Session 1 – Fertilisation techniques

Chair: Klaus Butterbach-Bahl

Co-chair: Per Ambus

Key note lecture - Philippe Rochette

Short presentations:

- Elizabeth Pattey
- Raia Silvia Massad

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Key note lecture

Fertilisation techniques and N_2O emissions

Philippe Rochette

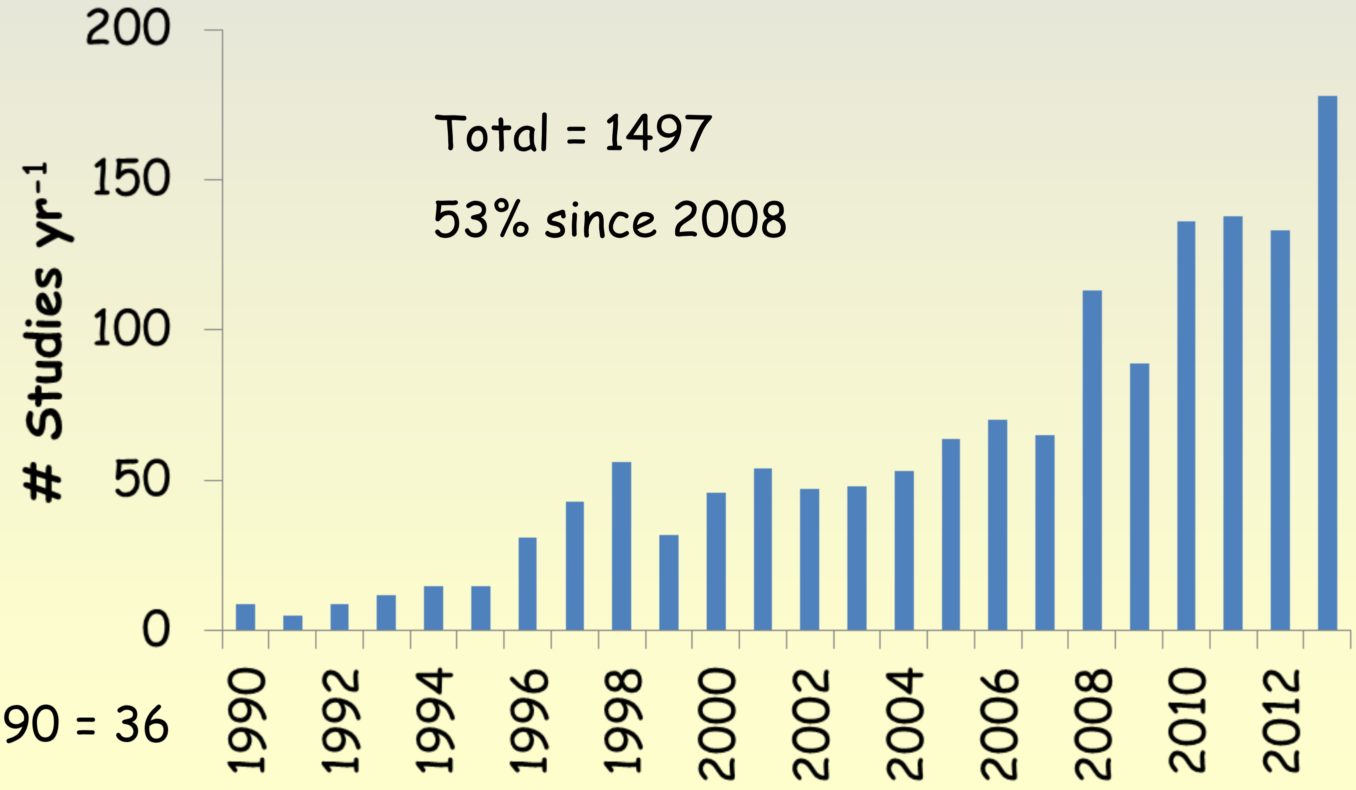
AAC, Canada

Nitrogen Fertilization Techniques and Soil N_2O Emissions

Experimental database to explore mitigation options

Philippe Rochette
Agriculture et Agroalimentaire Canada
Québec

Scientific papers "N_2O + Soil + Fertilizer"



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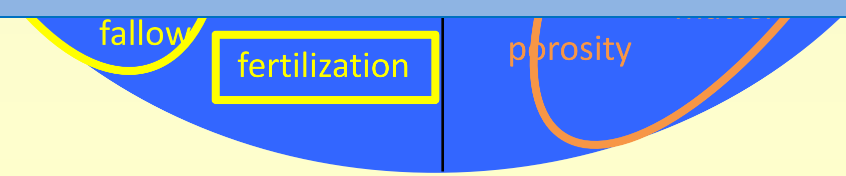
N Fertilizers Impacts on Soil N_2O Emission

- Following nitrogen fertilizer application, soil mineral N content is increased with associated risks for environmental losses (NH_3, NO_3, NO_x, N_2O)
- Nitrogen fertilizer use is the major source of N_2O emissions from agricultural soils (35% of direct emissions in Canada)
- Practices for mitigating fertilizer-induced emissions aim at:
  - Reducing soil mineral N concentration
    - Reducing N rate, improving N placement, timing and form, etc.
  - Avoiding fertilizer-, soil- or climate-induced conditions that favor N_2O-producing processes

N_2O controls – Conceptual Model

Nitrification ***Denitrification***

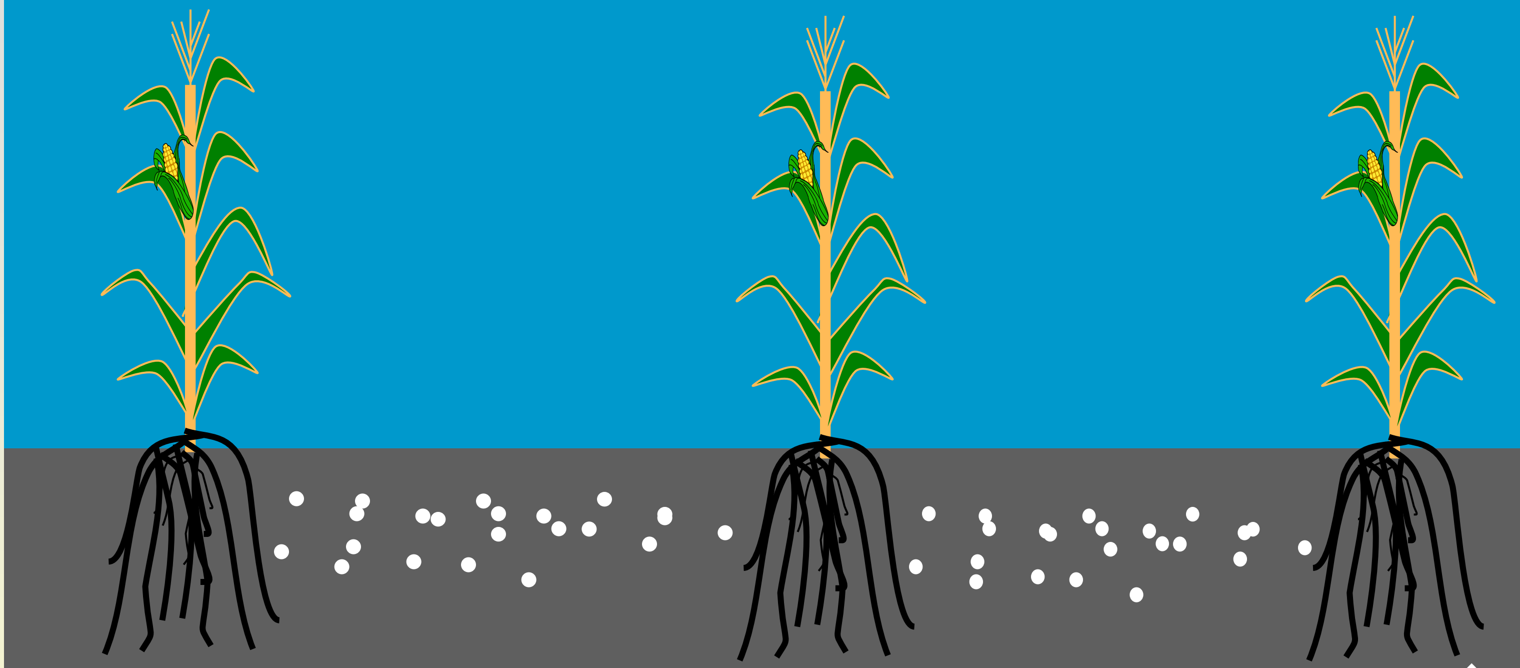
- **Fertilization** interacts with many other management practices, soil properties and climate
- Field studies inform on <u>specific situations</u> (soil x climate x farming practice)
- Generalization of results from field studies is a risky business



N Fertilization Practices affecting N_2O Emissions

- Application Rate
  - Emission Factor
- Type / Form
  - NH_4 vs NO_3
  - Source
  - Nitrification inhibitors
  - Controlled-release
- Placement
  - Banding vs Broadcast
  - Surface vs Incorporation
- Timing
  - Split application
- Mineral vs Organic
- Others
  - Biochar

N Fertilizer Rate

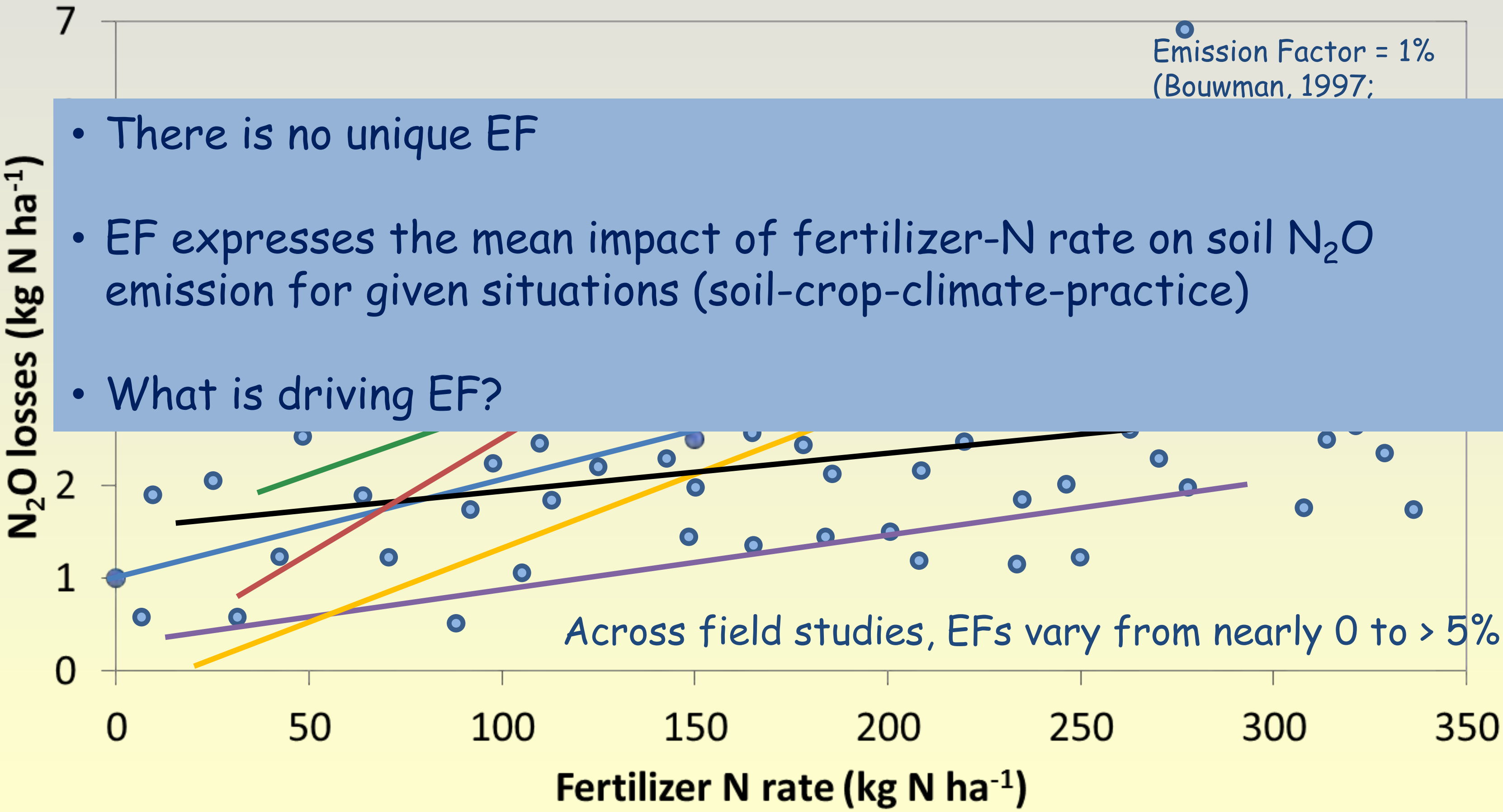


- Increases soil N concentration
- May change soil pH

Fertilizer-Induced EF

- Nearly all datasets indicate that N_2O emission increases with increasing N rate
- By how much?
- The emission factor (EF) is the most-often used index of N-driven soil N_2O emissions
- In 2007, IPCC recommended that when there is no information specific for a given situation, a default EF of 1% should be used (Bouwman et al., 2002)

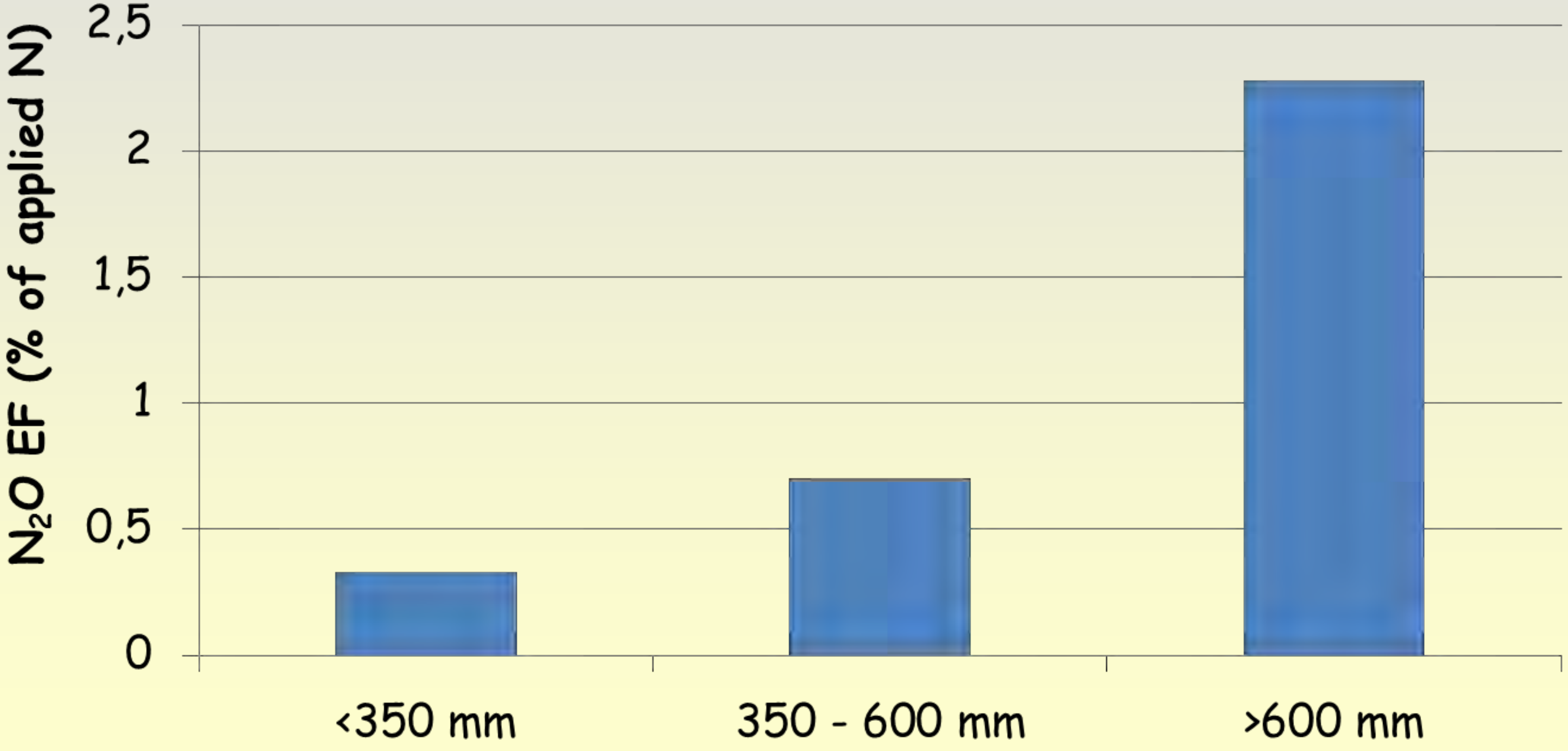
Fertilizer-Induced EF



- There is no unique EF
- EF expresses the mean impact of fertilizer-N rate on soil N_2O emission for given situations (soil-crop-climate-practice)
- What is driving EF?

