Impacts of Integrated Weed management in cropping systems on N2O emissions from soils

Anthony Vermue, Catherine Hénault, Arnaud Coffin, Nicolas Munier-Jolain, Bernard Nicolardot

Session 4 - Other management practices and combination of techniques

Chair: Alberto Sanz-Cobeña

Co-chair: Bob Rees

Key note lecture - Per Ambus

Short oral presentations:

- Abdalla Mohamed
- Joël Leonard
- Anthony Vermue, Catherine Hénault
- Yam Kanta Gaihre

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Key note lecture

Other management practices and N_2O emissions - Application of biochar as a tool to mitigate nitrous oxide emissions

Per Ambus

Center for Ecosystems and Environmental Sustainability

Chemical and Biochemical Engineering Department

Technical University of Denmark

Pyrolysis process

Heating of biomass without oxygen.

Biomass

Pyrolysis parameters

- Highest heating temperature (HTT)
- Heating rate
- Particle and gas retention time
- Active agents (steam, oxygen, CO_2)

Syngas
H_2, CO, CH_4, CO_2, H_2O +

Bio-oil
(e.g. CH_3OH, C_3H_6O, and C_6H_5OH)

Biochar

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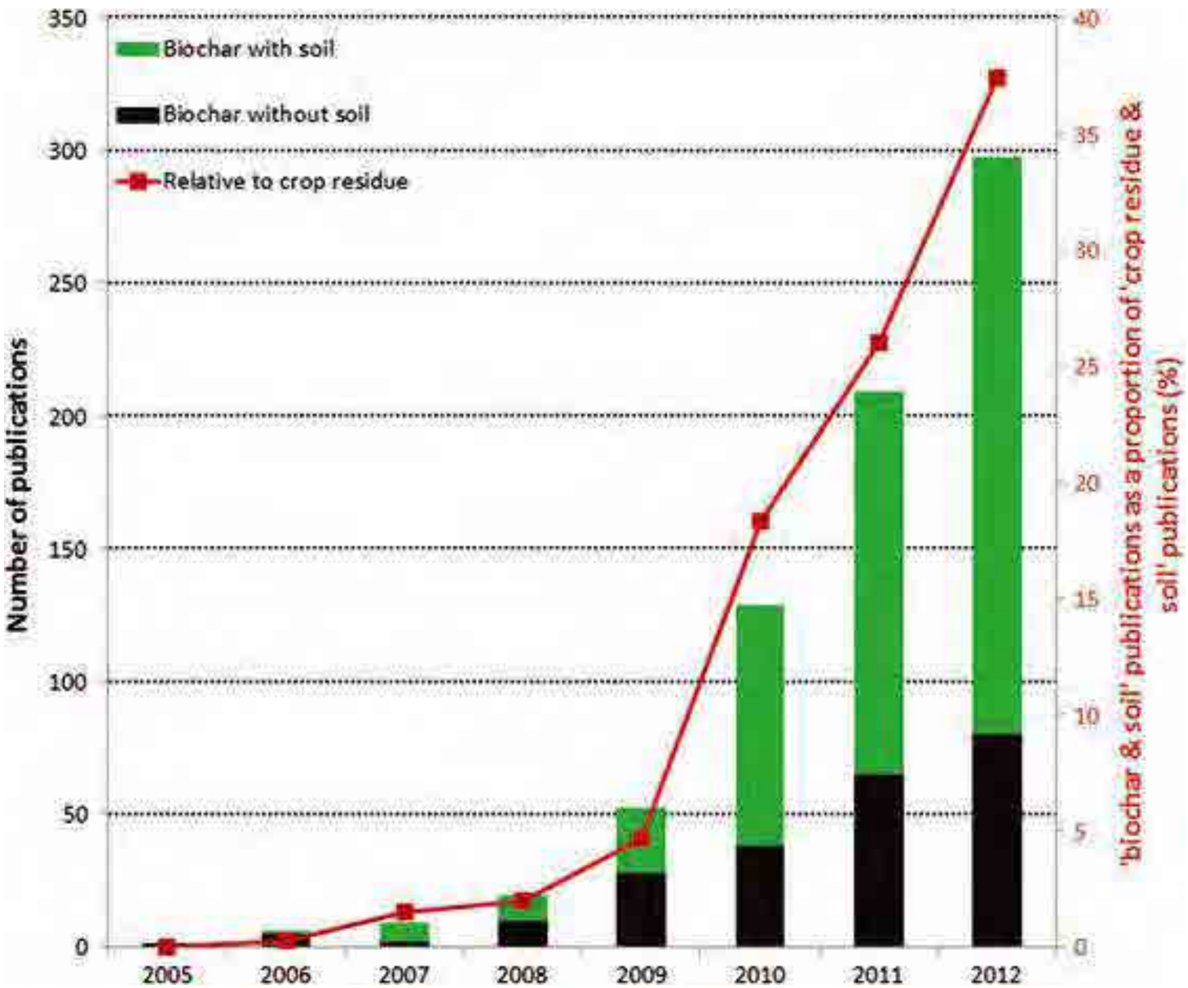
- Biochar sequesters **carbon**
- Biochar interacts with soil **nitrogen** availability
- Returns **nutrients** to the field (ash part)
- Biochar **increases pH** in acidic soils due to BC’s content of bases (Ca, Mg, K etc.). Short term liming effect.
- Forms **aggregates** with the soil particles and stabilizes the soil
- Increases the cation exchange capacity (**CEC**) of the soil
- Increase **soil microbial biomass**
- Increases **water** holding capacity
- Increases soil porosity and **aeration**



Verheijen et al. 2014

Slow pyrolysis

Maximizes biochar yields

Source: www.in-eco.com

Gasification

Maximizes gas yields

The viking gasifier, Risø-DTU

Fast pyrolysis

Maximizes bio-oil yields

Dynamotive

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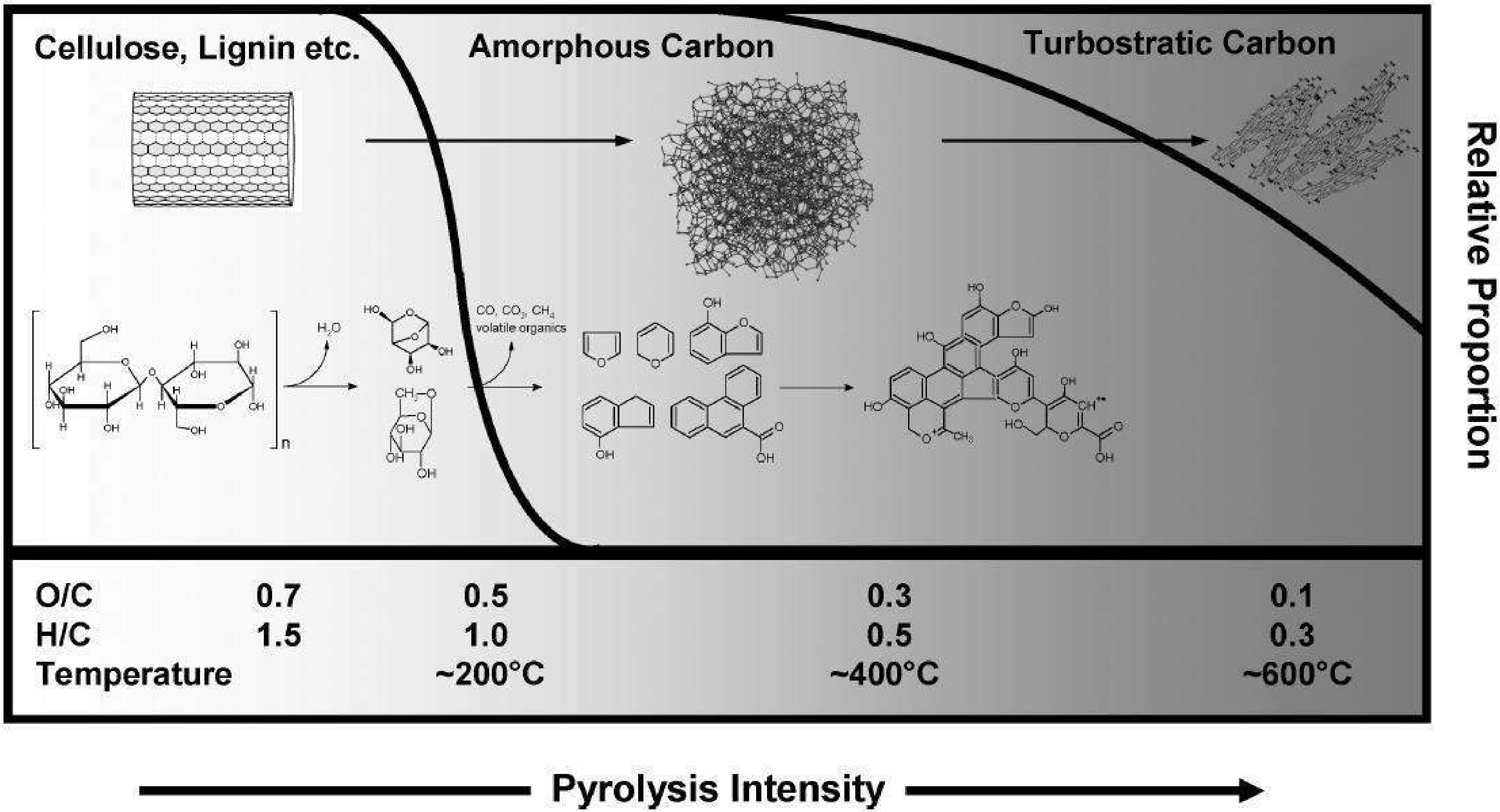
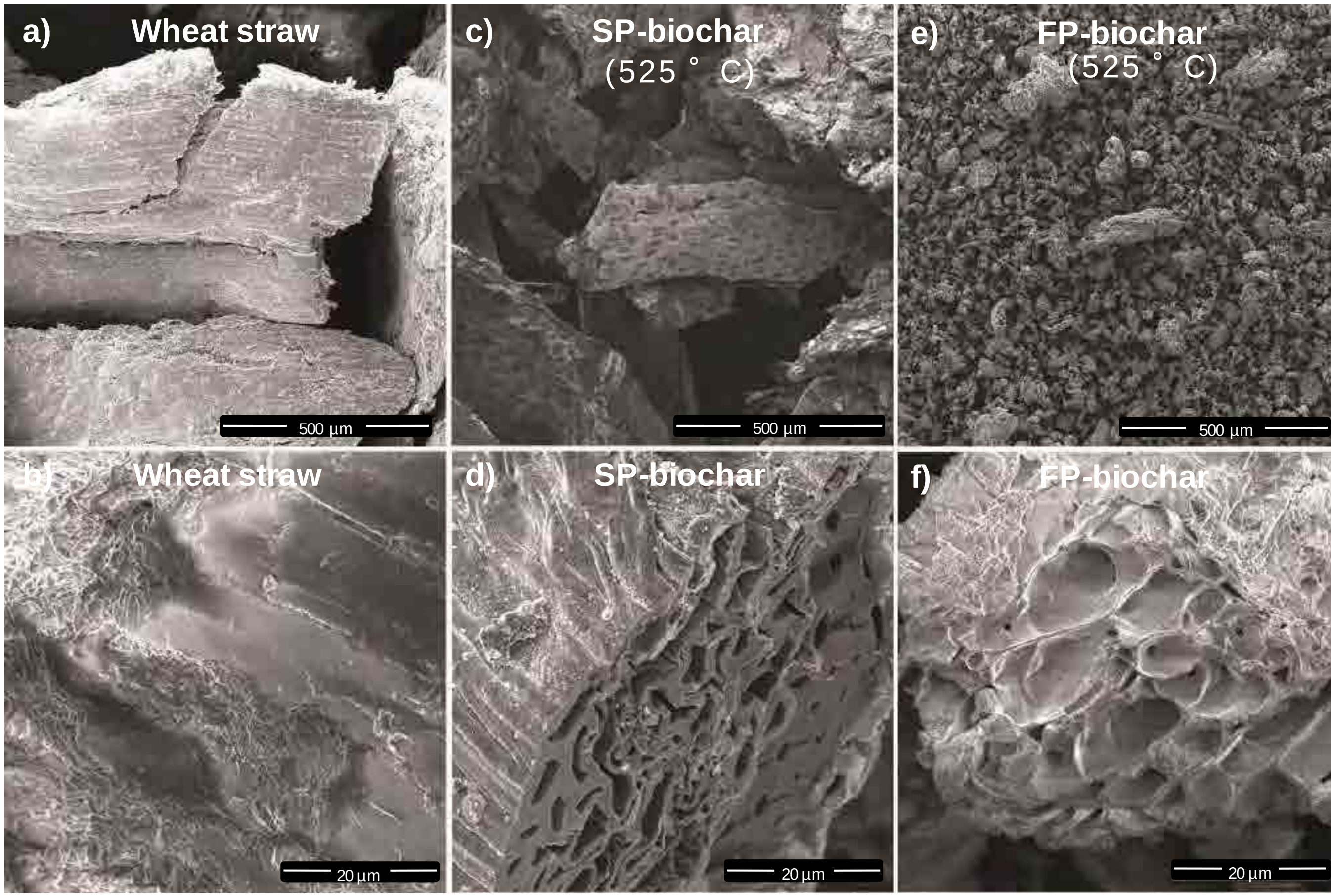
Feedstock transformation



Lehmann et al 2009.

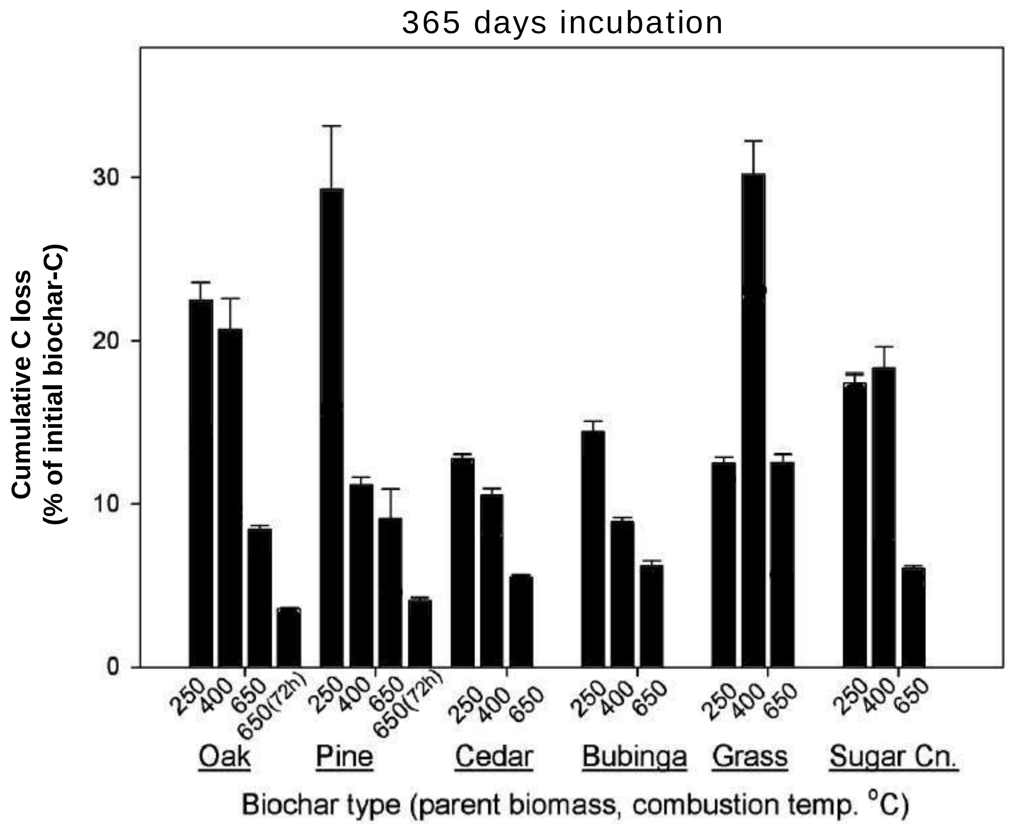
Biochar microstructure

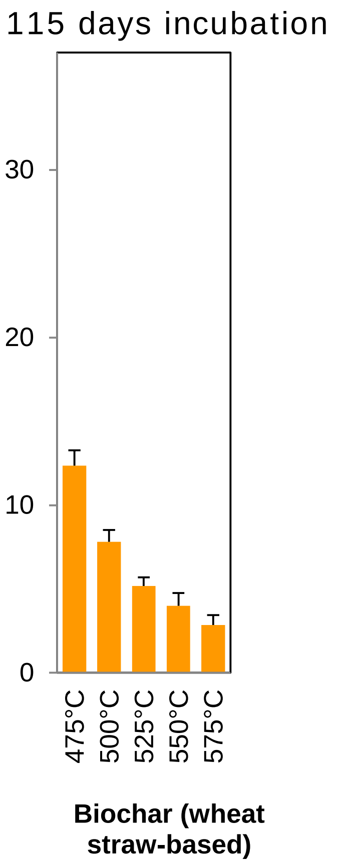


Beech wood

Bruun et al. 2012.

