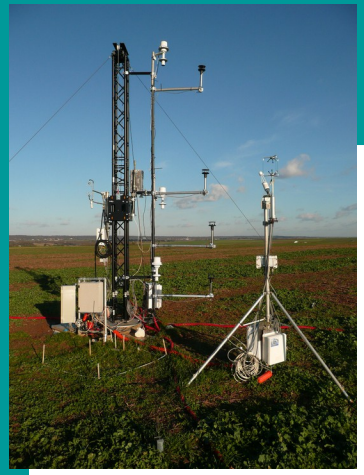

Measurement and modelling of N_2O emissions from oilseed rape: an overview of 20 years of research in France

Workshop on GHG emissions from oilseed rape cropping

Braunschweig, 4-5 March 2015

Benoît GABRIELLE[1], Pierre CELLIER[1], Catherine HENAULT[2], Marie-Hélène JEUFFROY[3]

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2: INRA, Soil Science Laboratory, Orléans, France
3: INRA, Agronomy Research Unit, Thiverval-Grignon, France

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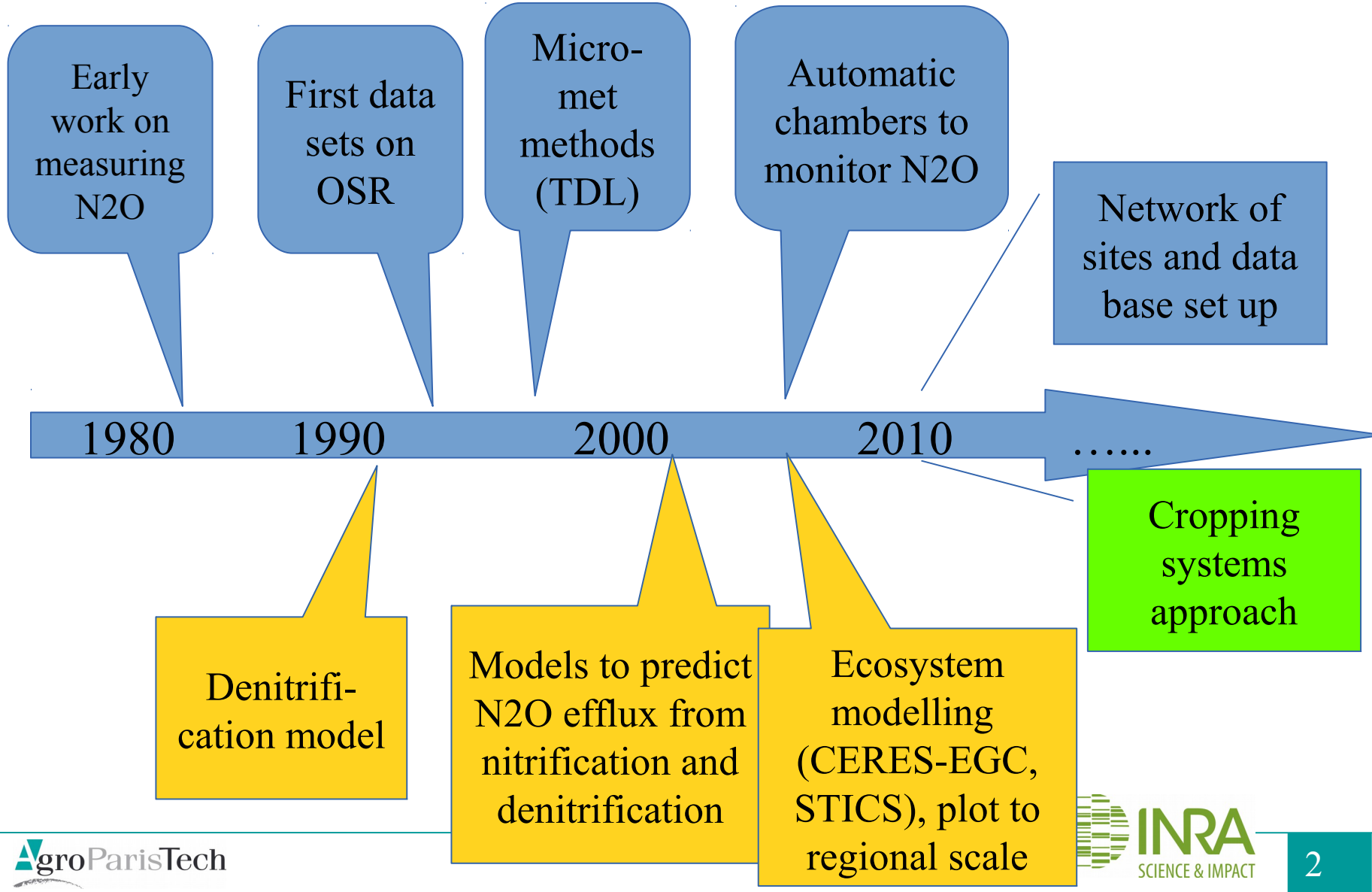
A historical perspective...



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Presentation outline

- Measuring and monitoring N_2O
- Biophysical modelling
- Scaling up and down
- Systems approach to mitigate emissions
- Conclusion and outlook

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Oilseed rape among the first crops monitored for N2O

Région		Référent	Période	Méthode	Flux max gN ha-1 j-1	Publi	BDI	Sol
Sud Ouest	Landes	Jambert Laville	90 - 95 - 96	CM MM	250	x	x	spodosol - podzol
	Landes	Mignot-Delprat	90-95	CM	120	?		
		Justes						
		Serça						
Sud Est		Serça						
		Renault						
Massif Central		Soussana Laville Hénault	depuis 2002	CM CA	20 / 100			basaltic andosol
Bretagne		Morvan Germon	2002	CM	75	x		luvisol redoxisol
		Durand P				x		
Bassin Parisien	Beauce	Hénault Nicoullaud Laville	98-2000	CM	20	x		haplic calcisol
	Beauce	Hénault Nicoullaud Laville		CM	10	x		neoluvisol
	Faux-Perche	Hénault Nicoullaud Laville		CM MM	100	x		gleyic luvisol
	Grignon	Génermont Hénault	2000	CM tunnel	40			
	Grignon	Laville	depuis 2006	CM CA	150			
Nord	Boigneville	Nicolardot	2003-2004	CM	20	x		haplic luvisol
	Boigneville	Mary	depuis 2008	CA	150			haplic luvisol
	Mons	Mary	depuis 2007	CA	130	en cours		orthic luvisol
Nord-Est	Reims	Parnaudeau		CS	5	x		
	Chalons/Champ	Cellier Hénault	94-95	CM MM	20	x	x	rendzic leptosol
	Colmar	Van Bischopinck				x	x	
	Bourgogne	Hénault	94	CM	20	x		
		Hénault Laville	95	CM MM	15	x		Gleyic luvisol
		Hénault	94-95	CM	20	x	x	Eutric Leptosol
		Hénault	94-95	CM	50	x	x	Gleyic luvisol
		Hénault	96-97	CM	75	x	x	Gleyic luvisol

Tableau en cours de construction

First data sets point to a large variability under OSR

Table 6 - *Comparison of the effect of different agricultural factors on the proportion of applied nitrogen lost as N_2O over a five month period following the N fertilization*

Facteurs étudiés*			**% de N appliqué émis en N_2O**
agronomique	climatique	pédologique	
Effet de la forme des fertilisants azotés apportés			
Colza fertilisé (170 kg N ha^{-1}) - nitrate d'ammonium - sulfate d'ammonium - urée - nitrate de potassium	Nord Est de la France - 1997	Luvisol (1)	0,53 0,55 0,42 0,42
Effet du niveau de fertilisation azotée apportée			
Colza fertilisé, dose - suboptimale - suboptimale + 100 kg ha^{-1}	Nord Est de la France - 1995	Moyenne de 3 types de sols différents	0,33 0,53
Effet des fluctuations interannuelles (conditions climatiques liées à l'année)			
Colza avec fertilisation suboptimale	Nord Est de la France - 1995 - 1997	Luvisol (1)	2,49 0,53
Effet lié aux caractéristiques des sols			
Colza avec fertilisation suboptimale	Nord Est de la France - 1995	Luvisol (1) Rendosol (1) Calcosol (1)	2.49 0.18 0.66

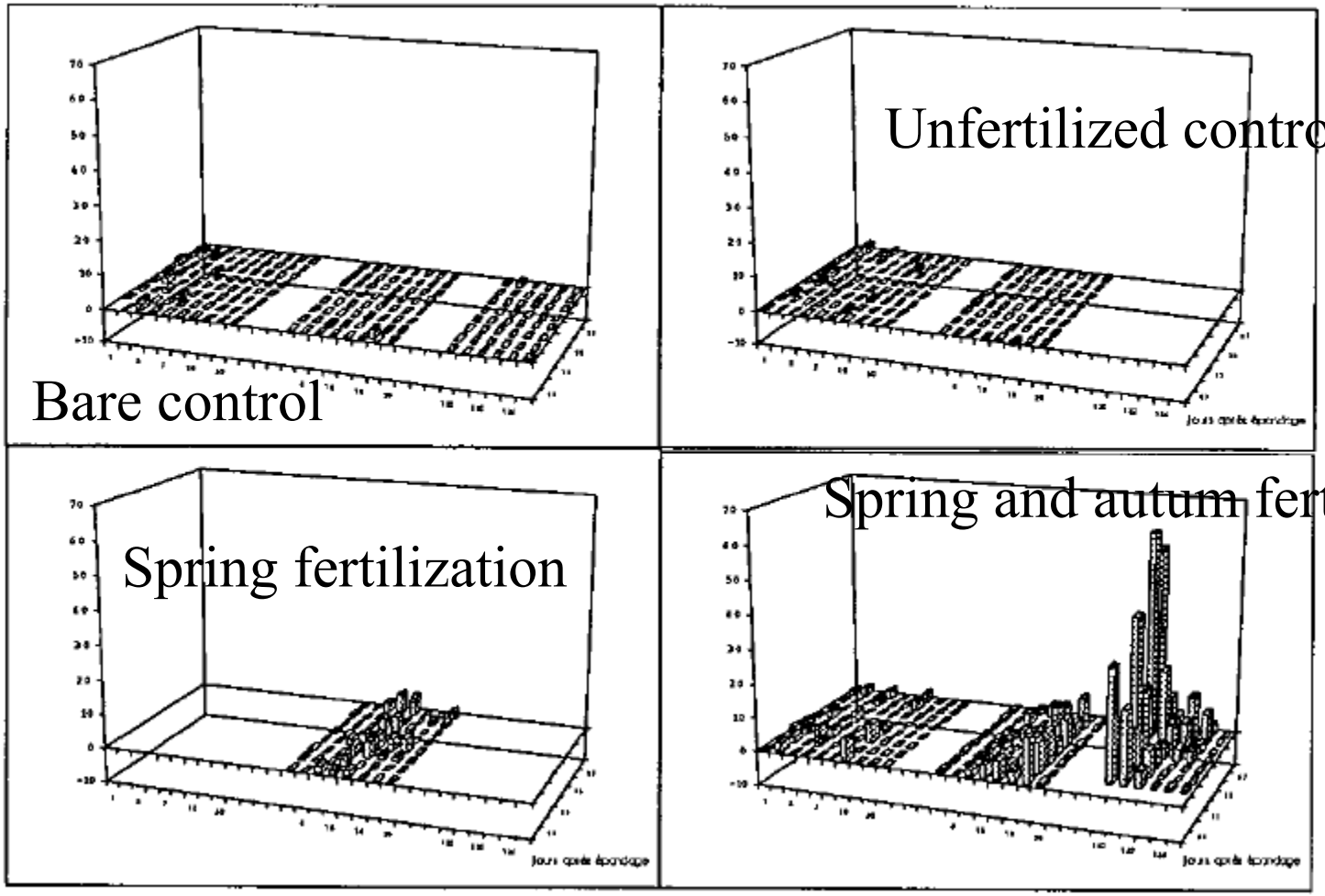
**: les facteurs étudiés sont mentionnés en caractères gras.*

(1) Luvisol : sol lessivé ; Rendosol : sol superficiel sur craie ; Calcosol : sol brun superficiel sur plateau calcaire.