Fertilizer-Induced N_2O Emissions in Canada

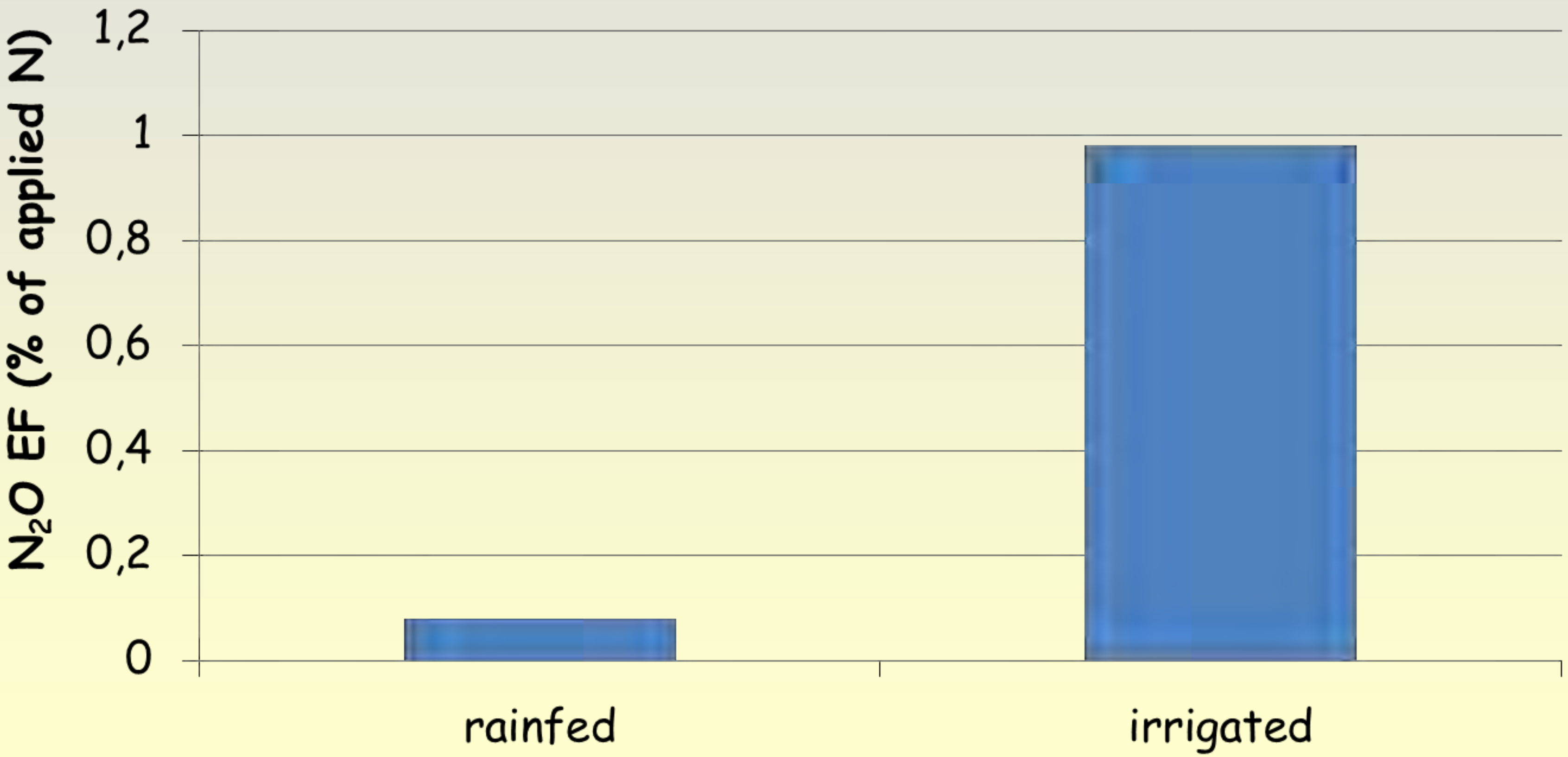
Impact of Rainfall



(Rochette et al., 2008)

Fertilizer-Induced N_2O Emissions in the Mediterrannean Climates

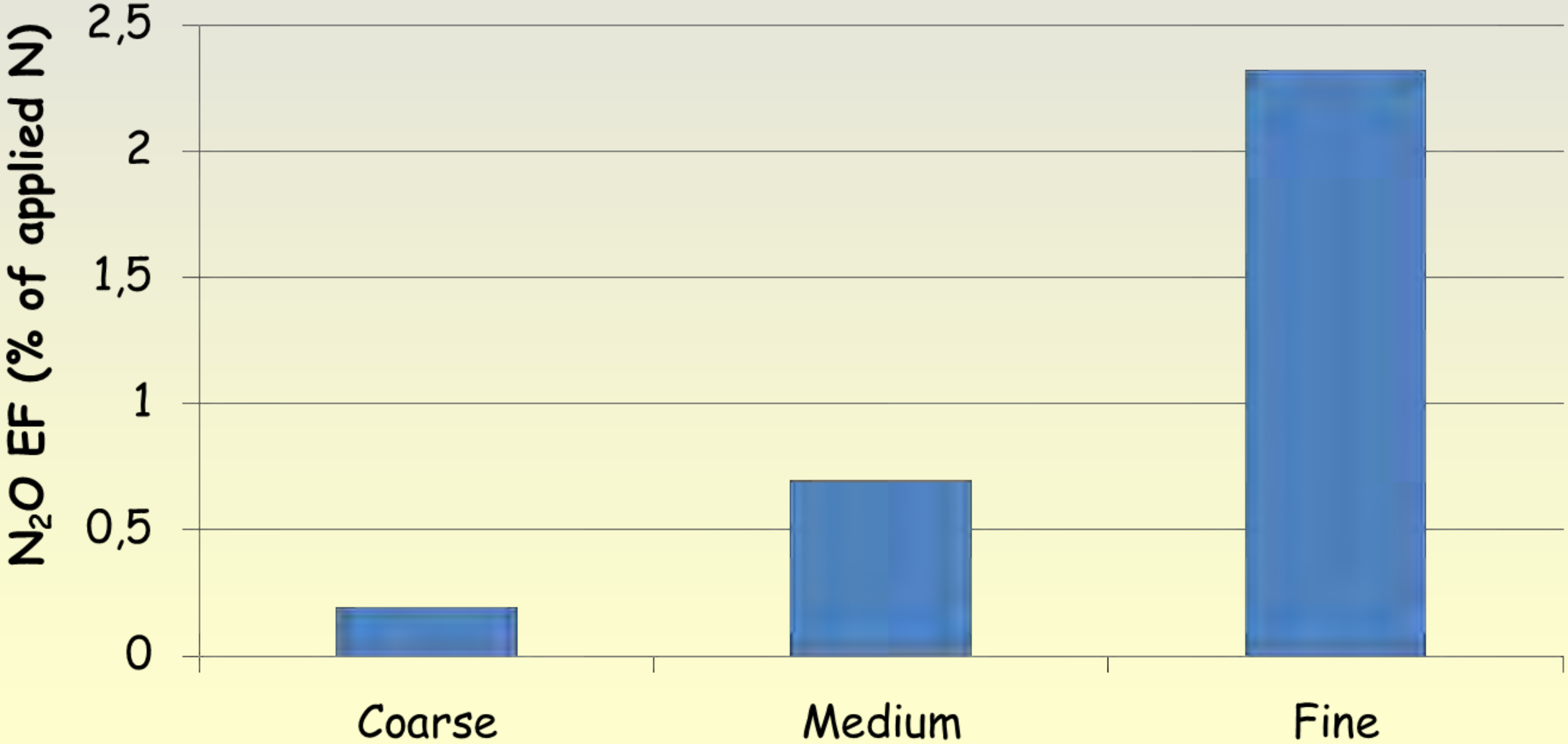
Impact of Irrigation



(Aguilera et al., 2013)

Fertilizer-Induced N_2O Emissions in Canada

Impact of Soil Texture



(Rochette et al., 2008)

Fertilizer-Induced EF

- EFs are mostly influenced by soil environmental conditions
- In Canada, 71% of the variability in EF among field studies is explained by differences in soil properties and climate
- EFs help target where adoption of mitigation practices will result in greatest decreases in N_2O emissions

Fertilizer-Induced EF

- IPCC default EF (1%) is a summary of literature prior to 2002 and is likely biased towards temperate humid conditions (globally biased)
- IPCC EF is not an interesting option for assessment of site-specific mitigation (locally wrong)
- We need models for predicting EFs for given situations
  - Simple relationships (rainfall, soil texture, SOM)
  - Complex models (Del Grosso et al., 2006; Smith et al., 2010)

Response of soil N_2O to N fertilizers
Linear or Non-Linear?

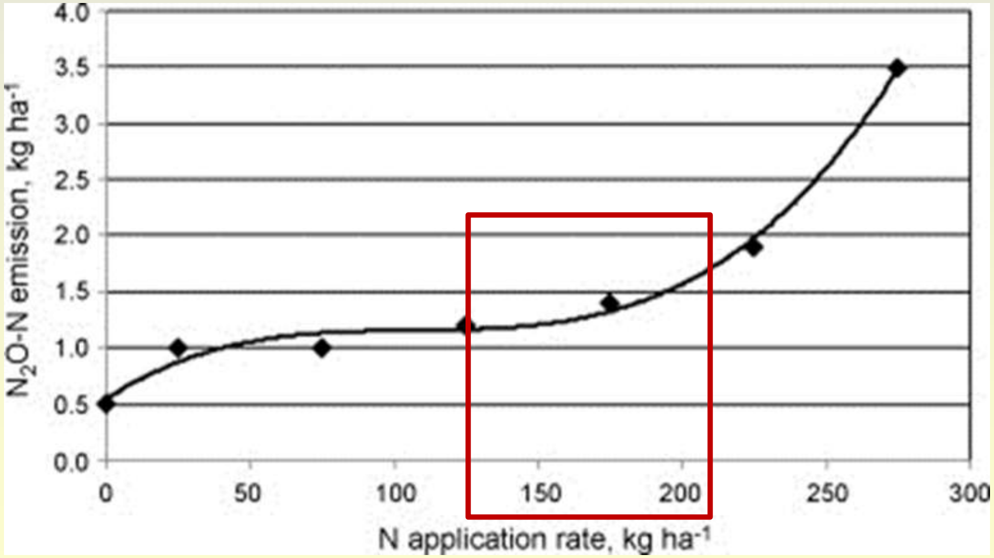
Is EF constant with N rate?

Metaanalysis (Kim et al., 2013)

- 26 datasets with ≥ 4 N rates
- 18 were non-linear
  - 16 were exponential
  - 2 were hyperbolic
- 4 were linear

Similar conclusion in France (Philibert at al., 2011)

Non-linearity is related to N rates in excess of crop needs (Van Groenigen et al., 2011)



(Snyder et al., 2009; based on Bouwman et al., 2002)

Good news for mitigating potential

Options for Reducing N-Ferilizer Rate

- Avoid excess
  - How is the threshold defined?
  - Reducing N rate below agronomic optimum may have perverse impacts such as increased acreage to maintain production (no net gain)

- Replace non N-fixing crops by legumes

- Account for “soil N supply” (previous-year crop residues; SOM)

- Optimize organic N sources

- Balanced crop nutrient supply

- Precision agriculture (Sehy et al., 2003)

  Site-specific N fertilization resulted in similar yields and in N_2O emissions 34% lower than uniform fertilization

N Fertilizer Type

- NH_4^+ vs NO_3^-
- Source (urea, AA, CAN, UAN, AN, AS,…)
- Nitrification inhibitors (DCD, nitrapyrin)
- Controlled-release (SCU, PCU, etc.)

N Fertilization - NH_4 vs NO_3

- In theory, NH_4 has a greater potential than NO_3 because it can contribute to both nitrification and denitrification processes.
  - $NH_4 > NO_3$ (Bouwman et al., 2002; Tenuta and Beauchamp, 2003; Velthof et al., 2003; Liu et al., 2007)
  - Urea was greatest (Tenuta and Beauchamp, 2003)

- In practice, interactions with environment often override this effect:
  - $NO_3 > NH_4$ under wet soil conditions (Velthof et al., 1996; Zanatta et al., 2010; Huang et al., 2014)

- "At this stage, it is difficult to say with any certainty weather a strategy based on urea or AN would result in the smaller N_2O emissions" (Harrison and Webb, 2001)

N Fertilizer Type

Direct comparisons

- Urea
  - = AA (Burton et al., 2008)

- No clear trend of fertilizer source impact
- Most of these differences can be explained by soil environmental conditions
- NH_4-based fertilizers emitting more in situations where nitrification was favored
- NO_3-based fertilizers emitting more in situations where denitrification was favored
- Difficult to assess from literature because N source is often confounded with placement method

N Fertilizer Type

- When all factors are included, difference among fertilizer types disappear (Stehfest and Bouwman, 2006)
- On average, no major gain of selecting of NH_4 over NO_3

- Urea is by far the most widely used N fertilizer
- Proposing fertilization strategies that account for the impact of urea on soil N_2O emissions should be a priority
- Need more research on the role of NO_2 accumulation (Venterea)

N Fertilization – Nitrification Inhibitors

- <u>Controlling nitrification is critical</u>
- Nitrification inhibitors are very efficient but…
- Half-life is temperature-dependent (Di and Cameron, 2004)
- Adds ≈ 10% to N fertilizer cost (Snyder et al., 2009)
- Is it an economical option? (Chambers et al., 2000; Harris et al., 2013)

Interaction with soil water content (Sanz-Cobena et al., 2014)

- … and pig slurry (Vallejo and Sanz-Cobena; Aita et al., 2014)

N Fertilization – Slow Release

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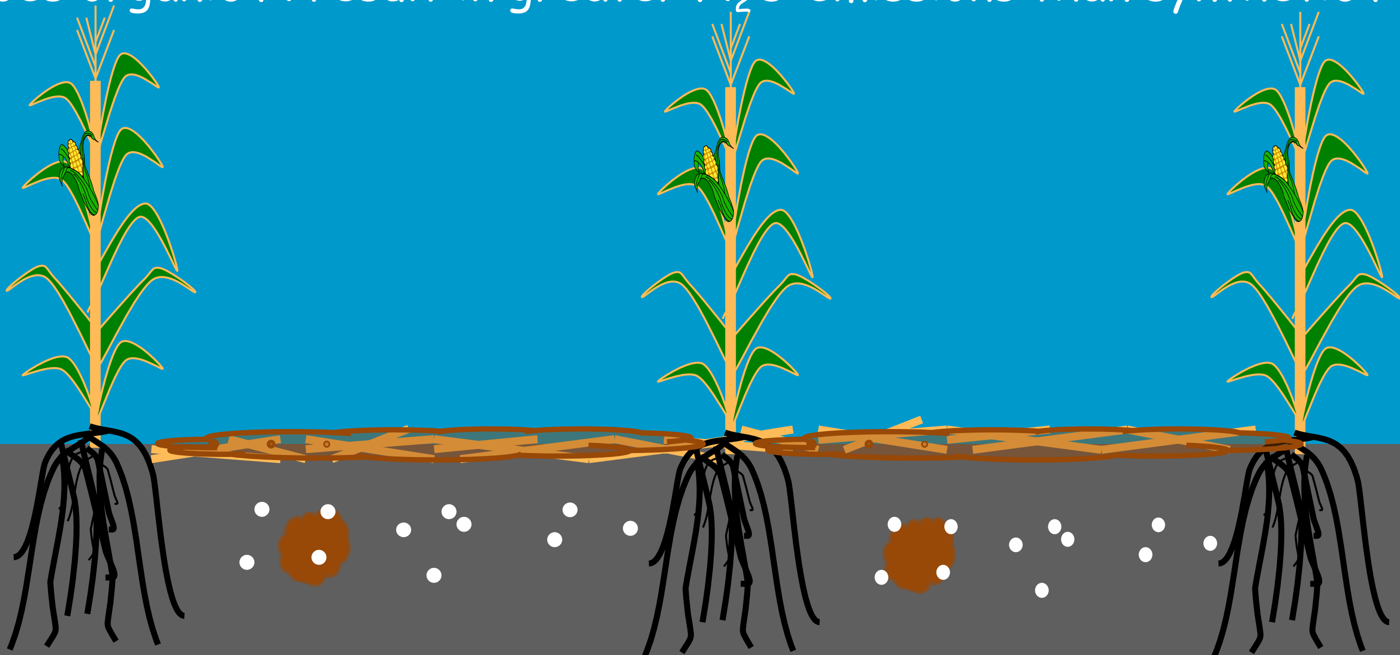
- Overall mean reduction but less efficient than nitrification inhibitors
- Interactions with climate and crop type
- May increase emissions when delayed N release occurs at a time of low plant uptake

Efficient Use of Organic N Sources

Does organic N result in greater N_2O emissions than synthetic N?

