Methods to Quantify N_2O Emissions in Agricultural Crop Production

National Emission Factors (Tier 1), Regional Emission Factors (Tier 2), and Process-Based Models (Tier 3)

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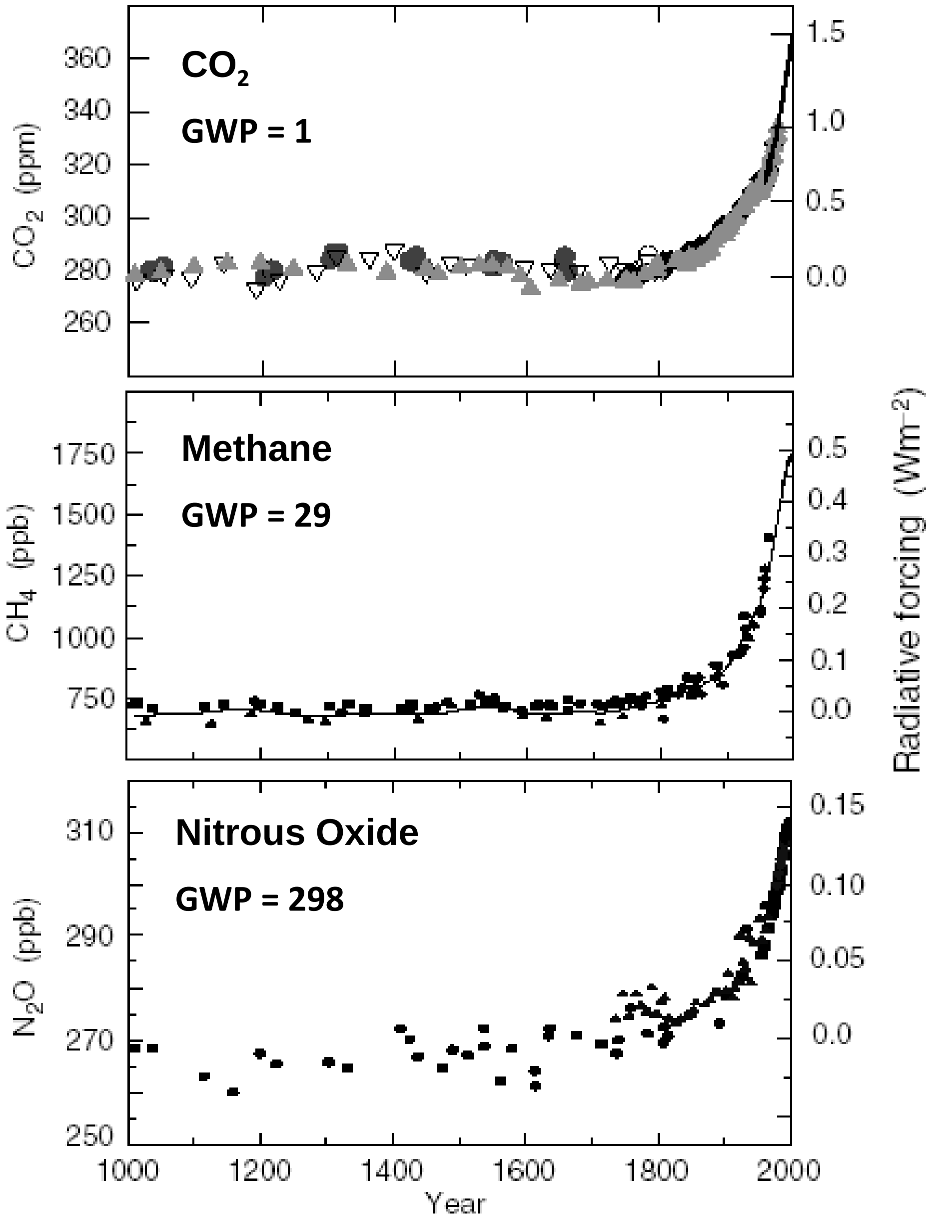
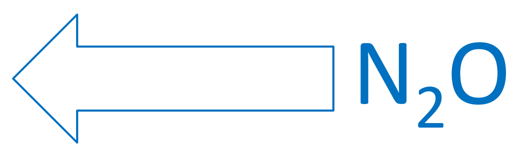
Atmospheric Concentrations from 1000 C.E.

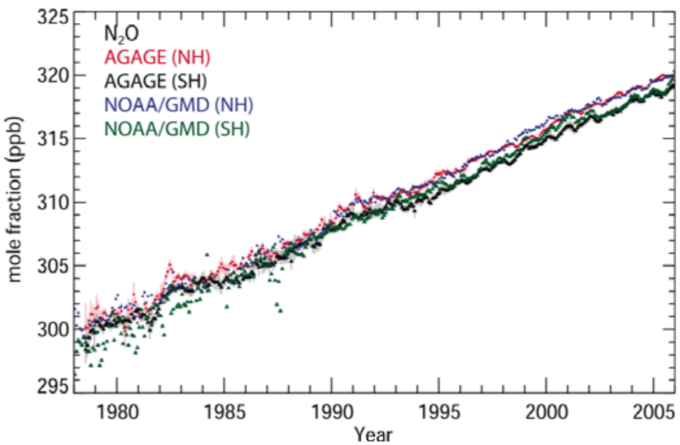


Atmospheric N_2O is Increasing at rates similar to the other 2 major biogenic gases



From IPCC (2001, 2007)

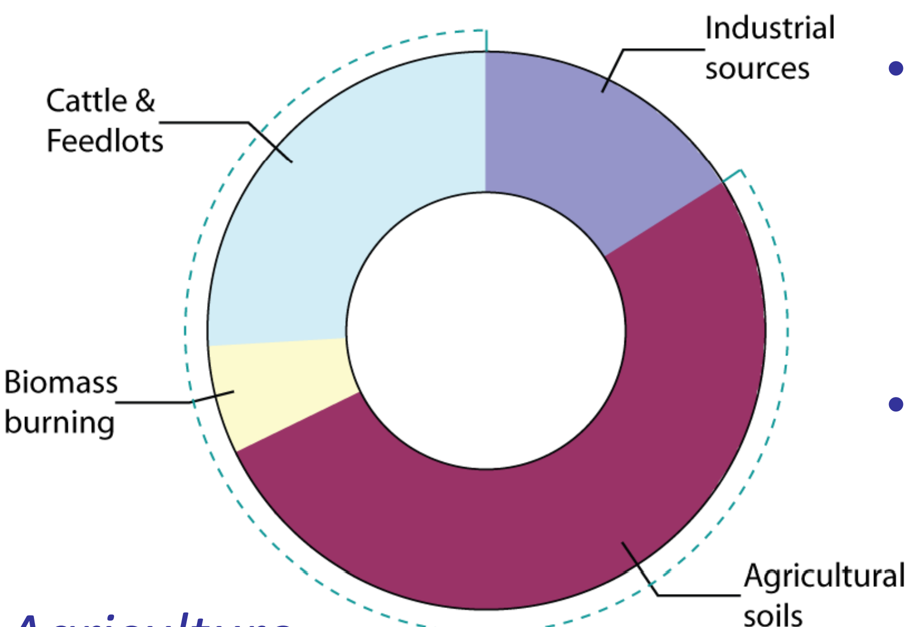
Atmospheric N_2O from 1976



The contemporary increase is largely due to agricultural intensification

- with a total annual impact ~ 1.2 Pg C_{equiv}

(compare to fossil fuel CO_2 loading = 4.1 PgC per year)