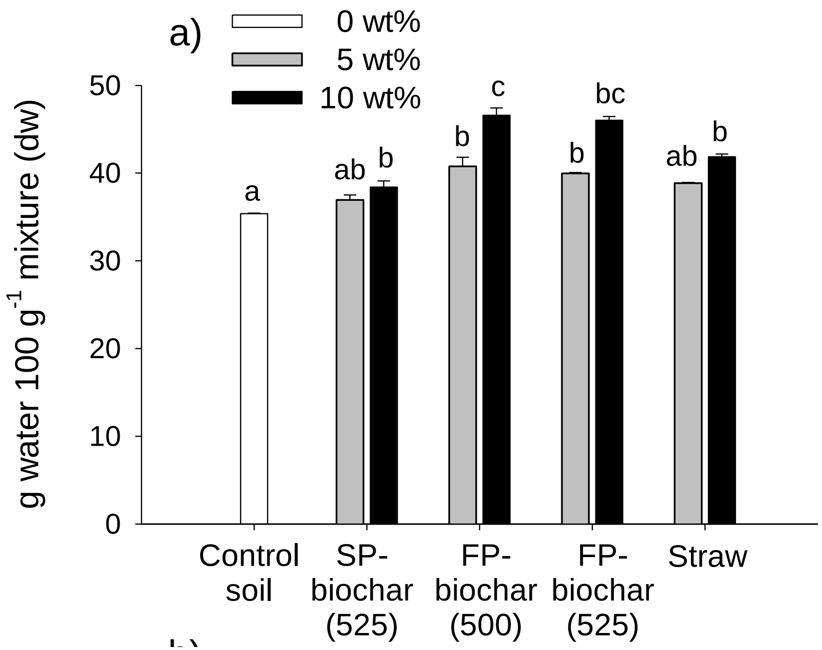
Biochars stability depends on pyrolysis temperature and feedstock

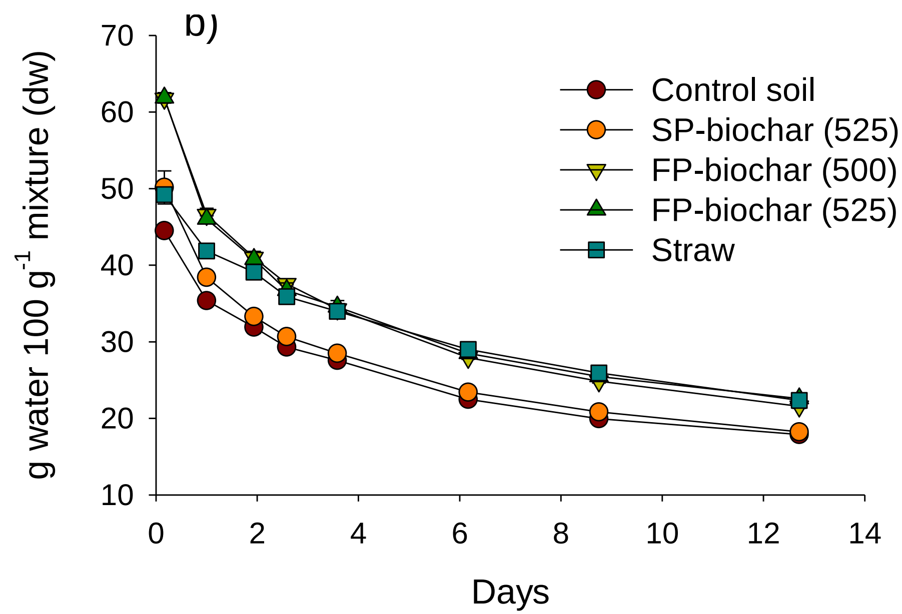




Zimmerman 2010 *Bruun et al. 2011*

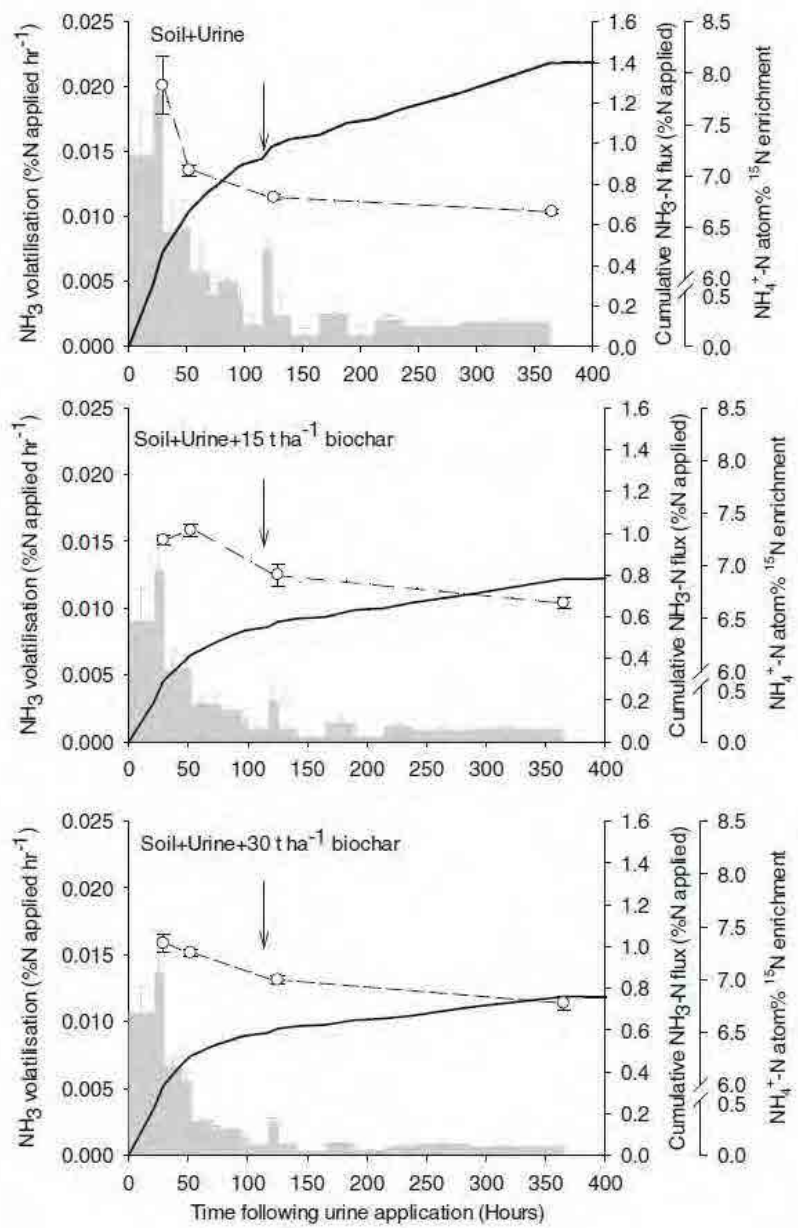
Biochar increases soil water holding capacity





Application of biochar (10 wt%) to a sandy loam soil improved the WHC of the soil by 32 %

Bruun et al. 2011



BC captures NH_3

Reduced NH_3 emission from urine spots

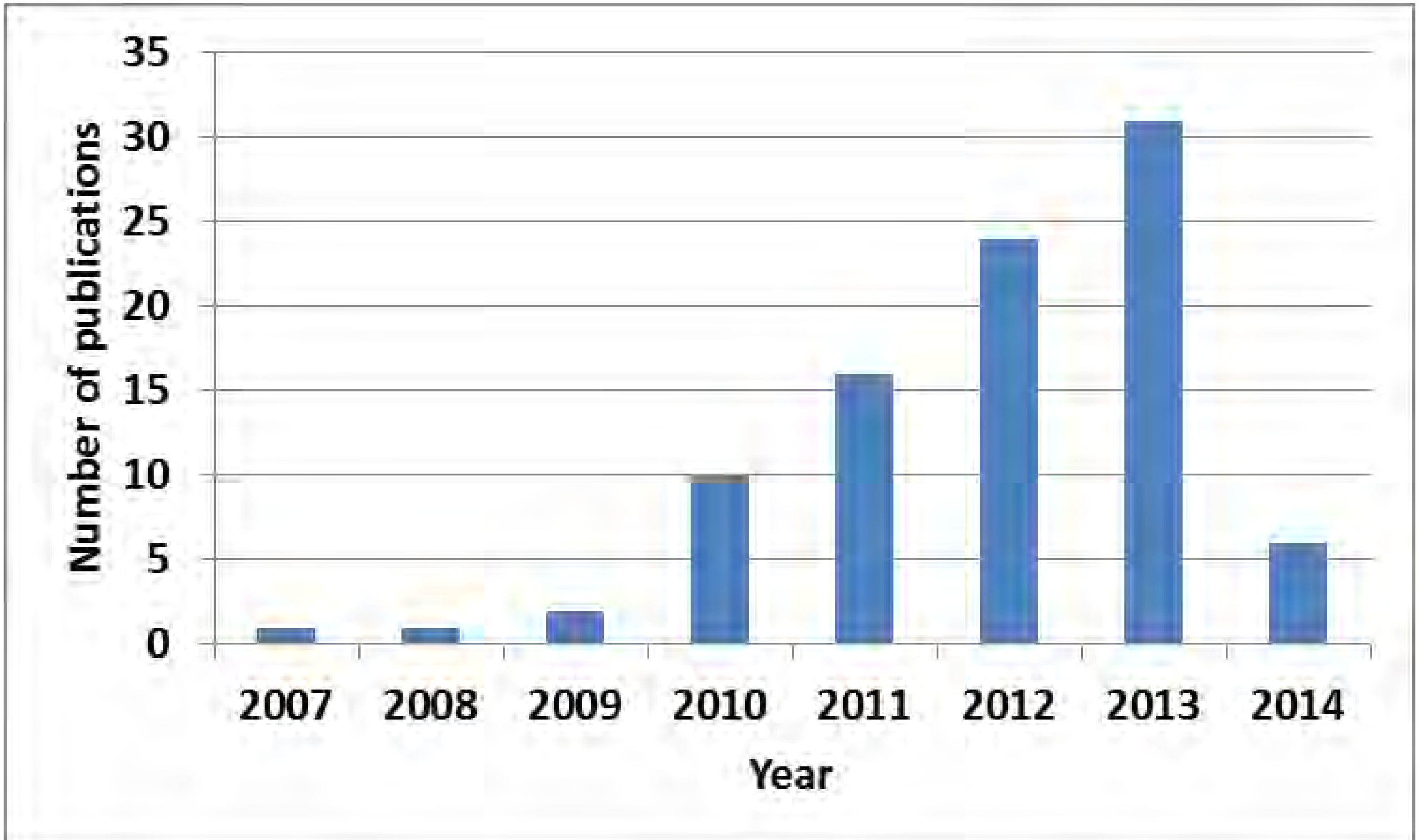
Adsorbed NH_3 is bioavailable

Taghizadeh-Toosi et al. 2012

Biochar and N_2O emissions ?

Photo: Greenpeace

91 WoS publications since 2007 [char* × nitrous oxide]



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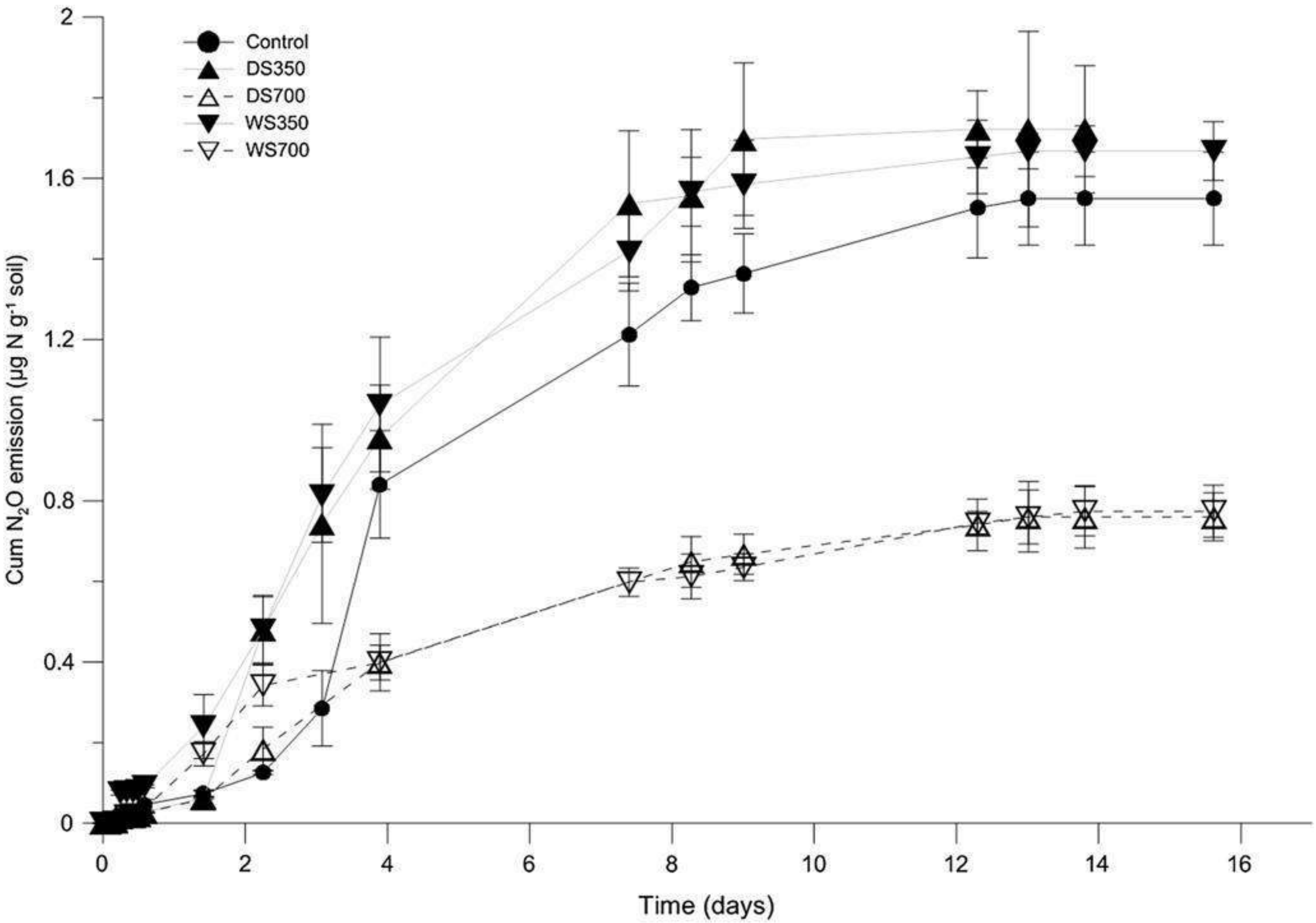
N_2O with different qualities of biochar



N_2O emission related to VOC content

Ameloot et al., 2013

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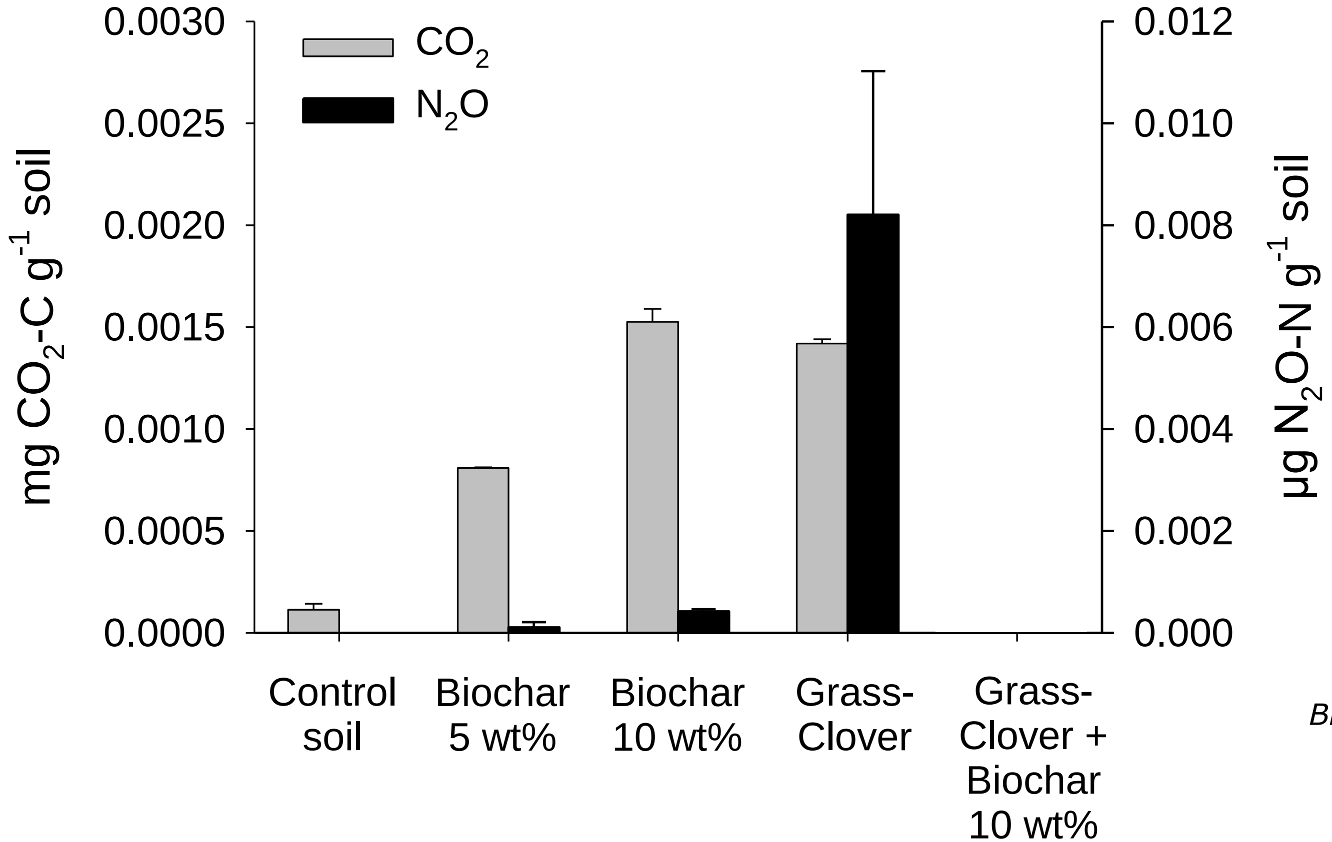
FP-biochar effect on N_2O soil emissions

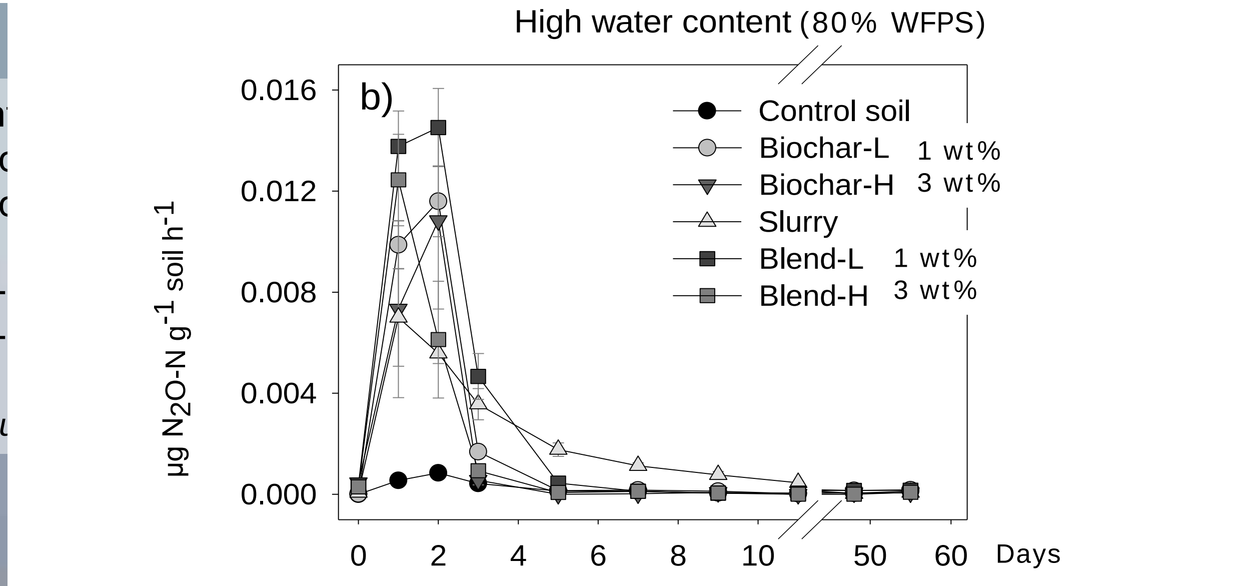


Bruun et al. 2011

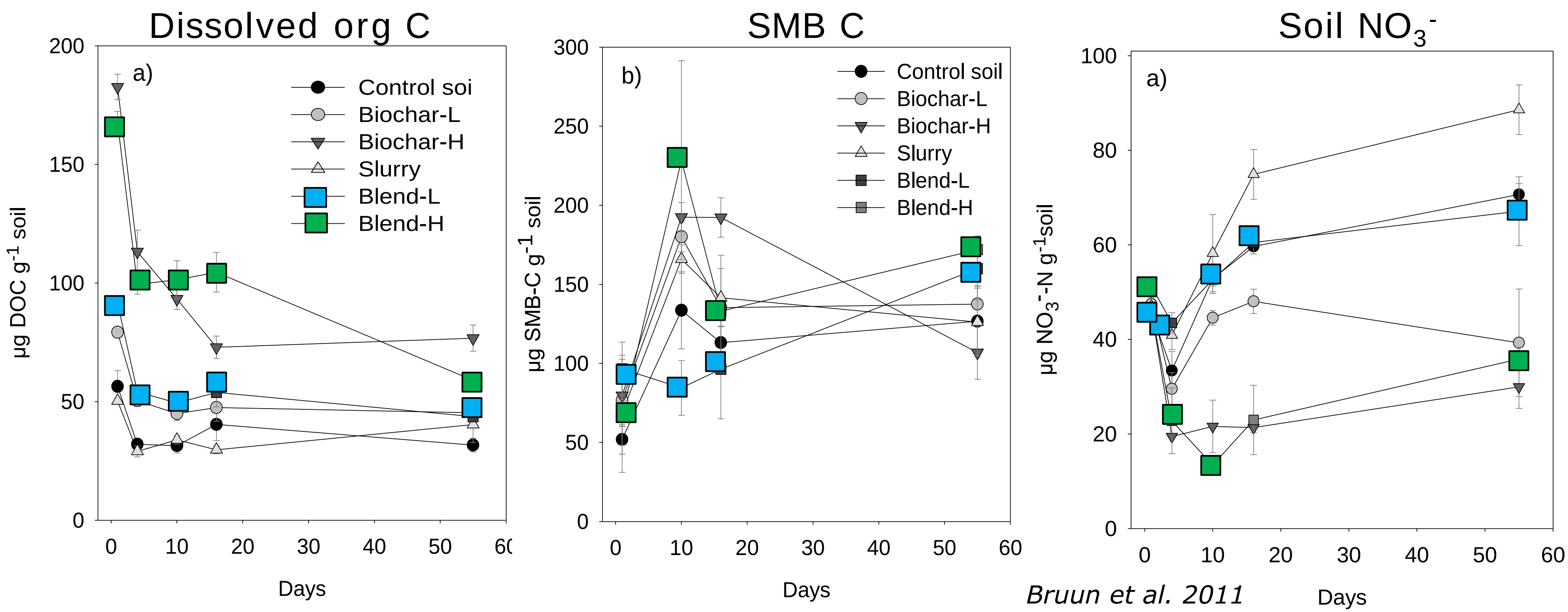
Combine biochar with fertilizers to reduce N_2O emission?