Emission factors

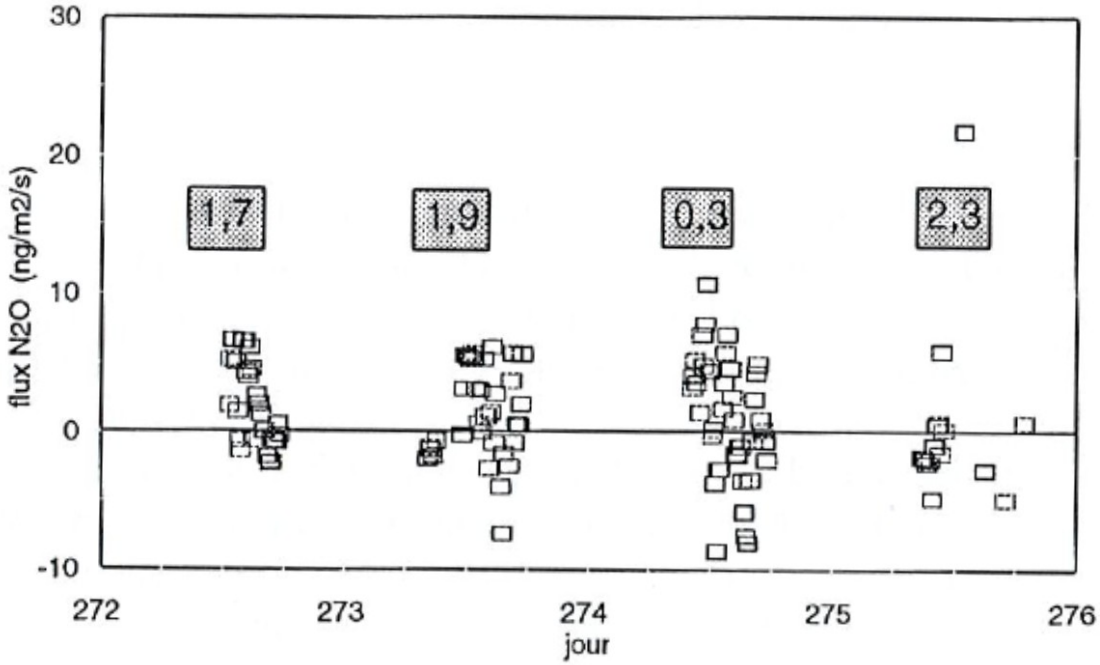
Germon et al., Etude et gestion des sols, 2003

Spatial variability vs fertilization effects



Measurements of N2O emissions over OSR in the Rafidin field (NE France) using static chambers and GC. Time axis is days after fertilizer application in the high-N plot (Gosse et al., 1999).

Micro-met monitoring proved challenging



Micro-meterological measurements of N2O emissions over OSR in the Rafidin field in the days following an autumn application of fertilizer N. Boxes indicate the daily totals in g N-N2O/ha/day (Gosse et al., 1996).

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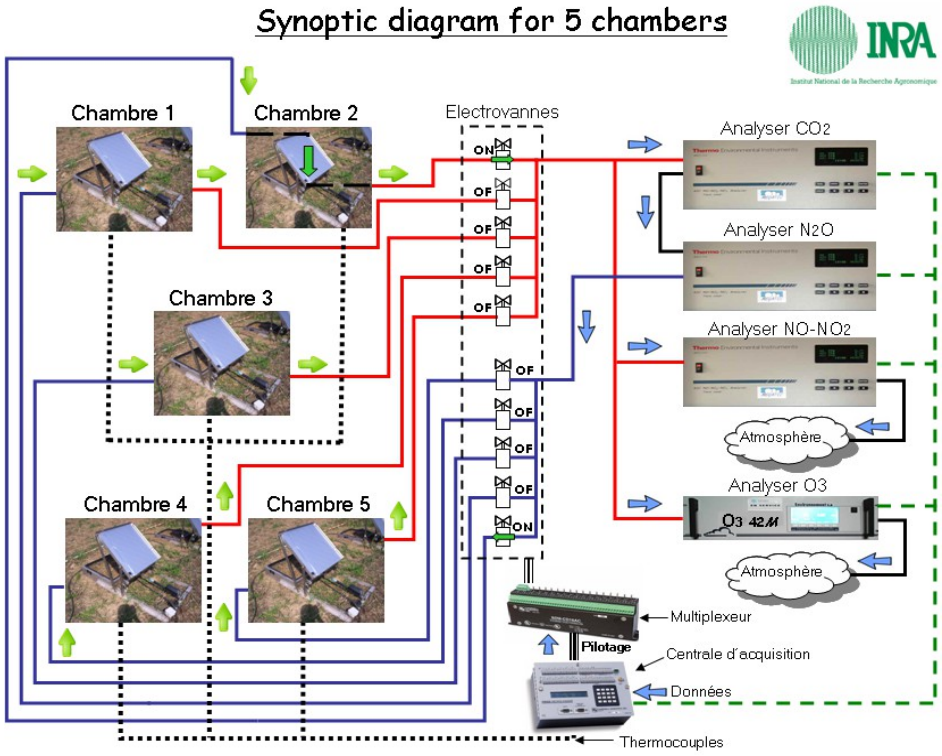
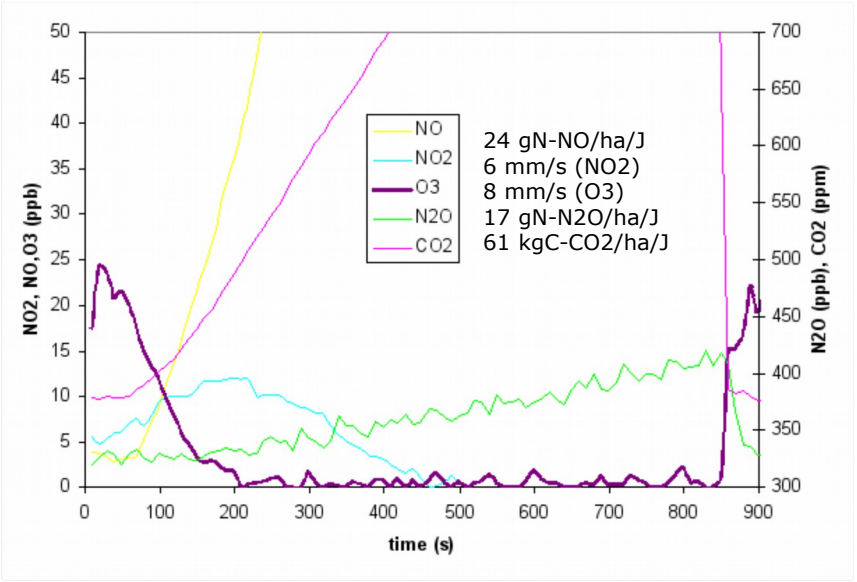
The development of automatic chambers ensured a continuous monitoring

(P. Laville, INRA)



$$F = \frac{V}{S}\frac{dC}{dt}$$

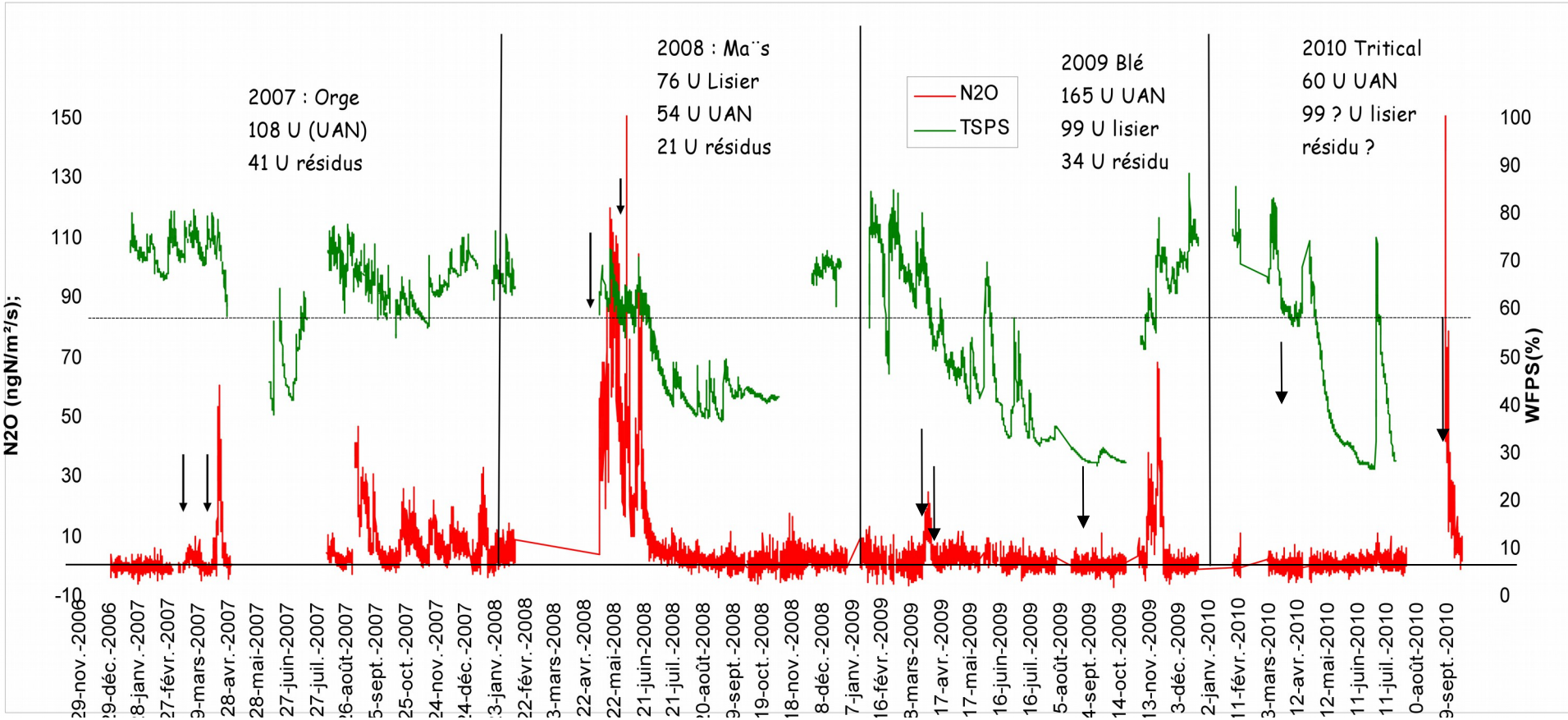


H= 10 cm
V=55 L

Measurement cycle of 90 minutes

Threshold emission levell ~ 2.5 ngN/m²/s

Time series of measured fluxes from 2007 to 2010 in Grignon



Loubet et al., Plant and Soil, 2011

Outline

- Measuring and monitoring N_2O
- Biophysical modelling
- Scaling up and down
- Cropping systems approaches to mitigate emissions
- Conclusion and outlook