- Industry is responsible for ~16% of anthropogenic source
  - Agriculture for the remainder
- with most of the agricultural increase (~60%) from cropped soils

Agriculture

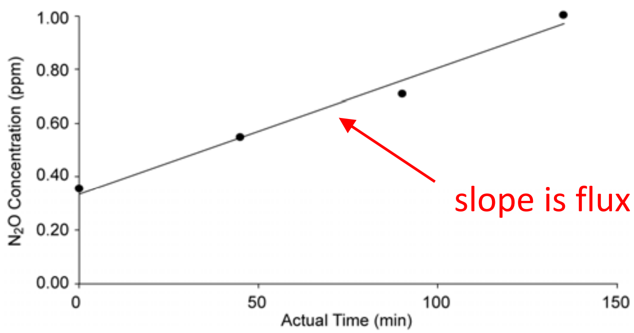
Source IPCC 2001, 2007; Prinn 2004; Robertson 2004

Measuring Nitrous Oxide Production in the Field

Static chamber method – simple but elegant

1. Chamber covers soil surface
2. Headspace samples removed over ~1 hour period
3. Vials removed to lab for gas (N_2O, CH_4, CO_2) analysis

4. N_2O flux = Rate of headspace N_2O accumulation

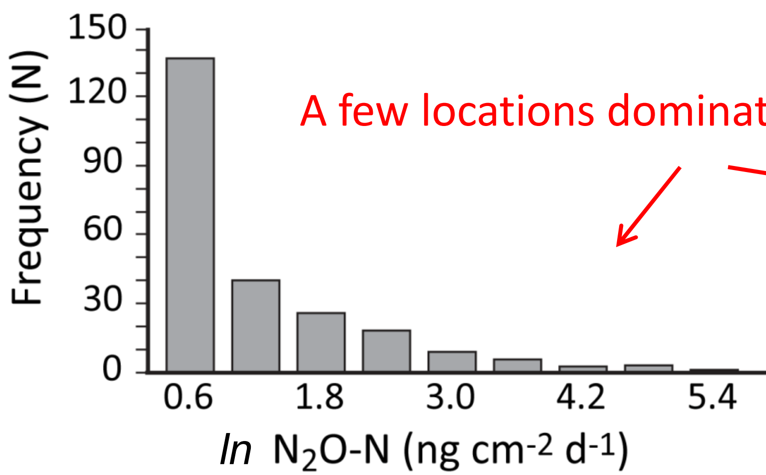


5. Eddy correlation not possible

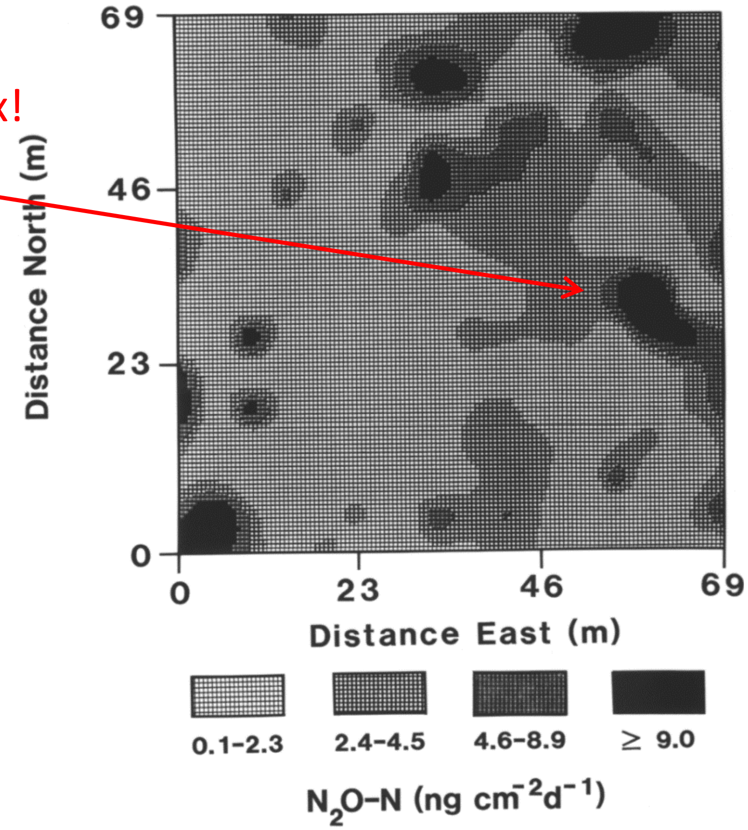
Challenges of chamber technique

1. Limited **spatial** coverage

We can deploy only a limited number of chambers to capture heterogeneous fluxes



A few locations dominate the flux!



