- Direct N_2O: produced and emitted from soils
- Indirect N_2O: produced and emitted elsewhere:
  - Following deposition of volatilized nitrogenous species
  - Following runoff and leaching of nitrate
  - Deposition of animal wastes

Modeling Approaches to Estimate N_2O

IPCC-1997 Modeling Approach:

$$\text{Total Ag. } N_2O = N_2O_{Direct} + N_2O_{Animals} + N_2O_{Deposition} + N_2O_{Leach}$$

N_2O_{Direct} = (fertilizer-N + manure-N + fixed-N + crop residue-N) * $\mathbf{EF_1}$ + histosol area * $\mathbf{EF_2}$

$N_2O_{Animals} = \sum N_{T1} * \text{N-excretion}_{T1} * AWMS_{T1} * EF_{3\ AWMS}$

$N_2O_{Deposition}$ = (Fertilizer-N * 0.1 + Manure-N * 0.2) * $\mathbf{EF_4}$

N_2O_{Leach} = 0.3 * Applied Nitrogen * $\mathbf{EF_5}$

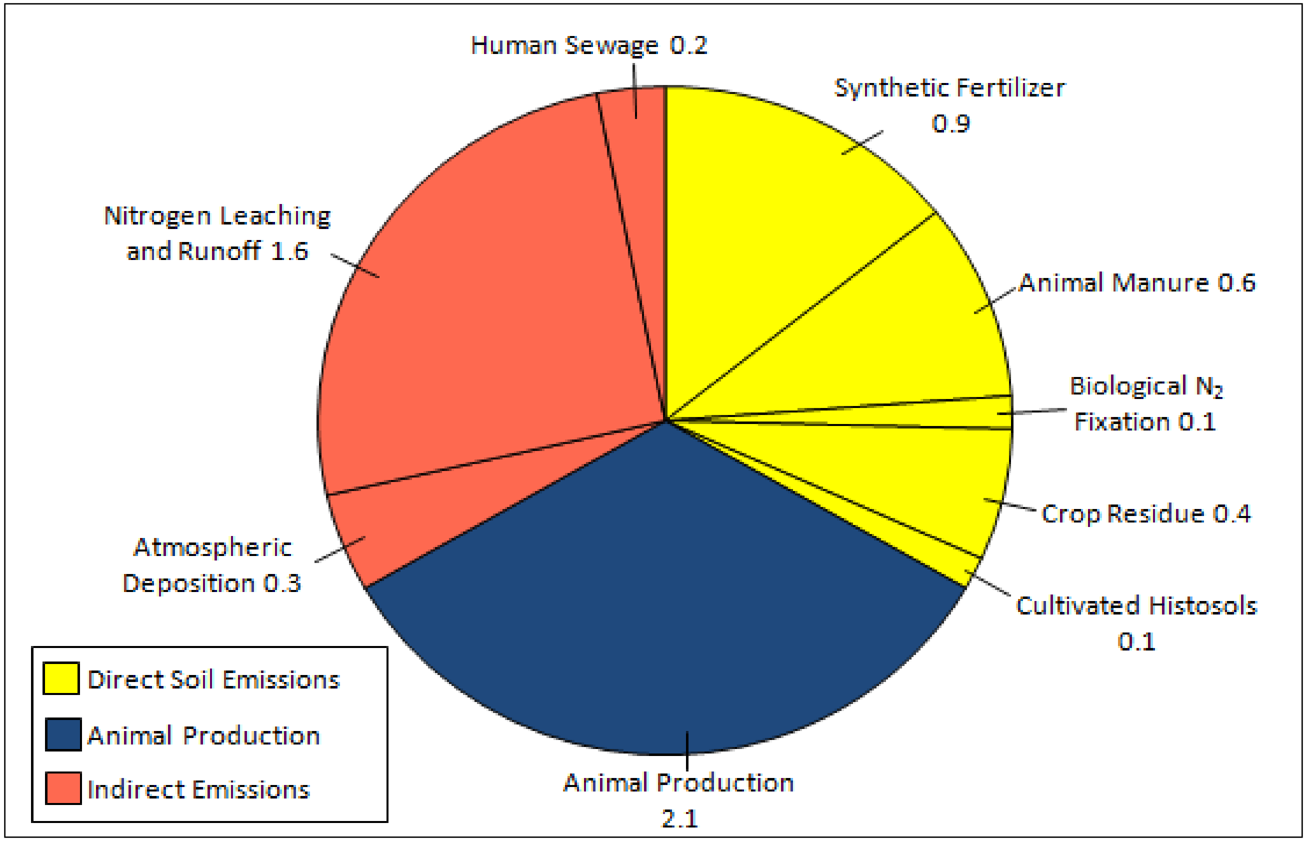
Default emission factors: (do not vary with crop, climate, soil, etc.)