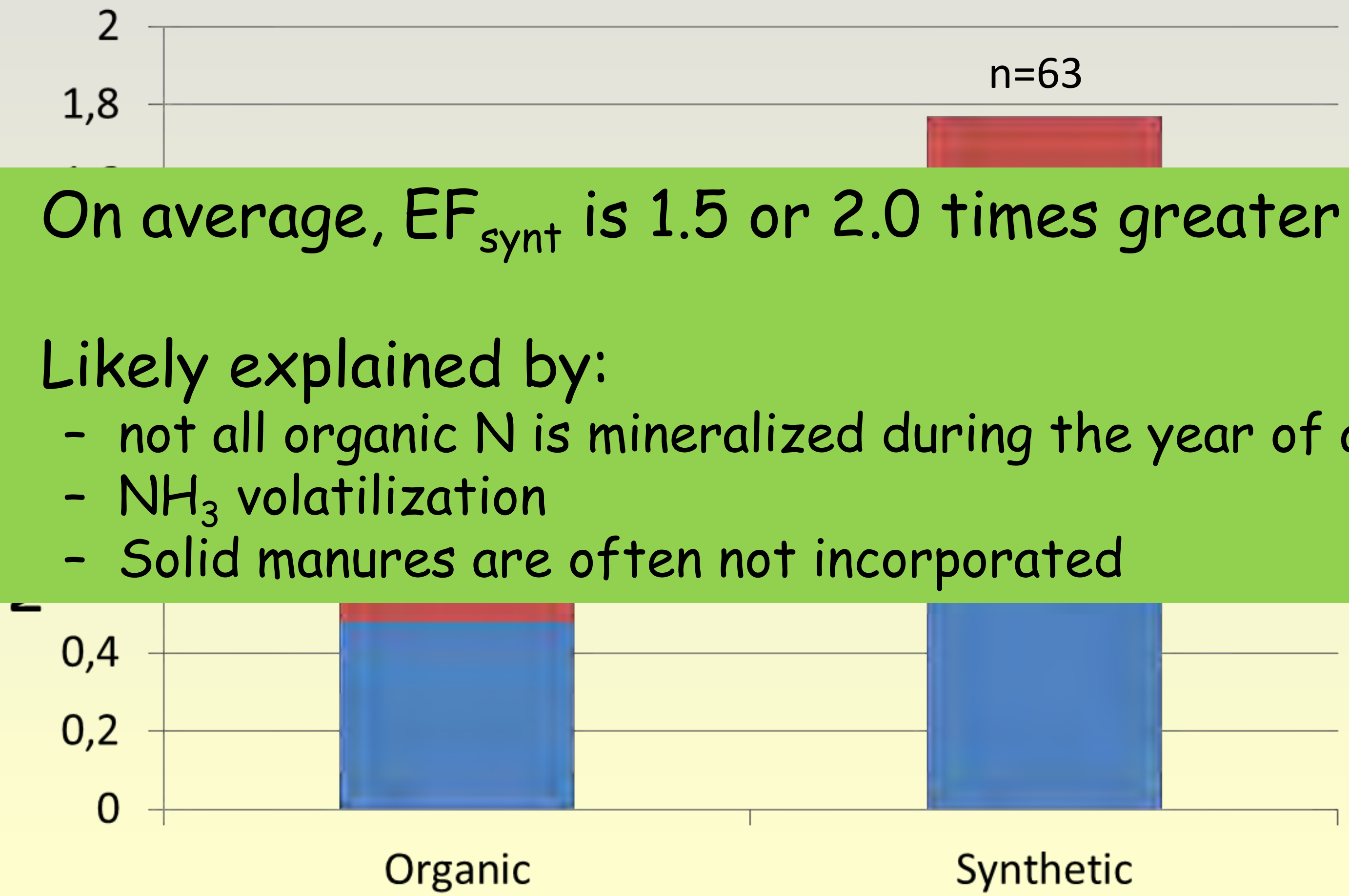


- Lower mineral N content
- May decrease soil bulk density

- Input of available C for denitrification
- Anoxic hotspots

N_2O Emission Factor
Organic vs Synthetic Sources

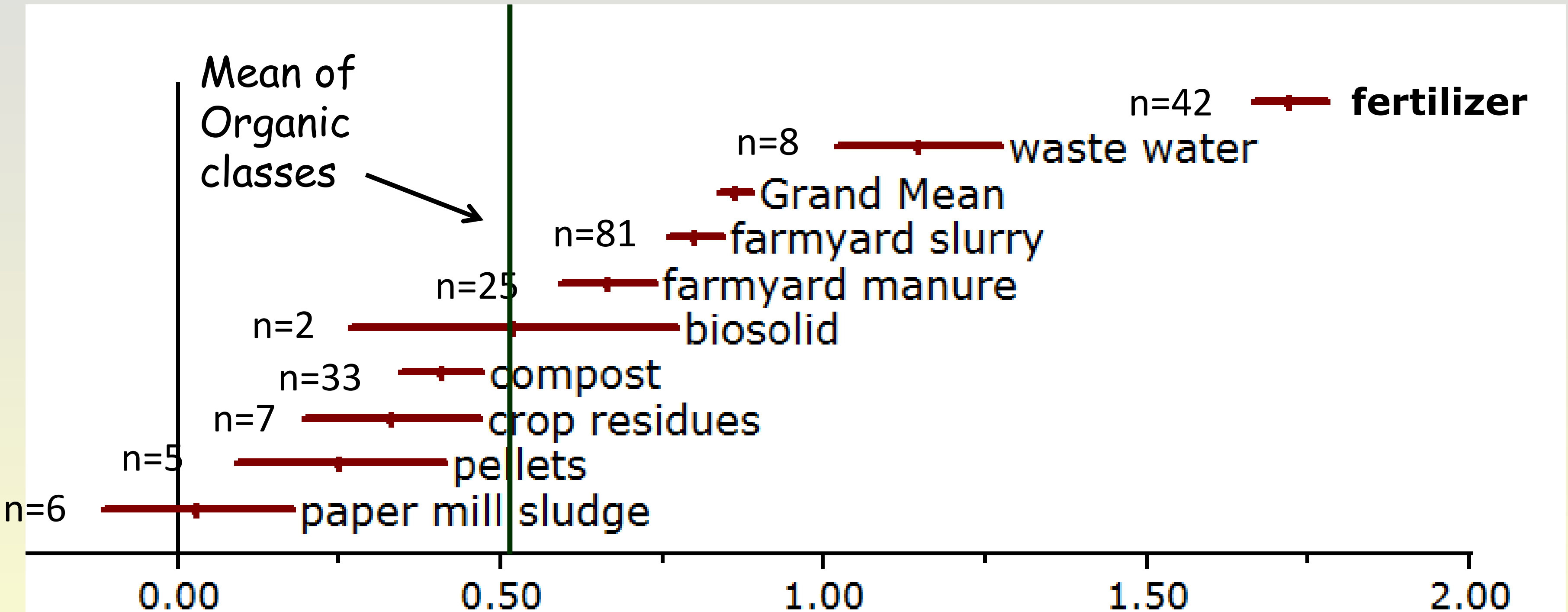
Direct comparisons



- On average, EF_{synt} is 1.5 or 2.0 times greater than EF_{org}
- Likely explained by:
  - not all organic N is mineralized during the year of application
  - NH_3 volatilization
  - Solid manures are often not incorporated

(Anaïs Charles, unpublished)

Organic amendments
Metaanalysis -Global data-



- EF_{org} (0.5%) is half the IPCC default EF
- EF_{org} decreases with increasing amendment "stability"

(Anaïs Charles, unpublished)

Confounding factors when comparing manure with synthetic fertilizer

- Predicting N_2O emissions from organic amendments is difficult because it requires adequate simulation of C and N dynamics
- Need for models predicting N_2O production based on organic amendments characteristics (not on source)
- DNDC predicted EF_{org} much smaller than EF_{synt} in UK (Cardenas et al., 2013)

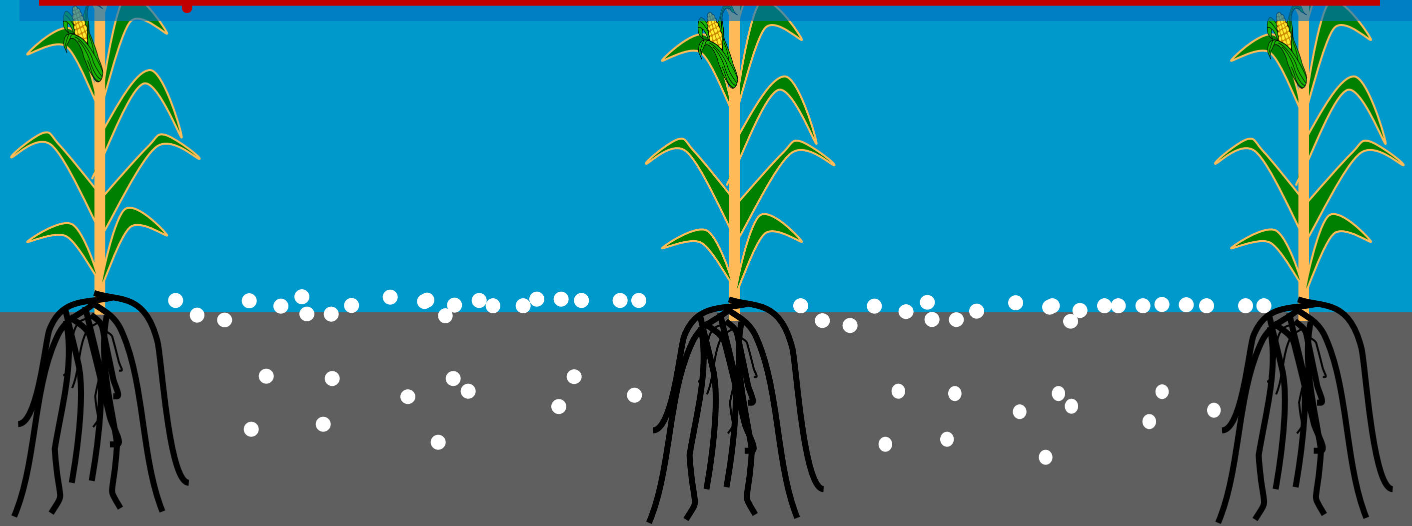
N Fertilizer Placement

- Surface Broadcast with and without Incorporation
- Banding vs Surface Broadcast
- Banding vs Surface Broadcast + Incorporation

Placement of N Fertilizer

Surface vs Incorporation

Depth and N concentration



- Decreases soil N concentration
- Improves N-Use Efficiency

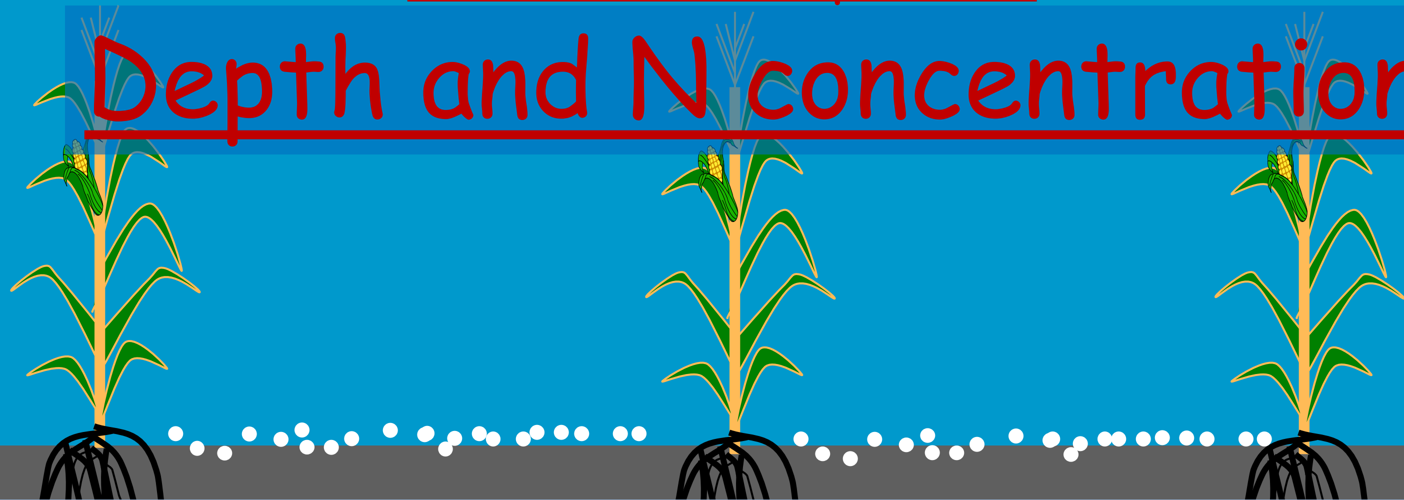
- Less-aerated environment

Net effect on N_2O?

Placement of N Fertilizer

Surface vs Incorporation

Depth and N concentration



Mean increase when incorporated to shallow depths

Stimulation decreases with depth?

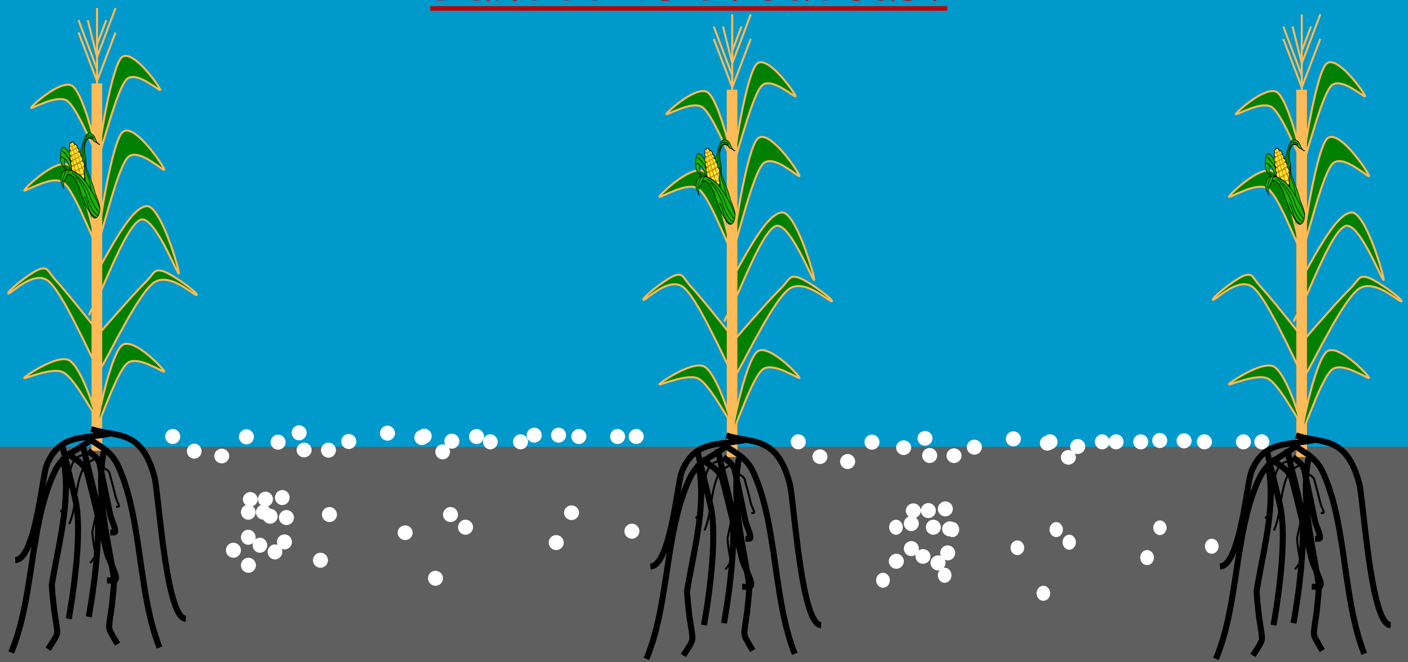
Very few field studies

006)

N should be placed below 5 cm in no-till soils because of stratification of SOM (Venterea and Stanenas, 2008)

Placementof N Fertilizer

Banded vs Broadcast



- Improves N-Use Efficiency
- Decreases soil volume in contact with N inputs
- May slow down nitrification (urea)

- Increased soil N concentration in the band (non-linear EF)
- NO_2 accumulation (urea)

Net effect on N_2O?

Placement of N Fertilizer

Banded vs Surface Broadcast

Depth & Concentration

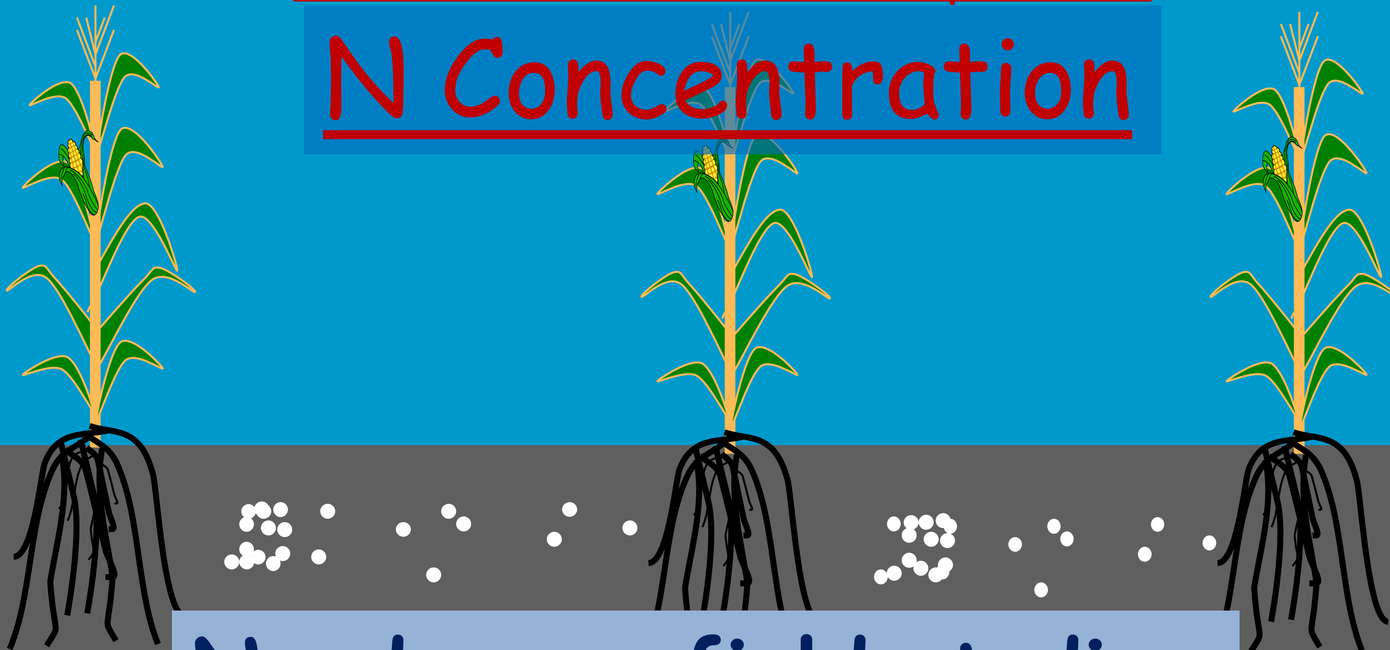
- Banding vs surface broadcast:
  - –Banding (urea) was greater : (Cheng et al., 2006; Engel et al., 2010; Smith et al., 2012; Halvorson and Del Grosso, 2013)
  - –Ba… f et al., 2003; Thompsen et al., 2010; Velthof and Mosquera, 2011 Alfa et al., 2014) or equal (Thompsen et al., 2010)
  - –Banding urea was equal (Cheng et al., 2002; Burton et al., 2008; Pfab et al, 2012)

Mean increase when banded

Placement of N Fertilizer

Banded vs Broadcast+Icorporation

N Concentration



Need more field studies

- Banding vs surface broadcast+incorporation:
  - Isolates the impact of banding
  - Urea banding was 2 times greater (Maharjan and Venterea, 2013) [explained by NO_2 accumulation]

The Ultimate Modelling Challenge?

- Banding and incorporation often increase N_2O emissions

…, we need to account for the impact of :

- N rate (non-linearity)
- N type (urea, AA)
- Plant N uptake
- Other environmental losses (leaching and volatilization)
- Stratification of soil physical, chemical and microbial properties (no till vs conventional)
- Multi-dimensional processes

- Manure…

N Fertilization- Split applications

- Inconsistent results likely due to interaction with climate (application of a fraction of N when soils are warmer)
- Accurate weather forecast would help (rain)
- N application is based on optimum timing for crop uptake; not for optimum soil conditions for low N_2O production
- More research is needed

Biochar

- Mean <u>reduction</u> of 54% in N_2O emissions (Metaanalysis; Cayuela et al., 2013, A.E.E.)

- Influenced by biochar feedstock, pyrolysis temperature and C:N ratio

- Lack of clear understanding of key mechanisms (Nelissen et al., 2014)
  - Greater NH_3 volatilization, microbial N fixation, and sorption of NH_4^+ and NO_3^-
  - Biochar pH effects

Do we have what is needed to explore mitigation options?