Source: Robertson et al. 1988

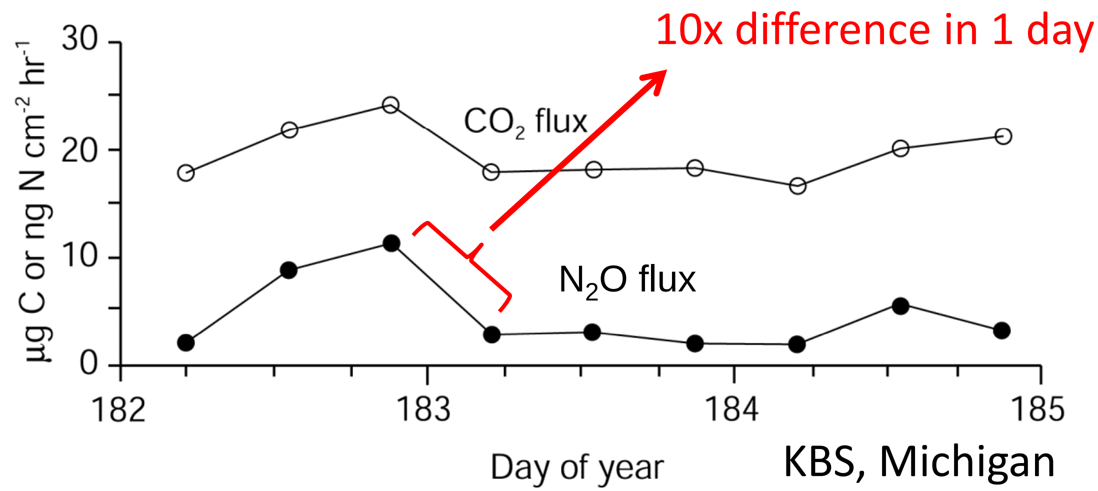
Source: P. Grace

Row – Interrow differences

Challenges of chamber technique

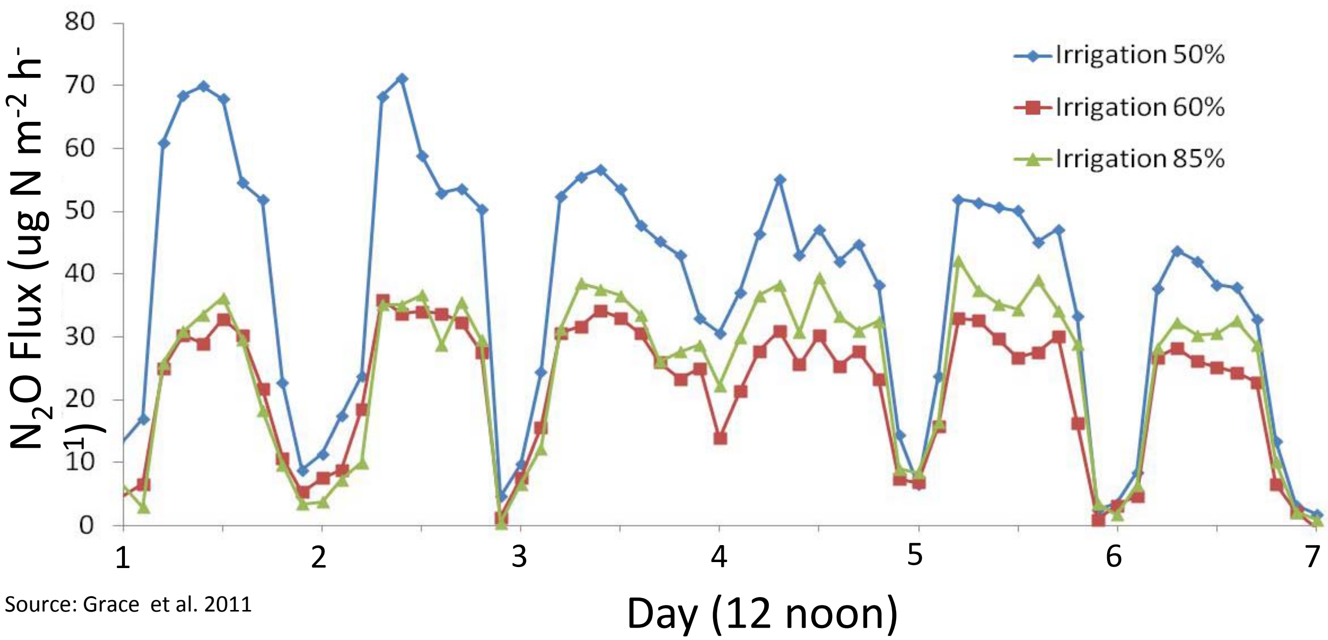
2. Limited **temporal** coverage

- Day-to-day fluxes can change rapidly



Source: Ambus & Robertson 1998

- Diurnal differences can sometimes be important



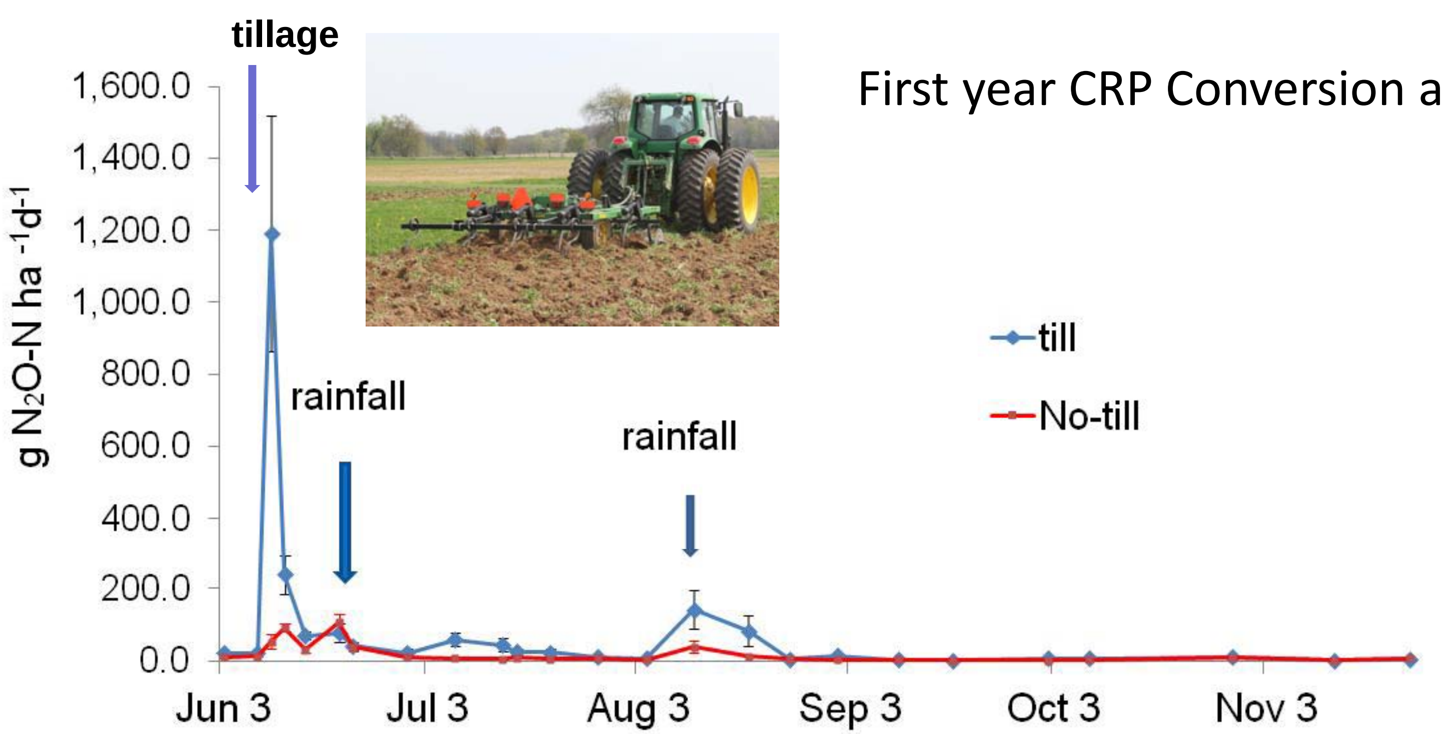
Kingsthorpe, Queensland

Source: Grace et al. 2011

Challenges of chamber technique, cont.