- **EF1 = 0.0125 (± 0.01) kg N_2O-N/kg N input**
- **EF2 = 5-10 kg N_2O-N/ha-yr**
- EF3 varies with type of Animal Waste Management System
- **EF4 = 0.01 kg N_2O-N/kg N volatilized**
- **EF5 = 0.025 kg N_2O-N/kg N leached**

Modeling Approaches to Estimate N_2O

Global N_2O Inventory using IPCC-1997 Modeling Approach

(Modeled for 1989; Total of 6.3 Tg N_2O-N)



Data from Mosier et al., *Nutrient Cycling in Agroecosystems* **52**, 225-248 (1998)

Modeling Approaches to Estimate N_2O

IPCC-2006 Modeling Approach:

Introduced concept of hierarchical tiers of methods:

- Tier 1: Simplest approach
  - Uses standard equations and default emission factors (like IPCC-1997)
  - All model inputs readily available from existing data sources (like FAO)
- Tier 2: Intermediate approach
  - Same methodology as Tier 1, but with region-specific data for crops, livestock, emission factors, etc.
  - Higher temporal and spatial resolution than Tier 1
- Tier 3: Most complex approach
  - High degree of spatial and temporal resolution
  - Uses process-driven emissions model, such as DAYCENT

Modeling Approaches to Estimate N_2O

IPCC-2006 Modeling Approach:

$$\text{Total Ag. } N_2O = N_2O_{Direct} + N_2O_{Deposition} + N_2O_{Leach}$$

$$N_2O\text{-}N_{Direct} = N_2O\text{-}N_{N\text{-}inputs} + N_2O\text{-}N_{OS} + N_2O\text{-}N_{PRP}$$

$$N_2O_{ATD}\text{-}N = [(F_{SN} * Frac_{GASF}) + ((F_{ON} + F_{PRP}) * Frac_{GASM})] * EF_4$$

$$N_2O_L\text{-}N = (F_{SN} + F_{ON} + F_{PRP} + F_{CR} + F_{SOM}) * Frac_{LEACH\text{-}(H)} * EF_5$$

Where:

- Each of the above terms is computed from several other terms
- $N_2O_{Animals}$ is no longer a separate term; now included in N_2O_{Direct}
- EF1 is reduced from the IPCC-1997 value of 1.25% of applied nitrogen
- EF1 = 0.010 kg N_2O-N/kg N (uncertainty of 0.003 – 0.030)