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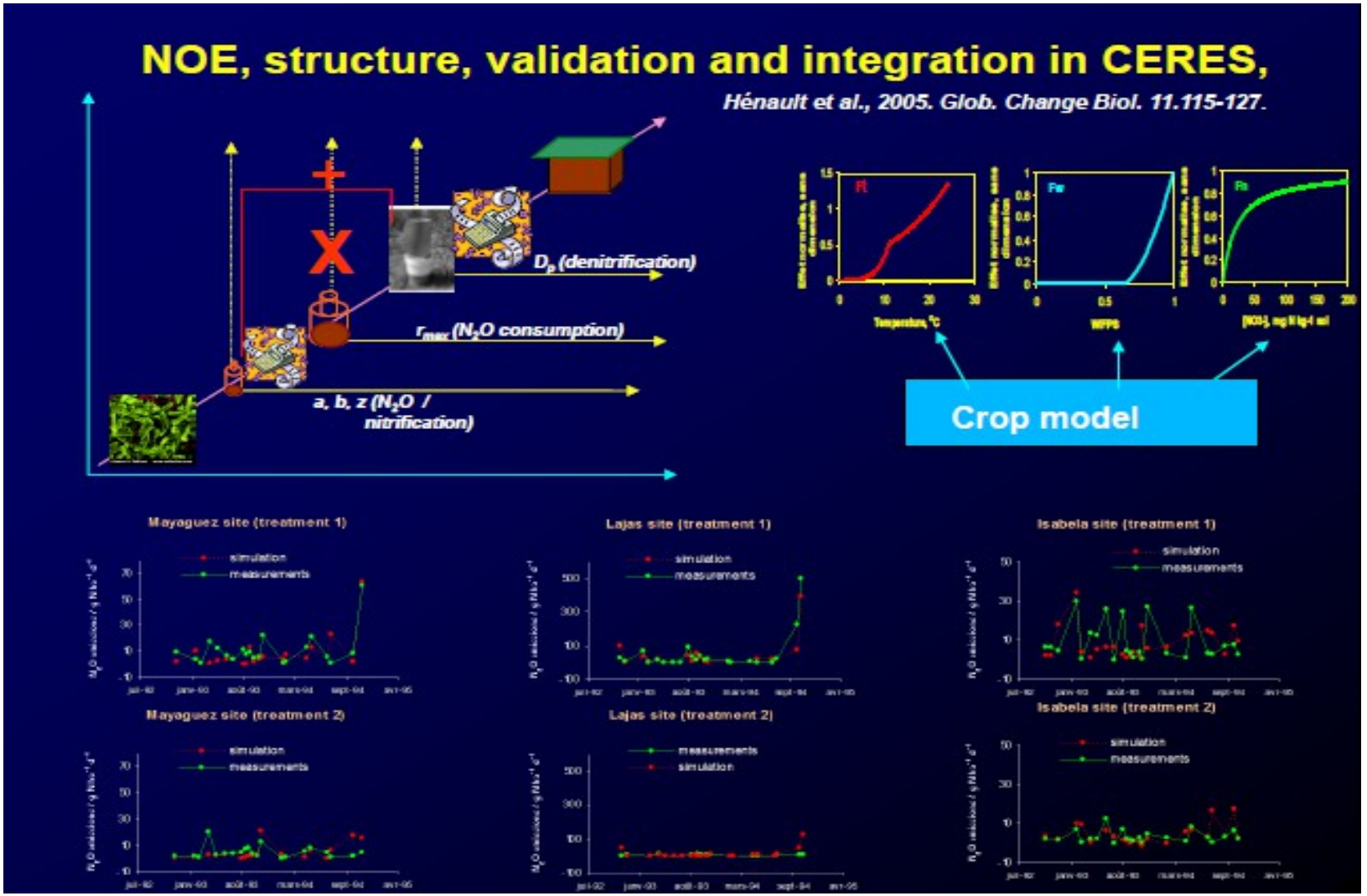
NOE, an algorithm for calculating N_2O emission at the field scale



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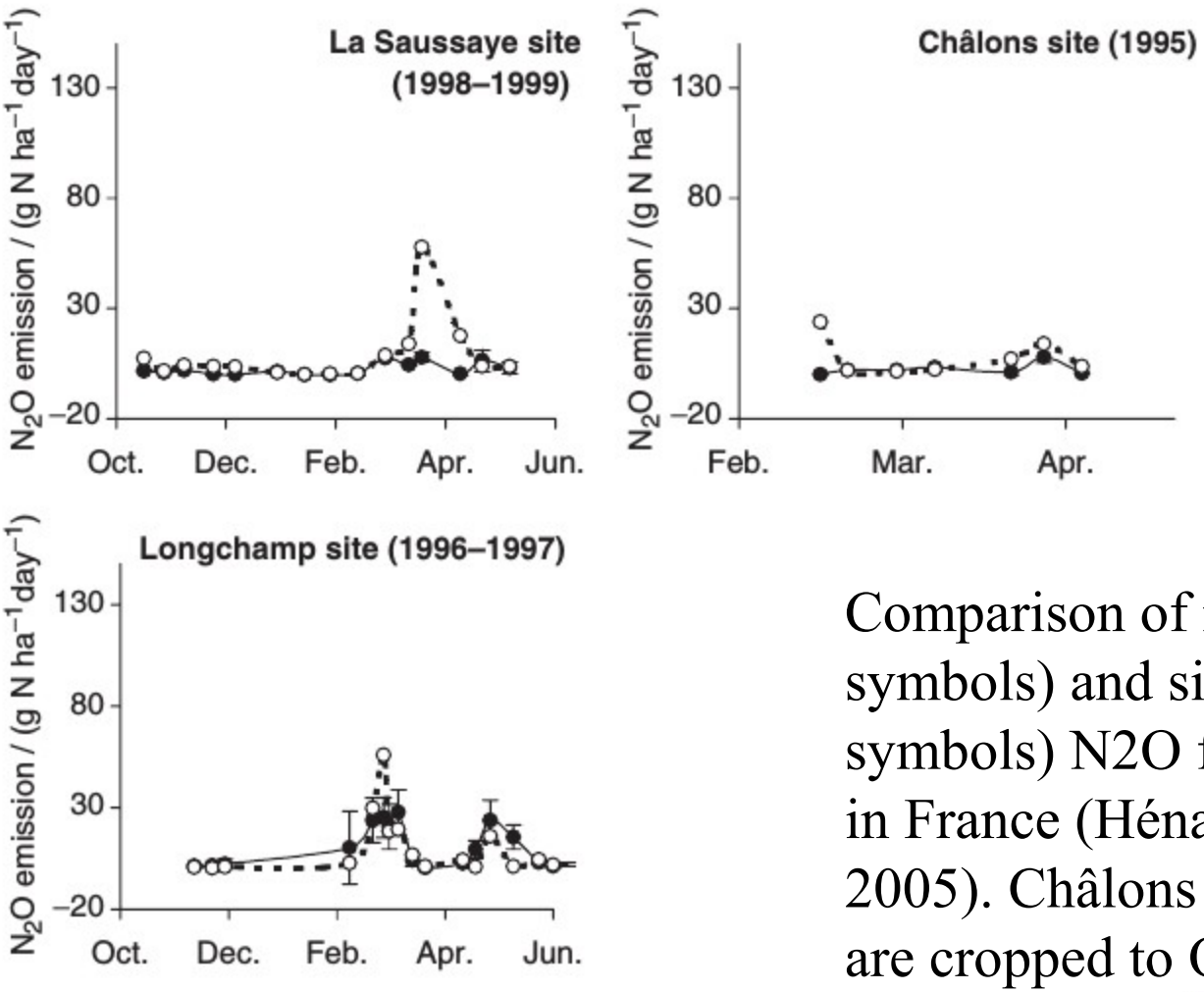
Field test of the NOE model



Comparison of measured (full symbols) and simulated (open symbols) N2O fluxes at 3 sites in France (Hénault et al., GCB, 2005). Châlons and Longchamp are cropped to OSR.

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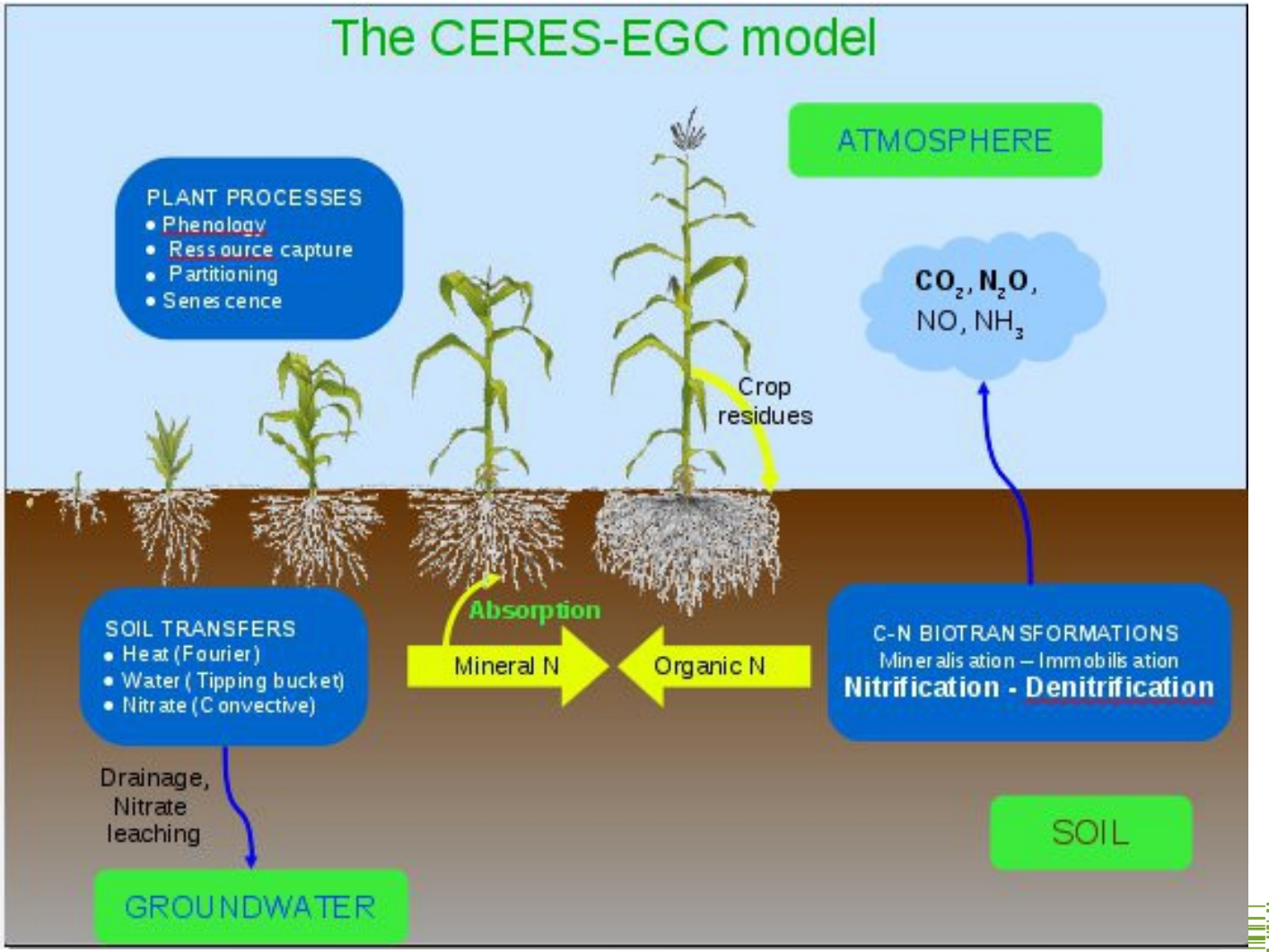
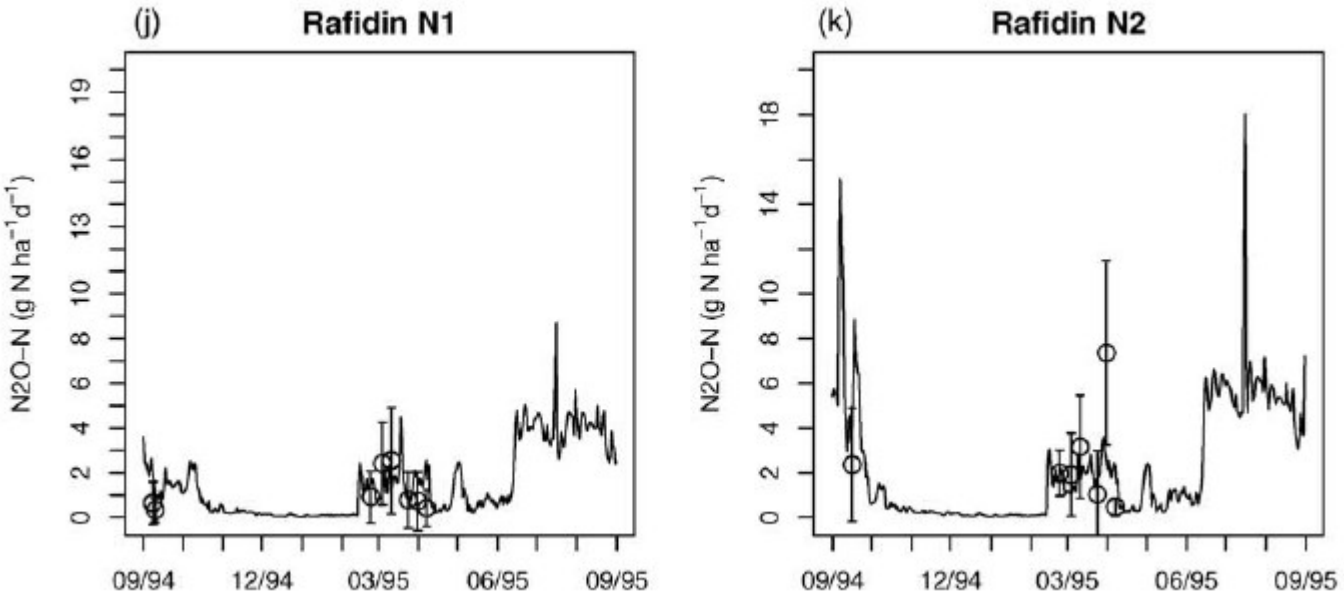
Integration into an ecosystem model