Option	# of studies	mitigation potential	uncertainty
Application rate	medium	medium	low
N fertilizer source	low	medium	medium
Nitrification Inhibitor	Medium/ high	high	low
Controlled-release	low	medium	medium
Placement	low	medium	high
Timing	low	low	medium
Precision Agriculture	low	high	low
Organic	high	high	medium

Holistic Approach

- Indirect emissions:
  - Contribution of NO_3^- to leaching
  - Contribution of NH_4^+ to volatilization

- GHG emission for N fertilizer production differs between types :
  - NH_3: 2.6 kg CO_2-eq kg^{-1} N
  - Urea: 3.2 kg CO_2-eq kg^{-1} N
  - NH_4NO_3: 9.7 kg CO_2-eq kg^{-1} N

- Account for interactions with soil, climate and other farming practices

- Additivity of impacts?

- Field measurements cannot answer all questions…

NH_4 vs NO_3 Confounding factors in direct comparisons

- NH_3 volatilization
- Strong interaction with soil type and climate
- Impacts of urea on soil pH
- Confounding effects of type and placement

Summary

- Equal rates? comparing EFs for different rates assumes linear response
- Area- or yield-based EFs?
- Decreasing N rate is the most-certain way to reduce N_2O emissions. However, probability of adoption is low when current rates are not excessive.
- Perverse effects such as increasing acreage
- Other options are needed that will lower emissions and maintain/increase yields.
- Little research on Timing
- Little research on precision farming.
- Complex situation because of indirect emission. They must be included but EF2 is highly uncertain.
- Pulse events

Modelling Soil N_2O Emissions following application of organic amendments

- DNDC predicted EForg much smaller than EFsynt in UK (Cardenas et al., 2013)
- Emissions from manures are often higher than from mineral fertilizers when applied on soils with low organic matter (Rochette et al., 2000; Velthof et al., 2003; Chantigny et al., 2009)
- Predicting N_2O emissions from organic amendments is difficult because it requires adequate simulation of C and N dynamics

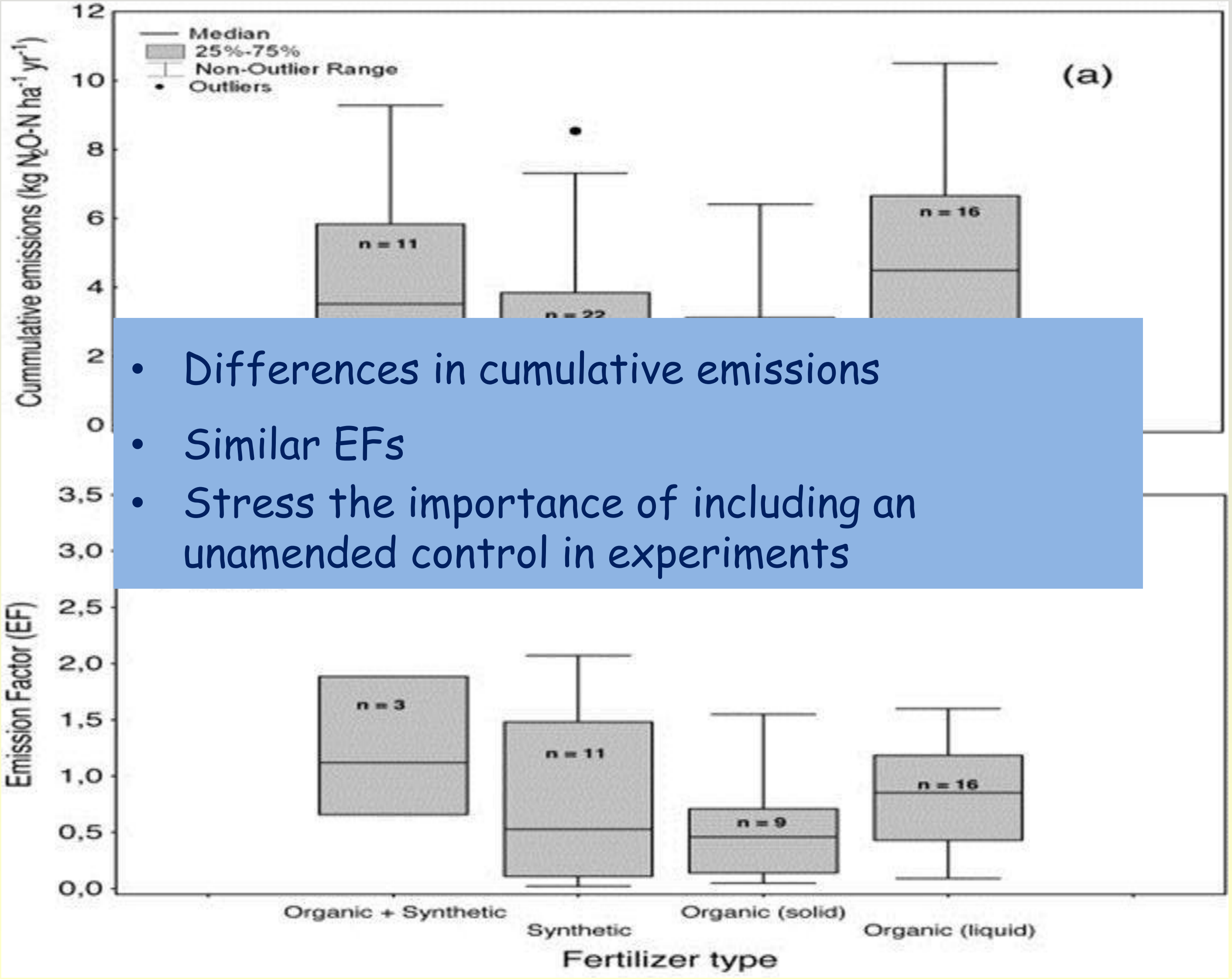
N Fertilization- Fall vs Spring

- In theory:
  - Increases the duration of the period with high soil N content in absence of crop N uptake
  - Snowmelt and spring thaw are known to favor N_2O emissions (and NO_3 leaching)
  - Cold temperature may slow down N transformations

- In practice:
  - Practice popular in in North American Prairie region
  - Crop yields are often unaffected (Grant et al., 2007)
  - N_2O emissions:
    - -Spring > Fall (Delgado et al., 1996; Rochette et al., 2004; Rowlings et al., 2013)
    - -Spring < Fall (Hao et al., 2001; Soon et al., 2011; Burton et al., 2008)

  - Raises the complex issue of soil N transformations and N_2O emissions during winter and spring thaw

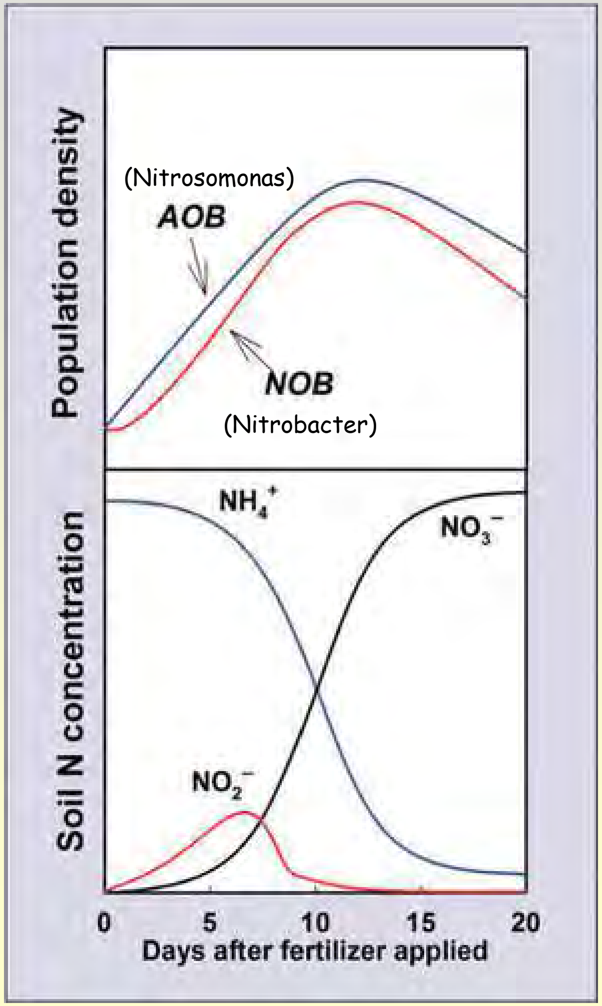
Soil N_2O from Organic Amendments in Mediterranean Climates Metaanalysis –(Aiguilera et al., 2013)



- Differences in cumulative emissions
- Similar EFs
- Stress the importance of including an unamended control in experiments

NH_4 vs NO_3

- N_2O production during nitrification
  - Generally has a lower N_2O yield than denitrification
- Accumulation of NO_2 following application NH_4-based fertilizers (Ventera and Rolston, 2000)
  - NH_3 toxicity
  - Nitrification-induced decrease in pH
  - $NO_2 \rightarrow HNO_2 \rightarrow N_2O$
- May explain large emissions following banding NH_4-based fertilizers (urea, AA)



(Venterea et al., 2012)

NH_4 vs NO_3

- Impact of NO_3 is more straightforward than that of NH_4
- Increase in denitrification when organic C is available and redox potential is low
- N_2O yield is usually greater than for nitrification
- Chemodenitrification may also be involved

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Short presentation

The importance of accounting for soil thawing in quantifying N2O emissions from cropland in response to N fertilization. – Comparison with DNDC predictions

Elizabeth Pattey

AAC, Canada

Agriculture and Agri-Food Canada | Agriculture et Agroalimentaire Canada

The importance of accounting for soil thawing in quantifying N_2O emissions from cropland in response to N fertilization. – Comparison with DNDC predictions

E. Pattey, W. Smith, B. Grant and R.L. Desjardins

GRA –N2O 2014, Paris

Elizabeth.Pattey@agr.gc.ca

Canada

GRADIENT FLUX RESOLUTION USING SINGLE-PATH TDL

- 30-min 2-level TDL gradient resolution:

  N_2O (1ppbv noise over 10s): 16 pptv

- 30-min Flux-Gradient resolution:

  [z_o=0.1 m s^{-1}; u_*=0.2 m s^{-1}; d=0.66m; z_2=3.25m; z_1=2.25 m]

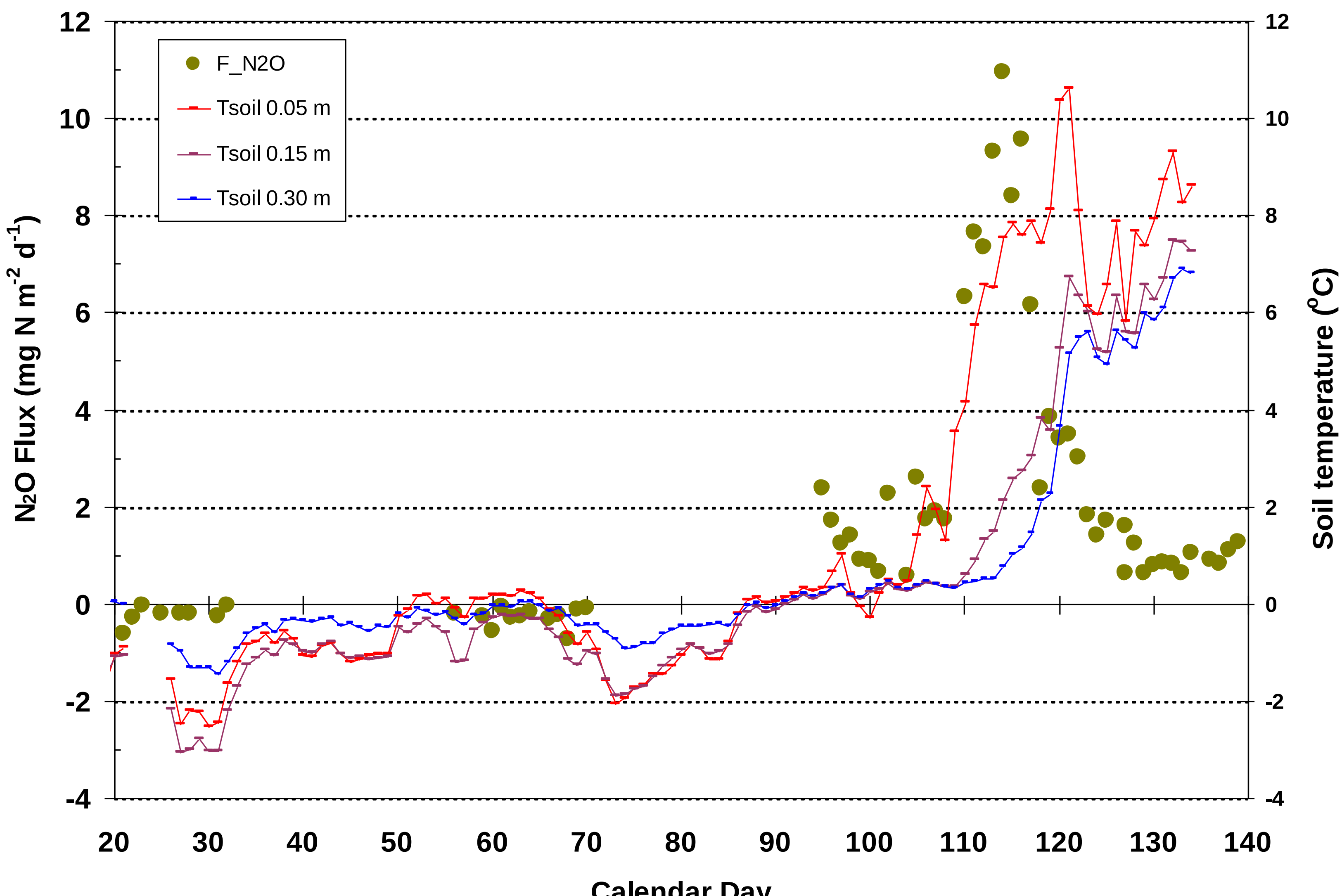
$$F(N_2O) \approx 7.7 \text{ ng } N_2O \text{ m}^{-2} \text{ s}^{-1}$$

$$4.9 \text{ ng } N_2O\text{-N m}^{-2} \text{ s}^{-1}$$

Pattey, E., Edwards, G., Strachan, I.B., Desjardins, R.L., Kaharabata, S. and Wagner Riddle C., 2006. Towards standards for measuring greenhouse gas flux from agricultural fields using instrumented towers. Can. J. Soil Sci. 86: 373-400.

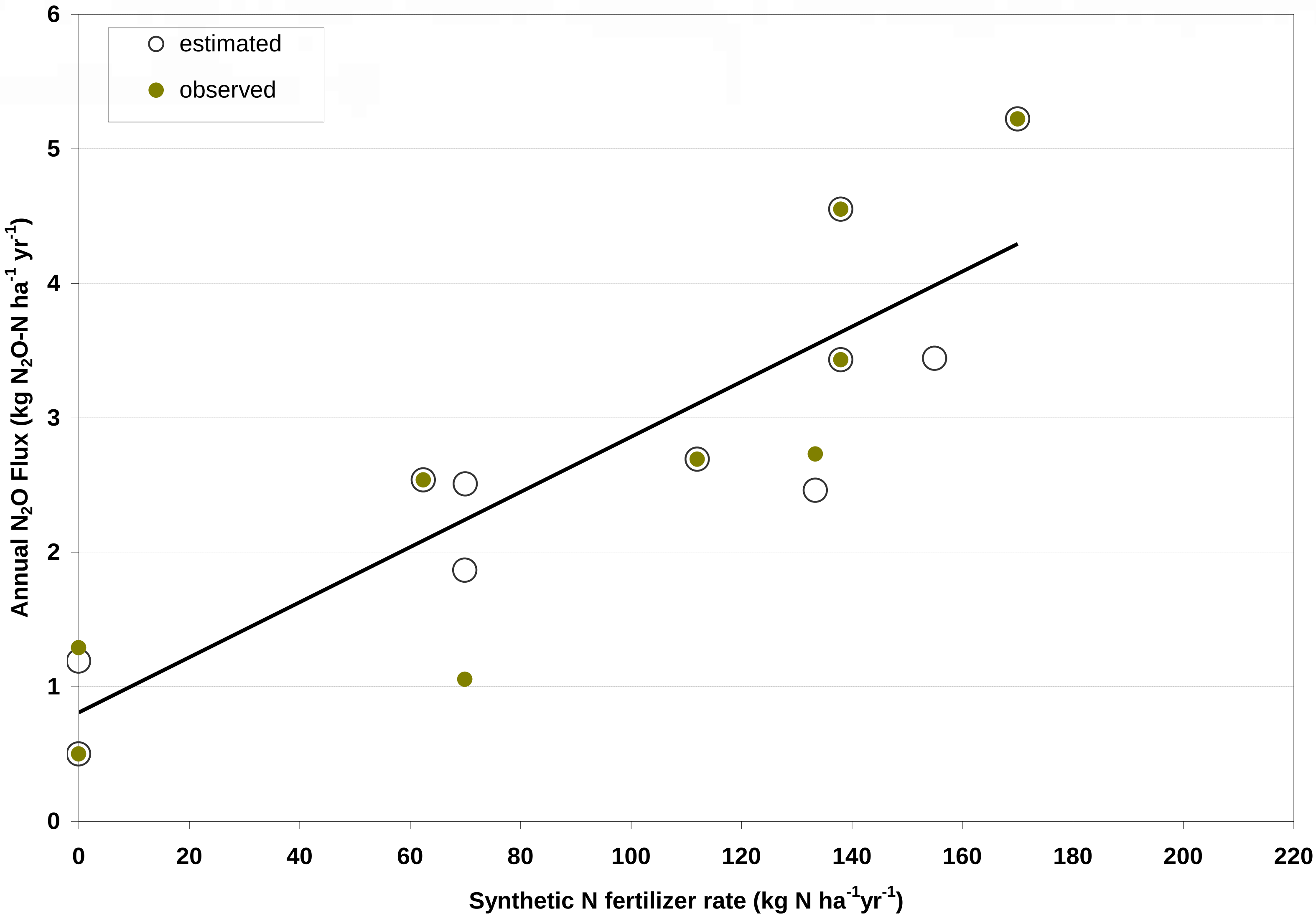
Flux towers are very suitable measurement approach … during snowmelt