1. Soil; ('con
2. + 1% bioc
3. + 3% bioc
4. + slurry ;
5. + slurry +
6. + slurry +

80% WFPS, Slu

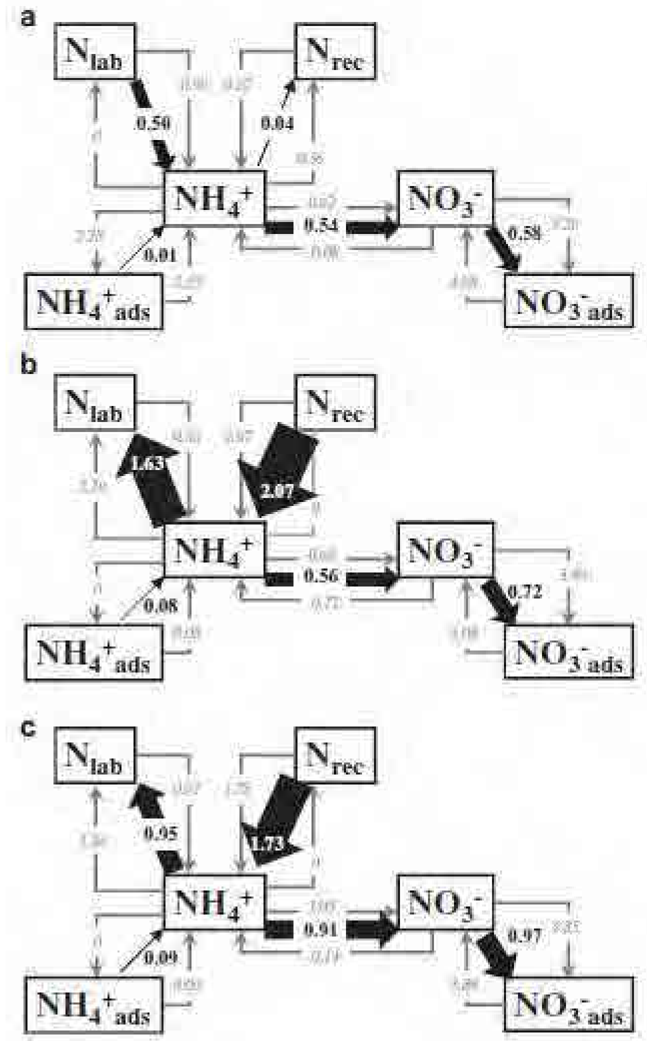


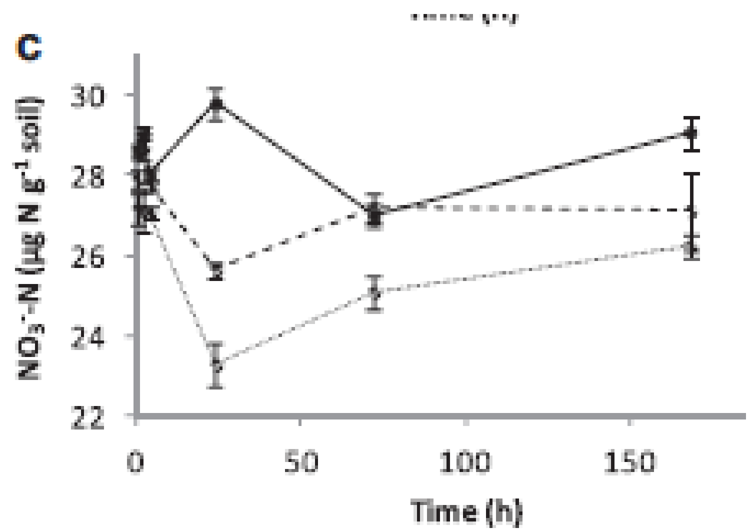
What caused the reduced N_2O with addition of biochar to slurry?



Bruun et al. 2011

Increased net adsorption of soil NO_3





Nelissen et al. 2012

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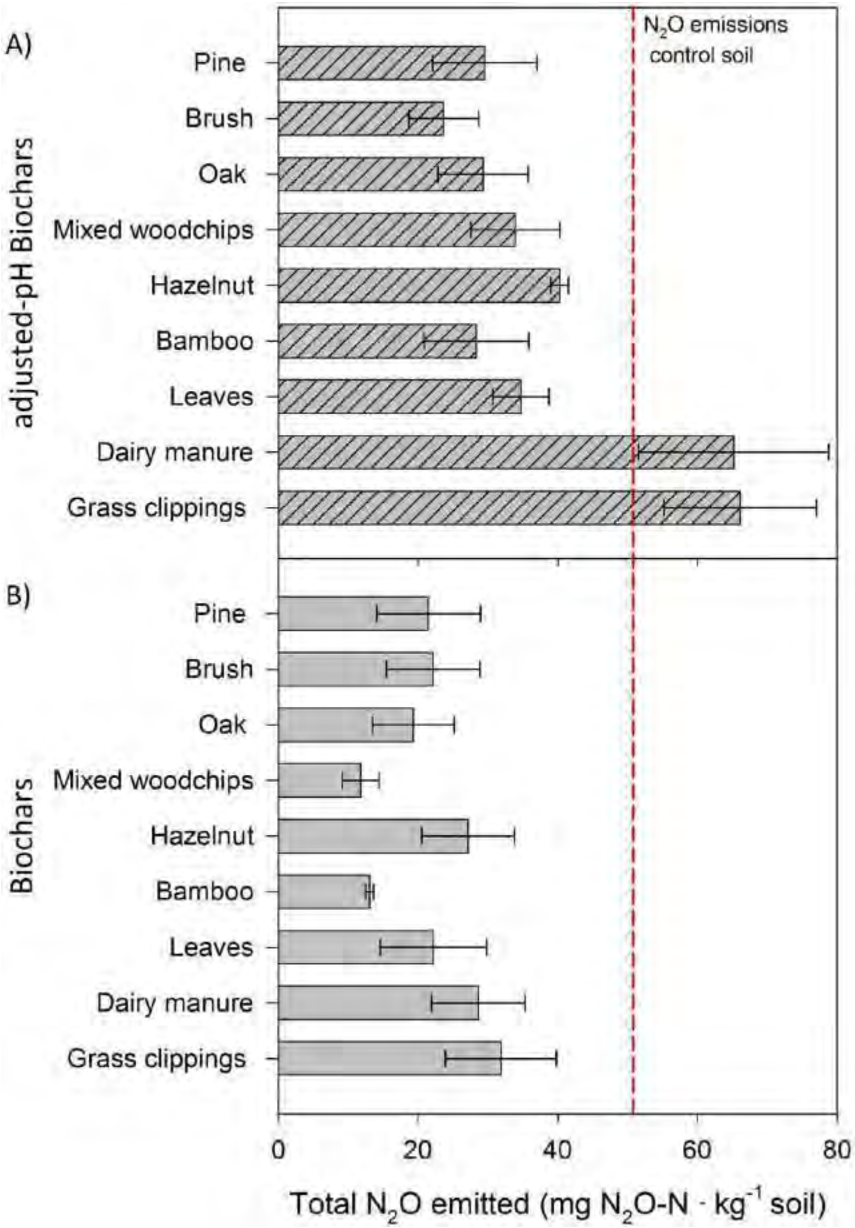


BC increases pH

Reduction of the $N_2O/(N_2+N_2O)$ ratio

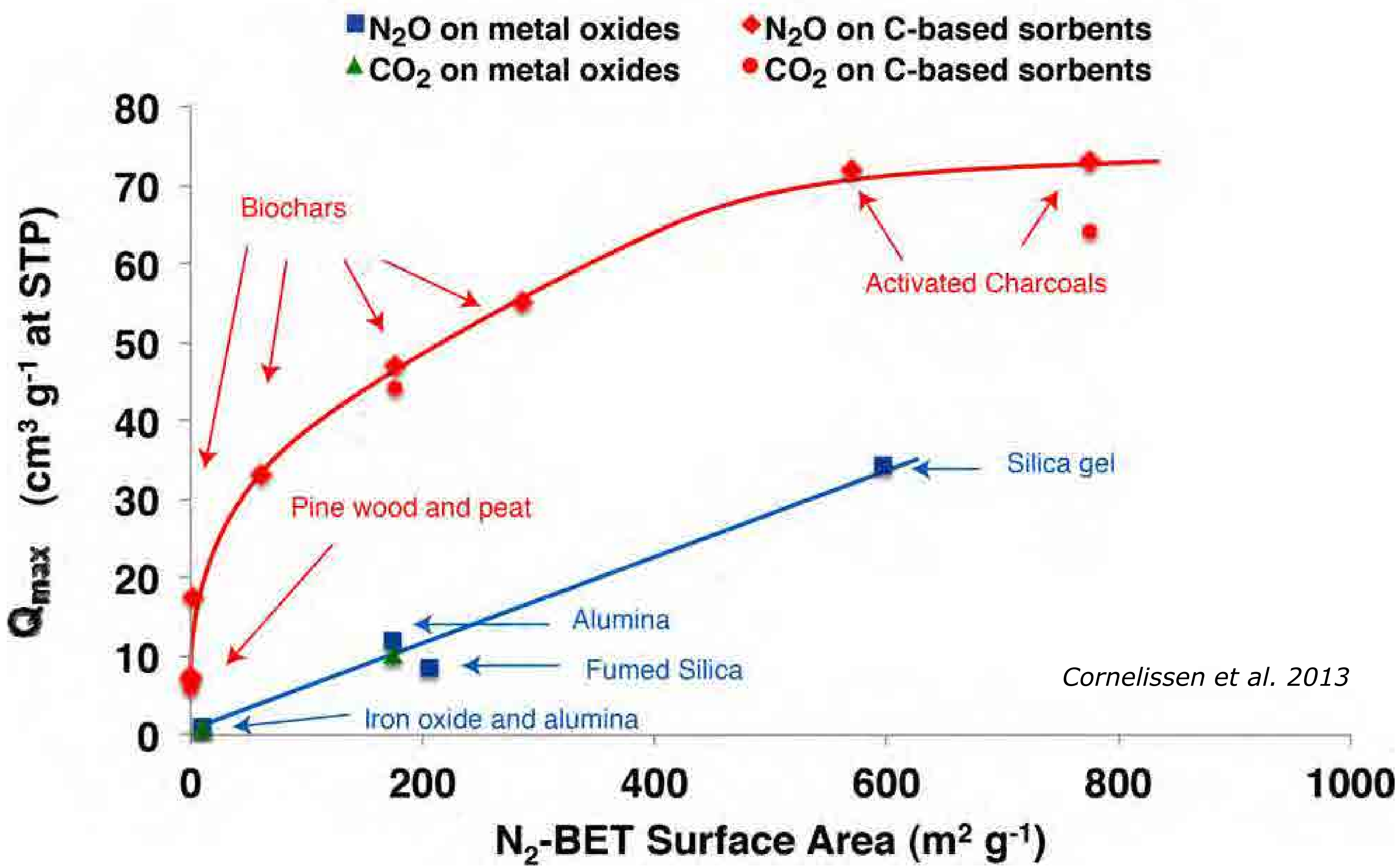
Biochar acid buffer capacity was identified as an important aspect for mitigation

not primarily caused by a pH shift in soil

'electron shuffle' effect

Cayuela et al. 2013

Q_{max} (20 °C) for N_2O and CO_2 sorption



Cornelissen et al. 2013

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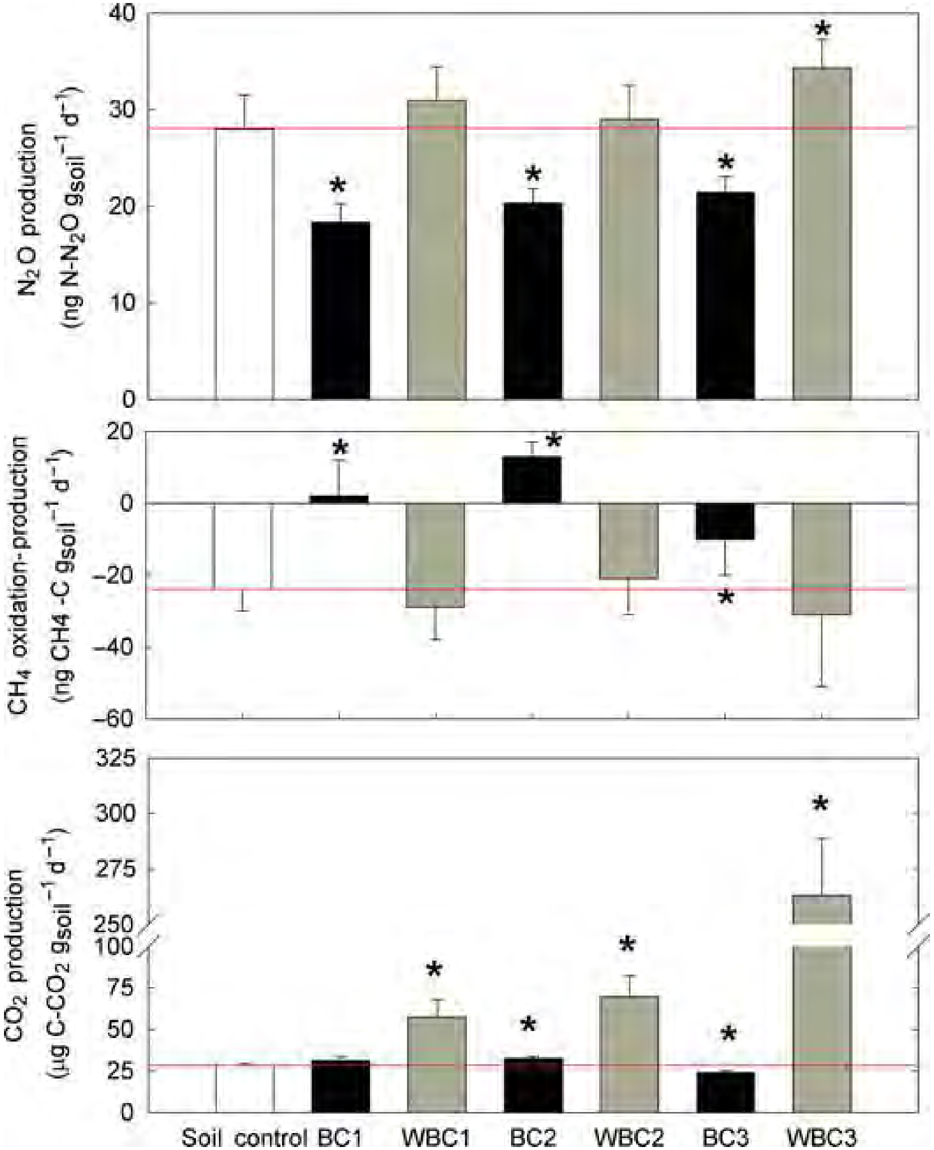


Age is important

Aging negates the biochar effect

Spokas 2013

17-19 March 2014
PARIS

Majority of studies show decreased N_2O emission with BC

A universal conclusion cannot be reached

what makes a biochar able to mitigate N2O emissions
what type of char/feedstock
management