- Seasonality and environmental **events** are important

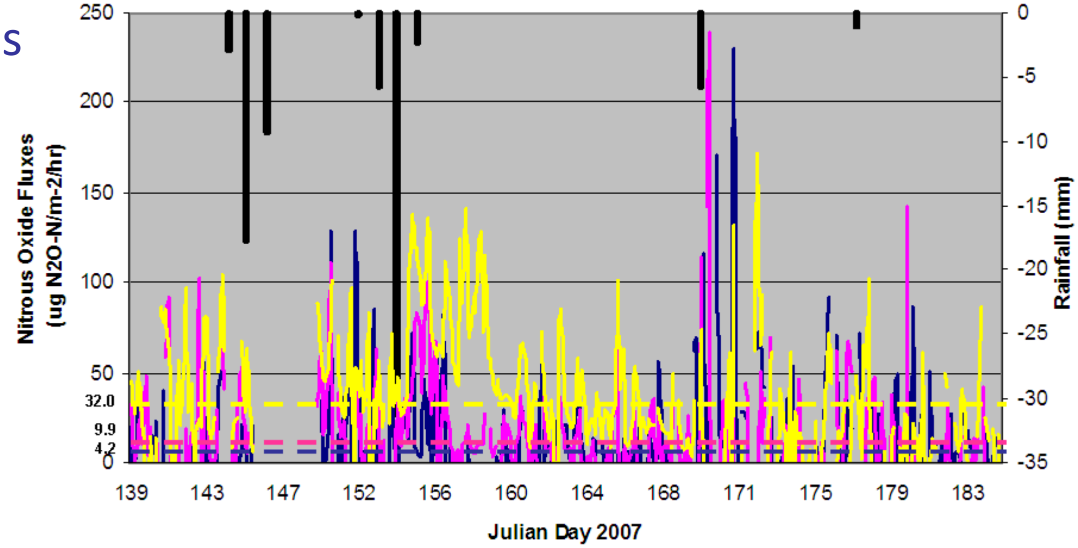
First year CRP Conversion at KBS, MI



Source: Ruan and Robertson 2011

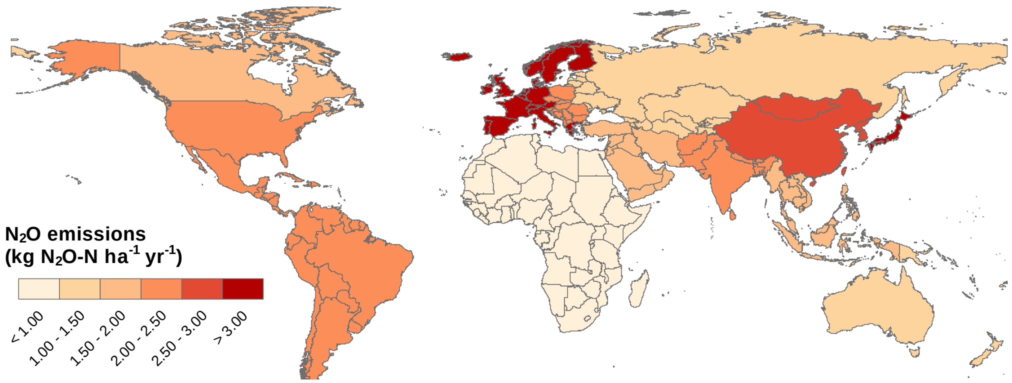
Challenges of chamber technique, cont.

- Event-based sampling and automated continuous chambers can solve many temporal issues



Challenges of chamber technique

Unique challenge for estimating global fluxes



Source: Birdanier & Conant 2011

- For any given local ecosystem, relatively low confidence in annual flux without a comprehensive sampling program

- Globally, constrained by known changes in atmospheric concentrations

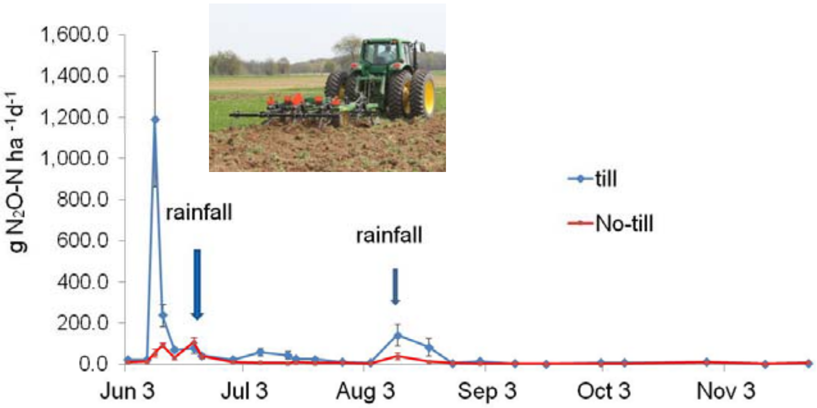
Global Source	Tg N_2O-N		
Industry		1.3	
Agriculture			
Soils	4.2		
Animal Waste	2.1		
Biomass burning	0.5		
Total Agriculture		6.8	
Total Anthropic			8.1
Total Non-Anthropic			9.6
Total Global Flux			17.7

Source: Robertson 2994, IPCC 2007

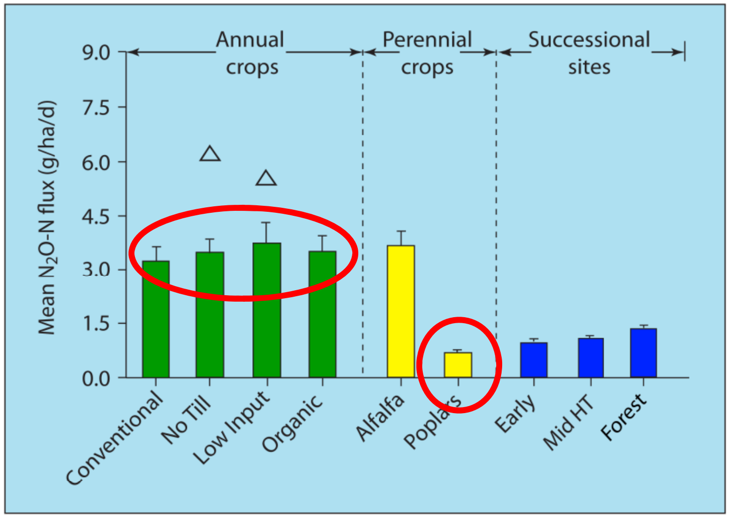
Challenges of chamber technique

BUT, importantly, this is not to say that we can't quantify the effects of land use change or cropping practices.....

- Well-designed sampling programs can capture major events



- And differentiate among different land use and cropping practices



- Basis for using IPCC methodologies to evaluate N_2O reduction strategies

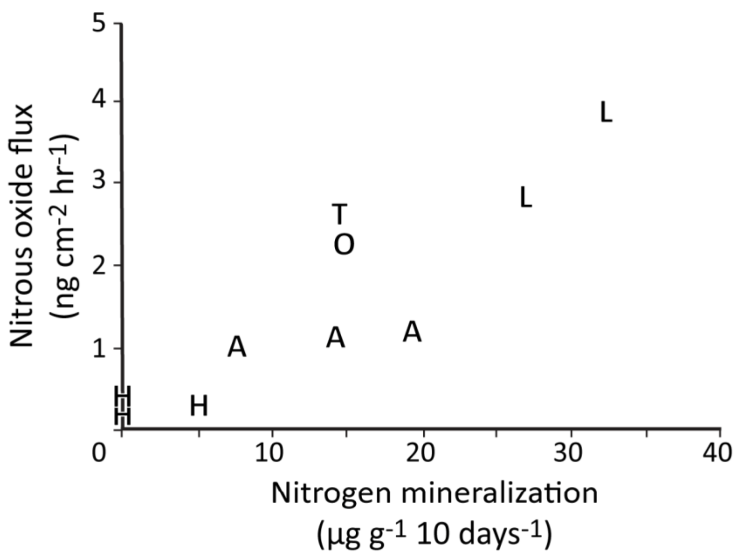
  ✓We can quantify differences among systems and practices with greater confidence than we can quantify annual fluxes