Permanent Site, Ottawa - Snowmelt 1997

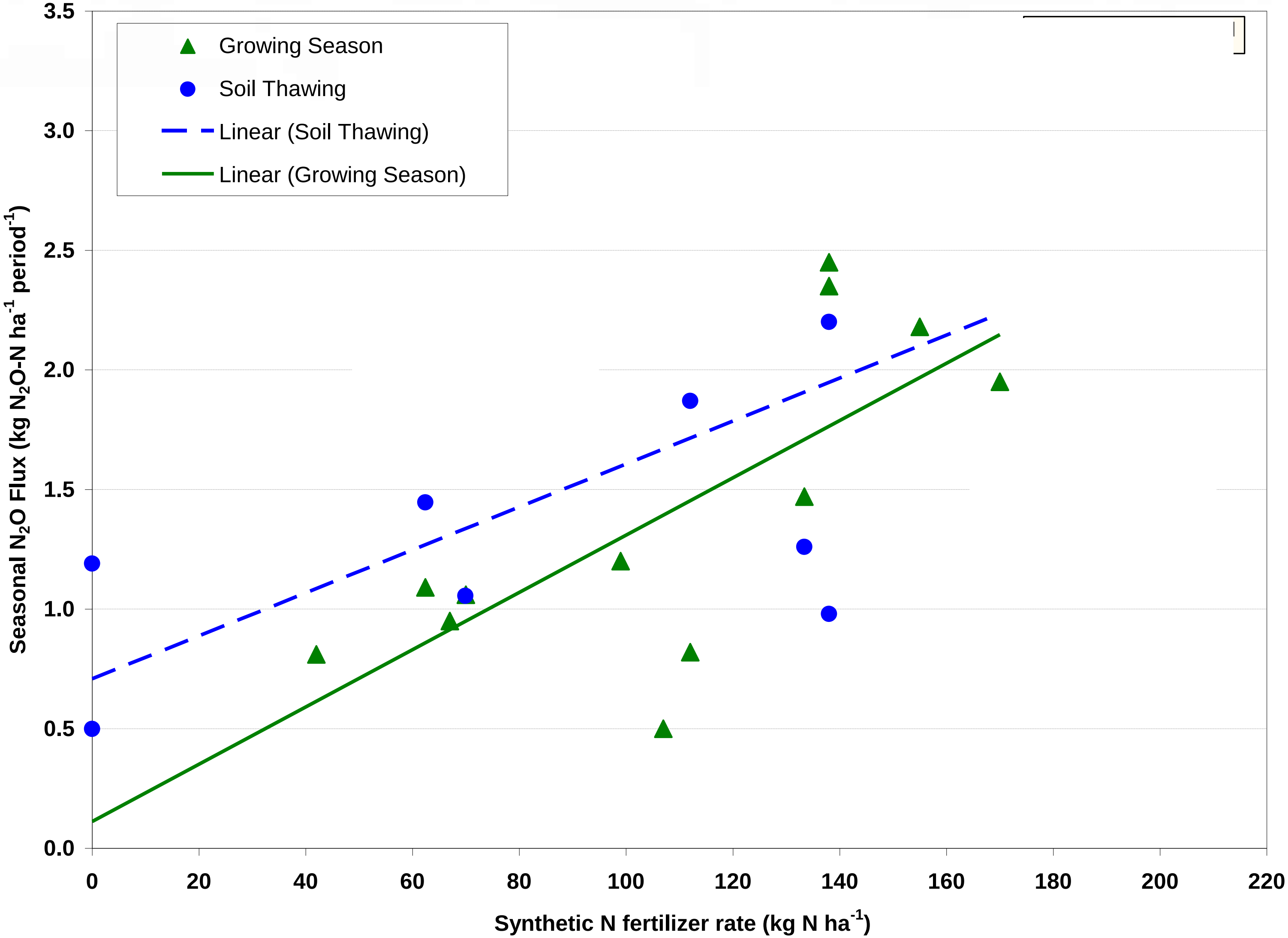


Pattey E., Edwards, G.C., Desjardins, R.L., Pennock, D., Smith W., Grant B., MacPherson, J.I., 2007. Tools for quantifying N_2O emissions from Agroecosystems. *Agric. For. Meteorol.*142(2-4): 103-119

Annual N_2O emissions in Eastern Canada

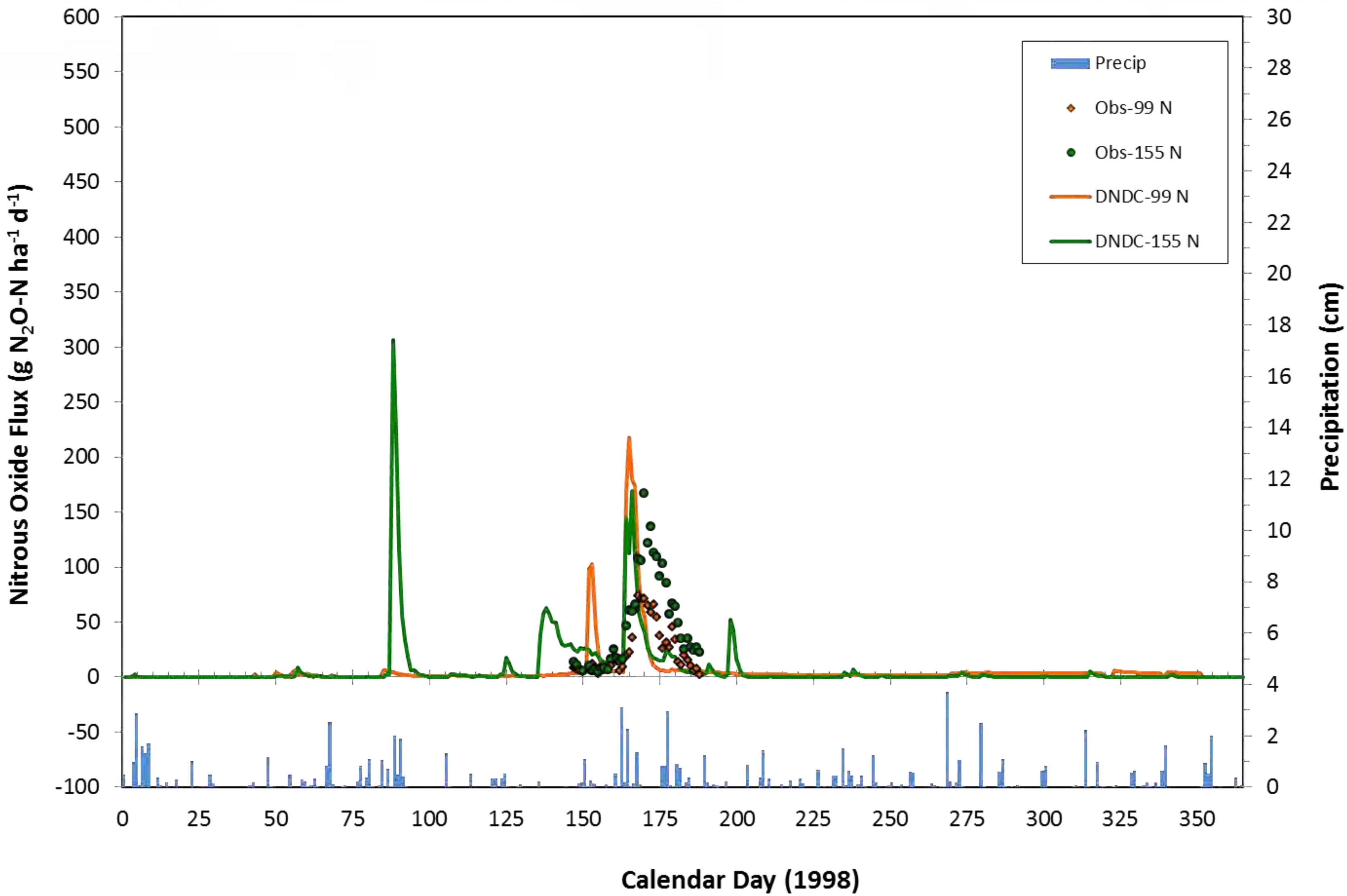


Seasonal N_2O emissions in Eastern Canada

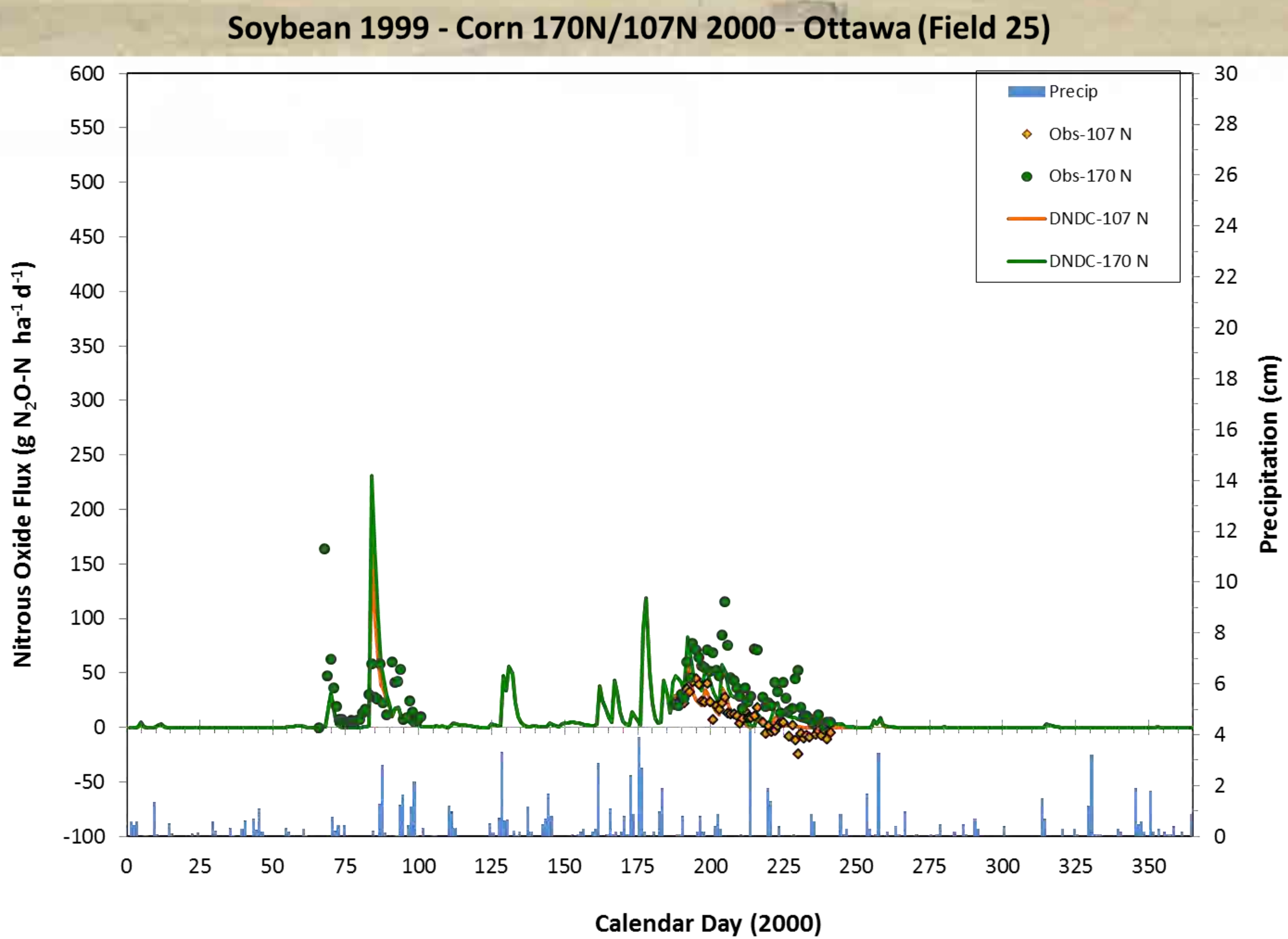


DNDC Predictions

Corn 155N/99N 1998 - Ottawa (Field 25)



DNDC Predictions

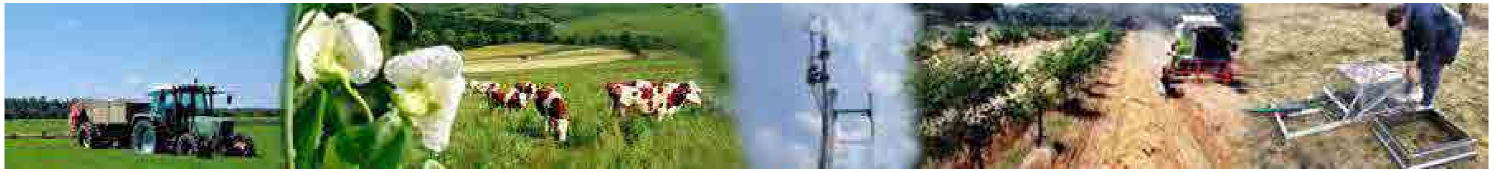


Short presentation

A budget of N2O emissions from fertilizer use over France: a comparison of three regional models

Raia Silvia Massad

INRA, France



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A budget of N2O emissions from fertilizer use over France: a comparison of three regional models

R.S. Massad [1], V. Prieur [2], E. Haas[3], I. Pison[2], M. Saunois[2], S. Klatt[3], M. Lopez[2], M. Scmidt[2], M. Schultz[4] and B. Gabrielle [1].

[1] INRA, AgroParisTech, UMR1091 EGC, 78850 Thiverval Grignon, France

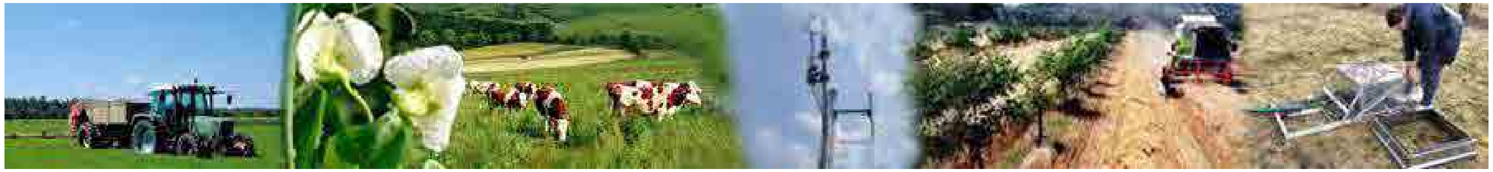
[2] CEA, CNRS, UVSQ, Laboratoire des Sciences du Climat et de l'Environnement (LSCE), Giff sur Yvette, France

[3] Institute of Meteorology and Climate Research (IMK-IFU), Karlsruhe Institute of Technology, Kreuzeckbahnstr. 19, 82467 Garmisch-Partenkirchen, Germany

[4] Norwegian Meteorological Institute, Oslo, Norway

17-19 March 2014
PARIS

Workshop "Experimental databases and model of N2O emissions by croplands: do we have what is needed to explore mitigation options?"



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WHY and For What?

✓Agricultural activities contribute to about **19 % of France s green house gas** emissions and to **84 % of total national N_2O** emissions in 2009 (CITEPA, 2011).

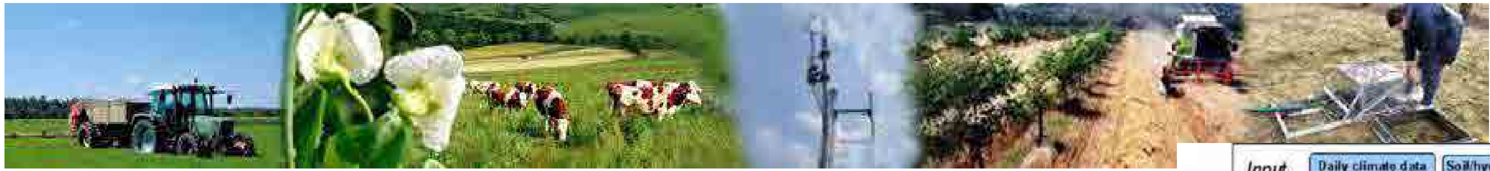
✓Agricultural emissions are influenced by several environmental factors

- soil **temperature**
- soil **moisture**
- **management** practices (N application, grazing regime, cutting, etc.)

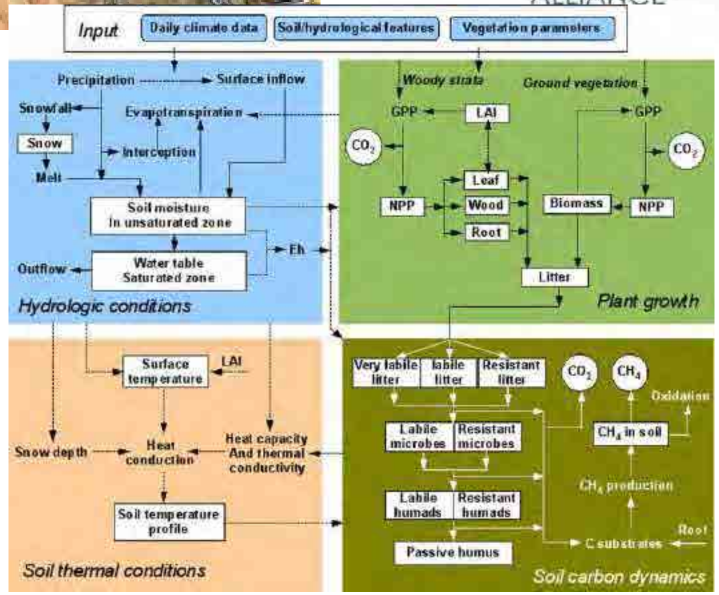
✓These controlling factors and soil properties interact at different **temporal** and **spatial** scales making it challenging to quantify and assess N_2O emissions at the regional scale.