Nitrogen availability

- Adsorption-desorption; N-source; N-mineralization

Organic **carbon** availability

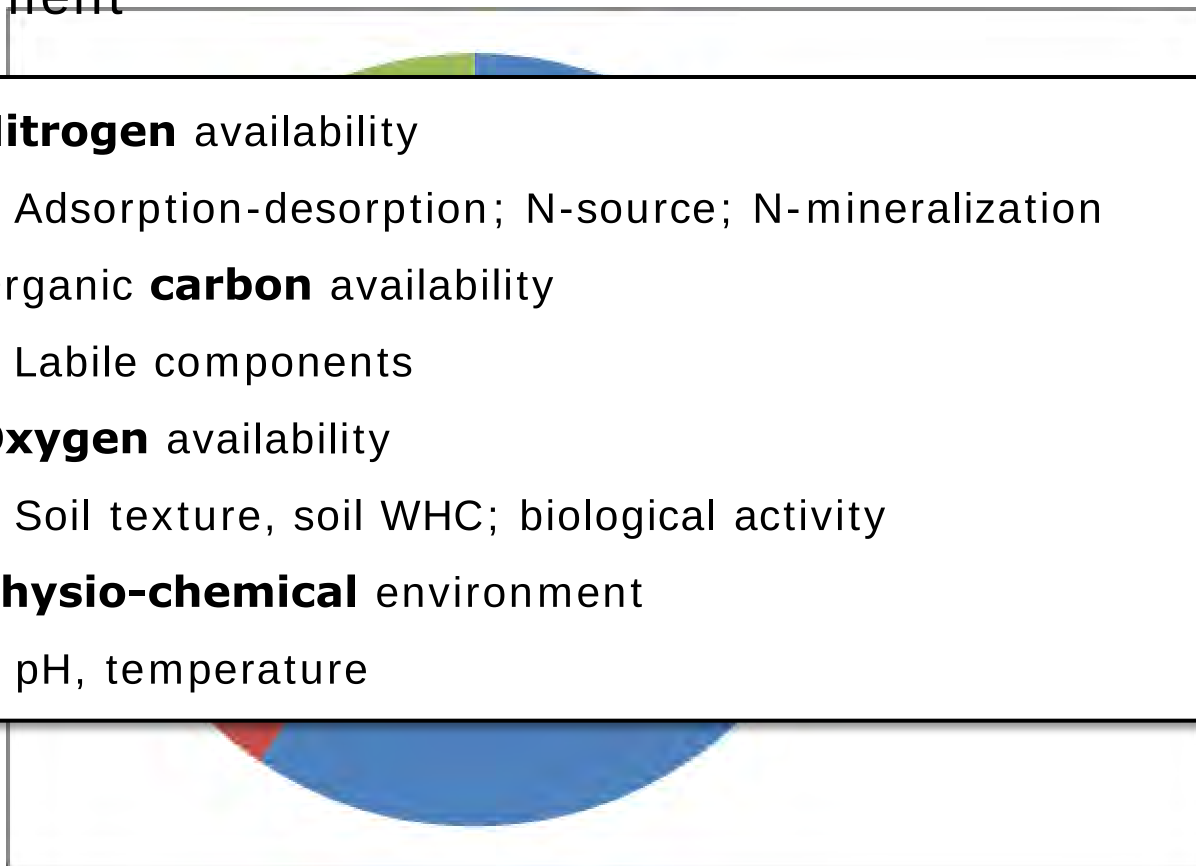
- Labile components

Oxygen availability

- Soil texture, soil WHC; biological activity

Physio-chemical environment

- pH, temperature



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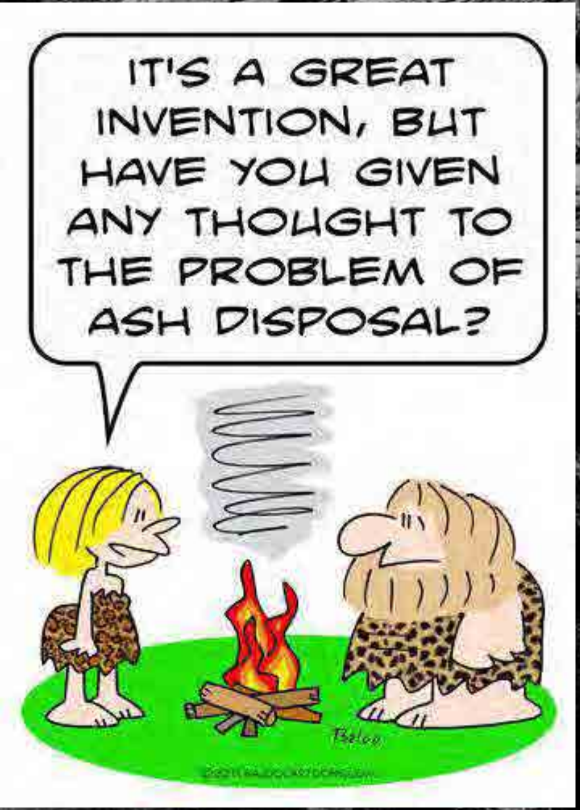
Thanks for your attention!



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Short presentation

Simulating the impacts of management practices on nitrous oxide emissions from cropland soils

Mohamed Abdalla[1,2], Pete Smith[1], Mike Williams[2] and Mike Jones[2]

[1]Institute of Biological and Environmental Sciences, School of Biological Sciences, University of Aberdeen, Aberdeen, UK

[2]Department of Botany, School of Natural Sciences, Trinity College Dublin, Dublin 2, Ireland

objectives

- To investigate the effectiveness of different management systems to mitigate nitrous oxide emissions from arable system.

i- Effectiveness of Reduced N

ii- Effectiveness of Reduced tillage

iii- Effectiveness of Reduced tillage-Cover crop

Materials & Methods

Field management dates for conventional and reduced tillage/cover crop systems during the experimental period.

Operation	Treatment date (day/month)	
	Reduced tillage–cover crop	Conventional tillage
Ploughing	18–27/8	18–25/2
Sowing	9–19/3	9–19/3
Fertilizer application	13–21/4 & 7–22/5	13–21/4 & 7–22/5
Sowing cover crop	8/8–13/9	–
Harvesting	5–21/8	5–21/8

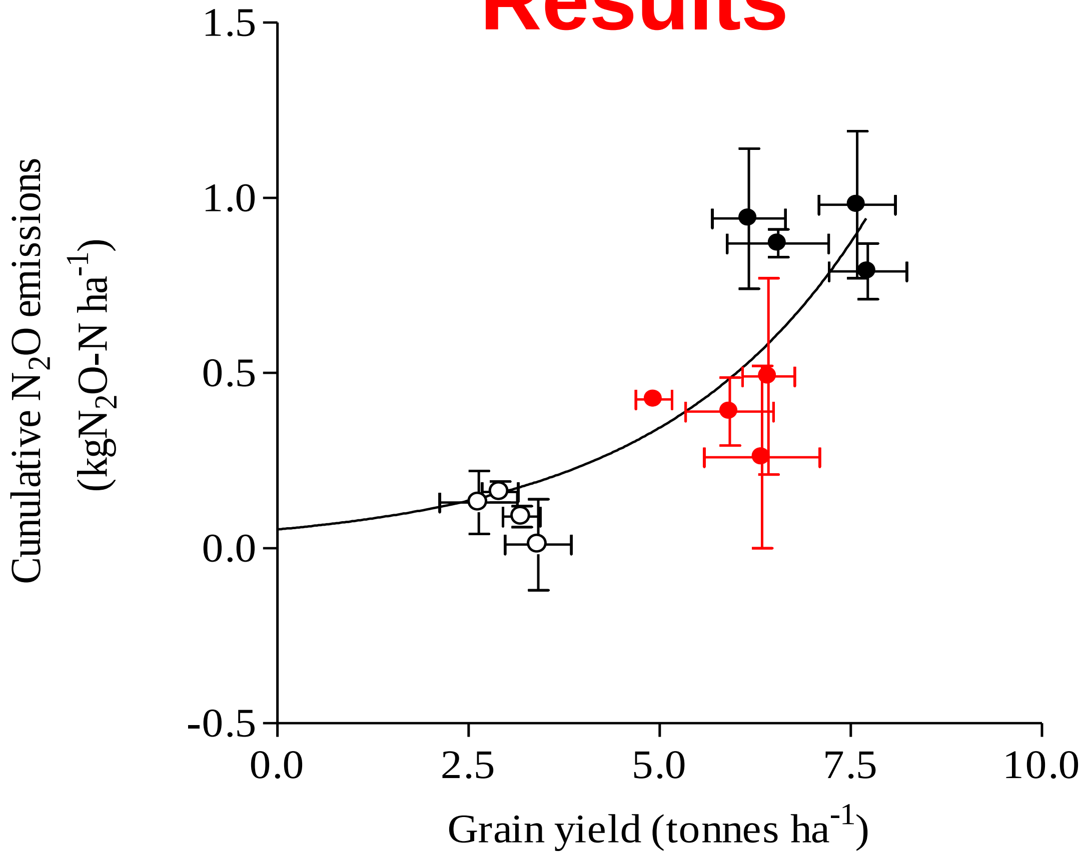
Results

N_2O emissions (kg N_2O-N ha^{-1})				Rd (%)
First year	Treatment	Observation	Model	
Conventional tillage	140 kg N ha^{-1}	0.788 a	0.780	-1
	70 kg N ha^{-1}	0.269 b	0.350	+30
	0 kg N ha^{-1}	0.002 c	0.110	+ >100
Reduced tillage	140 kg N ha^{-1}	0.978 a	0.590	-40
	70 kg N ha^{-1}	0.494 b	0.220	-55
	0 kg N ha^{-1}	0.087 c	0.030	-66
Second year				
Conventional tillage	160 kg N ha^{-1}	1.053 a	0.993	-6
	80 kg N ha^{-1}	0.563 b	0.450	-20
	0 kg N ha^{-1}	0.170 c	0.110	-35
Reduced tillage	160 kg N ha^{-1}	1.058 a	0.793	-25
	80 kg N ha^{-1}	0.567 b	0.320	-44
	0 kg N ha^{-1}	0.135 c	0.010	-93

•Measured EFs: 0.4 to 0.7%, whilst modeled EFs: 0.3 to 0.6%

Abdalla et al. (2009)

Results



- Exponential correlation: y = 0.053*e0.373x, (r^2= 0.69).
- Reducing the applied nitrogen fertilizer by 50 % reduce N_2O emissions by 57 % but only 16% of grain yield.

Abdalla et al. (2010)

Results

Table: Observed and simulated cumulative N_2O from RT-CC and CT over the experimental period.

Treatment	Cumulative N_2O emission (kg N ha^{-1})		
	Observation	Model	Relative deviation (%)
Reduced tillage–cover crop			
140 kg N ha^{-1}	2.42 a	1.56	−36
70 kg N ha^{-1}	2.17 a	0.91	−58
0 kg N ha^{-1}	0.87 b	0.76	−13
Conventional tillage			
140 kg N ha^{-1}	1.74 a	1.41	−19
70 kg N ha^{-1}	1.37 a	1.01	−26
0 kg N ha^{-1}	0.86 b	1.00	+16

Different letters are significantly different from each other ($p < 0.05$)

Abdalla et al. (2012)

Results

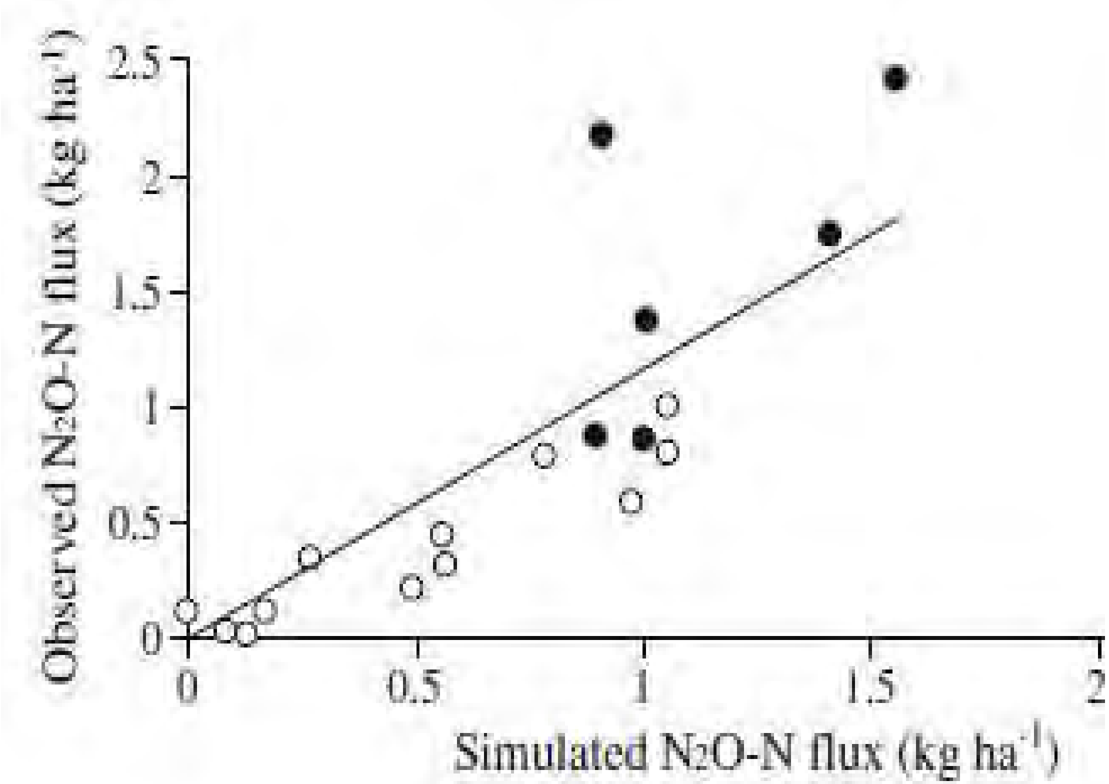


Fig.: Linear regression relationship between the model simulated and observed cumulative N_2O fluxes. Data of the reduced and conventional tillage plots from this study (filled circles) and from Abdalla et al. (2009) (open circles) were pooled together, $y = 1.2x$ and $r^2 = 0.70$

Abdalla et al. (2012)

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Results

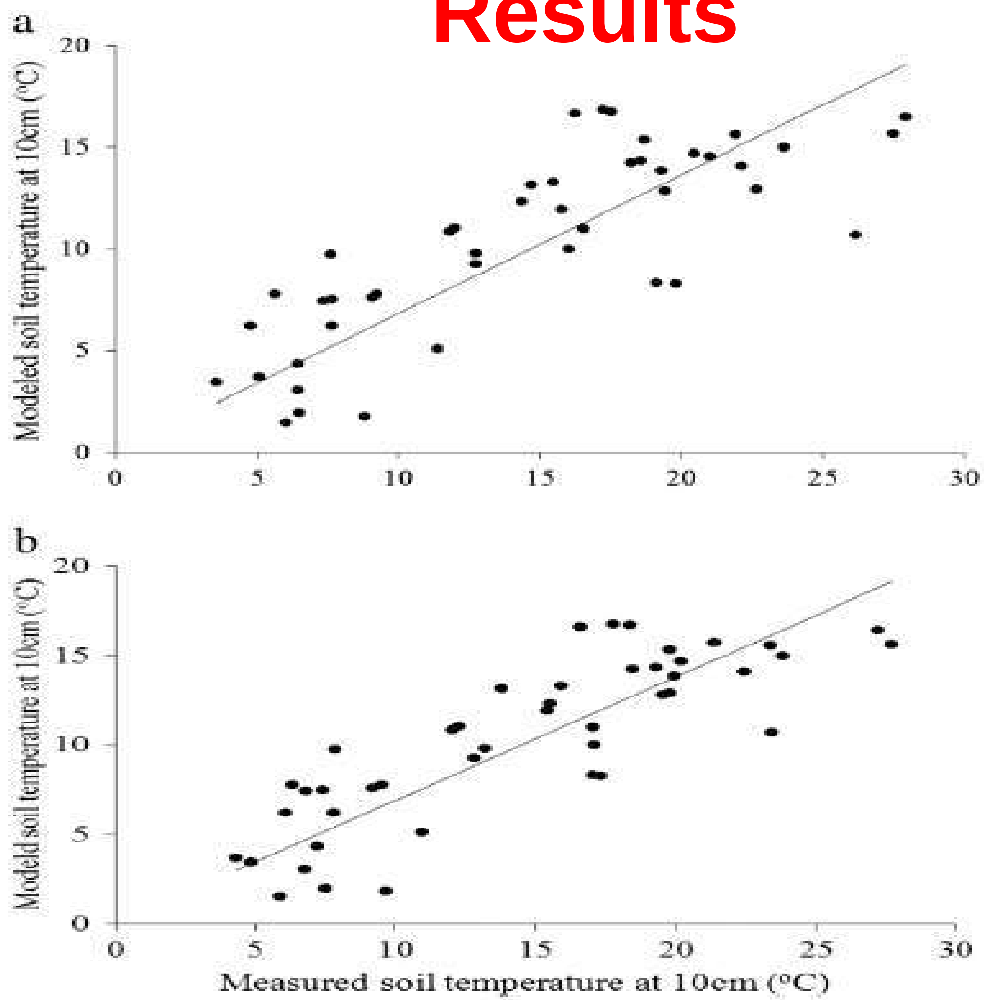

Fig.: Regression relationships (1:1) between the field daily mean measured and DNDC simulated soil temperature (10 cm depth) from the conventional (a; y = 0.5x+ 2.4 and r^2 = 0.65) and reduced tillage/cover crop (b; y = 0.6x + 1.7 and r^2= 0.7).

Abdalla et al. (2014)

Results

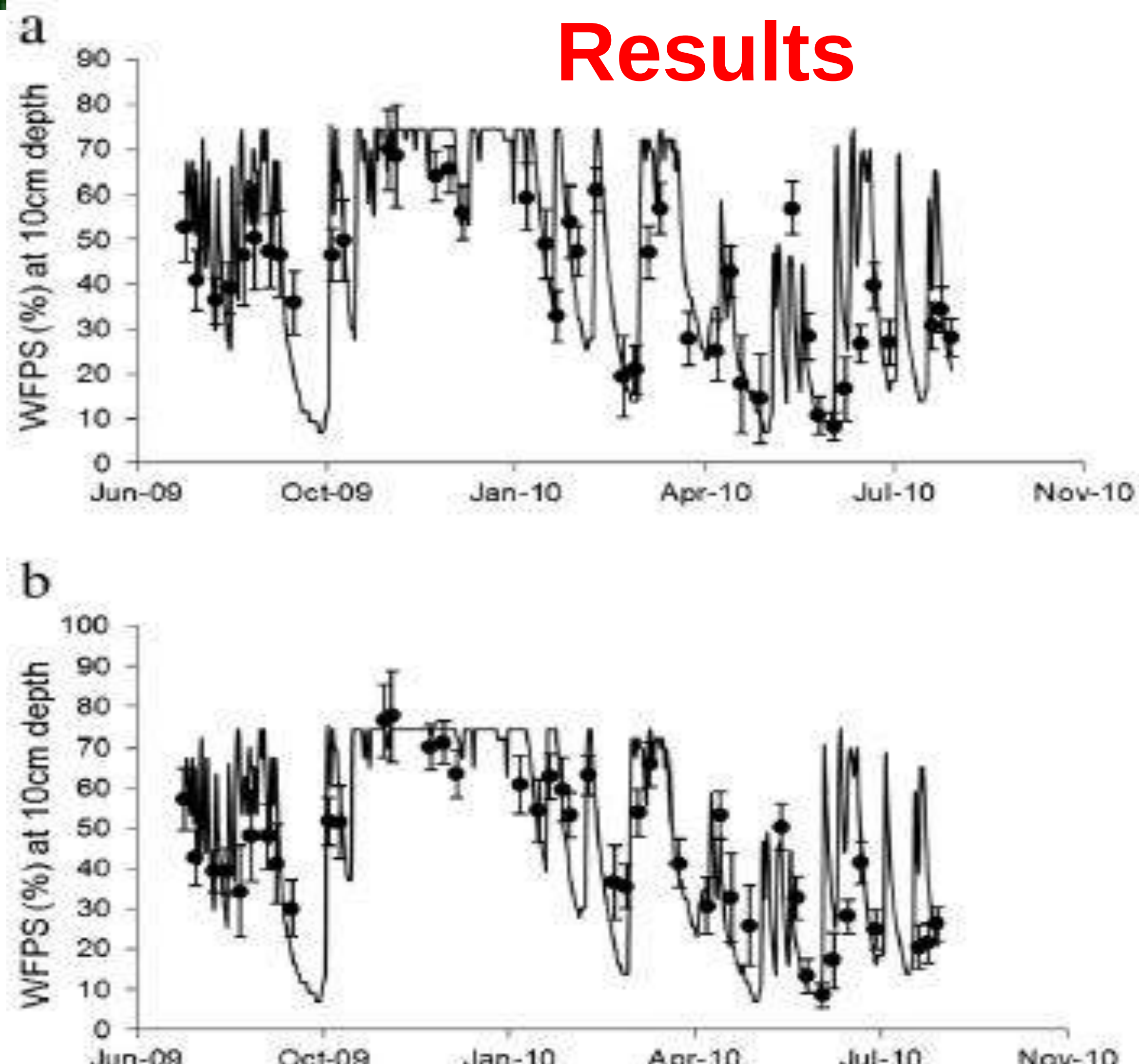

Fig.: Comparison between the DNDC simulated (lines) and field measured soil (●)WFPS (10 cm depth) from the conventional (a) and reduced tillage/cover crop (b). Error bars for measured values are ±standard deviation.