Modeling Approaches to Estimate N_2O

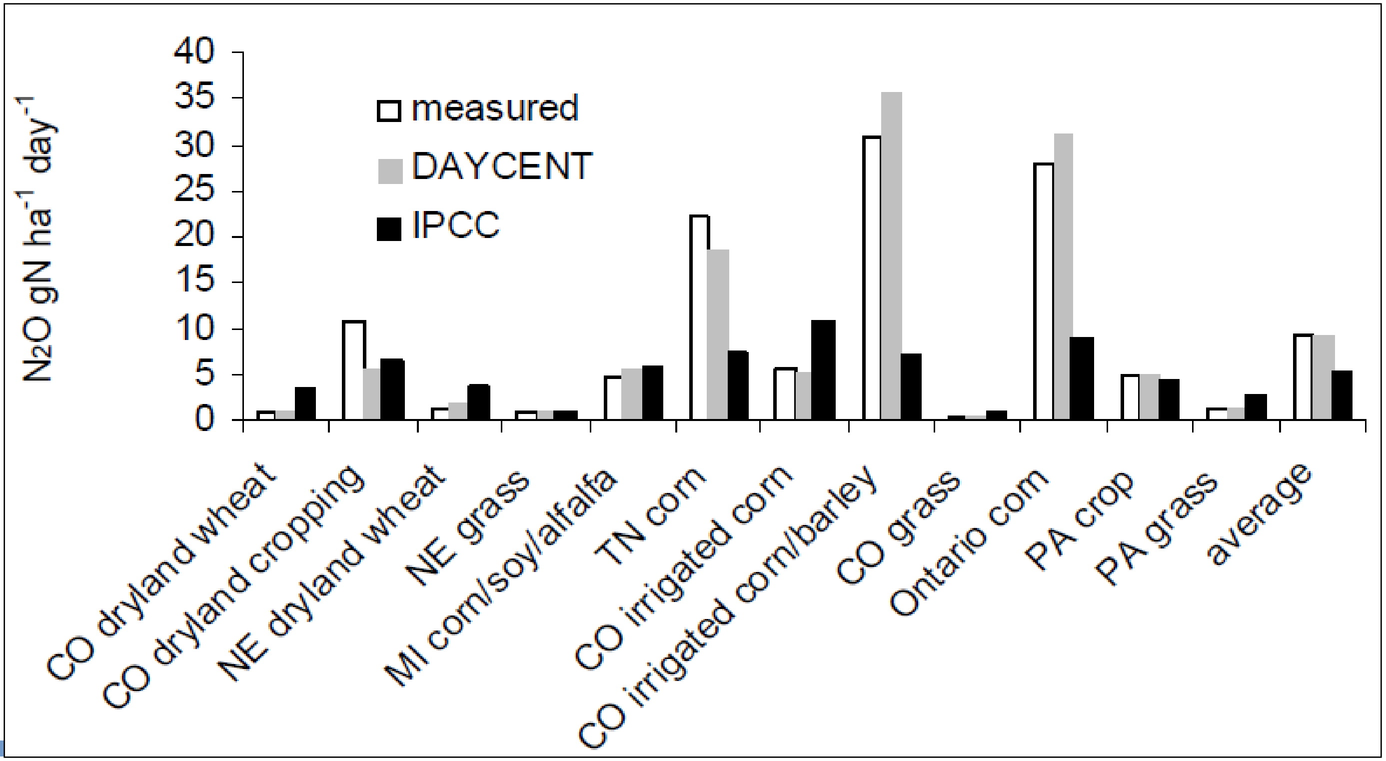
Process-Based Models:

- Process-based biogeochemical models simulate fluxes of N and C among atmosphere, vegetation, and soil
- N_2O emission estimates are based upon known physical/chemical processes of nitrification and de-nitrification
- Incorporate effects of temperature, pH, soil texture, soil moisture, crop type and cultivation practices
- Compared to simple emission factor approach (IPCC Tier 1), process-based models have much higher data input and computational requirements
- DAYCENT is one of the most widely used process-based models for N_2O estimates. DAYCENT is used by EPA in:
    1. Determination of U.S. GHG inventories
    2. Determination of biofuels' carbon intensities under RFS2 regulations

Modeling Approaches to Estimate N_2O

Comparison of IPCC (Tier 1) and DAYCENT Approaches:

- Difficult to compare because of different spatial and temporal scales
- U.S. EPA has compared measured and estimated N_2O results for 12 specific applications



Taken from EPA Inventory of U.S. GHG emissions and Sinks (2011)

Effects of N_2O on LCA of Biofuels

- GREET Model is used in many LCA studies
- GREET utilizes an IPCC Tier 1 approach for agricultural N_2O, with default values for:
  - Direct soil emissions: EF1 = 0.010
  - Volatilized/deposited: EF4 = 0.0010
  - Runoff/leached emissions: EF5 = 0.0023