➢ Improve the current estimates of biogenic sources of N_2O

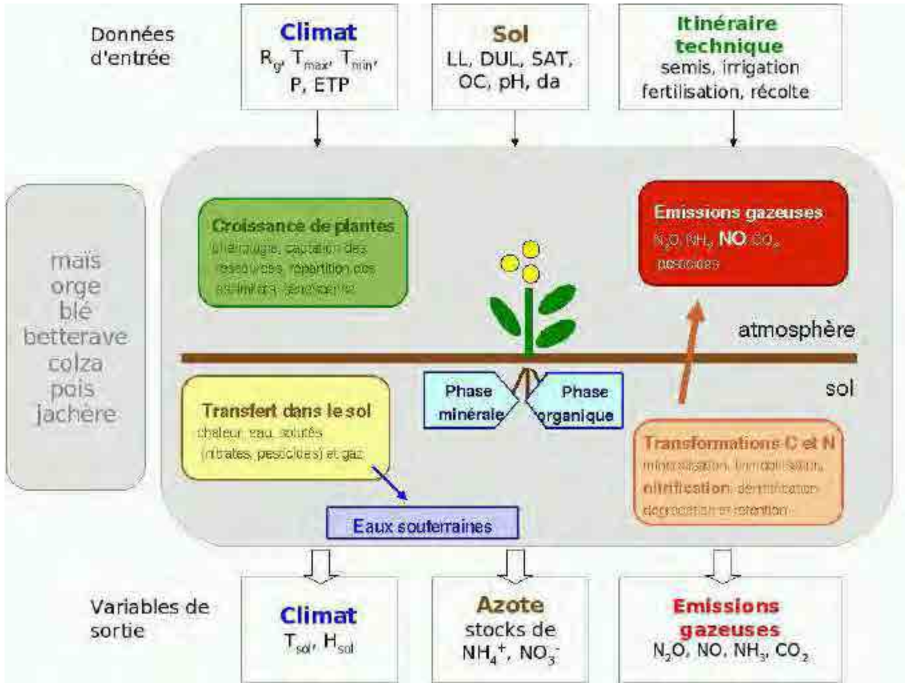
➢ Produce and assess maps of N_2O emissions from agricultural ecosystems at the regional scale using a bottom-up approach with biophysical models (CERES-EGC, Landscape-DNDC & ORCHIDEE-CN)



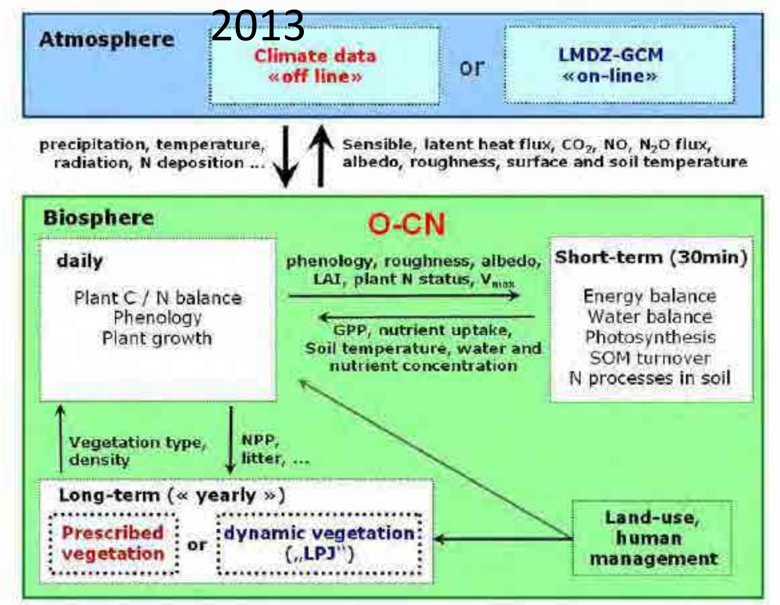
The models



Li et al. 1997, Haas et al. 2013



Gabrielle et al. 1998



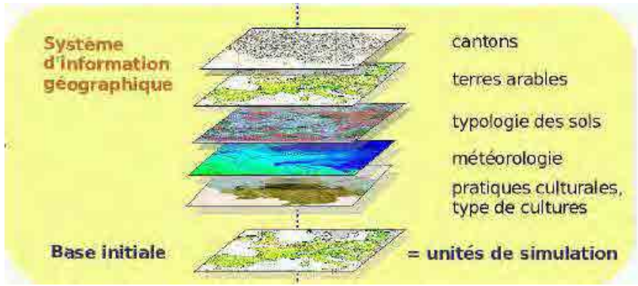
Krinner *et al.*, 2005, *GBC*; (modified)

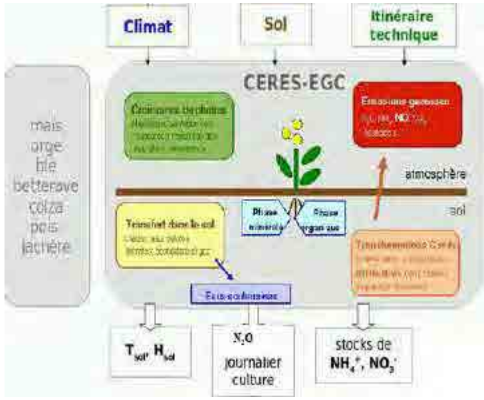
Spatialization-France

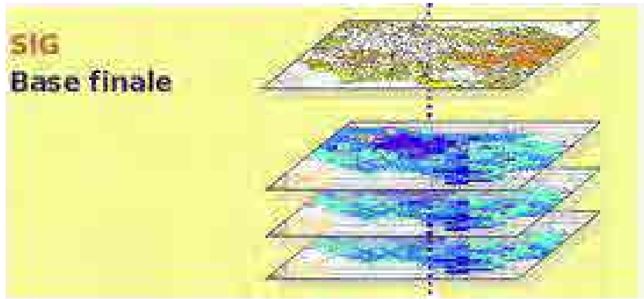
Preparing Spatialised Input data = simulation units

Simulating N_2O fluxes using CERES-EGC

Spatialised output N_2O fluxes weighed by simulation units







Soiltypes
Landuse
administrative regions
(cultural practices)
meteo

Daily N_2O fluxes (g N-N_2O /ha) for each culture

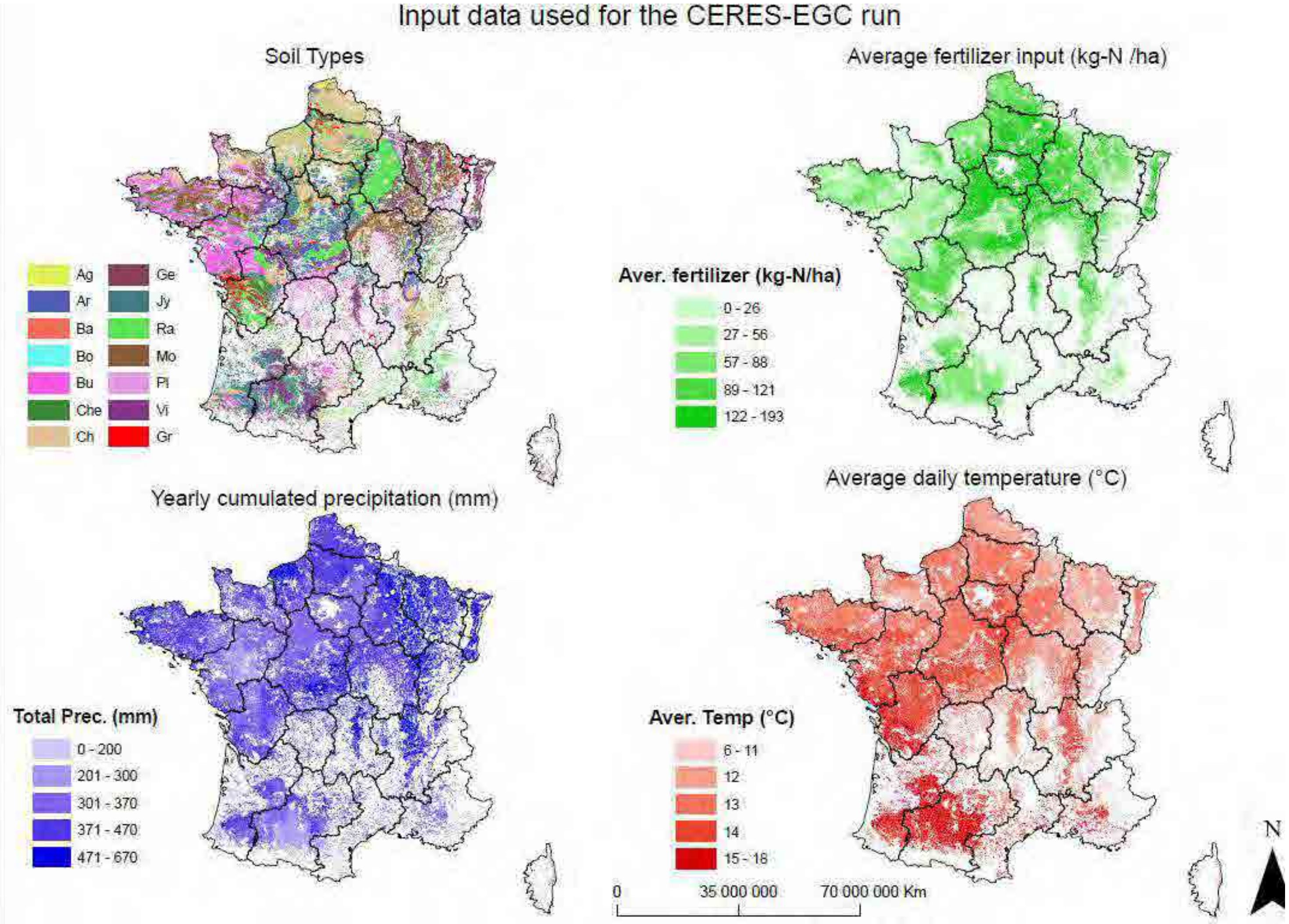
N_2O fluxes projected on Chimère grid

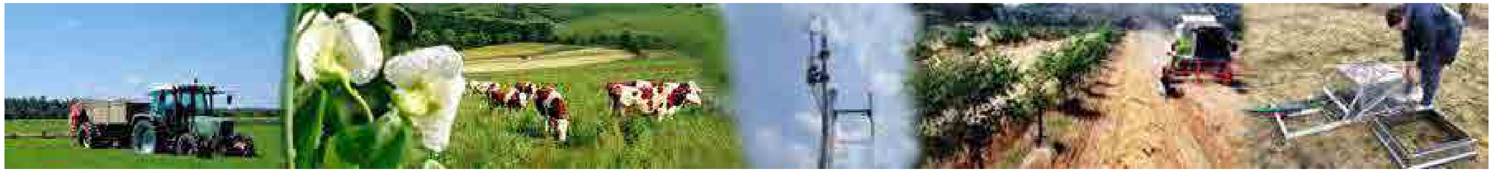
12120 simulation units over France

Total N_2O flux per simulation unit

Total N_2O flux per simulation unit

The Input data





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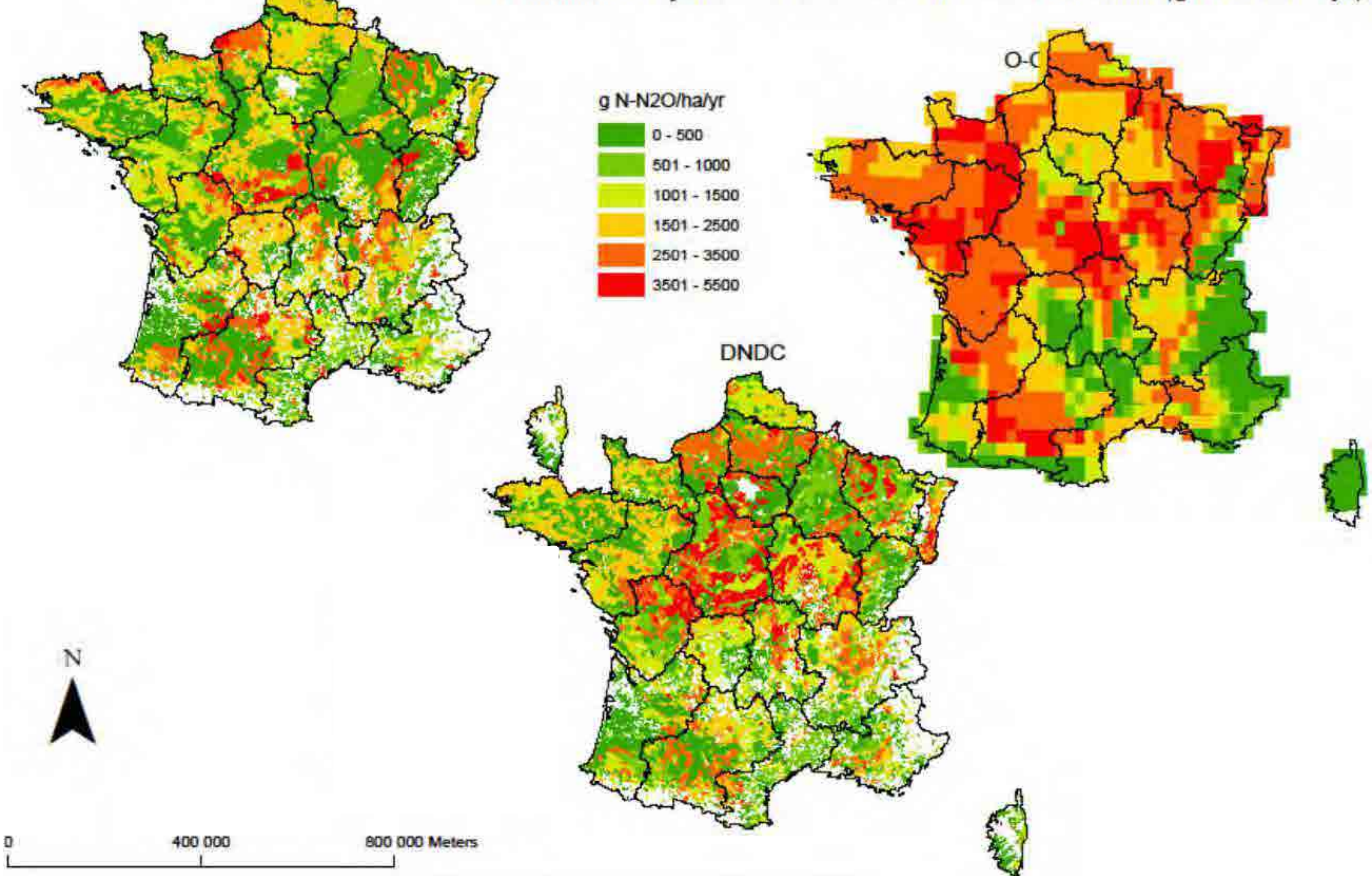
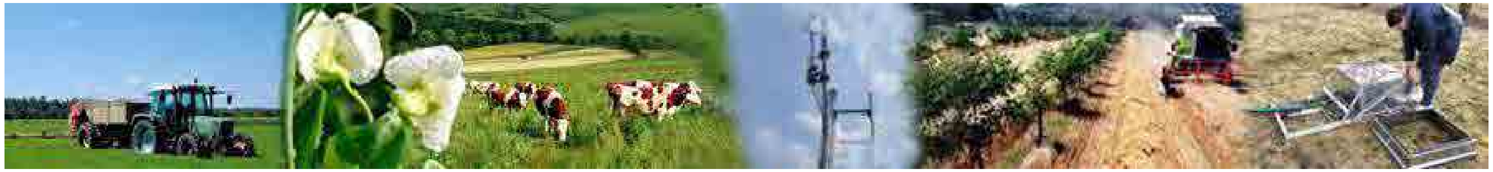
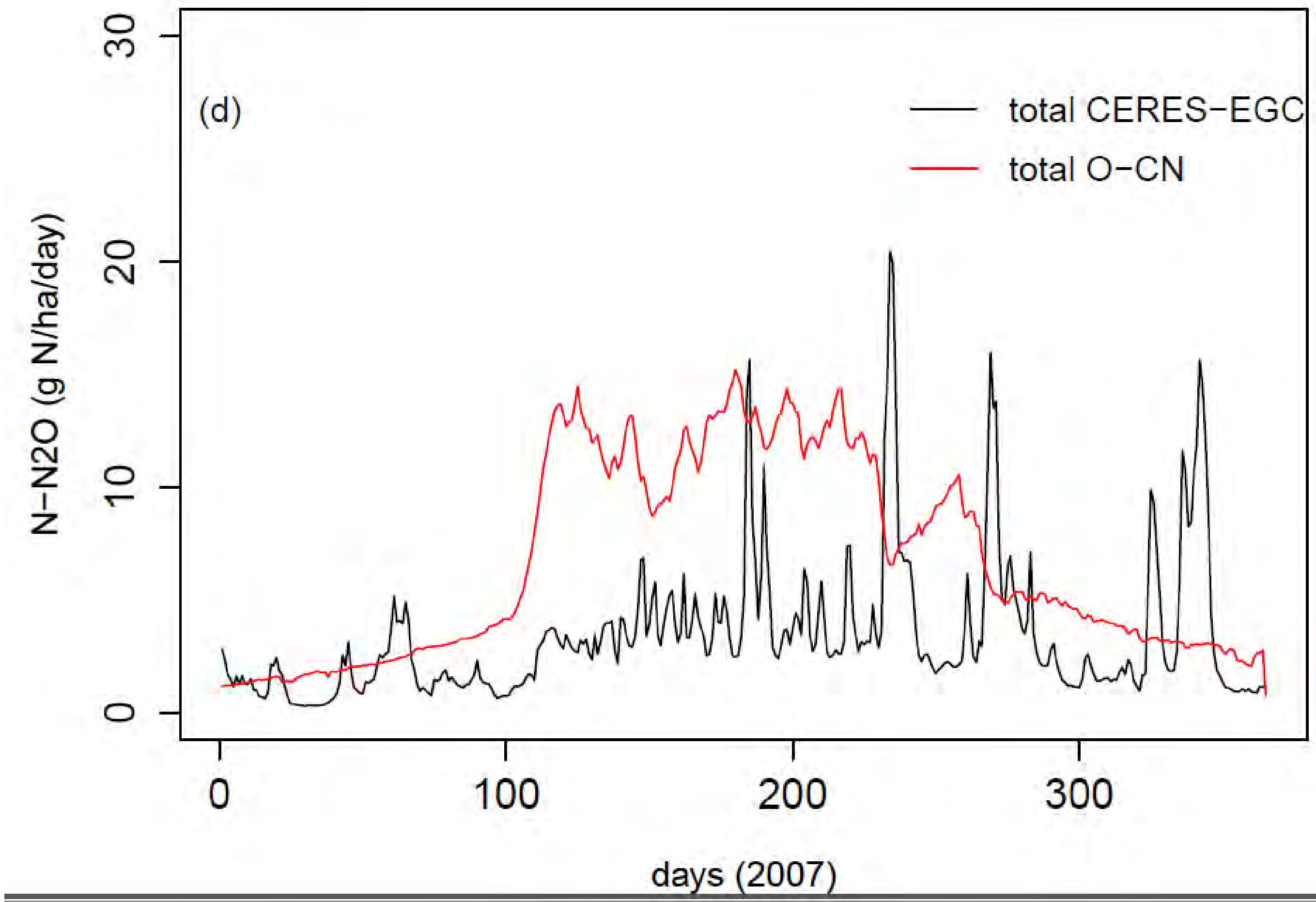
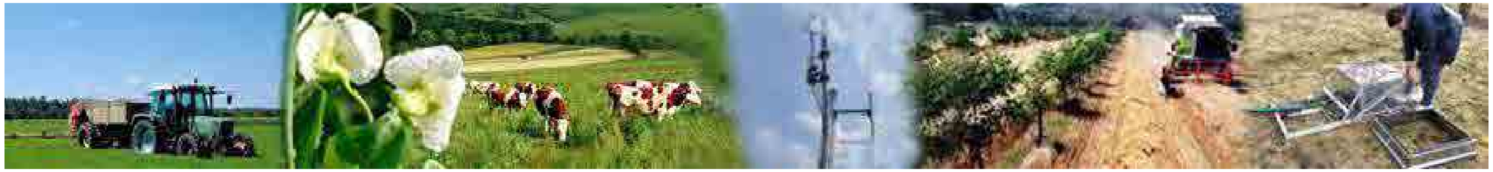
Spatial distribution of yearly N2O emission in France as simulated by the CERES-EGC and O-CN models (g N-N20/ha/yr)