Abdalla et al. (2014)

Results

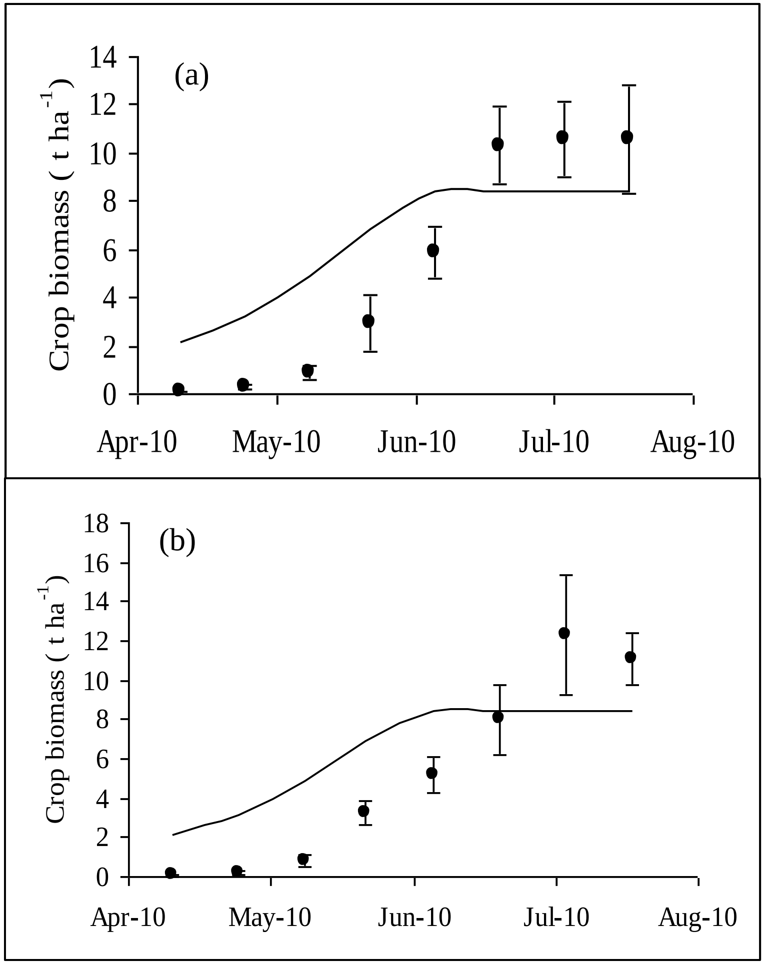

Fig.: Comparisons between the DNDC simulated (lines) and field measured (●) crop biomass from the conventional (a) and reduced tillage/ cover crop systems (b).

Results

Table: Comparisons between measured and simulated N_2O fluxes, biomass production (t C ha^{-1}), average soil nitrate, temperature and WFPS (at 10 cm depth) for the CT and RT-CC. For column, values with different letters for the same gas are significantly different from each other (P<0.05).

Management System	*Annual N_2O fluxes (kg ha^{-1}), biomass production (t ha^{-1}) and average soil nitrate (kg ha^{-1}), temperature (^{o} C) and WFPS (%).*					
	Measured	*Modelled*	*RD*	*RMSE*	*MAE*	*r^2*
Conventional tillage						
N_2O	3.8 a	0.96	75	0.01	0.0	0.01
Crop biomass (C)	4.2	4.0	- 6	0.8	1.7	0.29
Soil nitrate	19.2	52	+>100	8.0	29	0.52
Soil temperature	14.5	11.7	-20	0.9	-4.5	0.65
WFPS	43	45	+3	2.0	0.9	0.64
Reduced tillage/ cover crop						
N_2O	5.3 b	1.1	77	0.0	0.0	0.01
Crop biomass (C)	4.4	4.0	-10	0.8	1.7	0.26
Soil nitrate	23.0	31.6	+37	5.0	23.0	0.39
Soil temperature	14.6	11.7	-19	0.8	-4.5	0.70
WFPS	44	45	+1	2.0	0. 4	0.61

Abdalla et al. (2014)

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Conclusions

- The DNDC model can be successfully applied to estimate N_2O emissions under different management systems however, some model-limitations need to be addressed.

- Reducing N fertilizer by 50% is an acceptable strategy for low input agriculture in that there was no significant effect on grain yield or quality.

- The use of RT-CC as an alternative farm management system for spring barley, if the sole objective is to reduce N_2O emissions, may not be successful.

Short presentation

Simulation of the effect of some management practices on N_2O emissions using the STICS model

(preliminary results)

Joël Leonard

N. Brunet, C. Gaudnik, E. Gréhan, B. Mary, C. Peyrard

soil-crop model

- Main variables simulated
  - **Crop growth** (with generic crop representation); dynamics of **water**, **nitrogen**, **carbon** in plant and soil
- Management practices
  - **Complex rotations**: cover crops, intercropping, leguminous crops; possible to connect sequences
  - **N inputs** (mineral, organic): amount, form, depth, timing ; **crop residues** restitution/exportation
  - **Soil tillage**/soil structure (mixing, compaction), mulch effect
  - Irrigation, drainage/saturation
- N_2O
  - **Nitrification** and **denitrification**
  - **N_2O emissions** associated to both processes
  - Approach: **potential modulated by substrate availability** (NO_3, NH_4) and **environment** (T, water and O_2 via WFPS, pH) (Bessou et al., EJSS, 2010)

Field experiment

' SOERE ACBB', arable crops site, Estrées-Mons, France

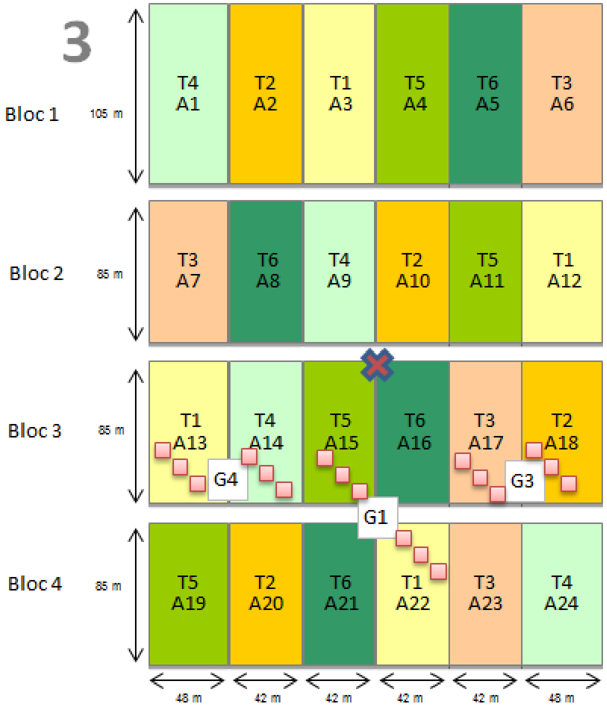
- Some of the main practices used to reduce the environmental impacts of cropping systems are represented
  - Reduction of tillage
  - Residues management
  - Reduction of nitrogen inputs
  - Cover crops / leguminous crops
- **Possible comparisons of treatments by pairs**

	Experimental Treatment	Crop Rotation	Soil Tillage	Crop residues	Nitrogen Inputs	Cover crop
T1	Conventional tillage	Spring Peas, Winter Rapeseed, Winter Wheat, Spring Barley, Corn, Winter Wheat	Conventional	Straw Incoporation	Integrated production	Non legume
T2	Reduced tillage	Spring Peas, Winter Rapeseed, Winter Wheat, Spring Barley, Corn, Winter Wheat	Reduced	Straw Incoporation	Integrated production	Non legume
	Reduced tillage & Straw exportation	Spring Peas, Winter Rapeseed, Winter Wheat, Spring Barley, Corn, Winter Wheat	Reduced	Straw Removal	Integrated production	Non legume
T3	Low Nitrogen Inputs	Spring Peas, Winter Rapeseed, Winter Wheat, Spring Barley, Corn, Winter Wheat	Conventional	Straw Incoporation	Low Mineral Inputs	Non legume
T4	Ecological Intensification	Spring Peas, Winter Rapeseed, Winter Wheat, Spring Barley, Corn, Winter Wheat	Conventional	Straw Incoporation	Low Mineral Inputs	Legume
T5	Integration of biomass crops	Switchgrass (duration : 6 years) Spring Peas, Winter Rapeseed, Winter Wheat, Spring Barley, Corn, Winter Wheat	Conventional	Straw Removal	Integrated production	Non legume

N_2O emissions

- **Continuous N_2O measurements**
  - **3 Automatic chambers per plot**, block replicate for one plot
  - Rapeseed- Mustard - Barley 2011-2013 (**603 days**)

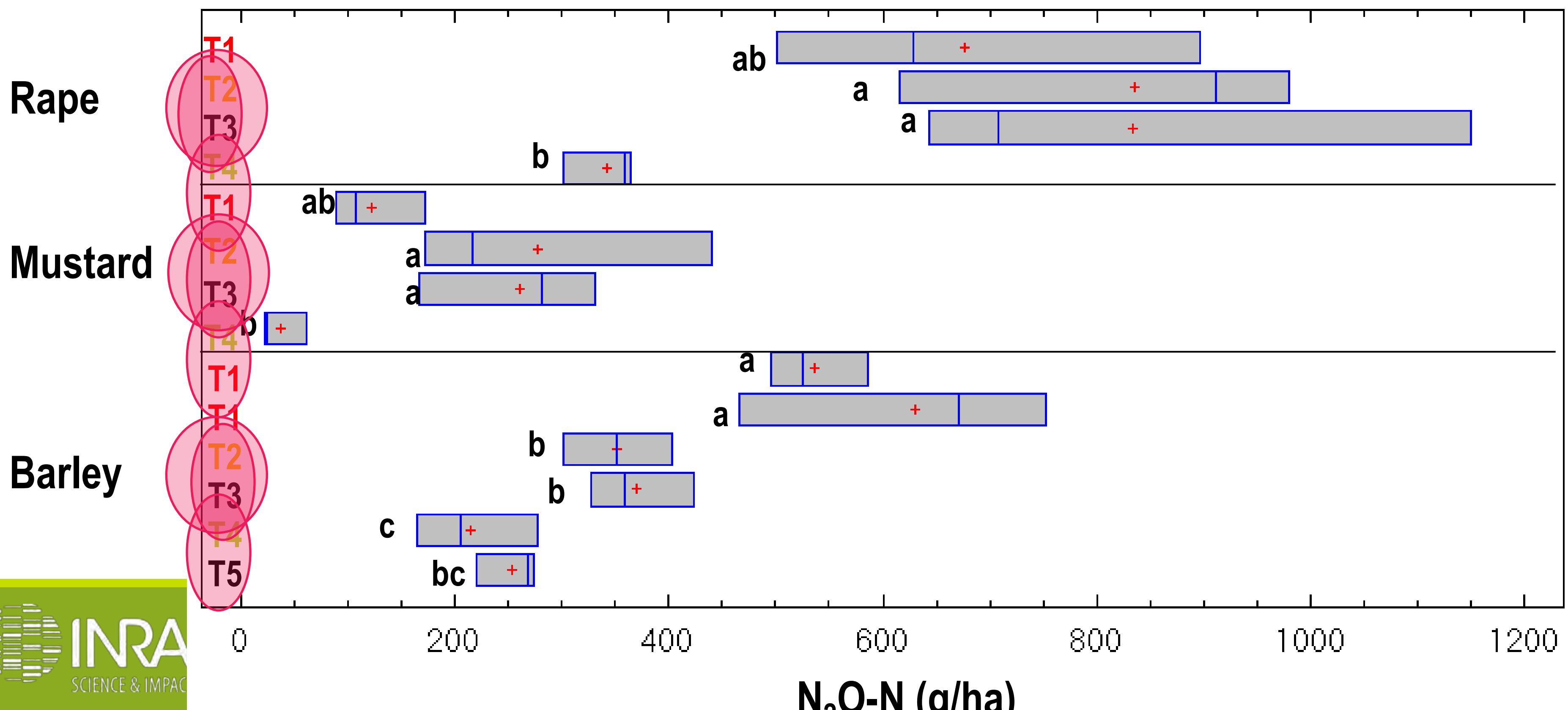
- Measurements of soil nitrogen, soil water, soil temperature, biomass…
  - Model initialization
  - Model evaluation : check control variables



Measured N_2O emissions

- Contrasts between crops, but for part explained by varying crop cycle duration
- Reduction in fertilization is the major effect (T4 vs. T1)
- Reduced tillage effect variable (T2 vs. T1, consistent with other results)
- No effect of residues management (T3 removed vs. T2)

T1 = reference system



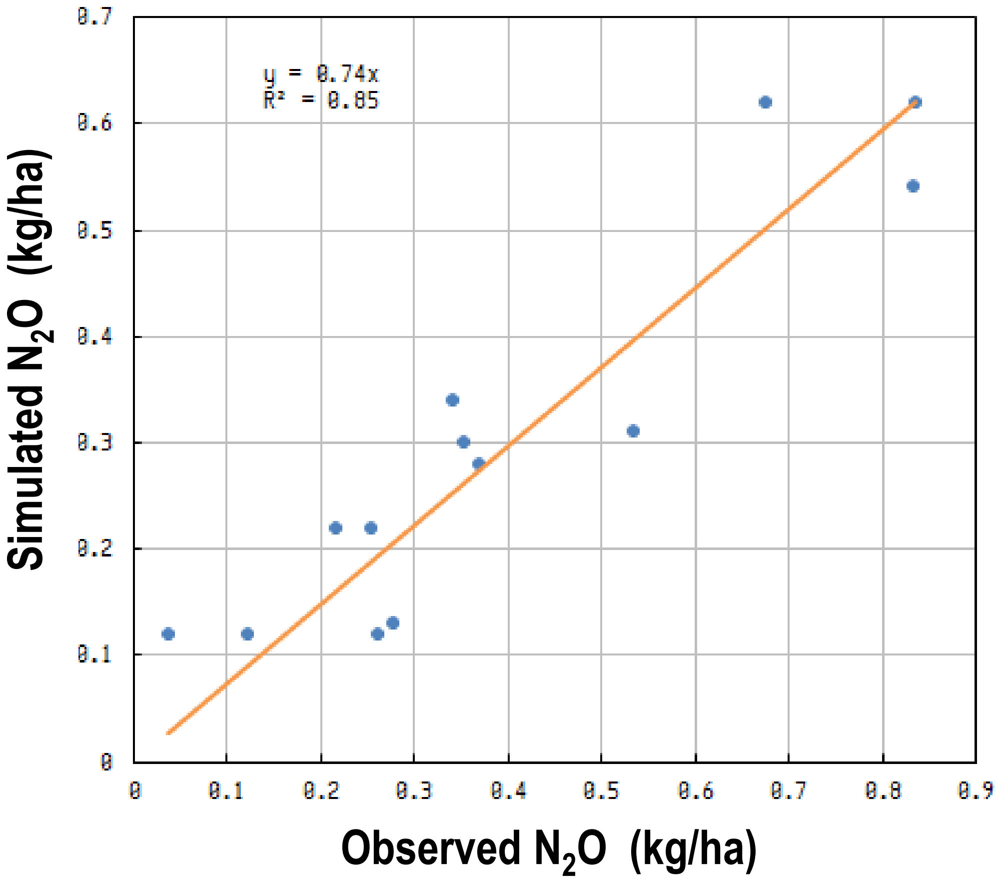
Global model performances

No calibration

- Main variations captured
- Underestimation of simulated emissions

Nitrification supposed (from model results) to be the main source of N_2O (77% of total)

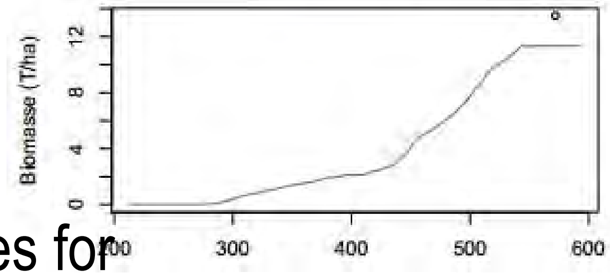
Cumulative observed and simulated N_2O emissions, by treatment and crop



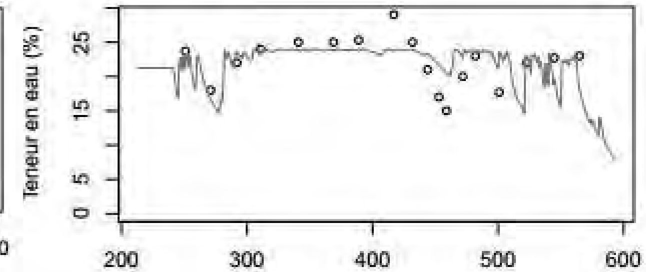
Modelling N_2O fluxes dynamics (ex. T1, rape)