Source: Robertson et al. 2000

II. IPCC Methodologies – **Tier 1**

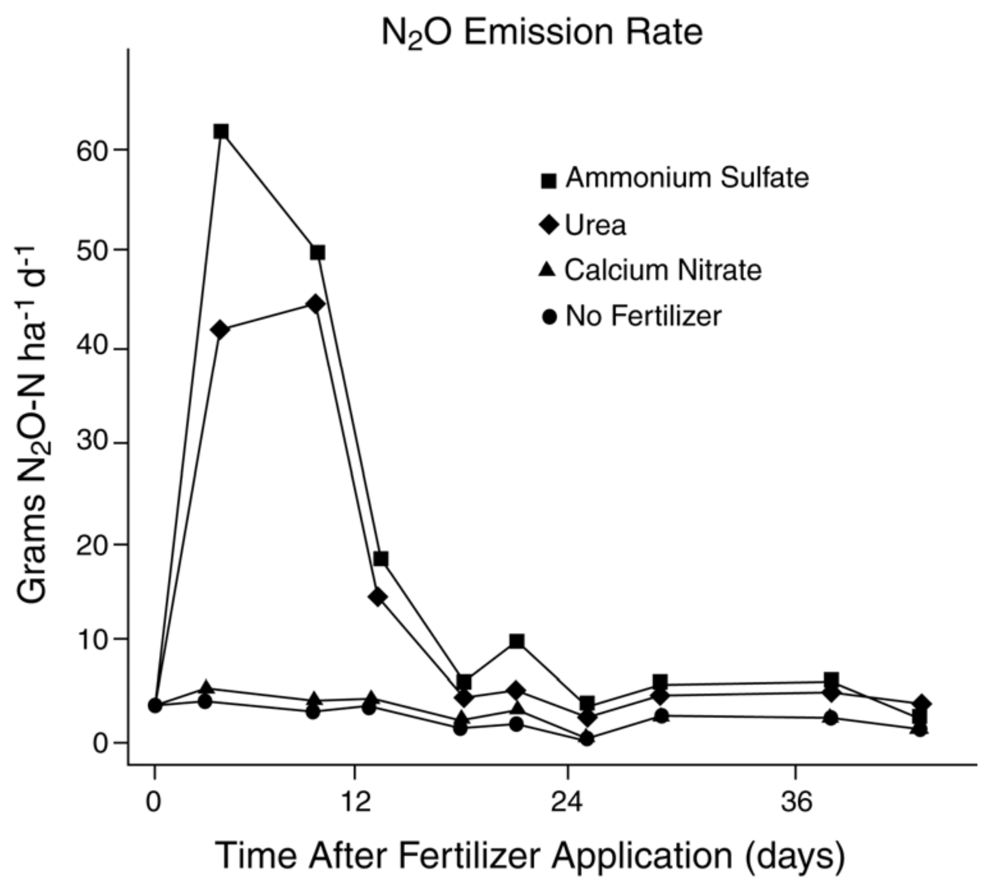
Based on recognition that soil nitrogen availability is best general predictor of N_2O flux

- Natural (unmanaged) ecosystems



Source: Matson & Vitousek 1987

- Fertilized crop ecosystems

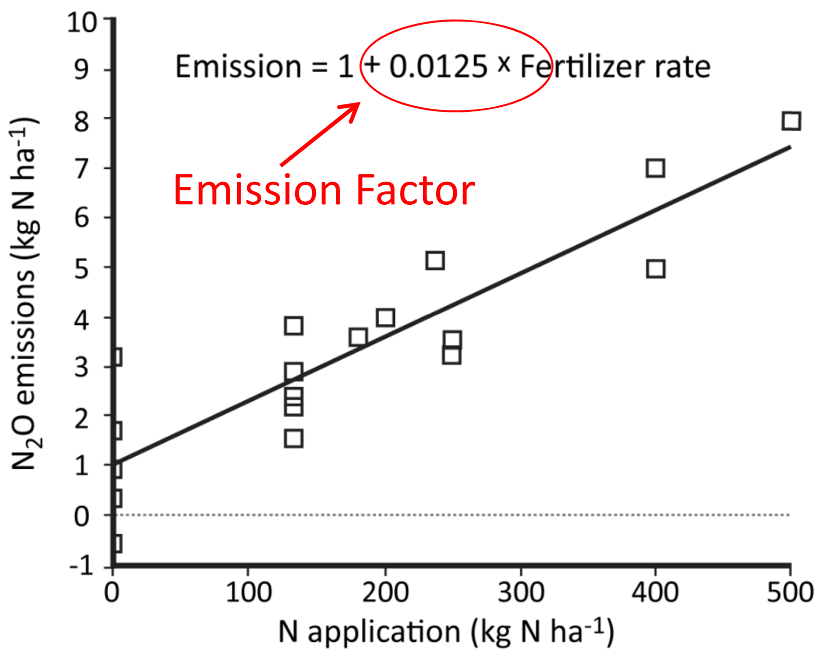


Source: Breitenbach et al. 1980

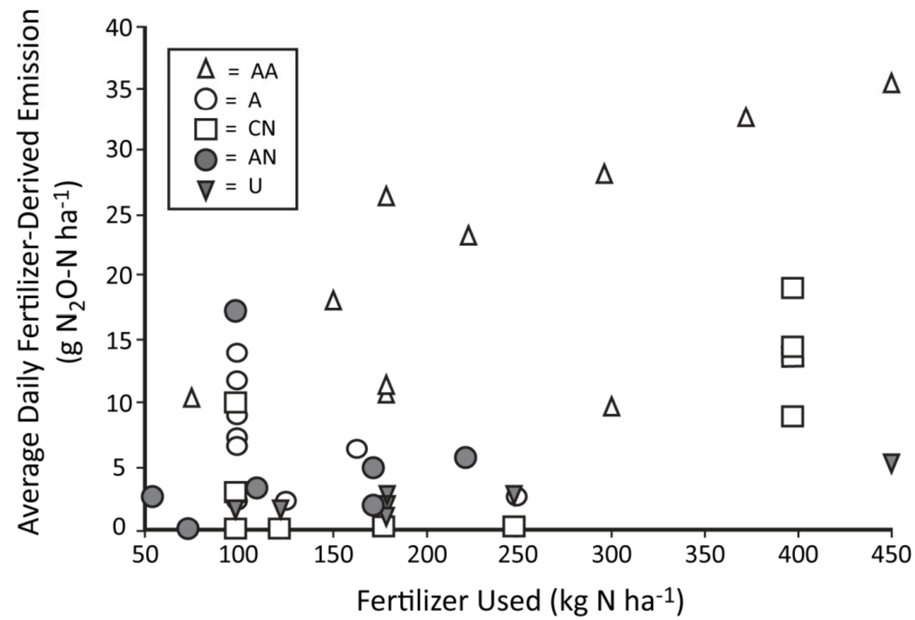
II. IPCC Methodologies – Tier 1, cont.

Early compilations

- Bouwman et al. 1996



- Eichner (1990)



- IPCC 2006

EF = 1.0% (0.25 – 2.25%)

II. IPCC Methodologies – Tier 1, cont.

Total Direct Soil N_2O Emissions

$$N_2O_{Direct} = (N_2O_{INPUTS} + N_2O_{ORGANIC} + N_2O_{PRP}) \times N_2O_{MW} \times N_2O_{GWP}$$

Where:

N_2O_{INPUTS} = Direct soil N_2O emission from N inputs

$N_2O_{ORGANIC}$ = Direct soil N_2O emission from the cultivation of organic soils (Histosols)

N_2O_{PRP} = Direct soil N_2O emission from urine and dung deposited on soil by grazing animals

N_2O_{MW} = Ratio of molecular weights of N_2O to N_2O-N (44/28)

N_2O_{GWP} = Global warming potential for N_2O (298)

II. IPCC Methodologies Tier 1, cont.

Direct Soil N_2O Emissions from N Inputs

$$N_2O_{INPUTS} = (F_{SN} + F_{ON} + F_{CR} + F_{SOM}) \times EF_{input}$$

Where:

N_2O_{INPUTS} = Direct soil N_2O emission from N inputs

F_{SN} = Nitrogen fertilizer – synthetic

F_{ON} = Nitrogen fertilizer – organic (e.g. manure, compost)

F_{CR} = Nitrogen in crop and cover crop residues (above and belowground)

F_{SOM} = Additional nitrogen mineralized from soil organic matter due to change in land use or tillage management