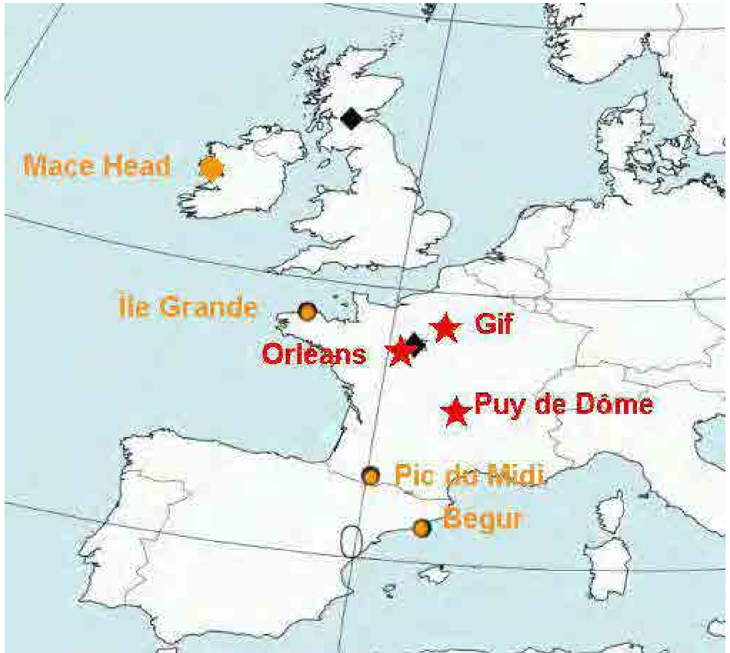


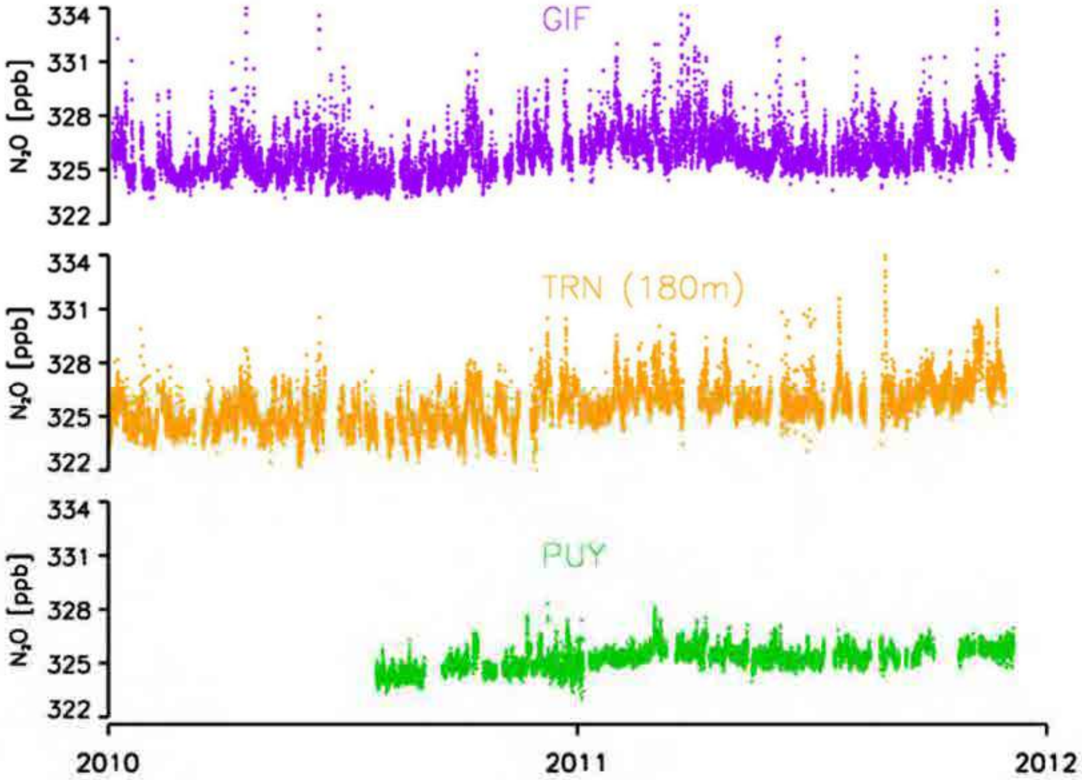
Yearly mean emissions over France



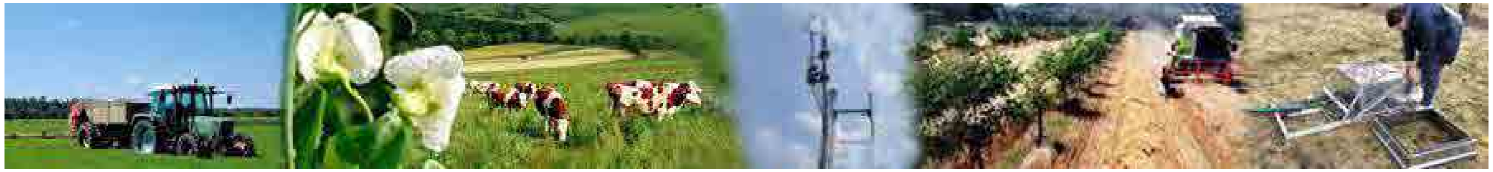


The measurements

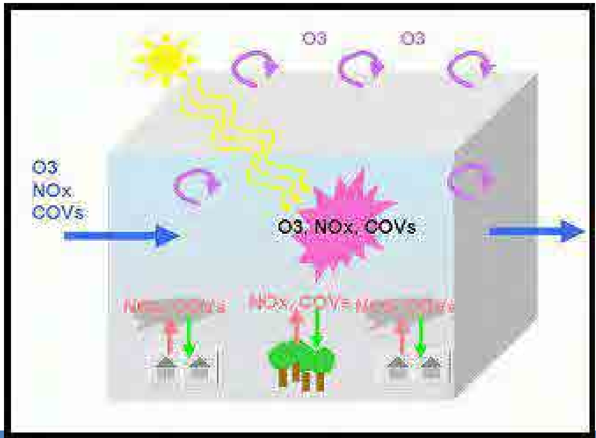




Measurement sites and Atmospheric N_2O mixing ratio using gas-chromatographic measurement systems equipped with ECD (Electron Capture Detector) *in 2010 and 2011 at the stations Gif-sur-Yvette (Gif), Trainou tower (TRN) and Puy de Dome (PUY).*



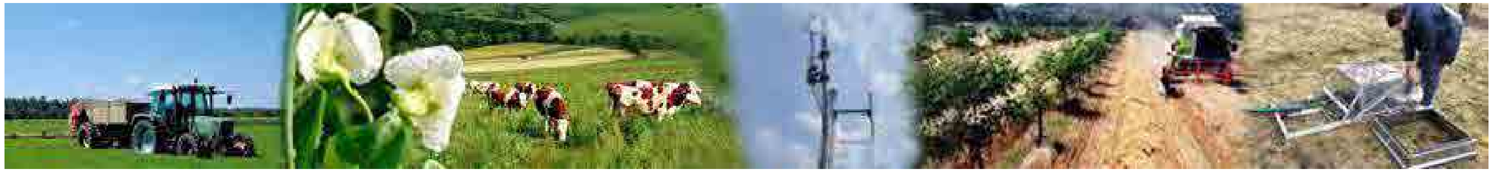
The link between ecosystem models and measurements



The Chimere Chemistry and Transport model

Besagnet et al., 2010

Flux scenarios	S1	S2	S3	S4	S5	S6
Anthropogenic EDGAR 4.0	X	X	X	X	X	X
Natural soils						
Bouwmann et al., 1995	X	X	X			
OCN-HR (Prieur 2012)				X		
CERES + OCN-HR					X	
DNDC + OCN-HR						X
Biomass Burning GFED-v2, van der Werf et al.	X	X	X	X	X	X
Oceans						
Nevison et al., 1995		X				
Nevison et al., 2004			X	X	X	X
PISCES (Bopp, pers. comm.)	X					



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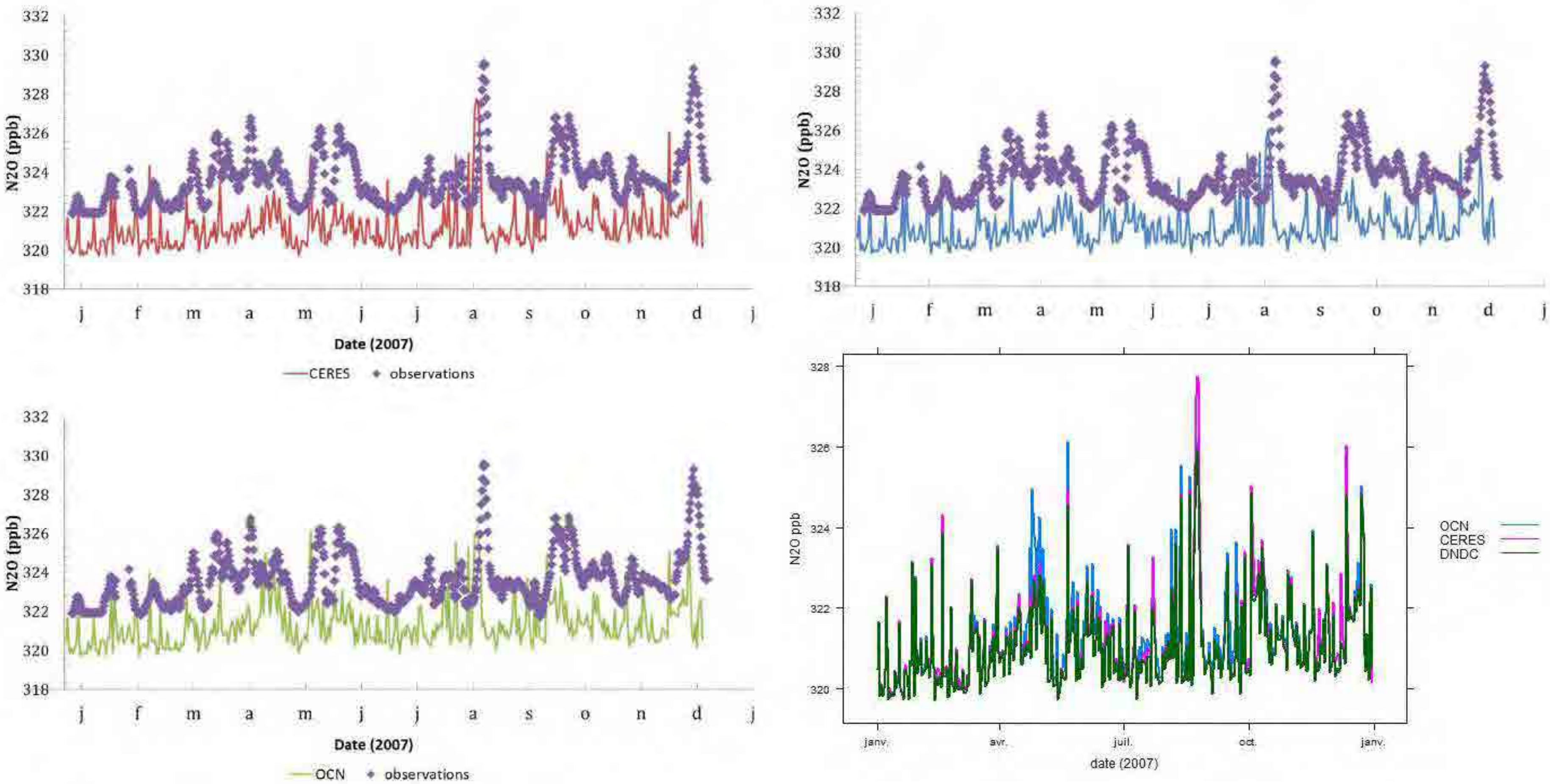
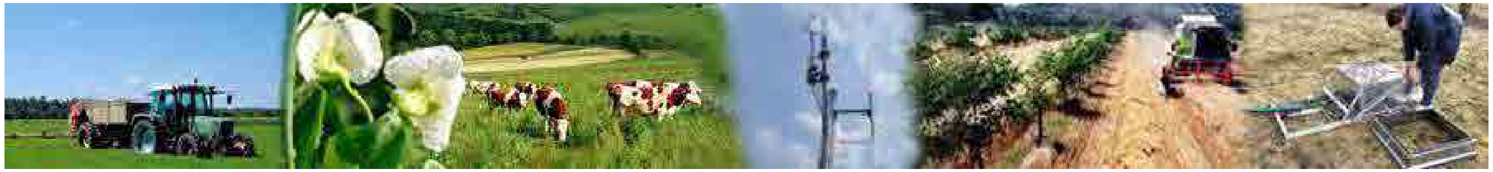
How do the models perform?



Giff sur Yvette



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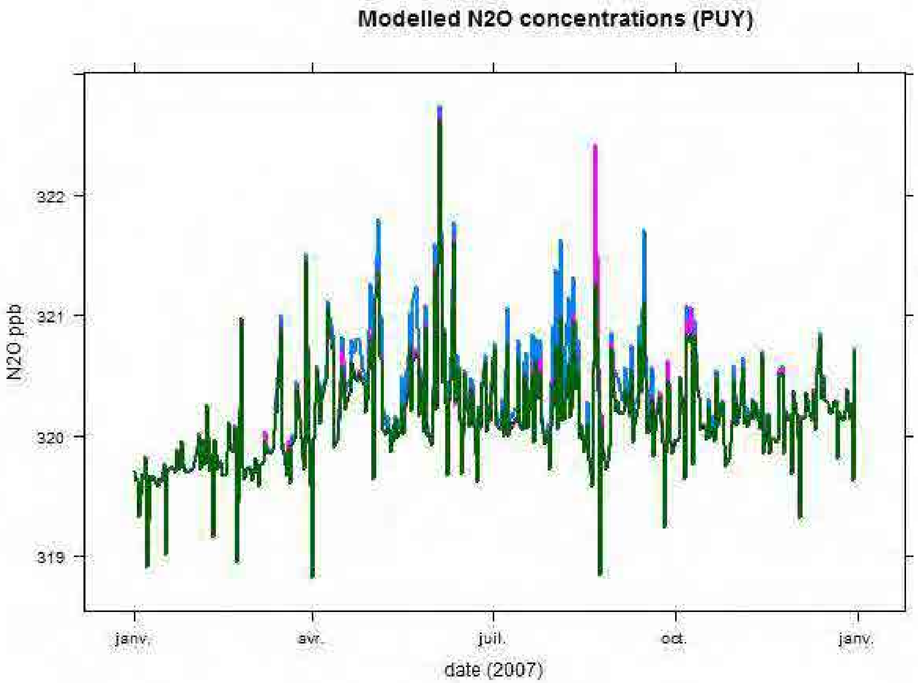
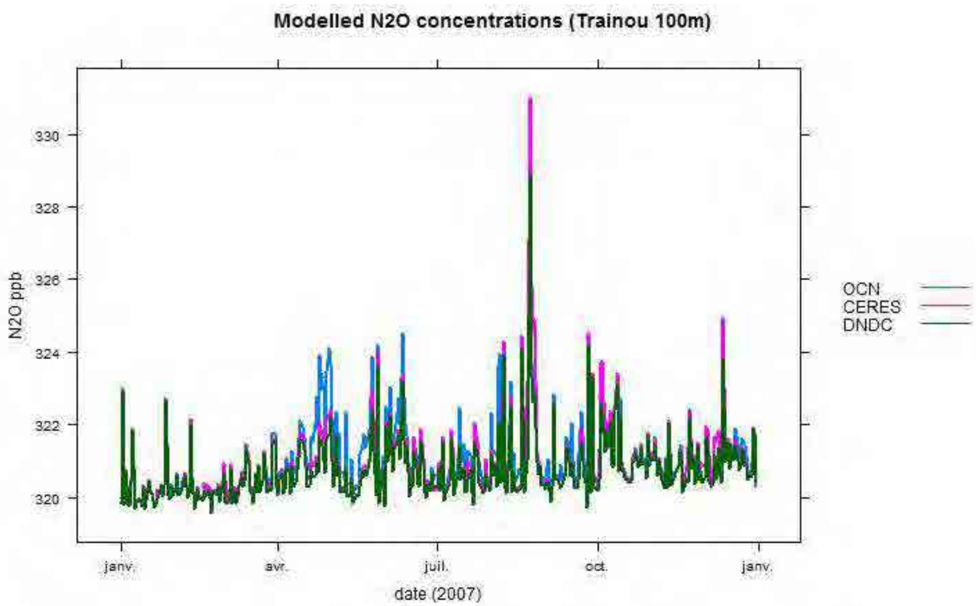
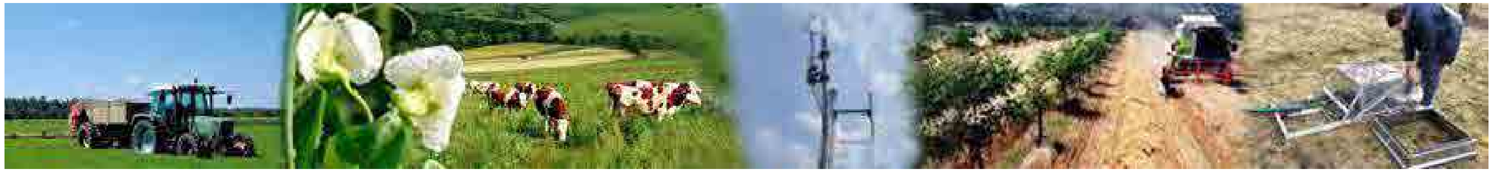
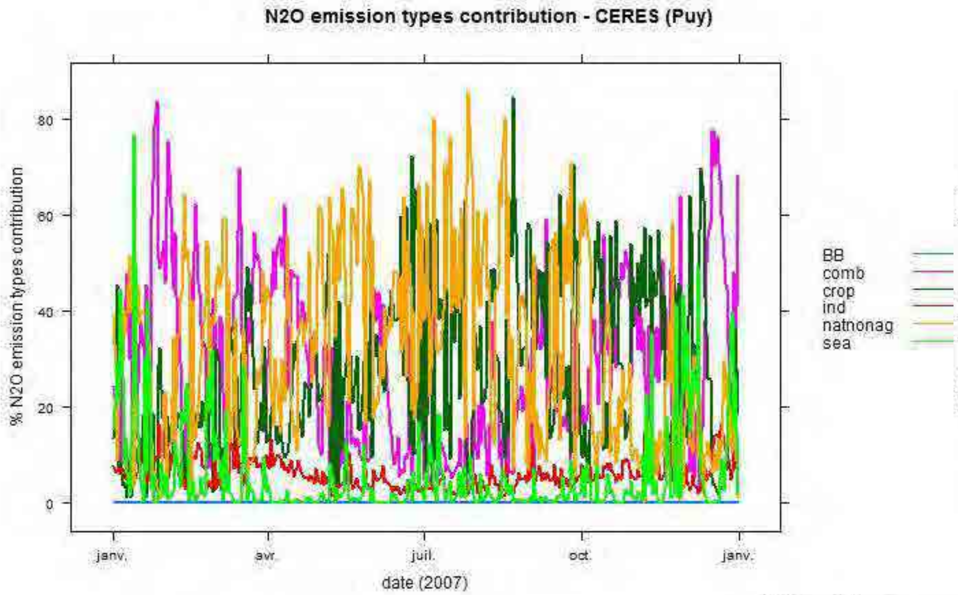
And at the other sites …