- Reasonable performances for simulating control variables

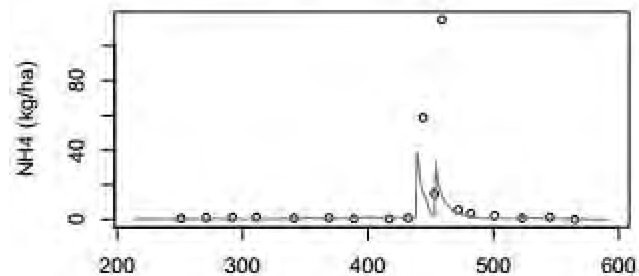
Biomass



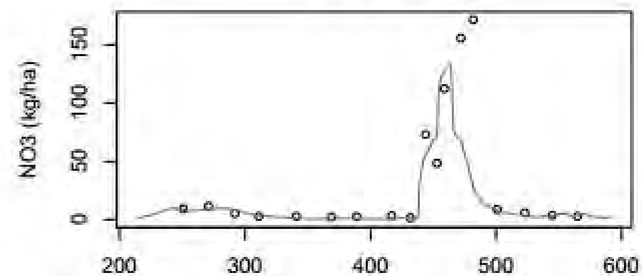
Water content



NH_4

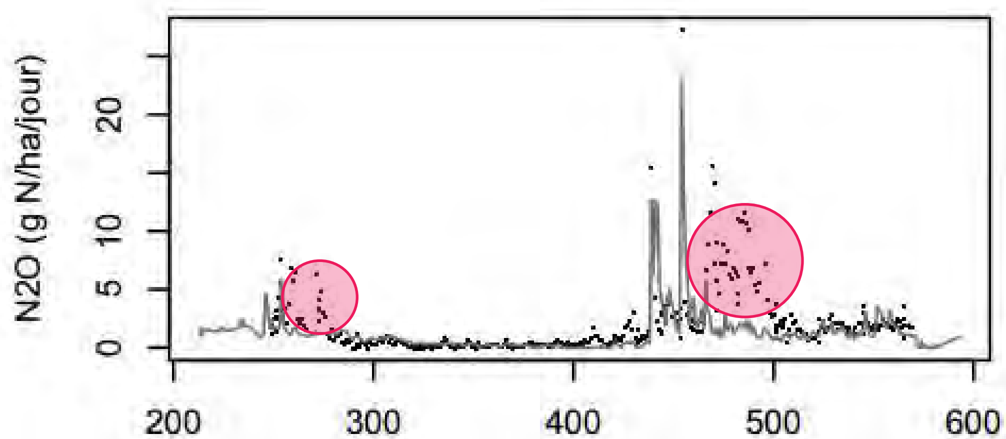


NO_3



- **N_2O** :
  - Correct order of magnitude of peaks
  - Some but not all features of the temporal dynamics captured

N_2O



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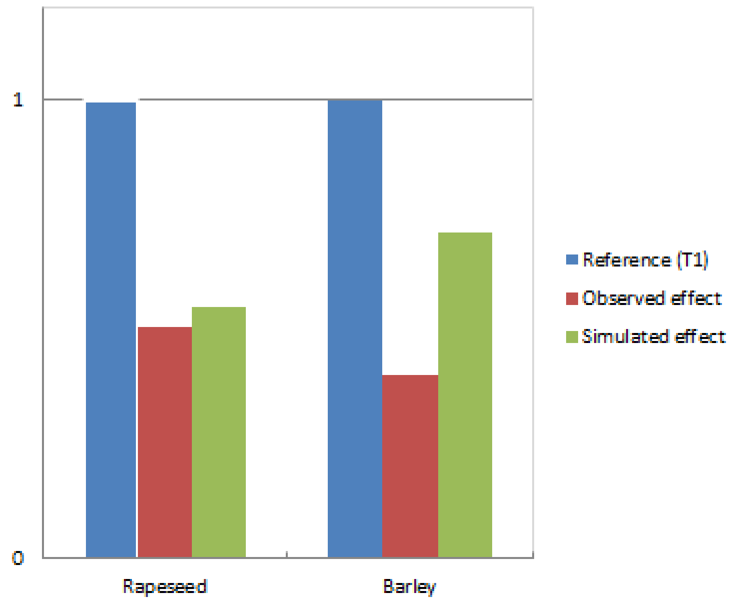
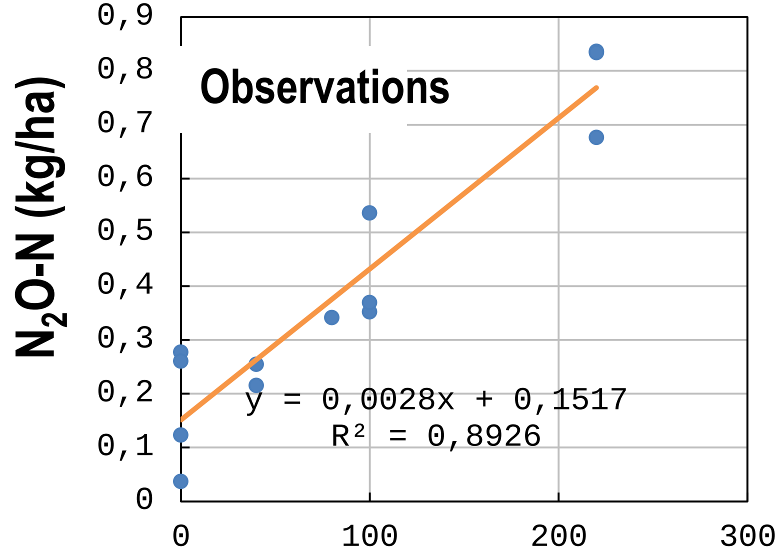
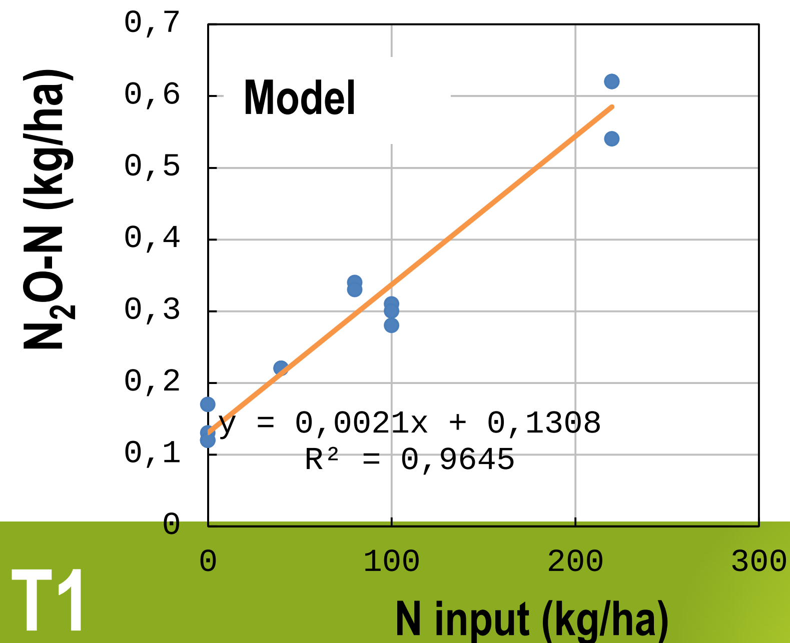
Simulation of the effect of fertilization

- **Correct order of magnitude: 0.21% N vs. 0.28% N << 1% IPCC**

- Relative effect
  - Correct for rapeseed
  - Underestimated for barley



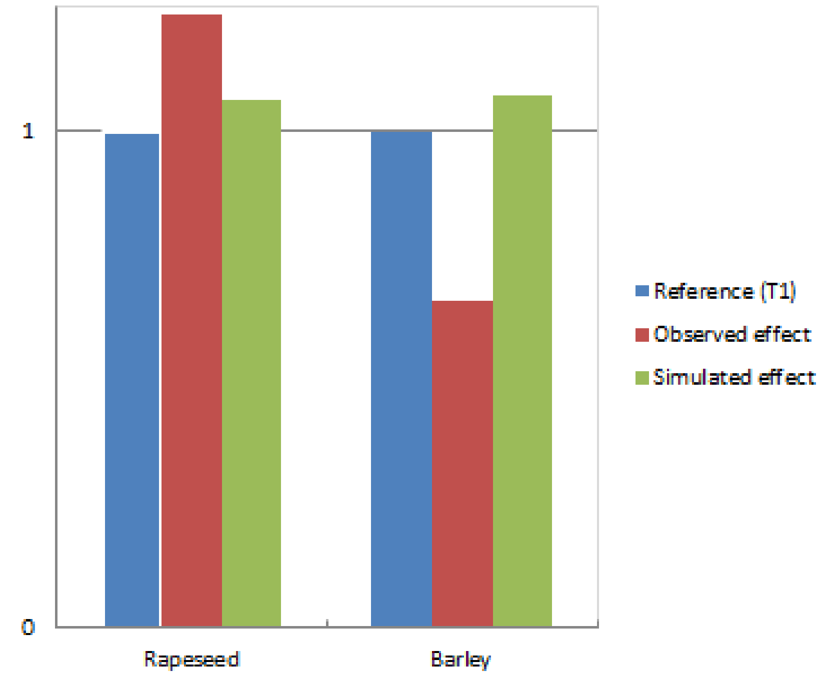




T4 vs. T1

Simulation of the effect of reduced tillage

- Measured emissions
  - a bit higher for rapeseed, **significantly lower for spring barley**
  - Only **absence of ploughing on T2/T1**, same superficial tillage operations than on T1

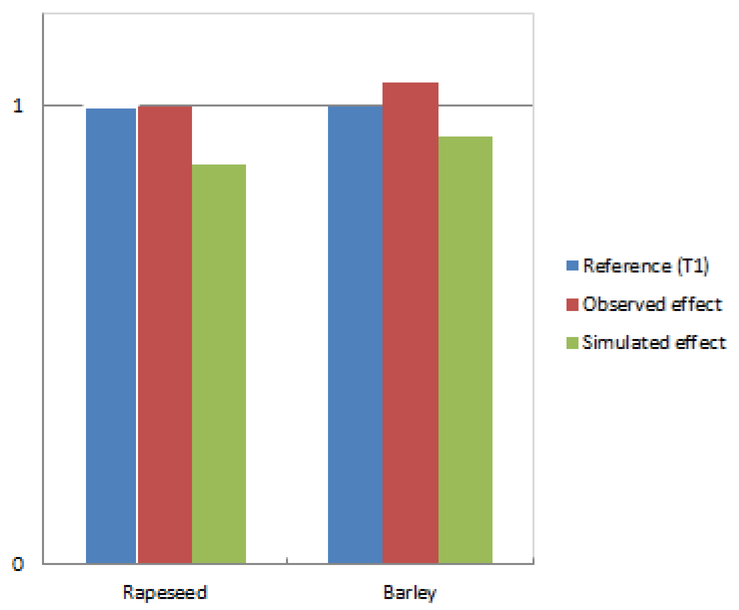


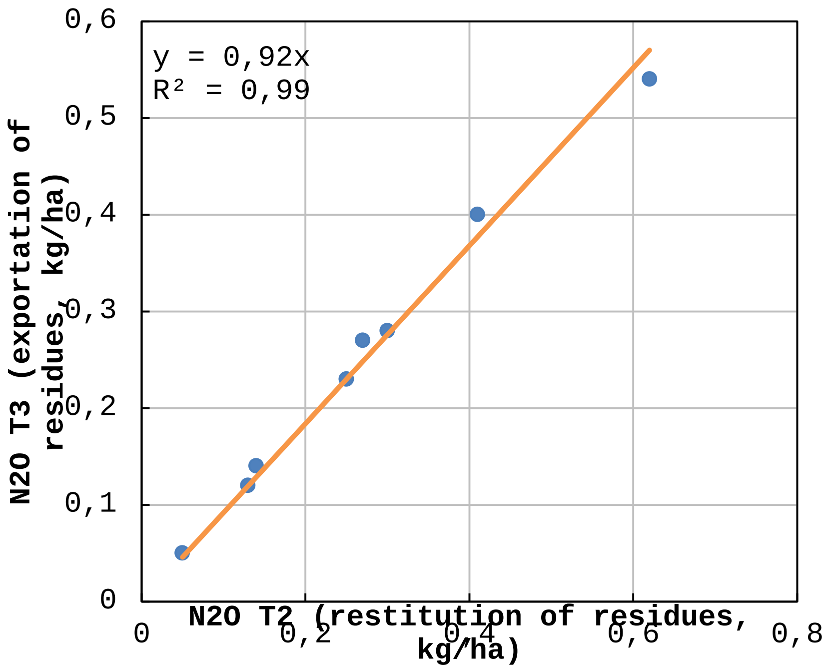
- Modelled emissions:
  - Slight increase in N_2O emission **if small increase in soil bulk density taken into account**
  - **No difference if the bulk density remains the same** (despite mixing effect of ploughing on mineral nitrogen concentration and water content)

T2 vs. T1

Simulation of the effect of crop residues restitution

- **No significant difference for observed emissions**
- Tendency to have slightly **lower simulated emissions when residues are exported**
  - -13 % on rapeseed following wheat with straw removed or not





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T3 vs. T2

Some conclusions

- Observed differentiation between treatments is still limited after 3 years
  - ➔ Nitrogen input remains the main effect, rather small EF
  - ➔ Little differentiation in soil physical conditions

- Reasonable performance of STICS (order of magnitude, dynamics) despite absence of calibration
- Possible to simulate the effect of the different treatments, but :
  - more contrast between treatments for observed emissions than for simulated one
  - Simulations sometimes not consistent with observations (tillage)

➔ Useful to isolate the effect of a given practice, because poor simulation performance for this practice can be hided by another dominant practice such as N input

Short presentation

Impacts of integrated weed management in cropping systems on N_2O emissions from soil

A. Vermue, C. Hénault, A. Coffin, N. Munier-Jolain, B. Nicolardot

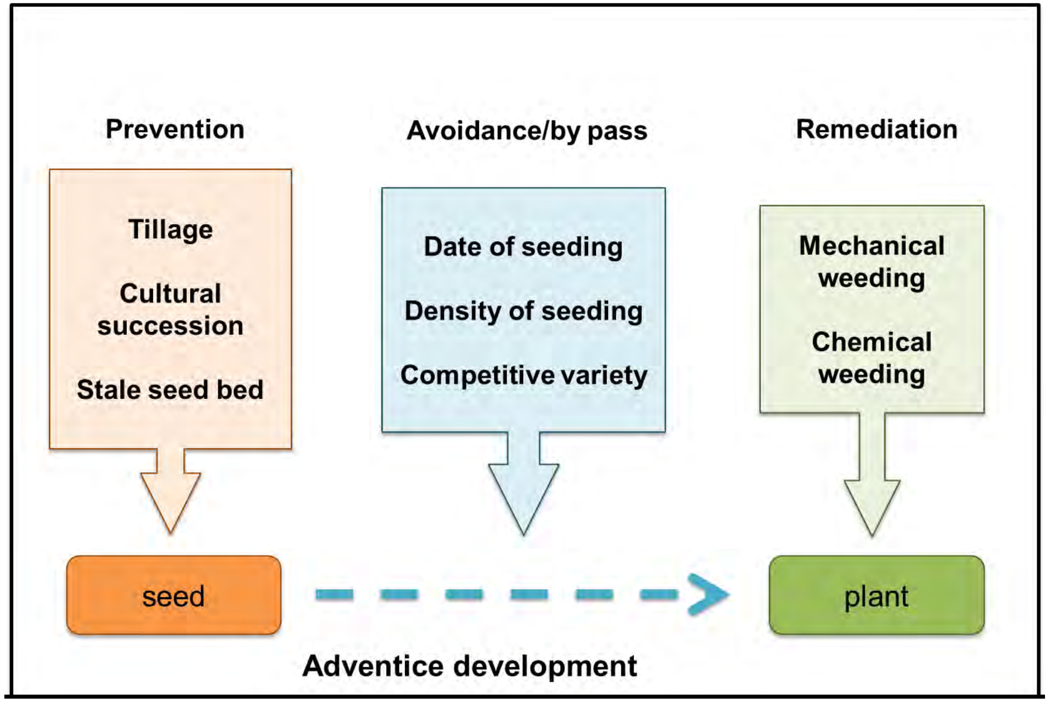
INRA SCIENCE & IMPACT

AGRO SUP DIJON Institut national supérieur des sciences agronomiques de l'alimentation et de l'environnement

Integrated Weed Management (IWM)

- **Definition**
  To reduce the reliance of cropping systems on herbicide, with limited environmental, economic and social impacts
  By the use of specific combinations of innovative agricultural practices

- **Means**



Objectives of the study

- ➪ To measure N_2O emission (together with ancillary variables) in cropping systems that includes some IWM systems

- ➪ To analyse the collected databa with a modelling approach (NOE algorithm, Henault *et al*., 2005)

The Experimental Site

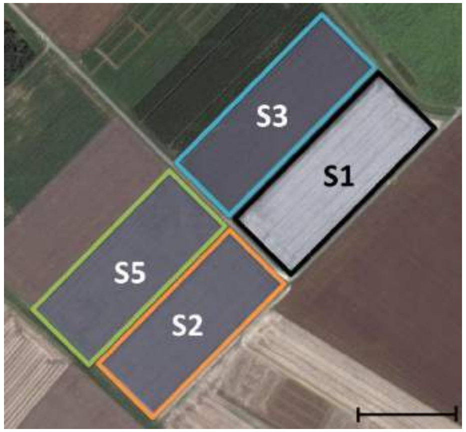
Eastern France (Dijon) – Semi-continental climate
Calcisoil (with spatial heterogeneity)

IWM : started in 2000

Crop system	**S1**	**S2**	**S3**	**S5**
Type of system	Reference	IWM	IWM	IWM
Specific agricultural practices	Conventional	Minimum tillage (2000-2007) . No tillage from 2008 Plowing, harrowing, mechanical weeding excluded	Mechanical weeding excluded Tillage operation allowed when necessary	Mechanical weeding and plowing allowed
Treatment frequency index	2,4	2,0	1,4	0
Plowing frequency	1 / year	-	0.4 / year	0.5 / year
Crop Rotation	Wheat/barley/rape	diversified	diversified	diversified
Mean annual fertilisation (kg ha^{-1})	178	133	103	130

Specific Field Measurements

(April 2012 – April 2013)



- **6 automated chambers per plot coupled to IR analyser**
- **4 TDR and thermistor probes per plot**
- **Periodical measurements of nitrogen contents and of bulk density**

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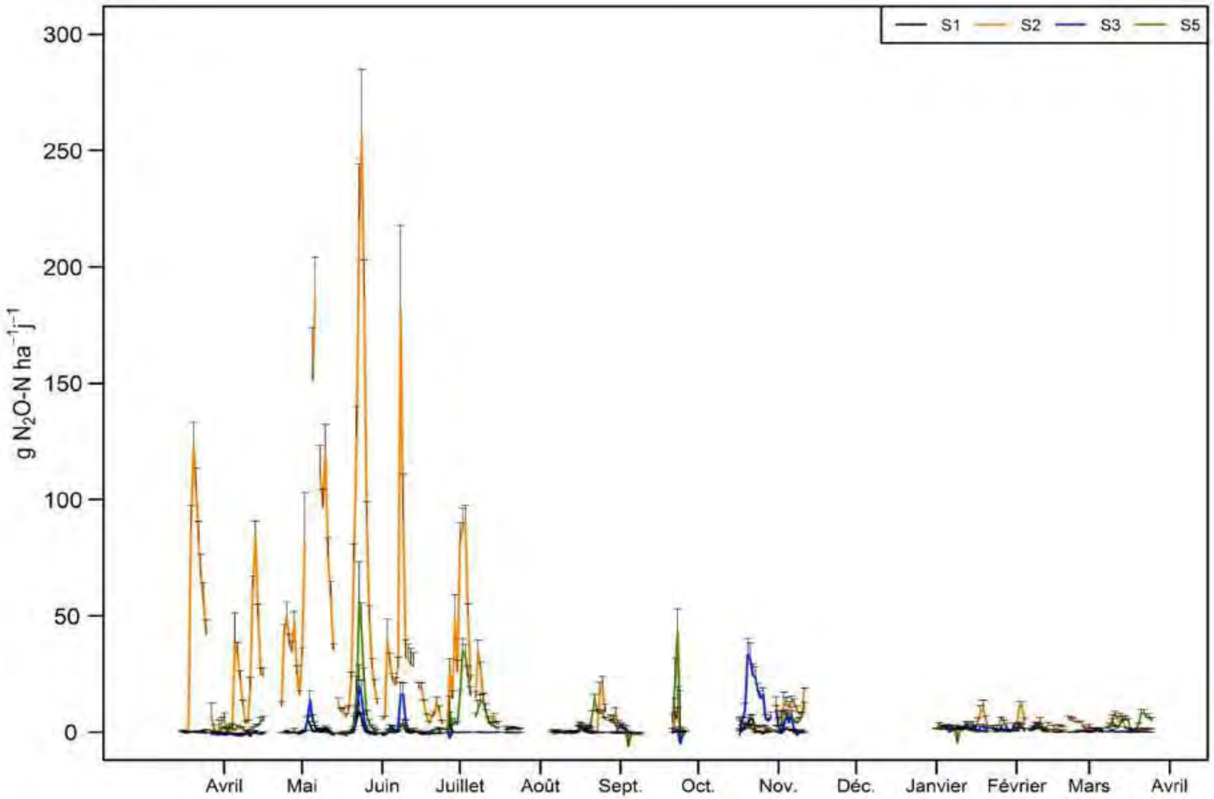
ON AGRICULTURAL GREENHOUSE GASES