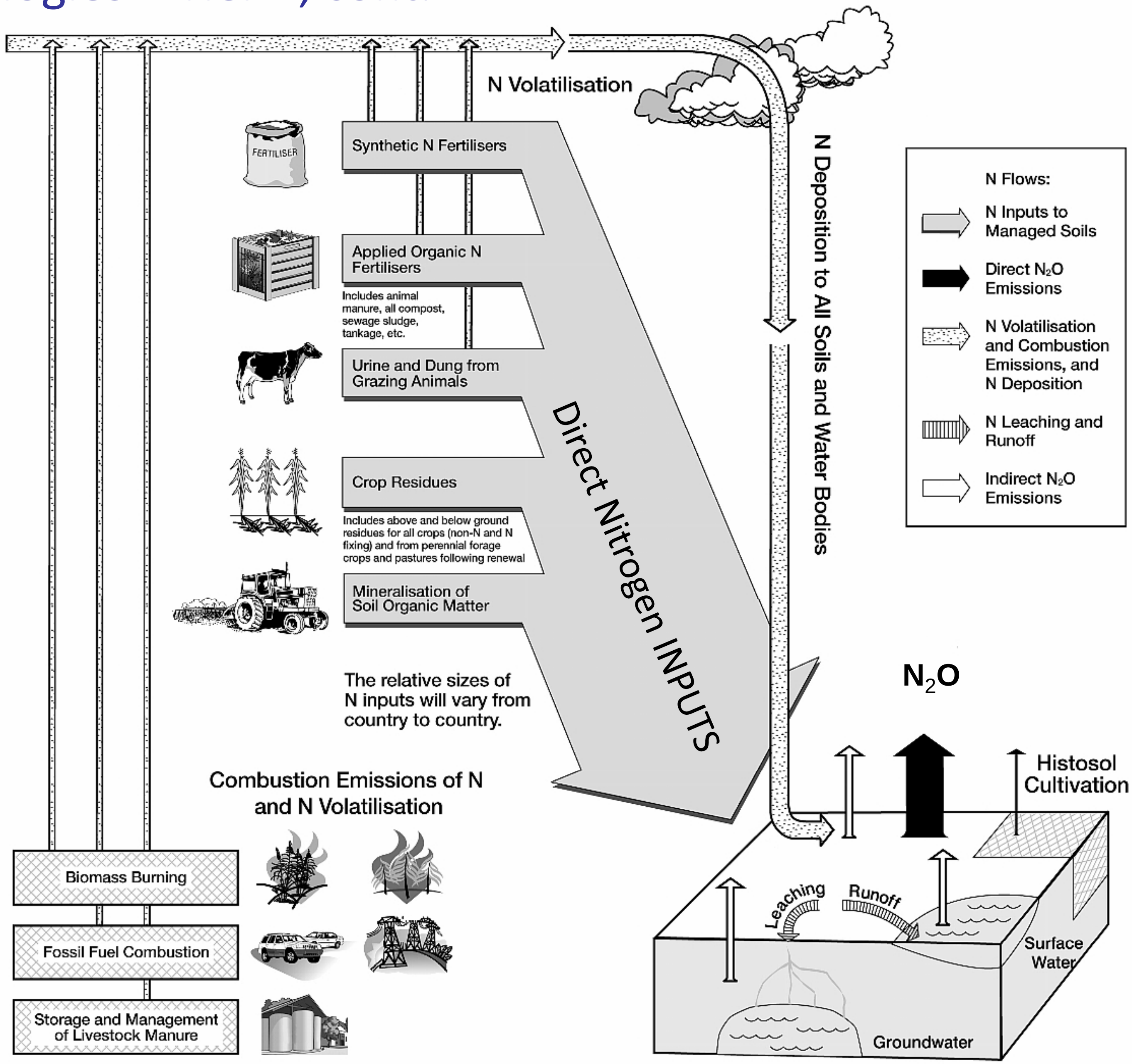
EF_{input} = Emission factor or proportion of applied N fertilizer transformed to N_2O;

IPCC Tier 1 EF_{input} = 0.01 (1%)

IPCC Tier 2 EF_{input} is dependent on specific practice and regional conditions.

II. IPCC Methodologies – Tier 1, cont.

Indirect N_2O



IPCC 2006

II. IPCC Methodologies – Tier 1, cont.

$$\mathbf{N_2O_{Agricultural\ Soils} = N_2O_{Direct} + N_2O_{Indirect}}$$

Total Indirect Soil N2O Emissions

$$N_2O_{Indirect} = (N_2O_{Vol} + N_2O_{Leach}) \times N_2O_{MW} \times N_2O_{GWP}$$

Where:

N_2O_{Vol} = N_2O emitted by ecosystem receiving volatilized N:

$$N_2O_{Vol} = [(F_{SN} \times FR_{SN}) + (F_{ON} \times FR_{ON})] \times EF_{VOL}$$

where F_{SN} = synthetic N; $FR_{SN} = 0.1$; F_{ON} = organic N, $FR_{ON} = 0.20$,

$EF_{VOL} = 0.01$

N_2O_{Leach} = N_2O emitted by ecosystem receiving leached and runoff N, when present:

$$N_2O_{Leach} = (F_{INPUT} \times FR_{LEACH}) \times EF_{LEACH}$$

where $FR_{LEACH} = 0.30$; $EF_{LEACH} = 0.0075$

II. IPCC Methodologies – Tier 1, cont.

Main limitation of Tier 1:

It's crude:

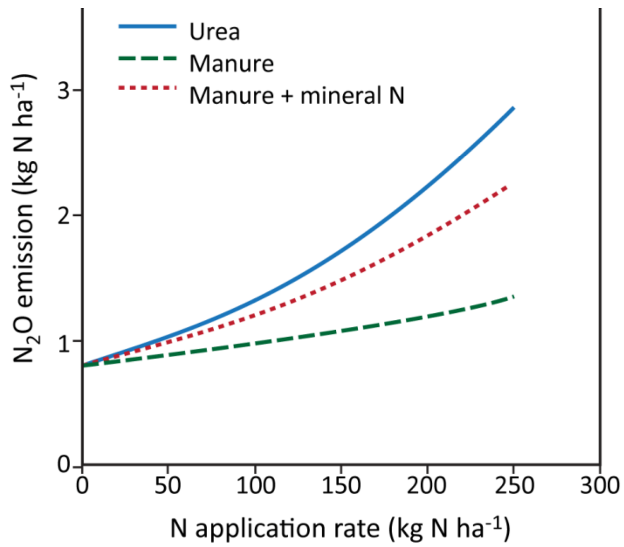
- Know that Emission factors differ by system and cropping practice

  EF = 1.0% (0.25 – 2.5%)

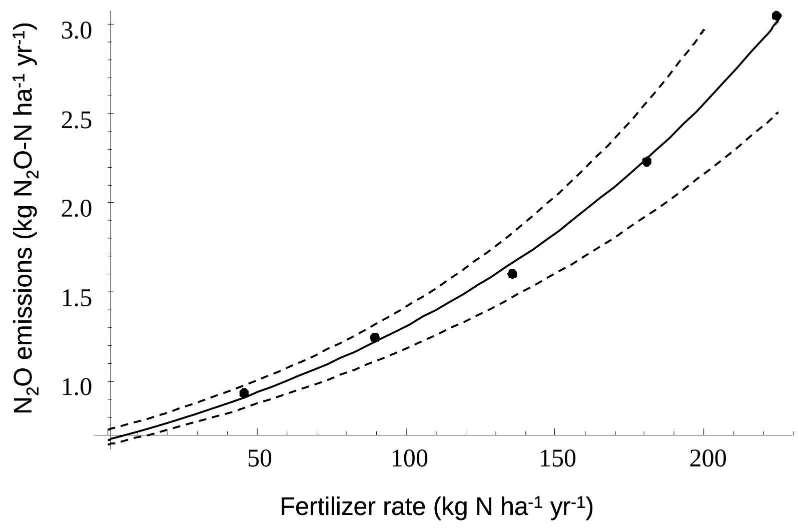
- Know that interactions can be complex
  e.g. tillage x soil texture