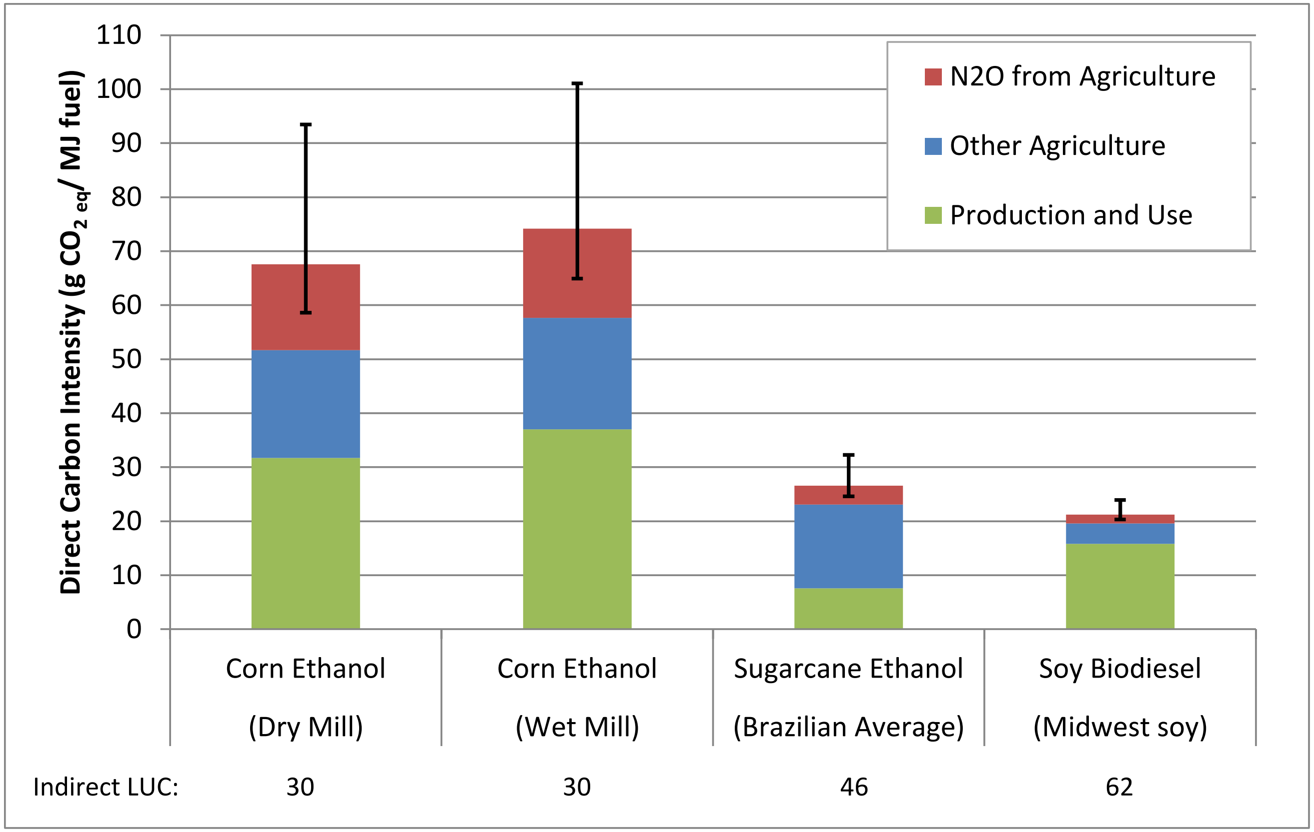
Total default value = 0.0133 kg N_2O-N/kg N inputs

uncertainty range of 0.0058 – 0.0348

Effects of N_2O on LCA of Biofuels

N_2O contributes a significant fraction to Total Direct Carbon Intensity for some Biofuels

Carbon Intensity from CARB Biofuel Pathways



Conclusions

- N_2O is an important GHG emission from agricultural activities. It has critical implications for total carbon intensity (CI) of some biofuels.
- N_2O emissions are influenced by numerous factors, many of which are ignored by application of IPCC Tier 1 methodology.
- Process-based biogeochemical models are the preferred means of estimating N_2O emissions – provided data inputs are available.
  - Limited comparative results suggest that process-based models give more accurate emissions estimates than a simple Tier 1 approach
  - A process-based model approach is necessary to evaluate the effects of crop type, soil type, climate, agricultural practices, etc. on CI
- When using a Tier 1 emission factor approach to estimate N_2O emissions, an uncertainty range of values should be evaluated.

Acknowledgements

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