Results of measurements



S1 – Conventional - wheat

S2 – IWM
No tillage –
herbicides - barley

S3 – IWM – reduced tillage – reduced herbicide - wheat

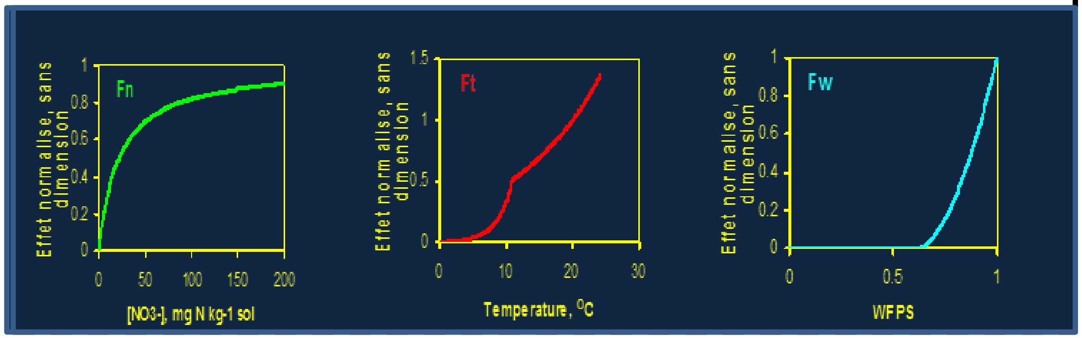
S5 – IWM zero herbicide
alfafa

system	S1	S2	S3	S5
Mean flux (g N-N_2O ha^{-1} d^{-1})	0.5	26.8	1.8	3.7
Cumul (g N-N_2O ha^{-1})	326 ± 168[c]	5226 ± 670[a]	177 ± 172[c]	777 ± 177[b]

The NOE Algorithm (Hénault et al., 2005)

Environmental fonctions

- Temperature (F_T, N_T)
- Soil moisture (F_W, N_W)
- Soil nitrogen ($F_{NO_3^-}$, $N_{NH_4^+}$)



Biological parameters

Soil capacity to reduce N_2O

Hénault *et al.*, 2001

Potential denitrification rate

Hénault et Germon, 2000

N_2O emission through nitrification

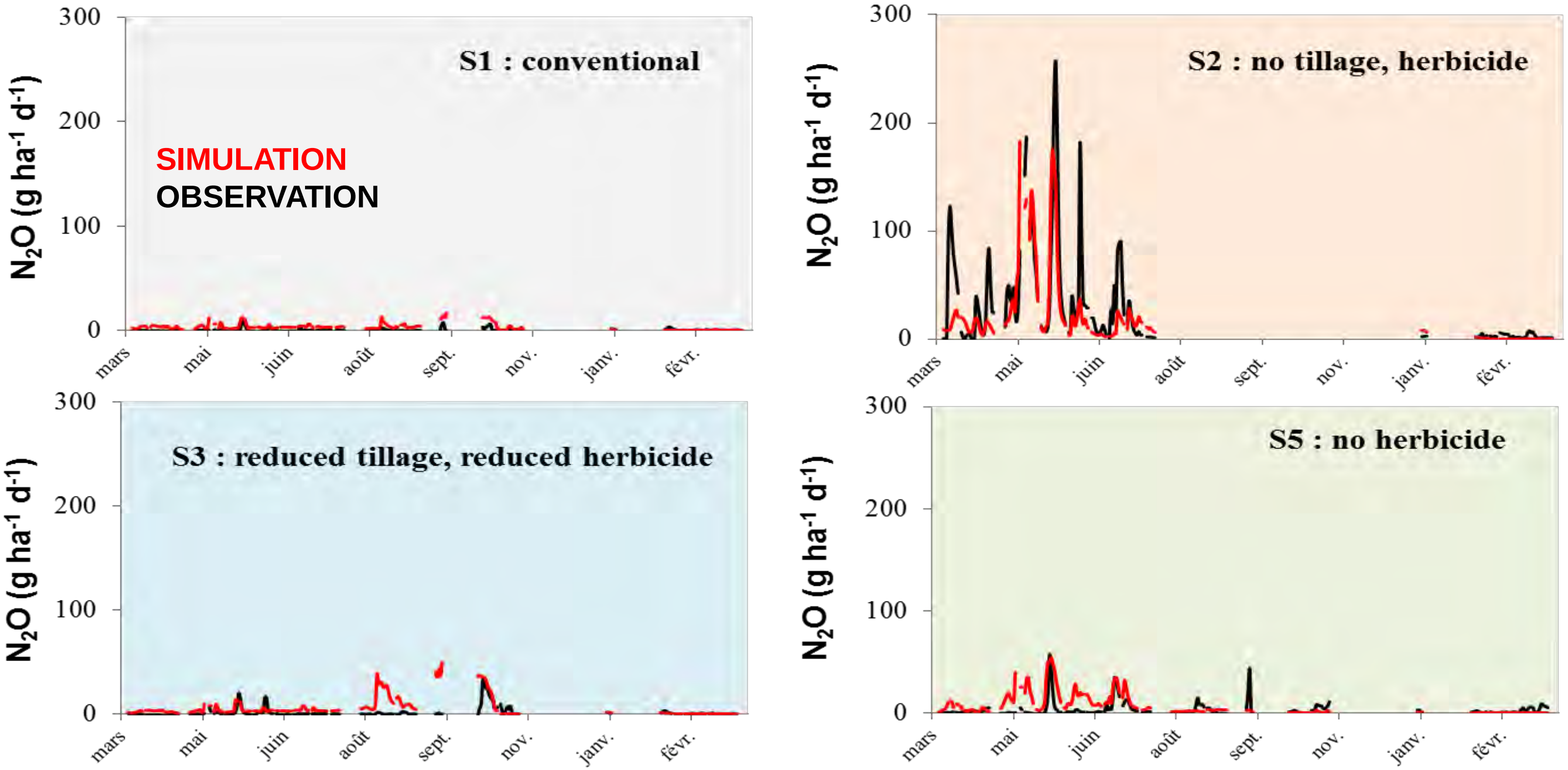
Garrido et al., 2002

$$N_2O_{\ total} = Rmax * (D_P * F_W * F_T * F_{NO_3^-}) + (z * N_W * N_T * N_{NH_4^+})$$

Denitrification

Nitrification

Results of simulations



system	S1	S2	S3	S5
observed cumul of emission (g N-N_2O ha^{-1}	81	4672	328	756[b]
Simulated cumul of emission (g N-N_2O ha^{-1})	706	3209	1360	1596

Main Conclusions

- Impact of IWM system on the intensity of N_2O emission : higher N_2O emission in the « no-till » IWM system during 2012-2013 (more investigations are required because of (1) possible interactions between soil variability and IWM and (2) temporal effect))

- The algorithm NOE was able to discriminate the N_2O emission intensity between the different IWM systems

- The analysis using NOE suggests that higher emissions on the « no-till » IWM system are due to :

    - higher potential denitrification rate
    - higher soil WFPS (soil moisture, bulk density)

Short presentation

Quantifying N-Emissions losses with Water and Nitrogen Management from Rice Paddy fields

Yam Kanta Gaihre

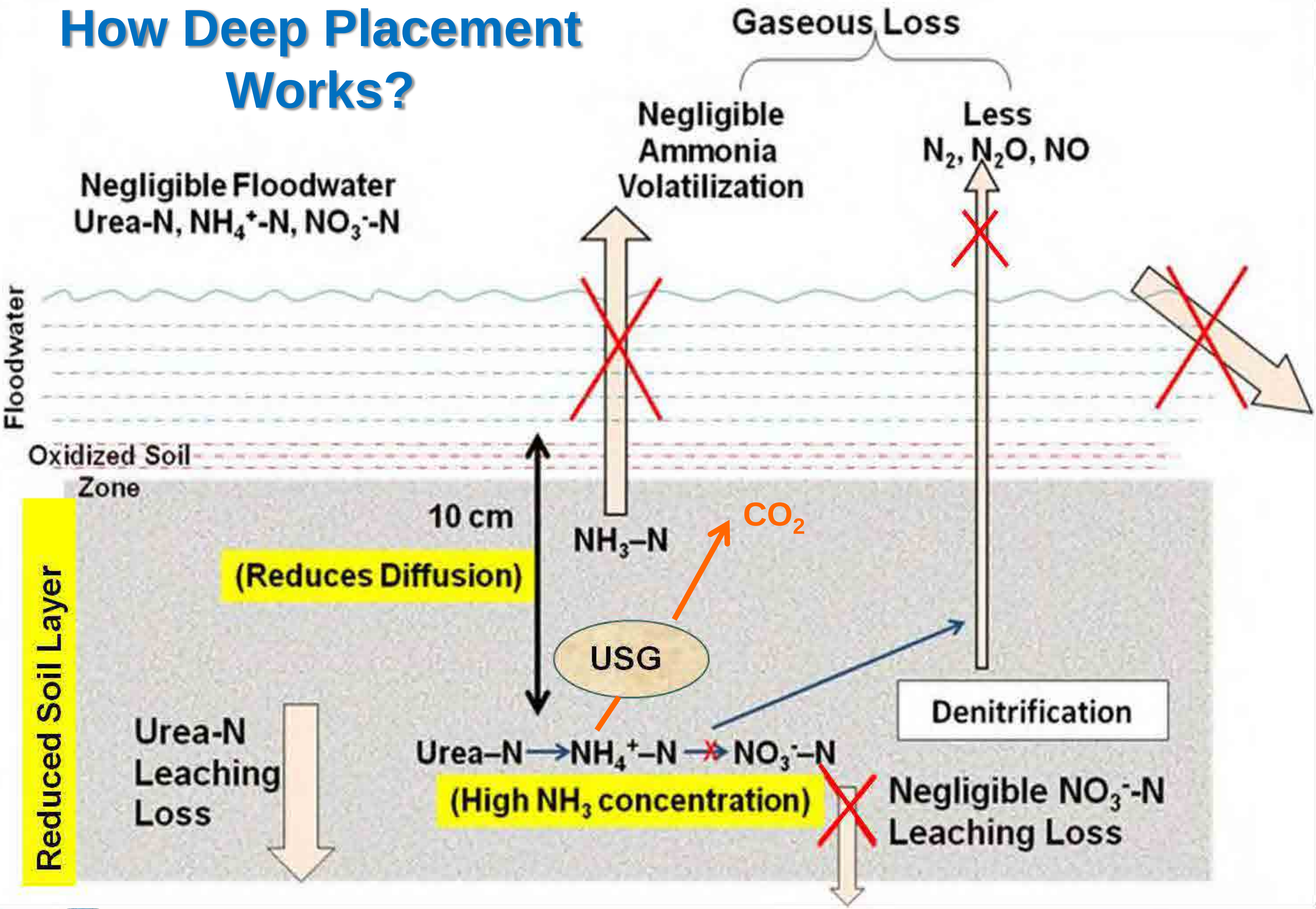
Materials and Methods

- Water management
  - Continuous standing water (CSW)
  - Alternate wetting and drying (AWD)

- Nitrogen management
  - Surface broadcast (split application)
  - Urea deep placement (5-7 cm between 4 hills of rice at the alternate rows)

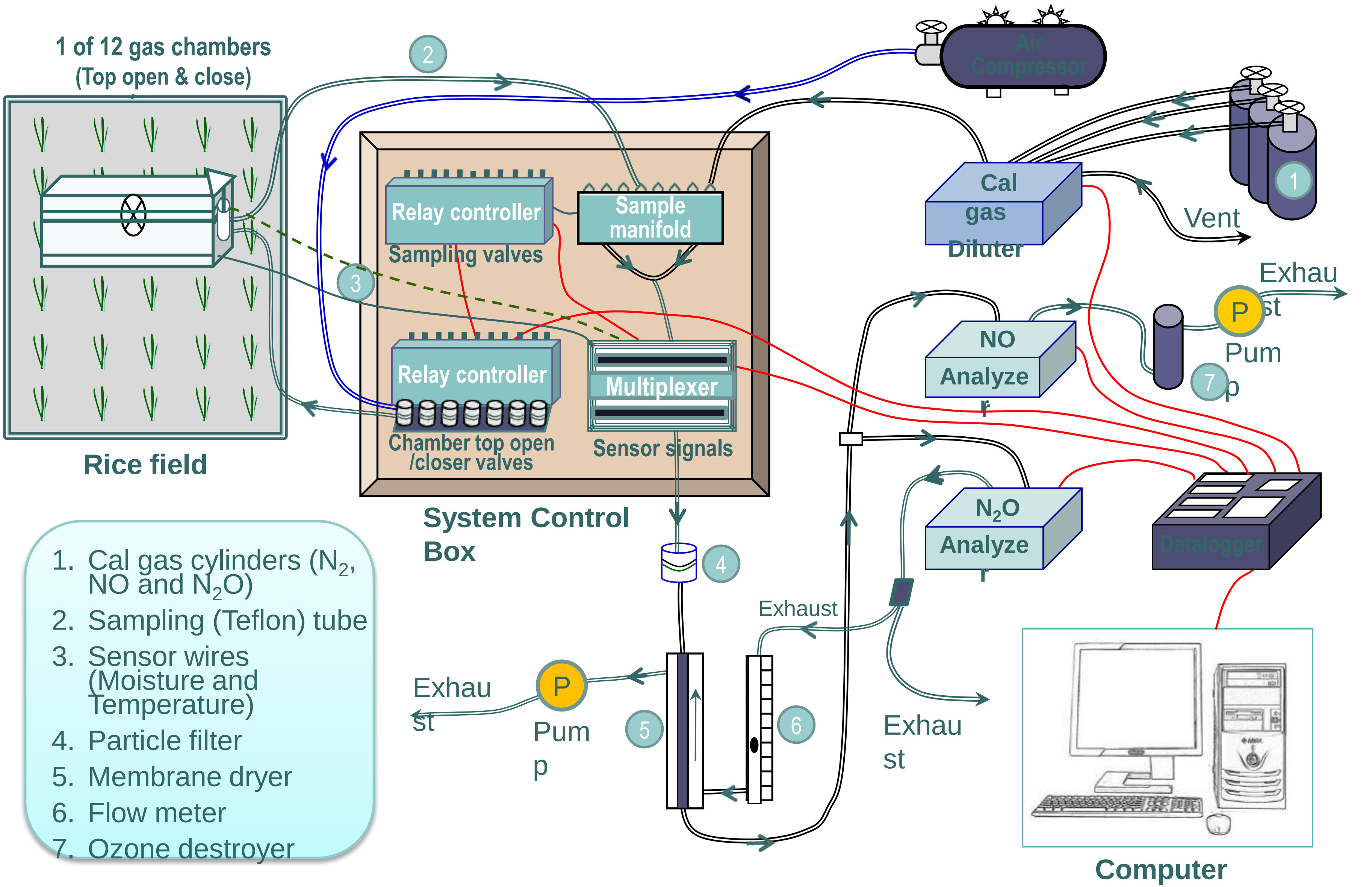
Prilled Urea | **Urea Briquettes**

How Deep Placement Works?



Methodology

- **Automated continuous measurement**
  - **N_2O (Gas Filter Correlation N_2O analyzer, Model T320U, Teledyne API)**
  - **NO (Chemiluminescence NO-NOx Analyzer, Model T200, Teledyne API)**
- **Data recorded using CR3000 (Campbell Scientific)**
- **Each chamber (57.1 liter) is sampled 8 times a day (3 hour interval)**
- **Chamber remains closed only for 40 minutes during each sampling time**



1. Cal gas cylinders (N_2, NO and N_2O)
2. Sampling (Teflon) tube
3. Sensor wires (Moisture and Temperature)
4. Particle filter
5. Membrane dryer
6. Flow meter
7. Ozone destroyer

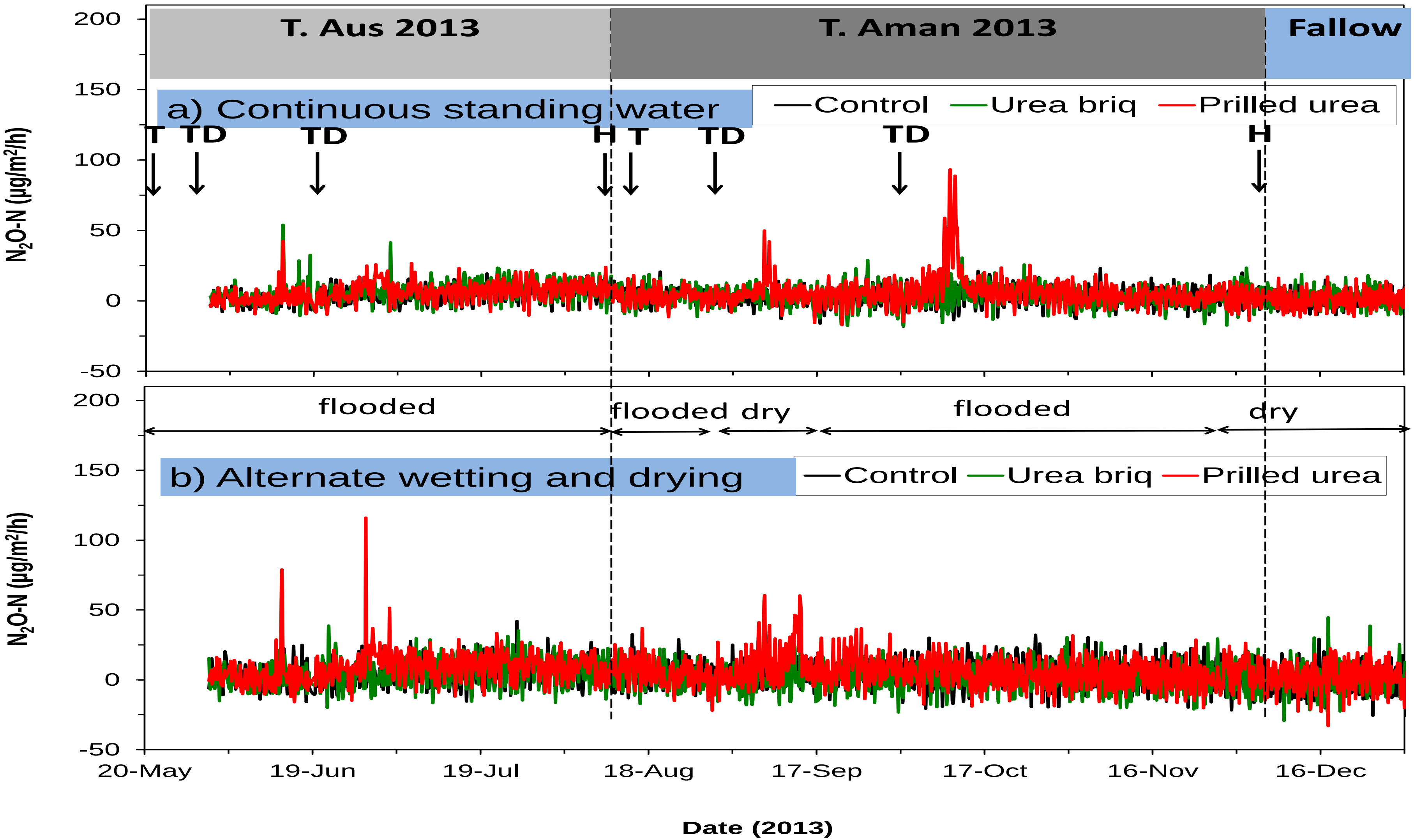
Schematic diagram of automated gas (N_2O and NO) sampling and analysis system