Gabrielle et al. 2006

Test of an ecosystem model in an OSR trial



Comparison of measured (symbols) and simulated (lines) N2O fluxes at 3 sites in France (Lehuger et al., AGEE, 2010).
N1 and N2 are two fertilization levels (135 and 270 kg N/ha).

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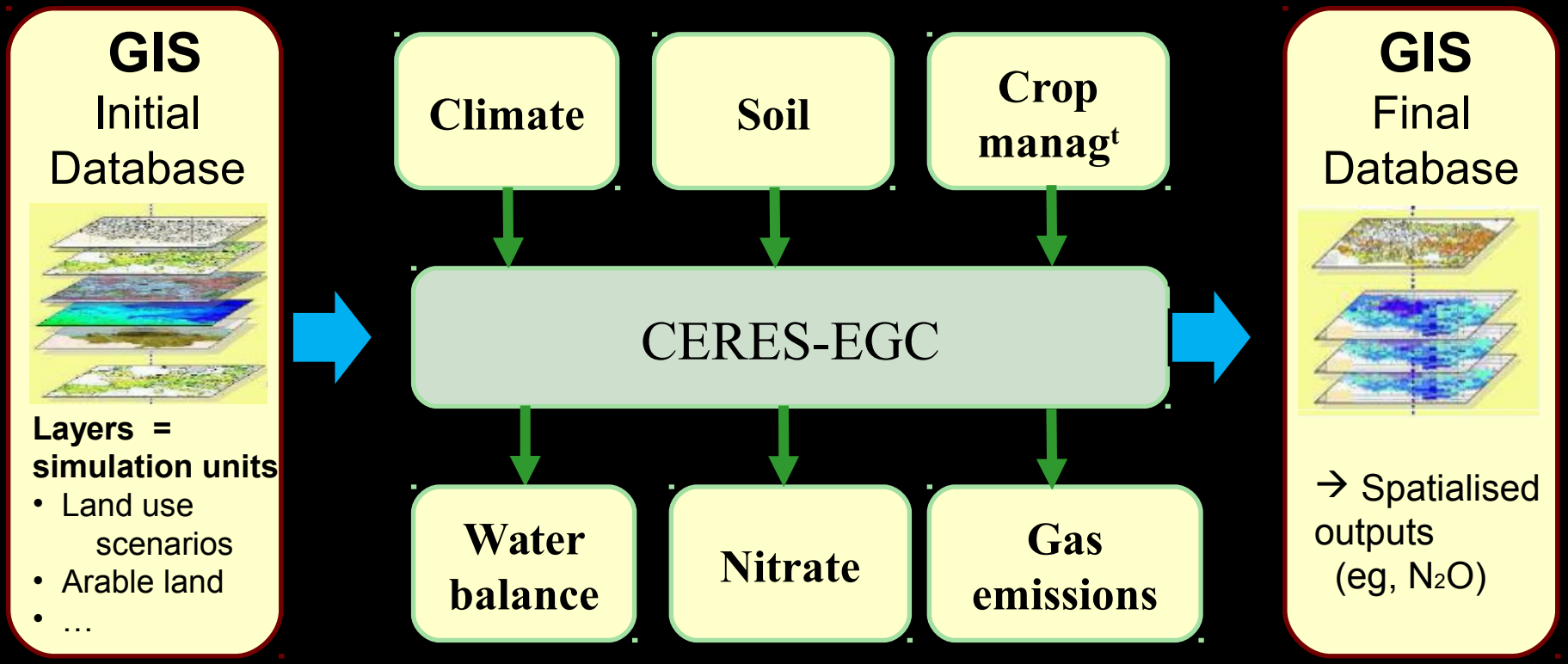
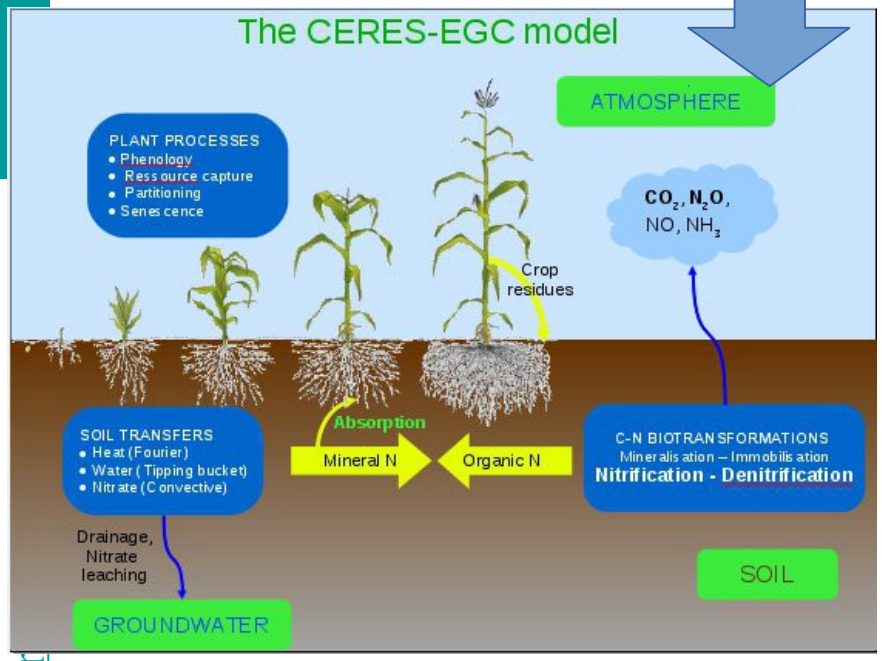
Regional extension



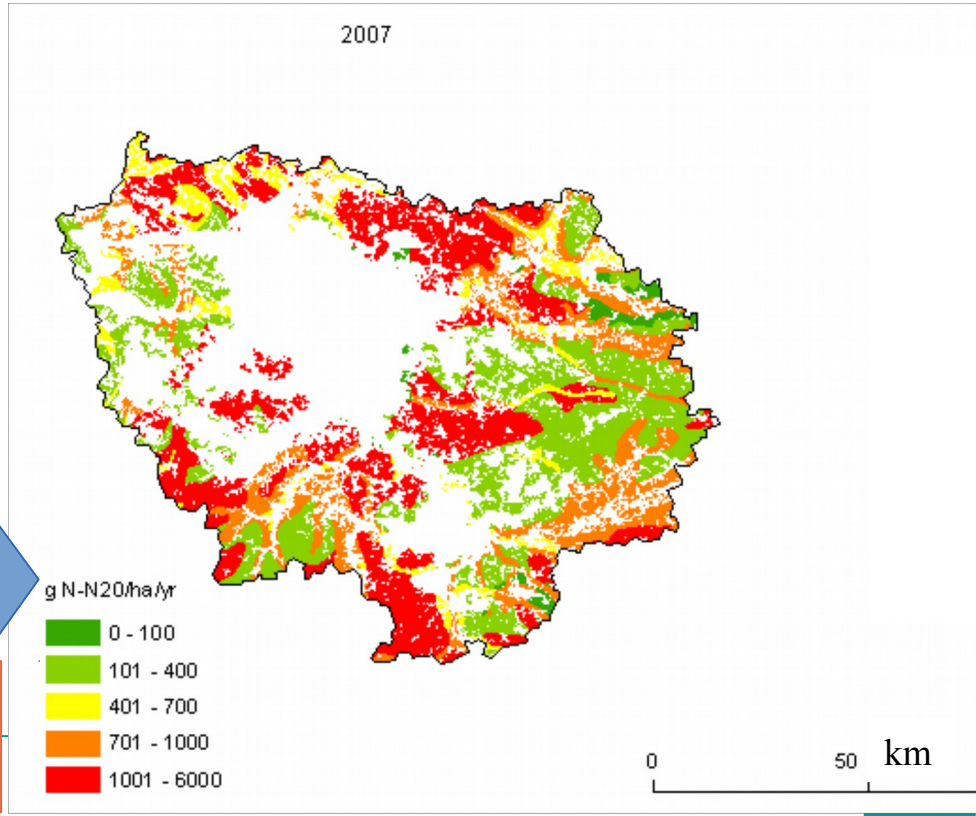
Rolland *et al.* 2007

Example in Ile de France

Climate : CRU-NCEP (Carboeurope IP)
Vegetation map : Corine land cover 250 m
Soil map : 1 : 1 000 000 EU soil map (JRC)
N fertilizer inputs : survey and census data
Biological N fixation : model-predicted