- Know that it's not necessarily linear:

Bouwman et al. 2002



Hoben et al. 2010



II. IPCC Methodologies – **Tier 2**

Allows for alternative Emission Factors for direct N_2O emissions from managed soils:

- **Nitrogen source** (e.g. anhydrous ammonia vs. urea vs. manure)
- **Crop type** (e.g. corn vs. cotton vs. tomatoes vs. perennial biofuels)
- **Management practice** (e.g. till vs. no till vs. cover crops)
- **Land use** (e.g. cropland vs. fertilized pasture)
- **Climate** (e.g. humid vs. semi-arid)
- **Soil** (e.g. fine vs. coarse texture, well drained vs. poorly drained)
- "or **other** condition-specific emission factors that a country may be able to obtain" (IPCC 2006)

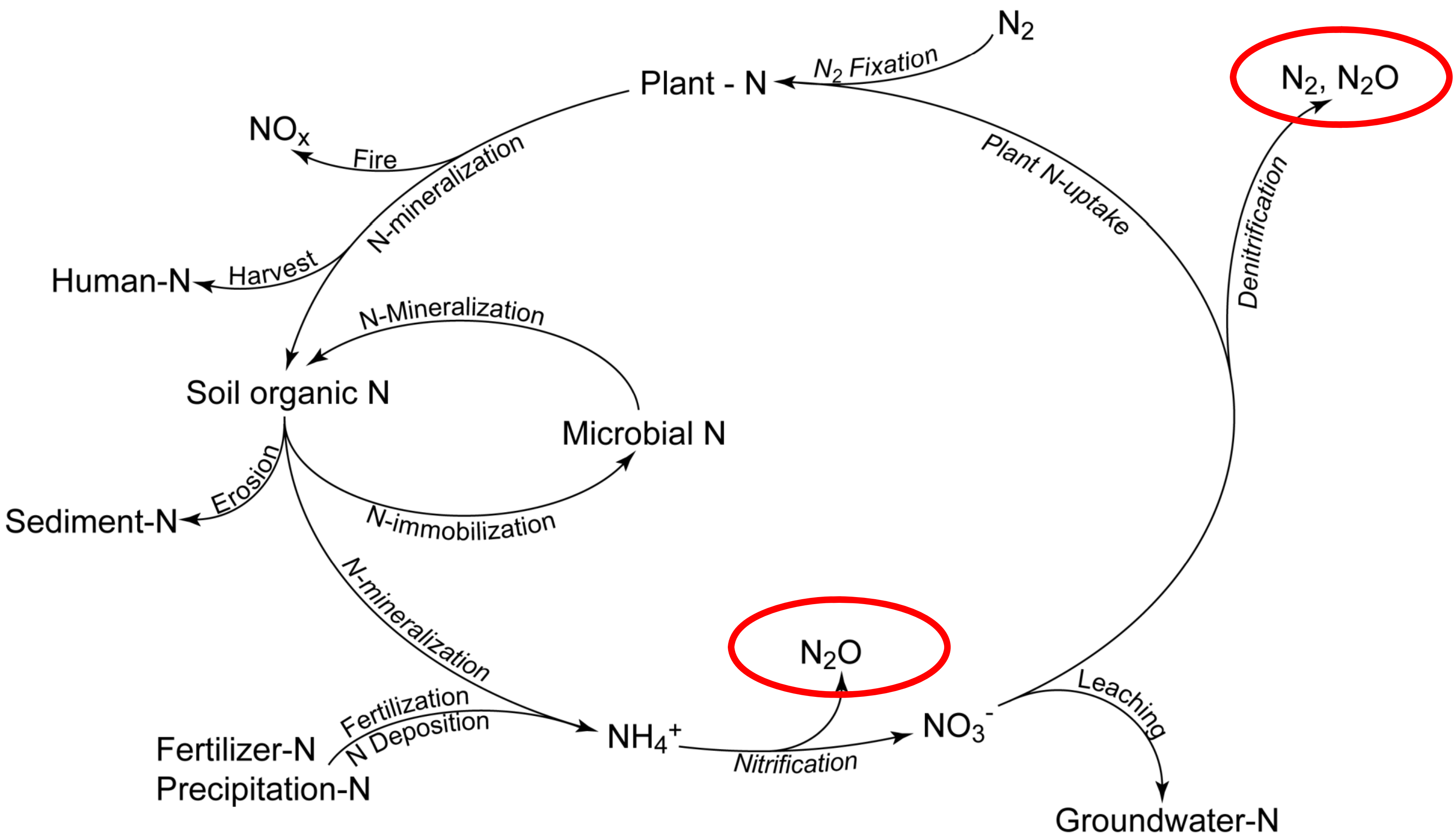
III. IPCC Methodologies – **Tier 3**

Process-based simulation modeling or direct measurements to estimate direct N_2O emissions

- Does not rely on Emission Factors
- Based on underlying knowledge of processes that produce N_2O in soil
- Major advantages
  - Integrate Tier 2 factors and their interactions in real-time
  - Ideally, generalizable to wide variety of soils, climates, & cropping systems