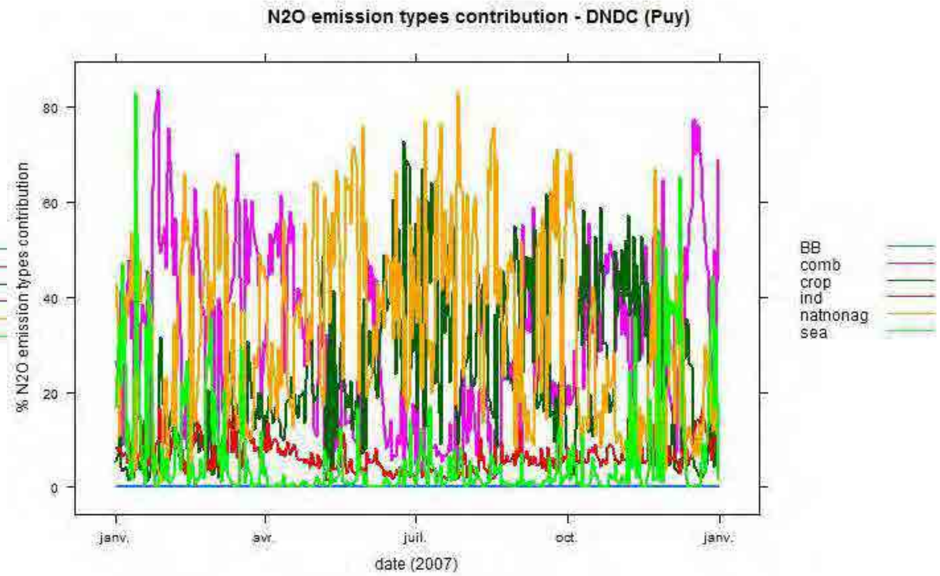


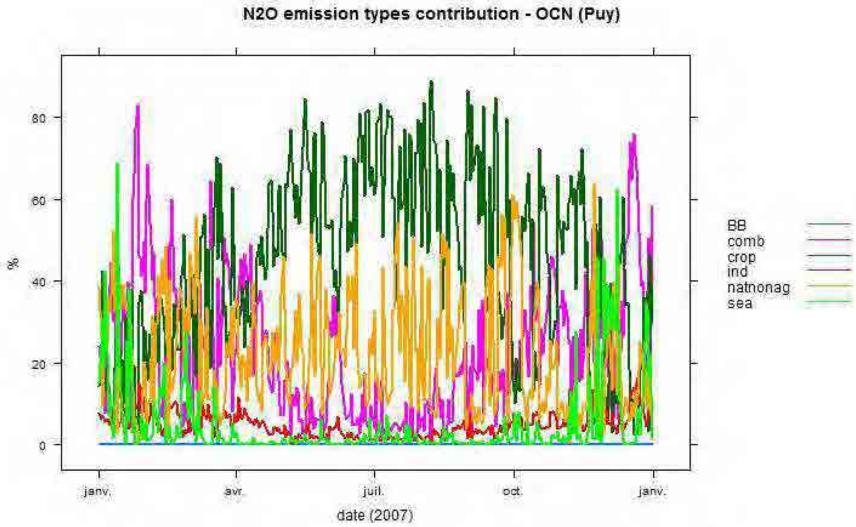


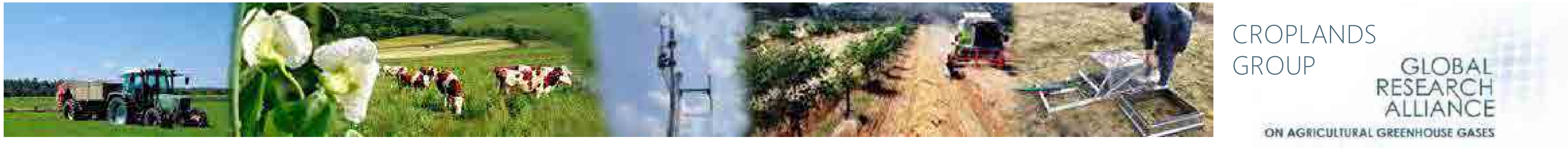


What are the main contribution sources?









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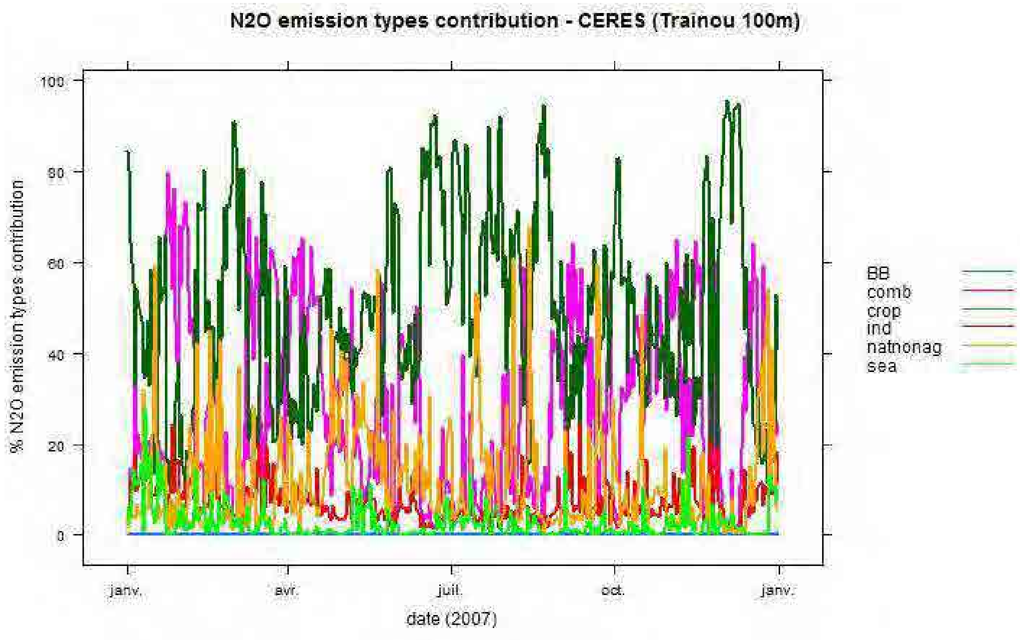
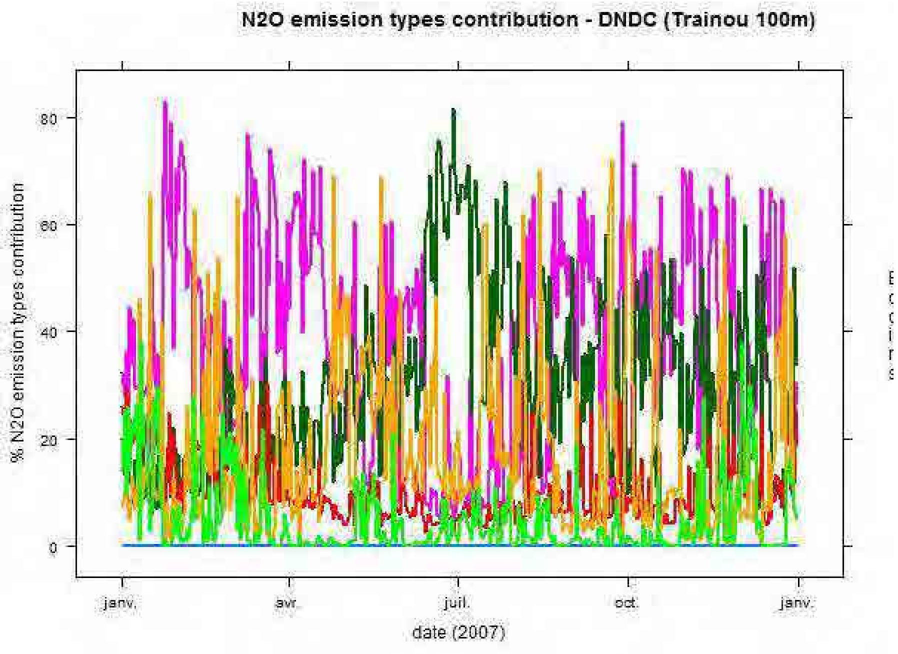
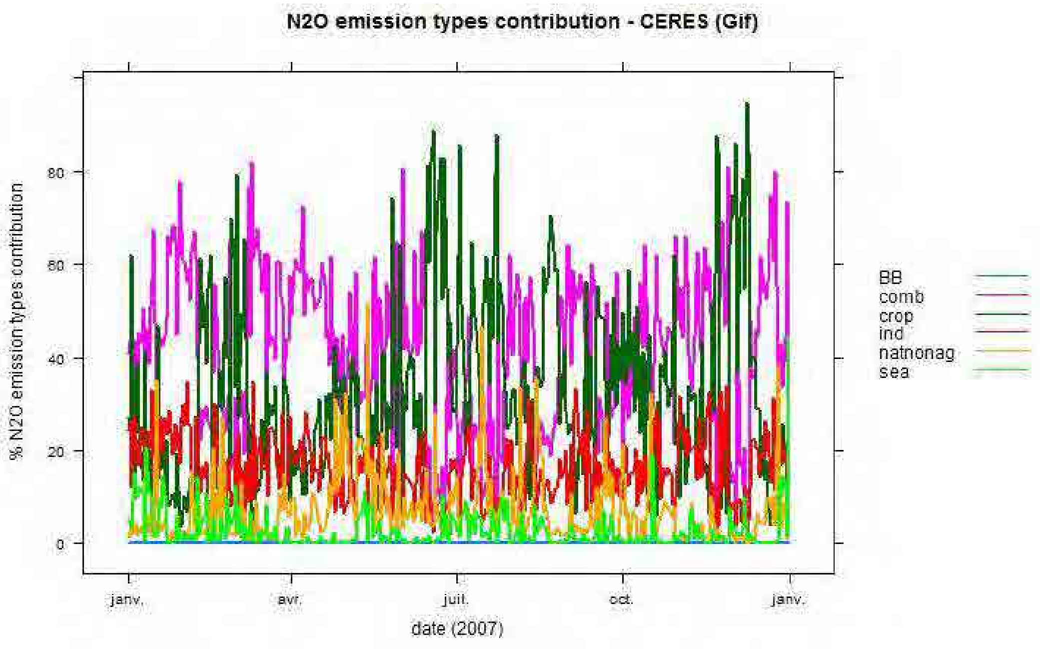
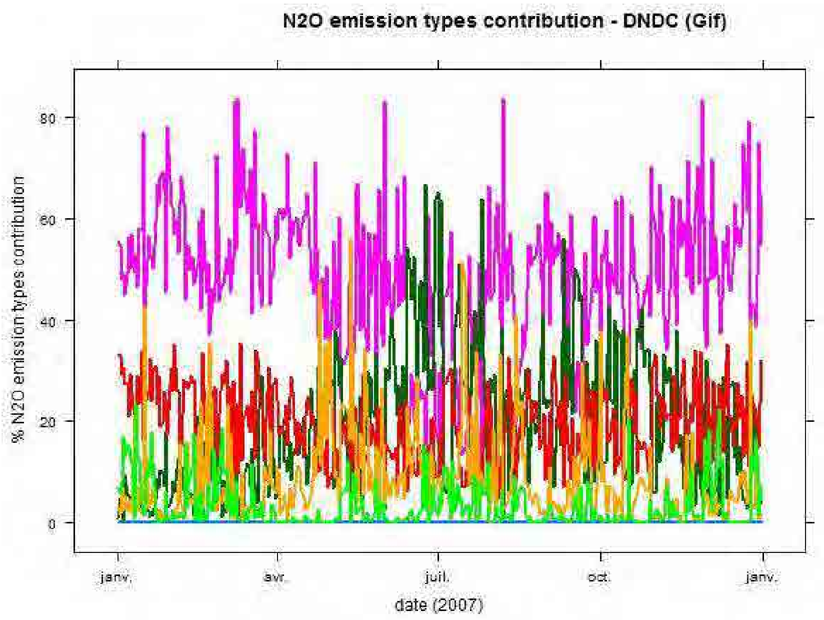




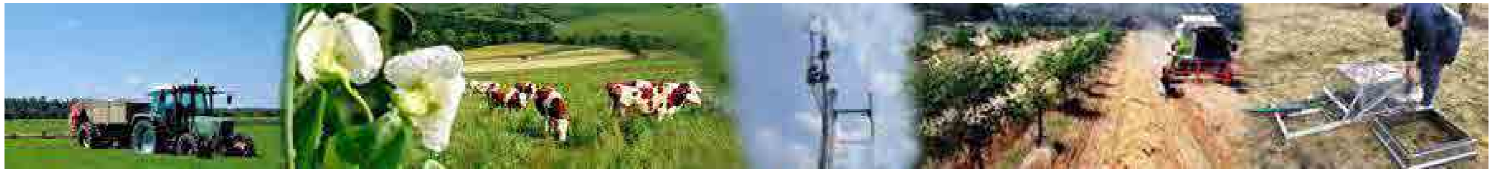
What are the main contribution sources?





Tentative N_2O budget for France (2007)

Gg N/yr	Edgar32 (2000)	O-CN (2007)	CERES (2007)	CITEPA (2007)
Industry and transport	51.89	24.25	24.25	24.25
Wastewater treatement	11.82	11.82	11.82	
Sub-total Non Biogenic	**63.71**	**36.07**	**36.07**	**24.25**
Land Use Change	2.86	2.86	2.86	2.86
Unfertilized forests end grasslands		20.90	20.90	20.90
Grazed or fertilized grasslands				10.62
Direct from Arable crops (N fixation)				6.47
Direct from Arable Crops (Mineral fert.)	40.86	39.56	20.10	30.23
Direct from Arable Crops (Organic fert.)	12.21			11.59
Indirect emissions (N leaching)	28.41	3.00	3.00	35.64
Indirect emissions (Atmos. deposition)	5.26		3.00	6.73
Indirect emissions (crop residues)	29.09			6.66
Manure (confined)	6.24	6.24	6.24	7.08
Sub-total Biogenic	**124.93**	**72.56**	**56.10**	**138.79**
TOTAL	**188.64**	**108.63**	**92.17**	**163.04**



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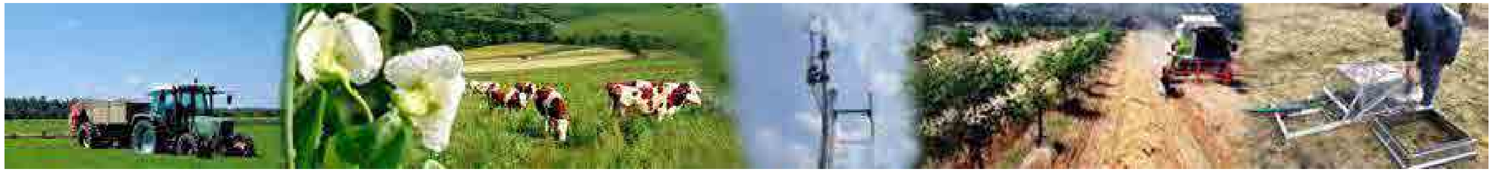
Take home message

- Emission models tend to undersetimate emissions when compared to concentrations retrieved in 3 tower measurements in France
- Estimates of direct emissions were closer between models and inventories, but still varied within a factor of 2
- We probably are missing some sources in the emission maps – probably linked to unavailability of data at the France scale (organic fertilizer application, etc.)
- Closing the gap with the top-down estimate implies that the lower end of the emissions is more probable, resulting in an emission factor of 0.5 % rather than the 1% (Tier 1 value)
- This would have a large impact on the GHG balance of crops in France, but should be mitigated by the fact that it strictly applies to 2007
- Similar estimates should be carried out for other climatic years to confirm this trend



Thank you for your attention