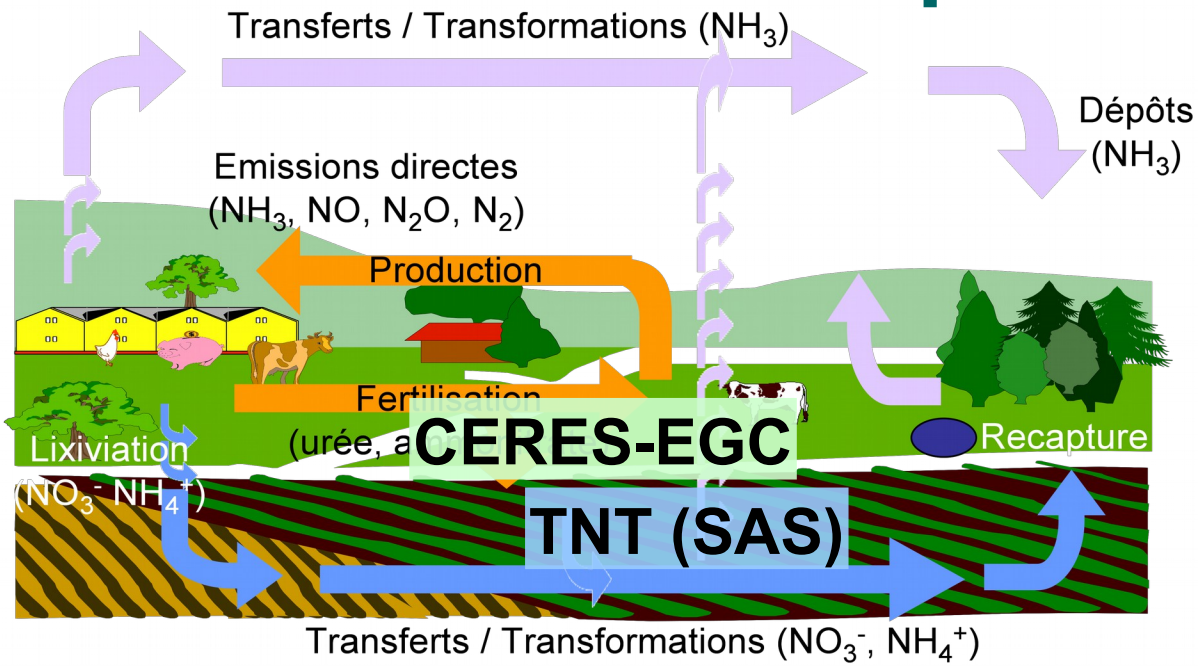
Schematic of CERES-EGC (Gabrielle et al., 2006)



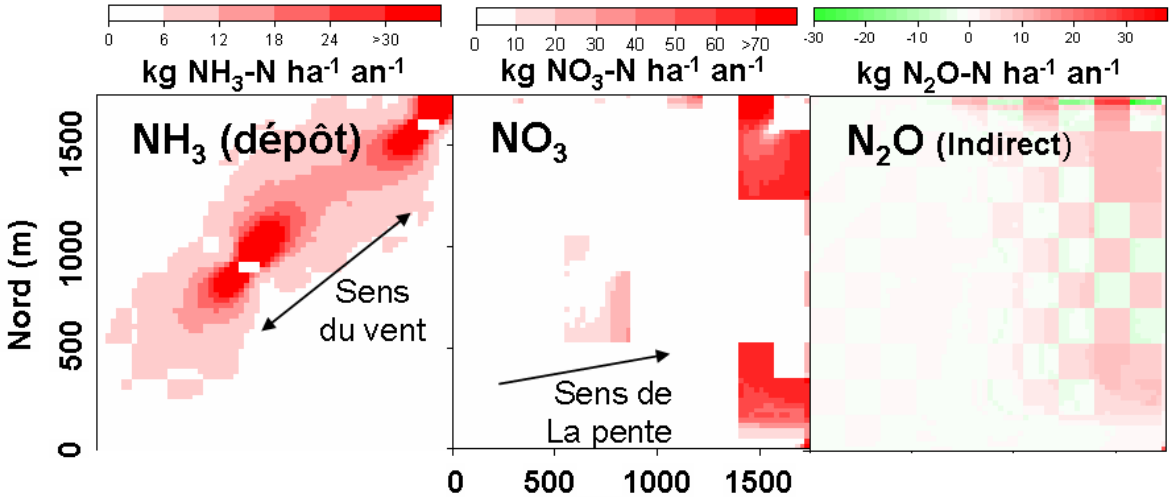
Map of annual fluxes over Ile de France in 2007

www.agr

Accounting for Nr flows at landscape scale : the Nitroscape model



Duretz et al. (2011)



Slide : JL Drouet, INRA

Outline

- Measuring and monitoring N_2O
- Biophysical modelling across scales
- Scaling up and down
- Systems approach to mitigate emissions
- Conclusion and outlook

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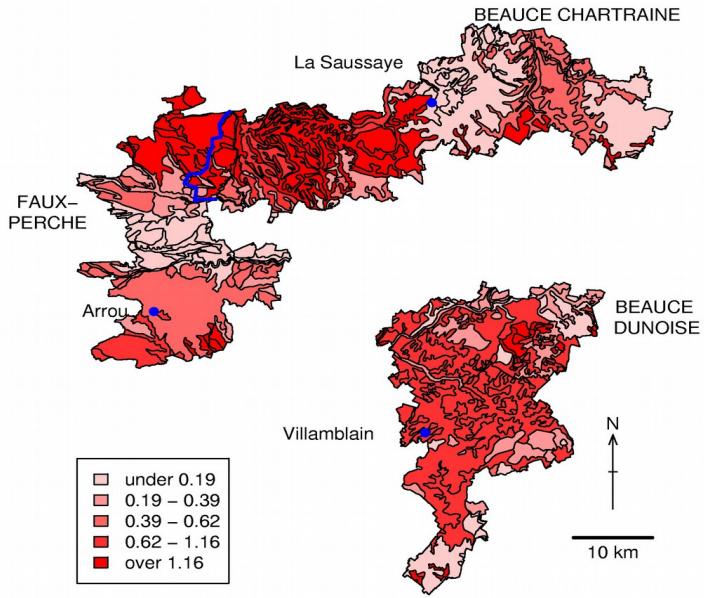
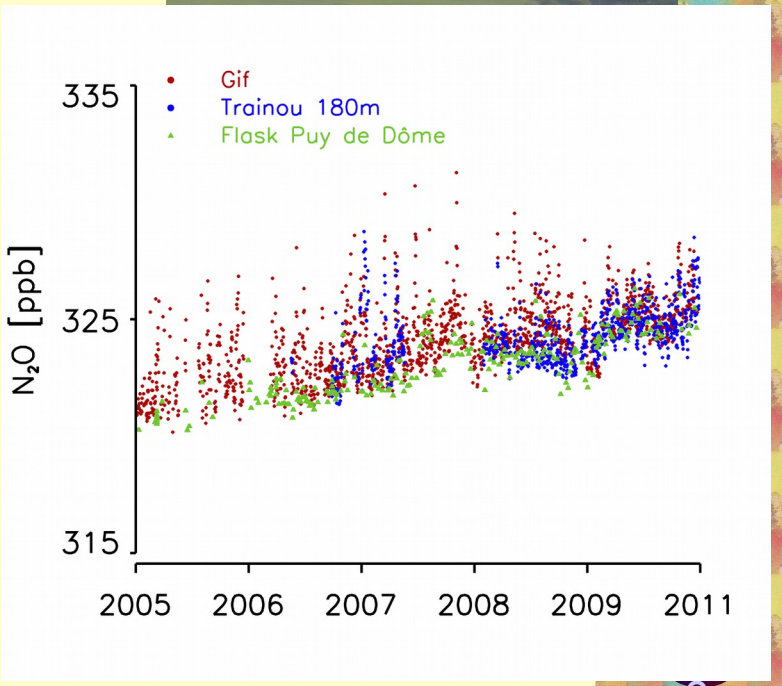
How to capture regional emissions ?



Simulation of N_2O fluxes (kg N_2O-N ha^{-1} yr^{-1}) over wheat crops in the Beauce region (central France). (Gabrielle et al., 2006).

Ecosystem models

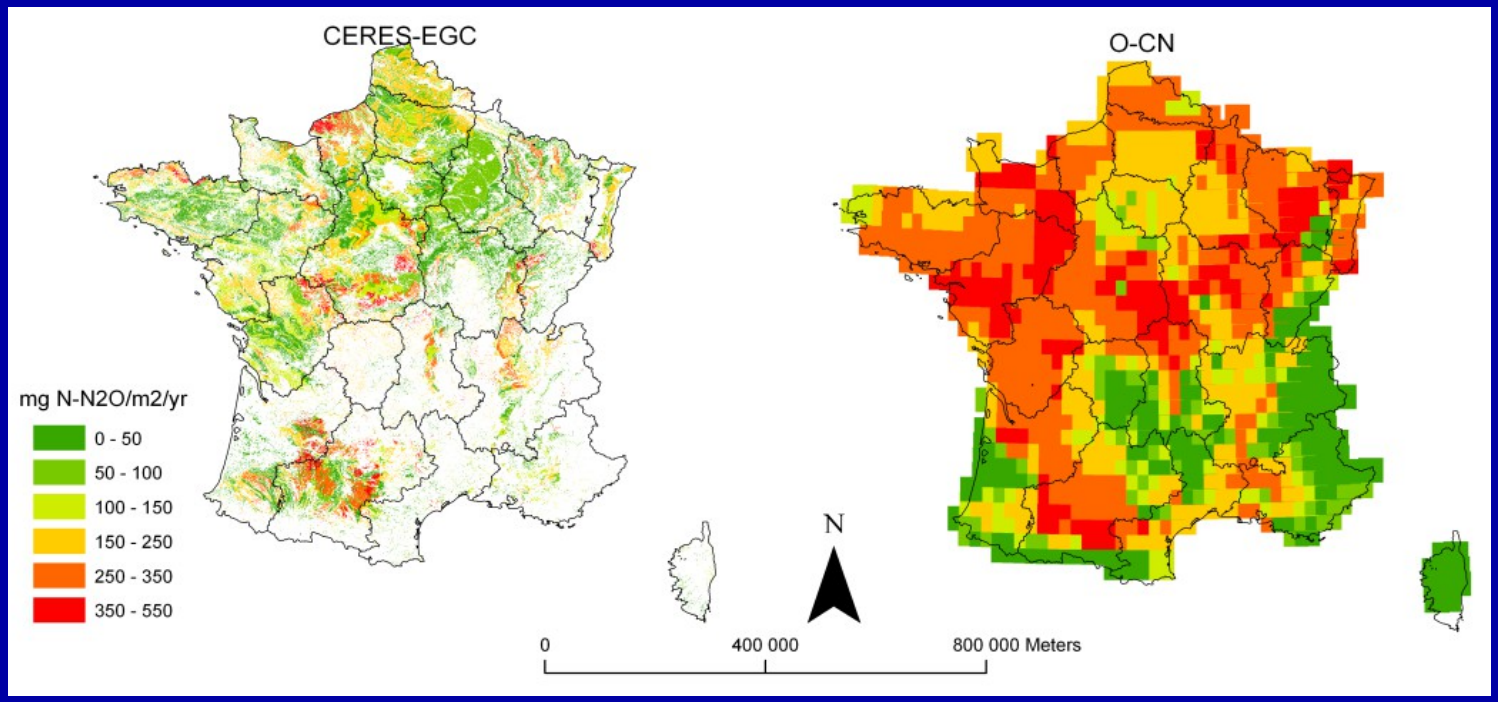
Chemistry-Transport models



The IMAGINE project (2010-2011); Gabrielle et al., 2012

Experimental sites

Emission modelling over France



	Total annual emissions in France (Gg/yr)	Average flux per simulation unit in France (kg N/ha/yr)
EDGAR 2000	35.2	0.65
IER 2000	50.1	0.91
O-CN 2007	39.6	2.27

Annual fluxes from cropland simulated with the agro-ecosytem model (CERES-EGC) and the terrestrial biosphere model (O-CN)

Annual budgets using inversion modelling

GgN/yr	Global inversion (S4)		OCN High_Res (S5)		CERES + OCN (S6)	
Emissions	Prior	Optimized	Prior	Optimized	Prior	Optimized
France	55	75	149	97	142	86
EU27	360	480	568	462	561	491

European Union between the three inversions performed.