III. IPCC Methodologies – Tier 3

Simulating N_2O based on simulation of N-cycle

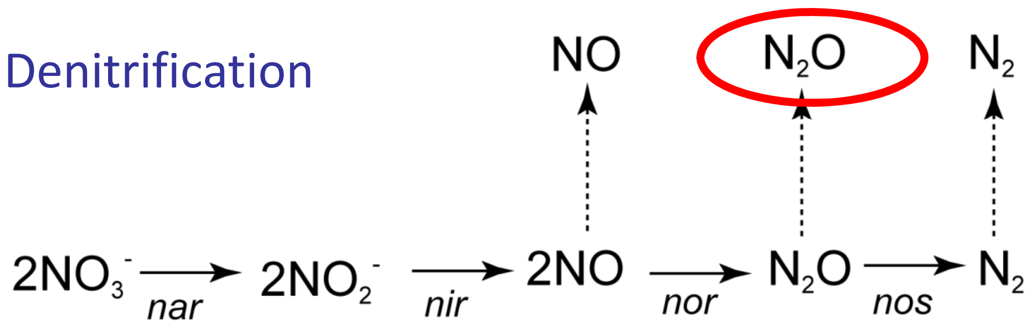


Source: Robertson & Groffman 2007

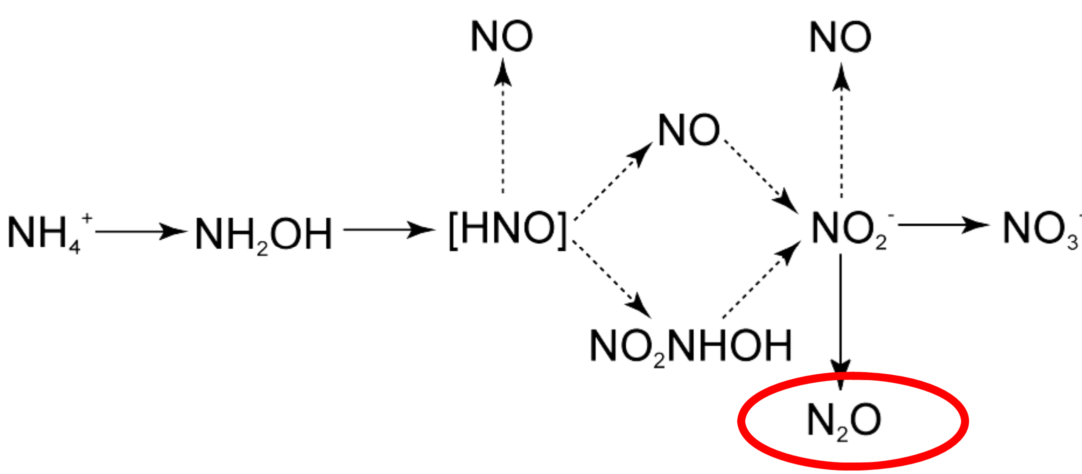
III. IPCC Methodologies – Tier 3

N_2O sources in soil

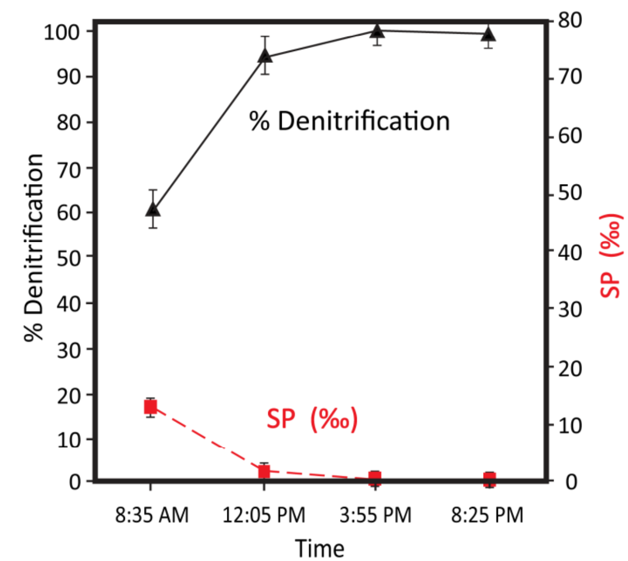
- Denitrification



- Nitrification



- Which dominates?

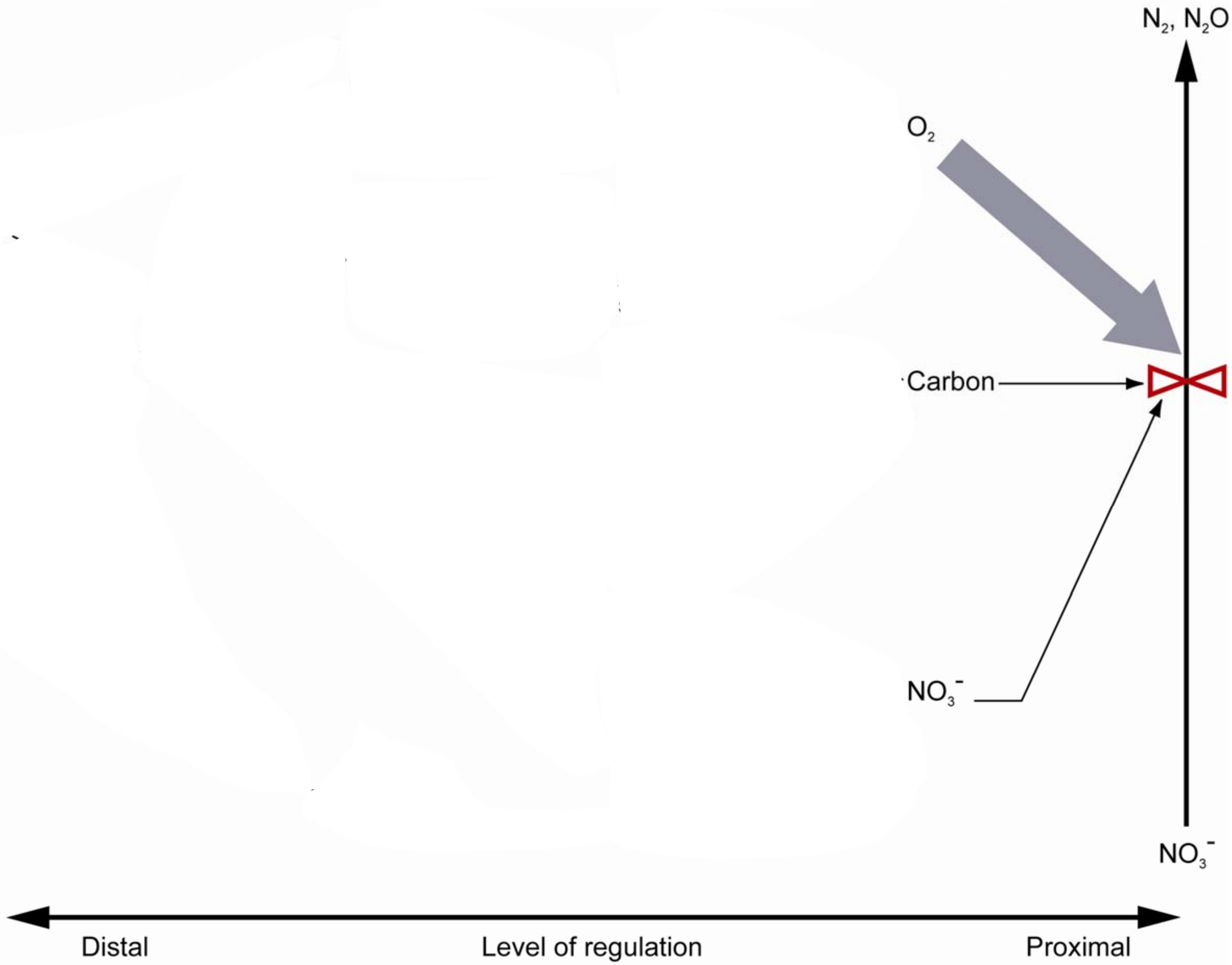


Source: Ostrom et al. 2010

Source: Robertson & Groffman 2007

III. IPCC Methodologies – Tier 3

Controls on Denitrification



Source: Robertson & Groffman 2007

III. IPCC Methodologies – Tier 3

Process-based simulation modeling

Limitations

- Incomplete understanding of underlying processes (e.g. nitrification vs. denitrification)
- Limited ability to predict daily fluxes (limited data sets)
- Incomplete knowledge of sensitivity to different management practices in different regions and crops

Number of models available

- DAYCENT, DNDC, ecosys, EPIC, APSIM, NLOSS, Expert-N, WNMM, FASSET, CERES-NOE
- Different strengths, different abilities; no formal inter-comparisons yet conducted

Conclusions

1. Methods to quantify N_2O emissions in crop production are differentially robust.

2. Tier 1 provides a reasonable first-order estimate for inventories and for estimating the carbon equivalents to be gained by reducing fertilizer rates

   - Although available evidence suggests that it is over-conservative in many instances

3. Tier 2 provides the ability to correct for geography (soils, climate), cropping systems (different crops), and cropping practices (different management)

   - For most systems Tier 2 emission factors await compilation

4. Tier 3 provides substantial long-term promise for improving both inventories and reduction credits

   - But the poor availability of data prevents models from being tested in a systematic way across geographies and cropping practices