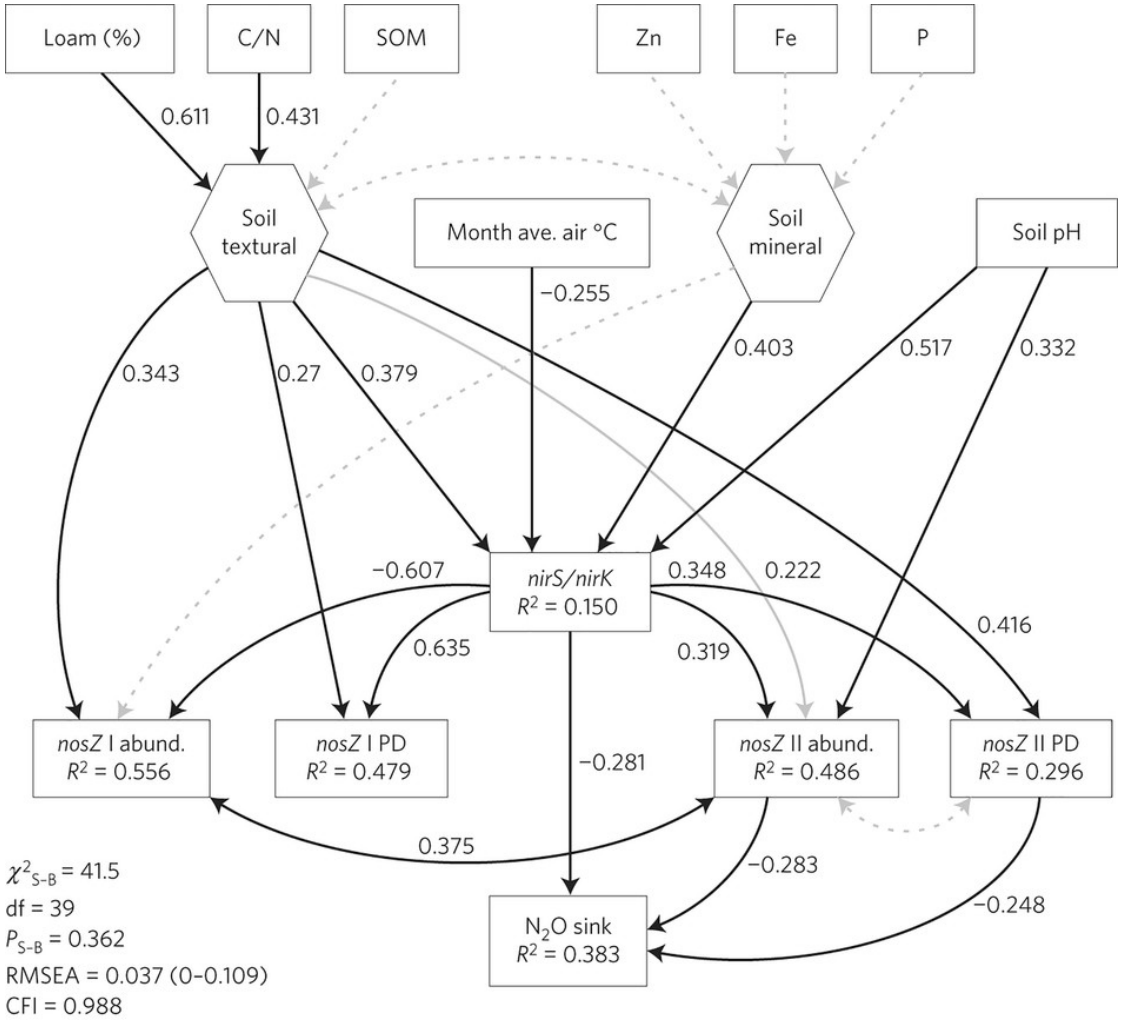
- Prior emissions are different between the scenarios, with much lower emissions in S4 than in S5 and S6 for France and EU27 .
- These converging results are obtained using two different atmospheric models and different inversion setups.
- The overall emission factor for cropland is lower than the IPCC Tier 1 value (1%)

Averaged regional emissions per crop type

	Winter wheat	Sugar Beet	Oilseed Rape	Miscanthus on SBeet	Miscanthus on fallow
Gaseous losses					
N_2O : CERES-EGC	2.51	3.31	1.42	0.97	0.87
ADEME	2.80	2.78	2.72	0.71	0.71
Nitrate leaching	9.8	20.7	2.1	20.3	25.2
	40.0	17.7	40.0		

Nr losses for various energy crops in 2007 (kg N ha^{-1} y^{-1}). ADEME corresponds to the use of fixed emission factors as opposed to biophysical modelling with CERES-EGC. Gabrielle et al., 2014.

Scaling down : gaining insight into microbiological drivers



Structural equation model accounting for the effect of biophysical variables on the abundance of microbiological communities regulating the N2O sink capacity of soils. Philippot et al. Nature Clim. Change, 2014

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Gaining insight into gas exchanges within soil porosity

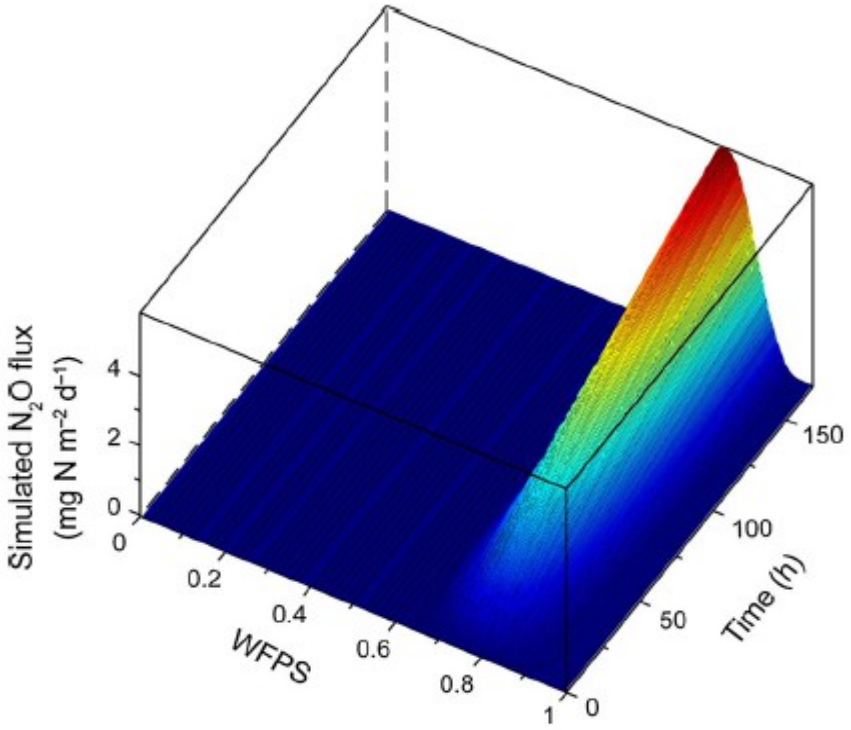

Fig. 1 Simulated nitrous oxide flux with time for water-filled pore space in the range [0, 1]. At time = 0 h, initial conditions were applied. For the next time increments, the nitrous oxide production module, and the gas transport and equilibrium modules were activated

A new relationship between soil water filled pore space and soil N2O emission including a gas transport and an equilibrium modules. This function allows to simulate N2O peaks during wetting/drying phases in soils (Rabot et al., Biogeochemistry, 2014)

Outline

- Measuring and monitoring N_2O
- Biophysical modelling across scales
- Scaling up and down
- Systems approach to mitigate emissions
  - Inclusion of legume crops (pea)
  - Use of a DSS for fertilization
  - Designing low-carbon cropping systems
- Conclusion and outlook

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Testing the effects of introducing a legume crop in rotations, in a field trial in Grignon (Paris area)

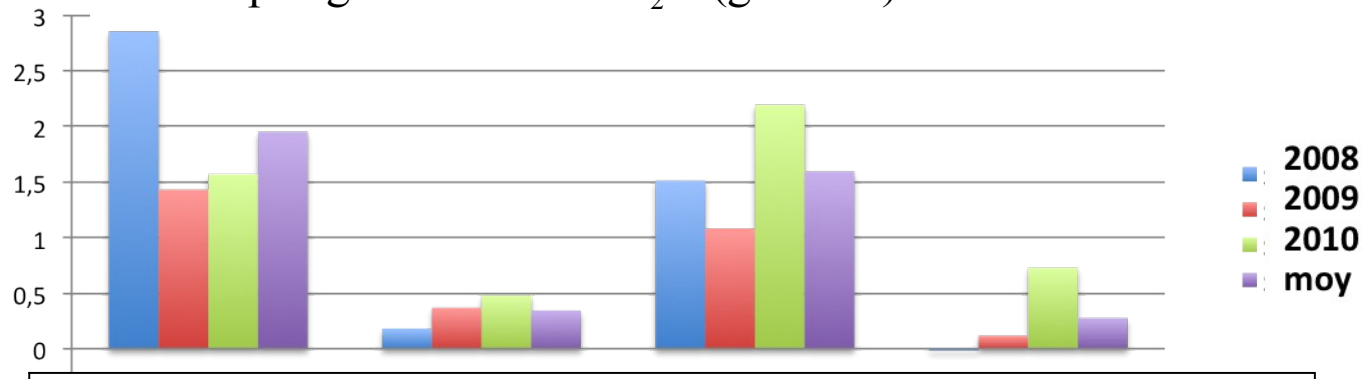
2006/2007	2007/2008	2008/2009	2009/2010
Wheat or Barley	Wheat (N/no N)	OilSeedRape	Wheat (N/no N)
	Wheat (N/no N)	Pea	OilSeedRape
	Wheat (N/no N)	Pea	Wheat (N/no N)
	Wheat (N/no N)	Wheat (N/no N)	OilSeedRape
	OilSeedRape	Wheat (N/no N)	Wheat (N/no N)
	OilSeedRape	Wheat (N/no N)	Pea
	Pea	OilSeedRape	Wheat (N/no N)
	Pea	Wheat (N/no N)	Wheat (N/no N)

Fertiliser rates calculated with the balance-sheet method (adapted according to the preceding crop)

→Comparison of crops, preceding crops and rotations

Variation of emissions according to crop type

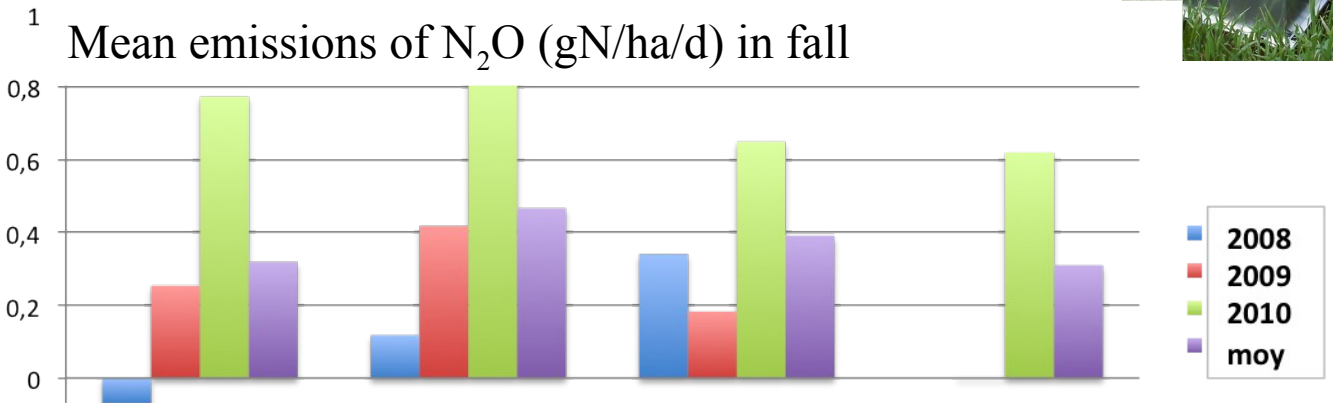
Mean spring emissions of N_2O (gN/ha/d)



OSR:	Pea	Wheat	Unfertilized wheat
1.95	0.34	1.59	0.28

➔ **No effects of previous crops on fall emissions**

Mean emissions of N_2O (gN/ha/d) in fall

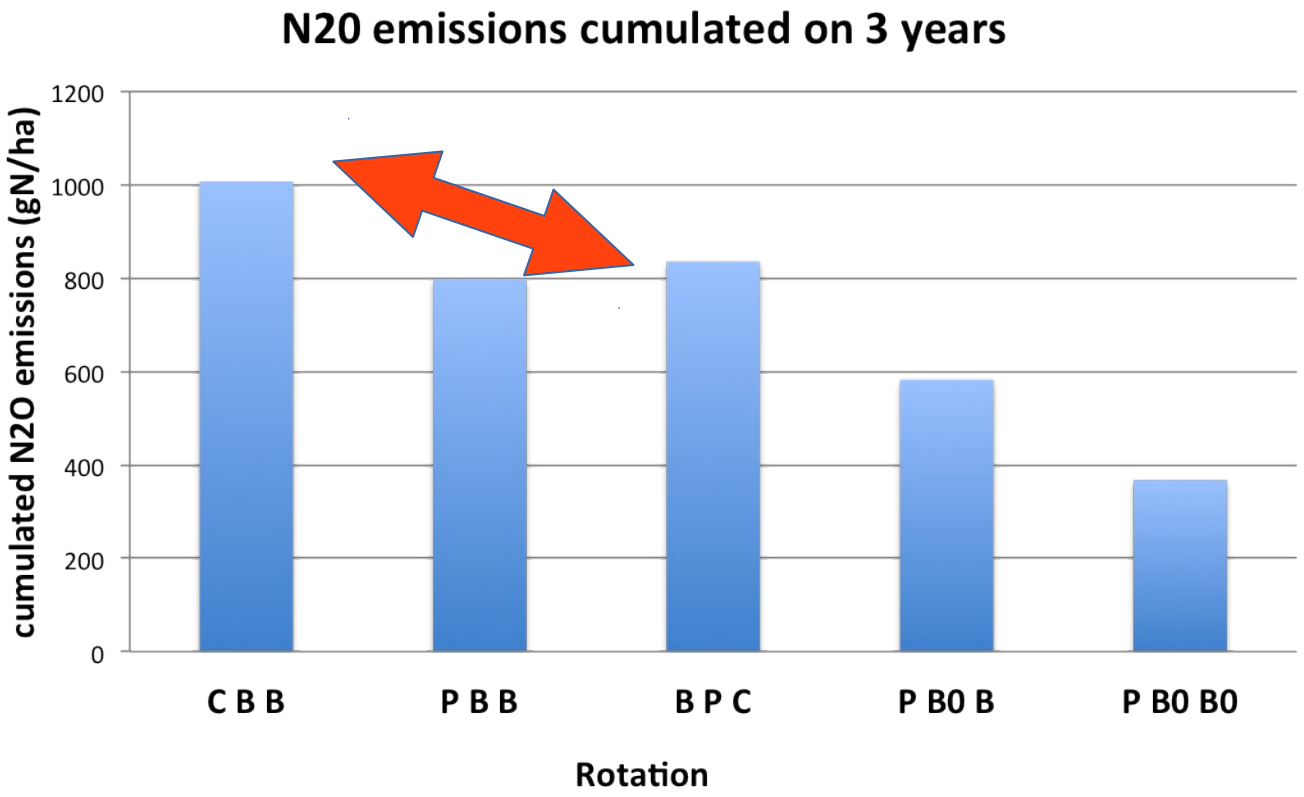


Previous crop: **OSR** **Pea** **Wheat** **Unfert. Wheat**

Preceding crop

Jeuffroy et al., 2013

Comparison of rotations



→ A strong effect of the rotation on the cumulated N2O emissions (for 3 years)
→ The rotation without pea has the highest emissions
→ Rotations including 1 Pea and 2 fertilized crops have 20% less emissions
→ Rotations with 1 pea and 1 unfertilized crop have 50% less emissions

Jeuffroy et al., 2013

Overview of fertilization practices for OSR in France

Region	Inorganic N Fertilizers Applied (Kg N ha^{-1})		Fertilization gap (Kg N ha^{-1})
	Current practices	Recommended practices	
Burgundy	165.2	108.8	56.4
Centre	161.6	164.0	-2.4
Champagne-Ardenne	168.6	144.9	23.7
Haute Normandie	170.0	150.8	19.2
Ile de France	166.6	156.6	10.0
Lorraine	158.1	102.1	56.0
Picardy	167.0	136.5	30.5
Poitou-Charentes	158.2	134.5	23.7
National Average	164.4	137.3	27.1

Fertilizer N input rates in the 8 major OSR producing regions of France, in 2012. The recommended rates were obtained using the 'N ruler' decision support system (Ben Aoun et al., submitted).

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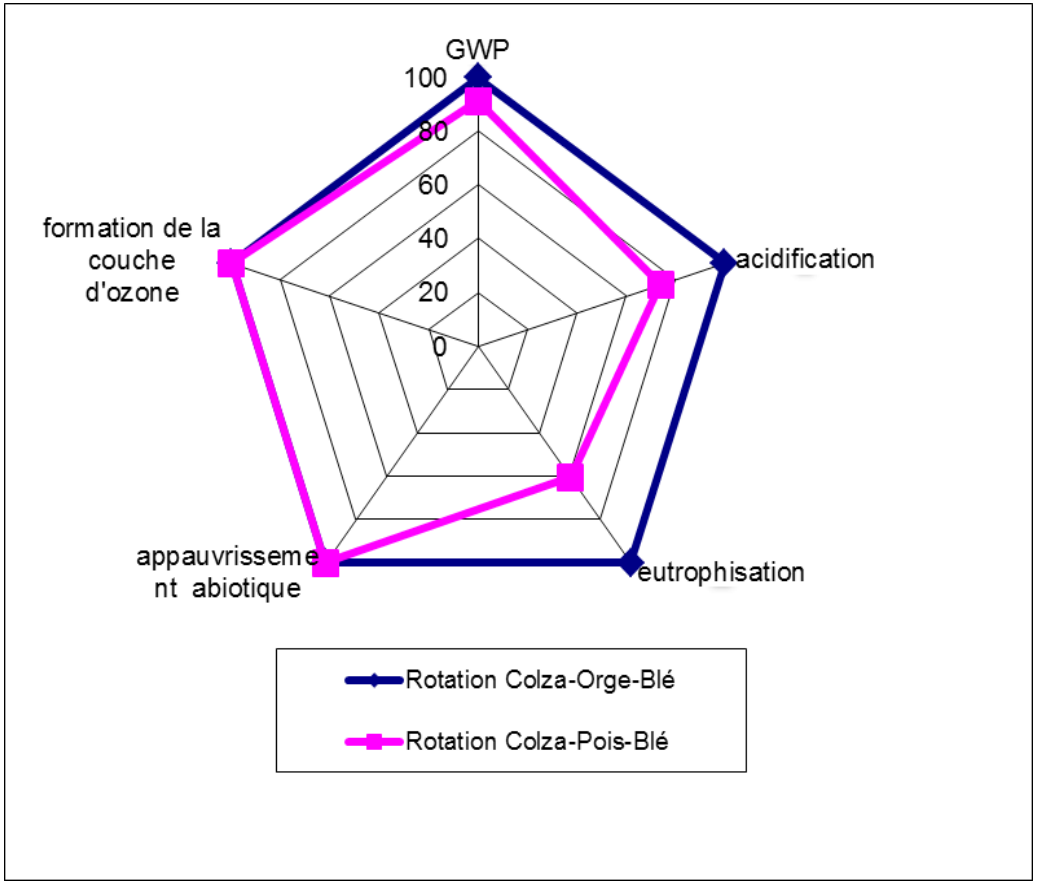
Benefits of using a DSS on N_2O emissions from OSR

Region	Direct N_2O Emissions		Potential Saving (in %)	Indirect N_2O emissions		Potential Saving (in %)
	Current practices	Best practices		Current practices	Best practices	
Burgundy	1.26	1.20	4.9	1.09	0.97	10.6
Centre	1.69	1.69	- 0.1	0.86	0.85	0.7
Champagne-Ardenne	0.94	0.88	6.5	1.28	1.18	7.9
Haute Normandie	2.28	2.20	3.5	1.95	1.90	2.5
Ile de France	1.43	1.42	0.6	0.90	0.90	-0.1
Lorraine	0.93	0.86	7.6	1.36	1.17	14
Picardy	1.91	1.90	0.9	1.27	1.20	5.6
Poitou-Charentes	1.20	1.17	2.7	0.63	0.58	7.4
Weighted average	1.42	1.38	**3.1**	1.10	1.03	**5.8**

Effects of generalizing the use of the 'N ruler' fertilization DSS on direct and indirect N2O emission rates, according to an ecosystem model (Ben Aoun et al., submitted).

Coming back to the inclusion of a legume crop



Effect of including a legume crop in rotations with OSR on LCA results for bio-diesel (Ben Aoun et al., in prep)

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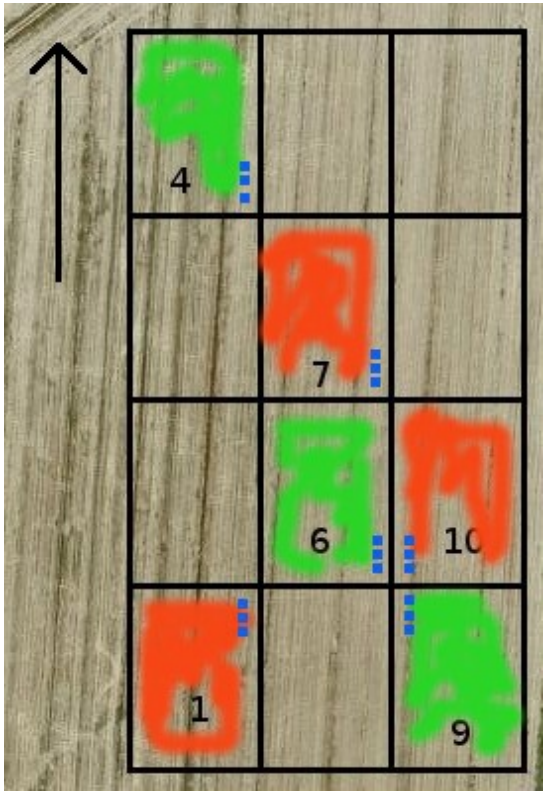
Designing cropping systems to reduce GHG emissions

The 'Innovative Cropping Systems under Constraints' experiment in Grignon (40 kms W of Paris) aimed at developing cropping systems:

- meeting **specific targets :**
  - Maintain satisfactory yields
  - Diversify crops
  - Enhance biodiversity
  - Reduce soil erosion
  - Decrease energy consumption
  - Decrease depth in tillage operations
  - Reduce nitrate leaching
  - Reduce N inputs



- achieving one main **constraint: 50% reduction in GHG emissions ("50%GHG" system)**

Goglio et al., 2013

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Cropping systems overview

The reference system

(Productive with high environmental performance: PHEP)

- **Reduced N** inputs through **legumes**
- Reduced nitrate leaching **with cover crop** before spring crops
- **Only 1 deep tillage** operation every 5 years
- **5-year crop rotation: Faba Bean-WWheat-OSR-WWheat -Barley**

The 50%GHG system

- **Increasing carbon stock with cereals and** crop residue return
- **Minimum tillage** (spring crops) or **no tillage** (winter crops)
- N_2O emission **reduction through legumes (Fabaceae)** and cover crops
- **Fertilizer application related to weather conditions**
- **6-year rotation: Faba Bean-OSR-WWheat-Barley-Maize-Triticale**

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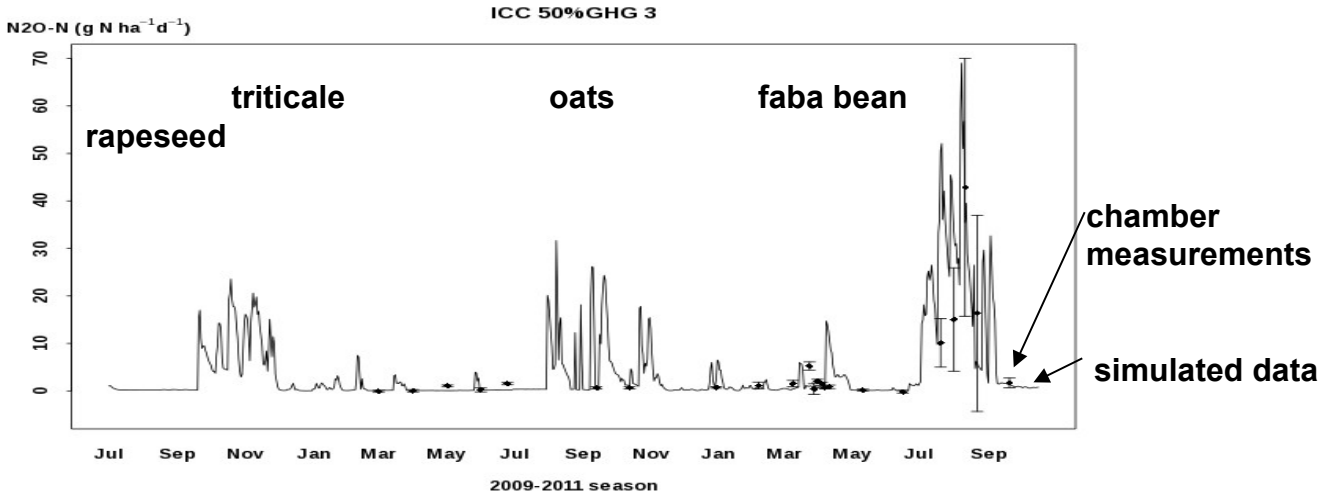
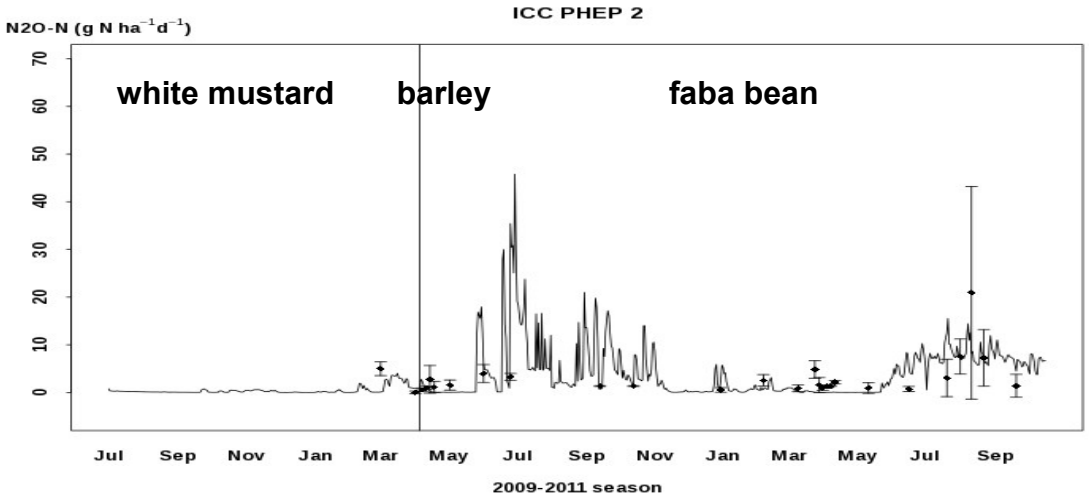
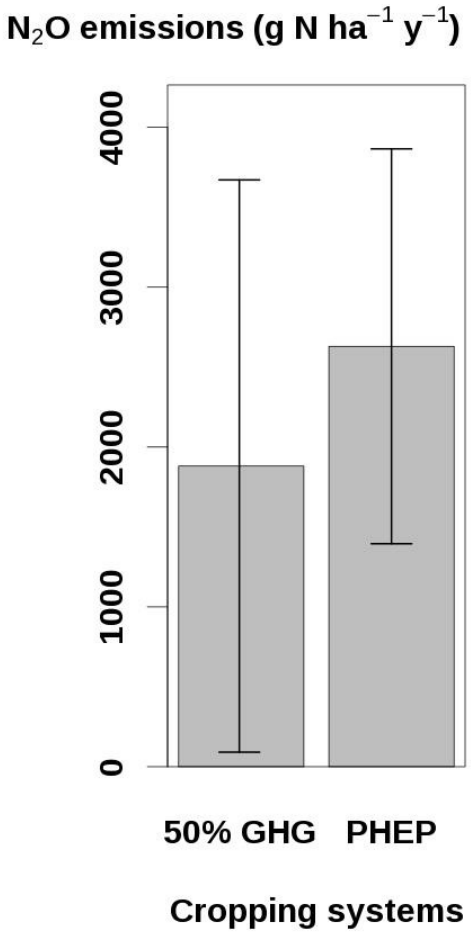
Simulating the differences between the 2 systems

Field-measured (♦) and simulated (lines) N_2O emissions in the 50%GHG (top) and PHEP (reference, bottom) cropping systems trial.





The 50%GHG systems does mitigate N2O emissions



Simulated N2O emissions over 30 years of the PHEP and 50%GHG cropping systems in Grignon (Goglio et al., 2013).
This translates as a 29 % reduction of life-cycle GHG emissions on a GJ basis (of biomass energy content).

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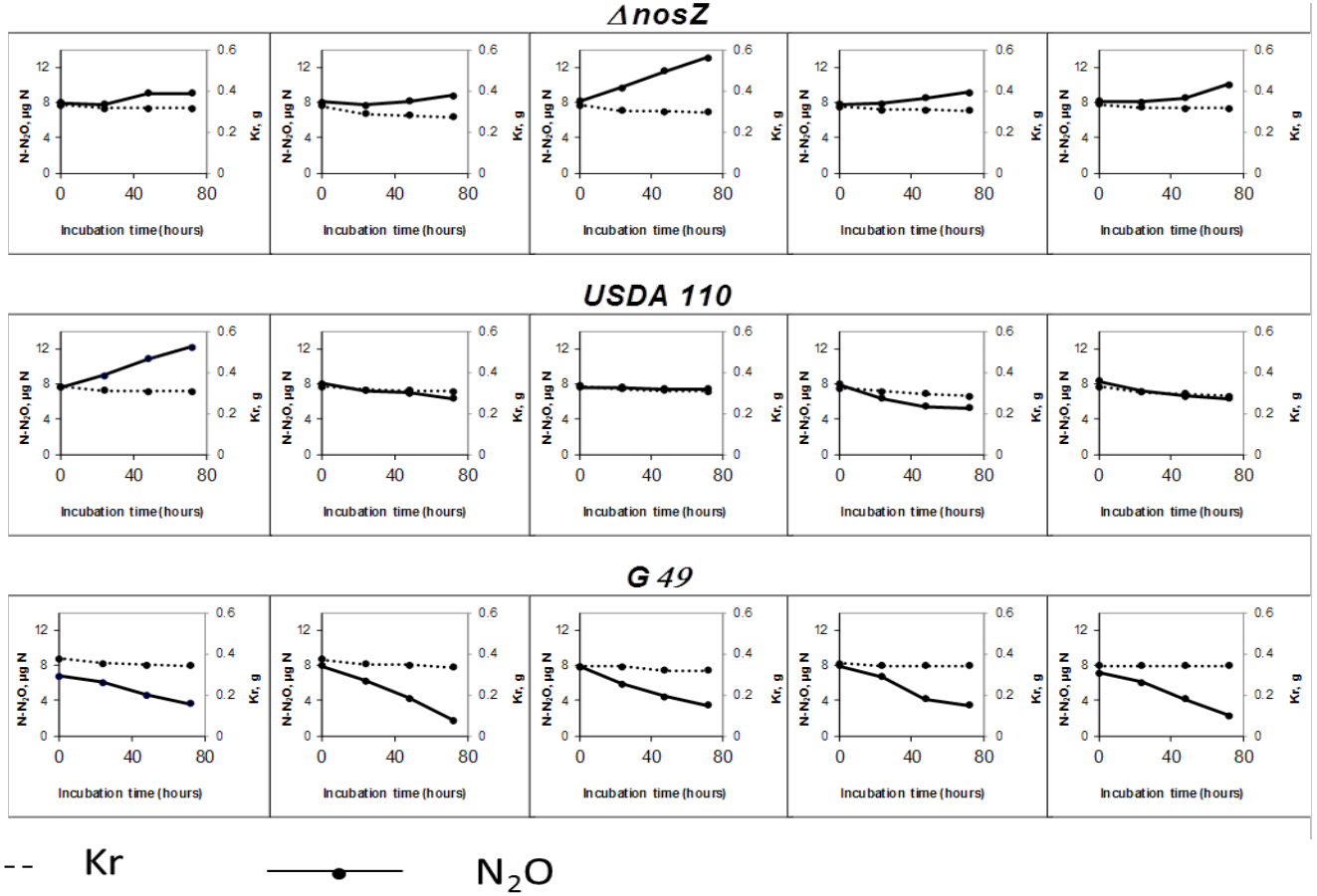
Using the couple Leguminous-Rhizobia to reduce N_2O

Soil inefficient to reduce N_2O



The inoculation of rhizobium strain G49 to soja plants has allowed to create, at the greenhouse scale, a system acting as a sink for N_2O (Hénault et Revellin, 2011)

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Conclusion & outlook

- An overall data base of ~30 site-years has been collected for OSR and may be used for further analysis (calculation of EFs – see talk by C. Le Gall - or modelling)
- Biophysical modelling helped gain insight into the main drivers (climate, soil moisture and N content, fertilization)
- Fertilization is the main management driver, but there is a strong interplay with other soil factors (eg, soil pH) or drivers (biological)
- There are clear benefits of a systems approach to reduce N2O emissions (20-30% mitigation potential)

- Some avenues for progress in understanding and mitigating N2O emissions from OSR:
  - Continuous monitoring using automatic chambers and micro-met
  - Include microbiological parameters/drivers in models
  - Paired experiments to investigate management factors
  - Modelling and mitigation at landscape scale (for indirect emissions)
  - Cropping systems experiments to explore combination of practices (agro-ecology at field to landscape scales)

G Braque – an oilseed rape field (c) Guggenheim Bilbao Museum

Thank you for your attention

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