USAID
IFDC
Integrating Green House Gas Emissions Mitigation into the Feed the Future Bangladesh Fertilizer Deep Placement Rice Intensification Project
B: Continuous Standing Water (CSW) Condition
Treatment
Description
Check
UDP
UDP
PU
UDP
NPK briquette
PU
NPK briquette
Replication: 3
Date of transplanting: 11 January 2014
R1T1
Control
R1T2
UDP-N78
CHAMBER

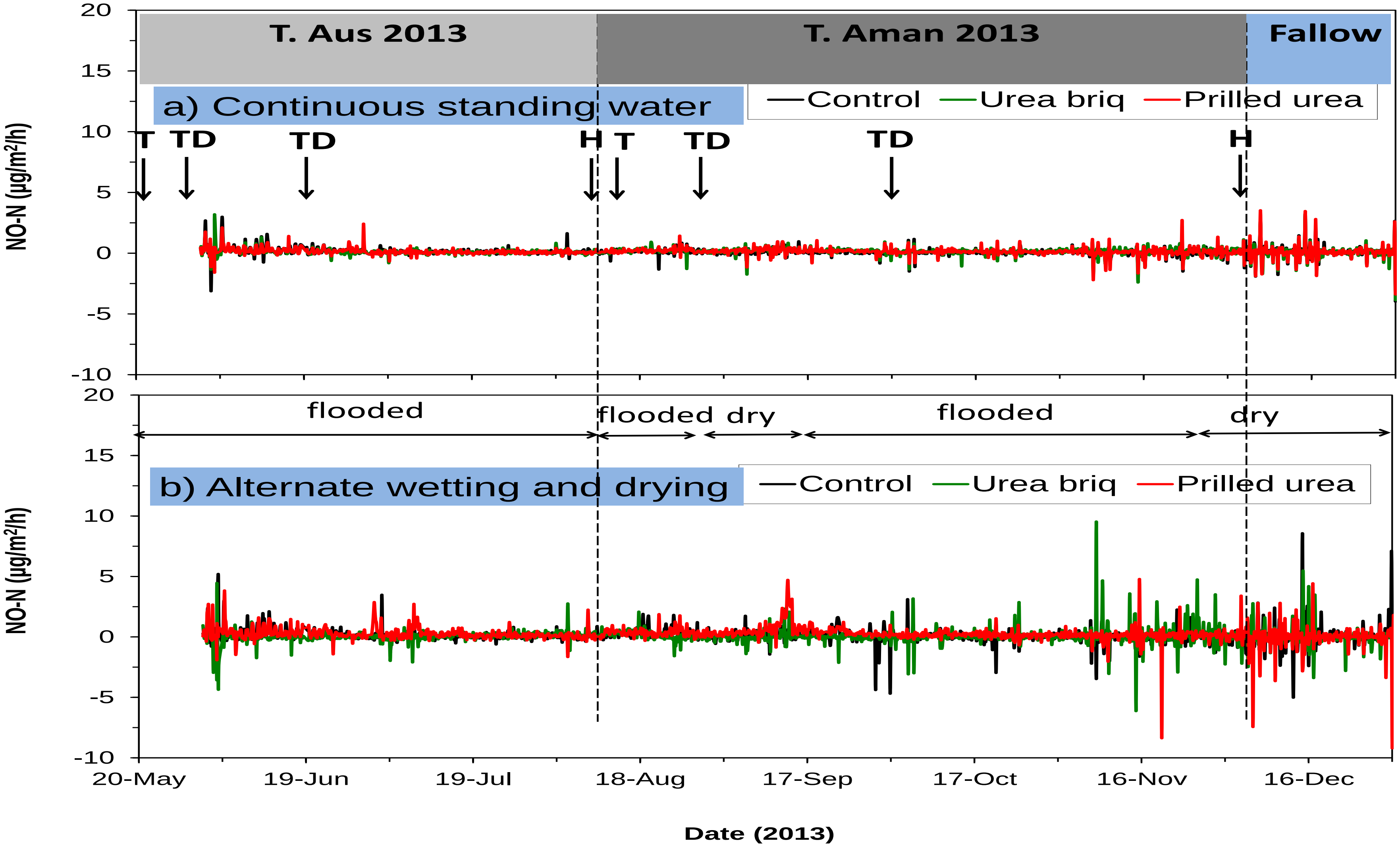
- Two locations in Bangladesh
  - Bangladesh Agricultural University (BAU)
  - Bangladesh Rice Research Institute (BRRI)

- Growing season
  - T-Aus (Wet season, June-August)
  - T-Aman (Wet season, August-Nov)
  - Boro (dry season, Jan-April)

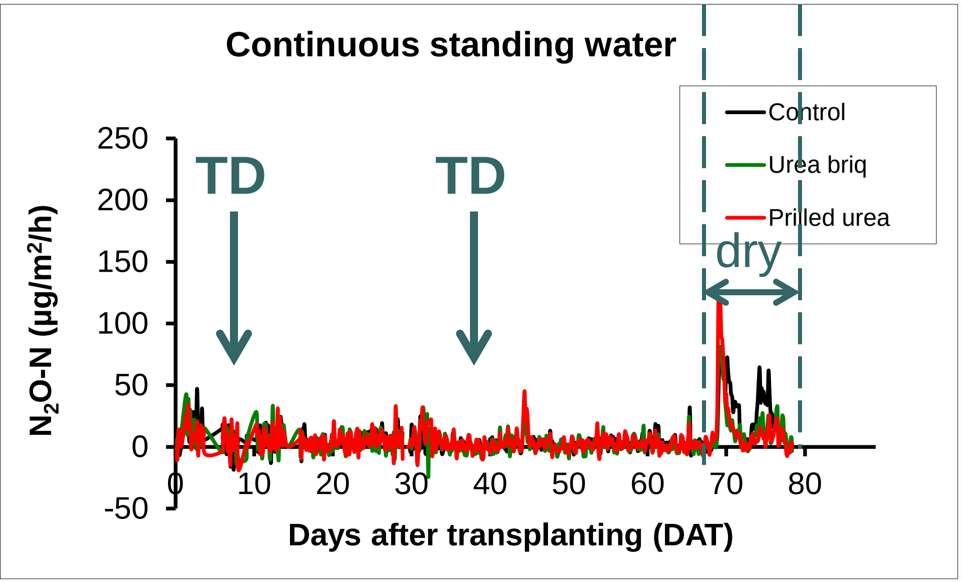
N_2O emissions at BAU

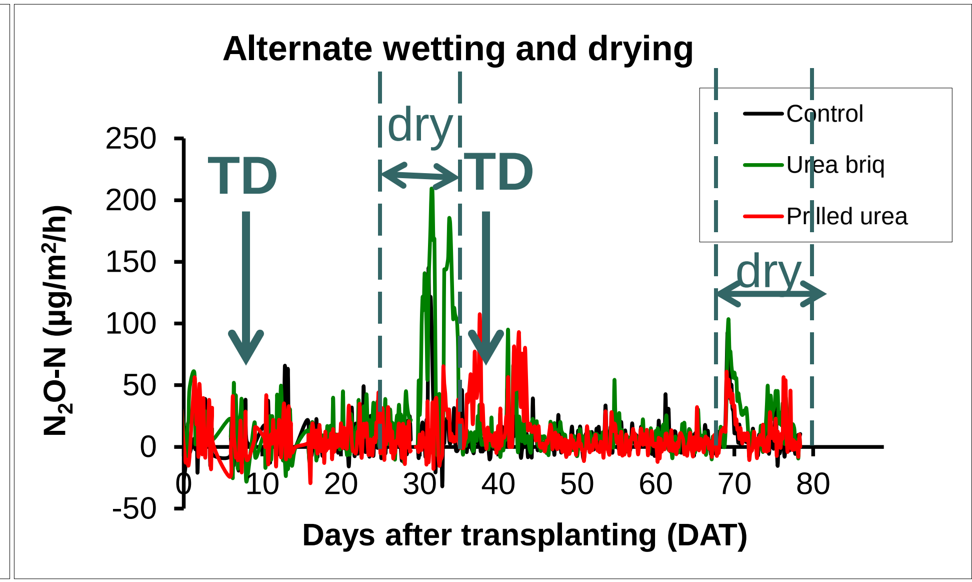


NO emissions at BAU



N_2O: Aus 2013


Continuous standing water
Control
Urea briq
Prilled urea
TD
TD
dry
N2O-N (µg/m2/h)
250
200
150
100
50
0
-50
0
10
20
30
40
50
60
70
80
Days after transplanting (DAT)


Alternate wetting and drying
Control
Urea briq
Prilled urea
TD
dry
TD
dry
N2O-N (µg/m2/h)
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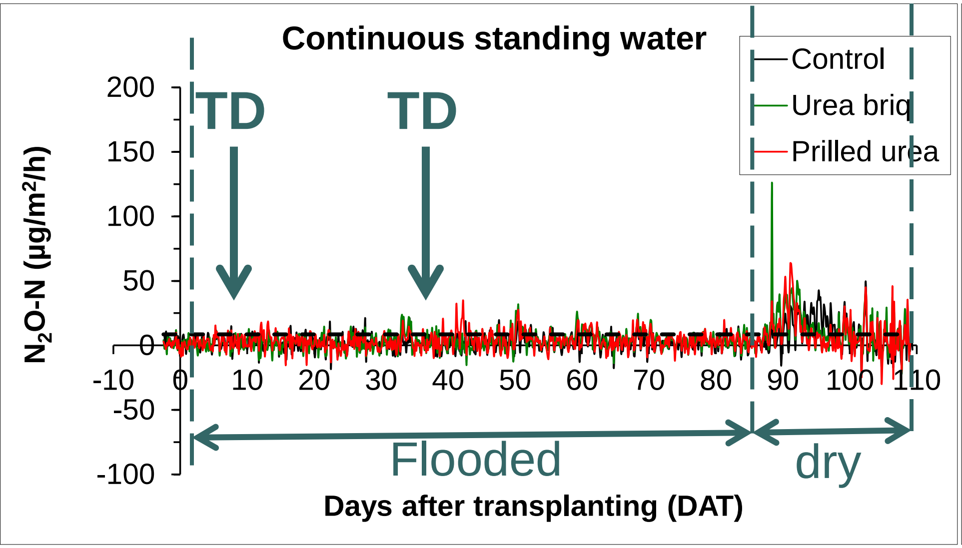
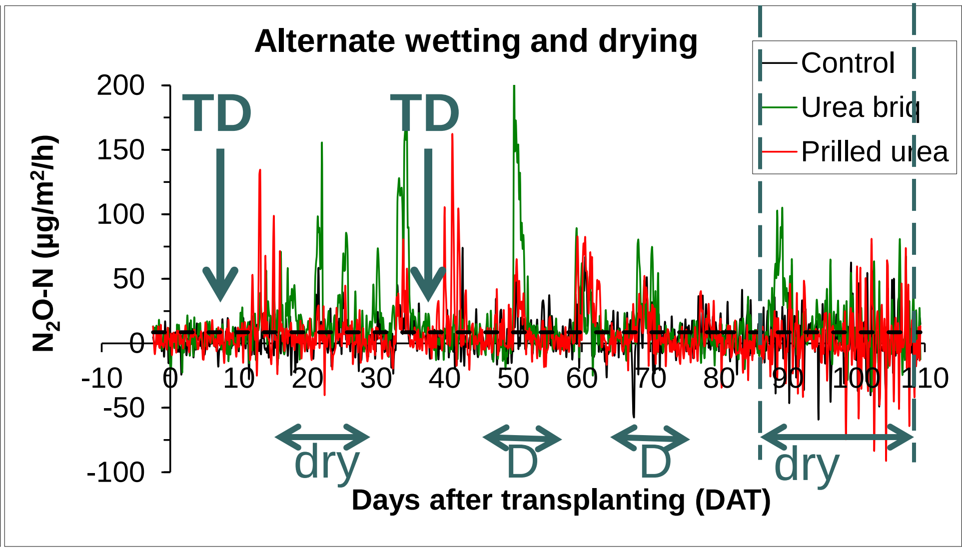
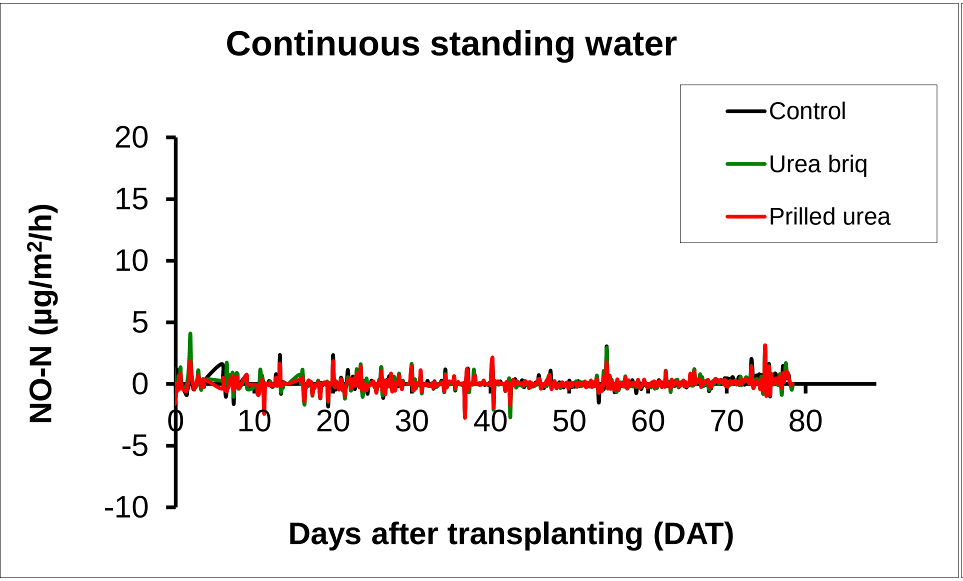
200
150
100
50
0
-50
0
10
20
30
40
50
60
70
80
Days after transplanting (DAT)

N_2O: Aman 2013





NO: Aus 2013


Continuous standing water
Control
Urea briq
Prilled urea
NO-N (µg/m2/h)
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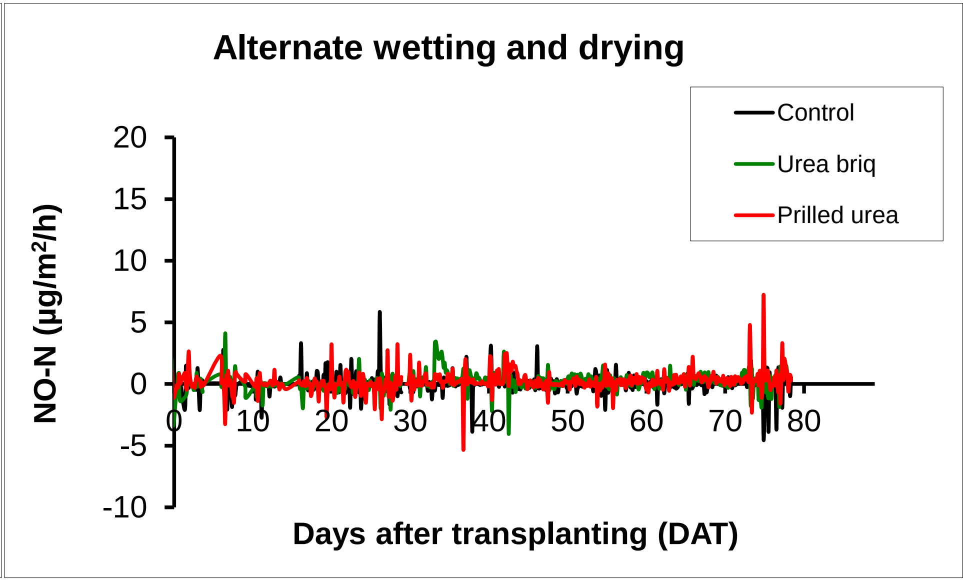
Days after transplanting (DAT)


Alternate wetting and drying
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Urea briq
Prilled urea
NO-N (µg/m2/h)
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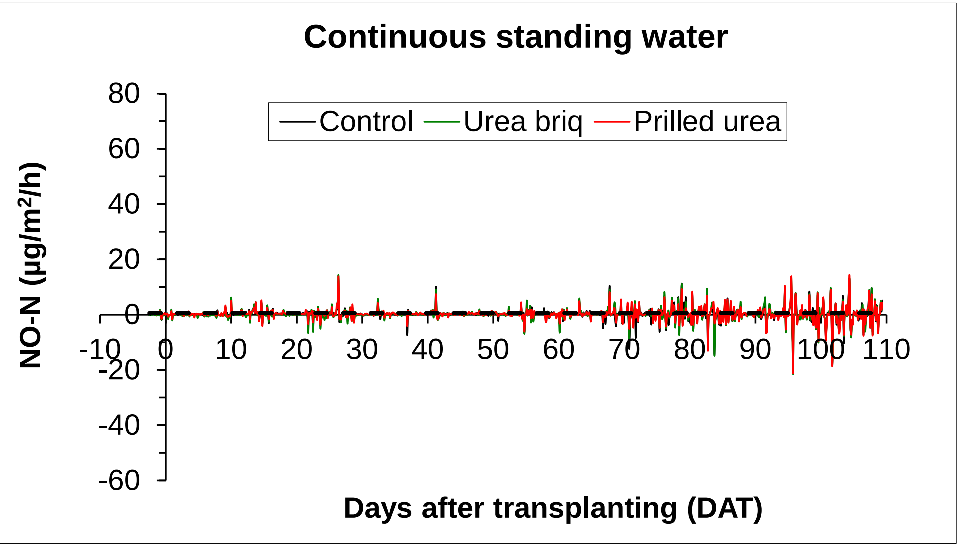
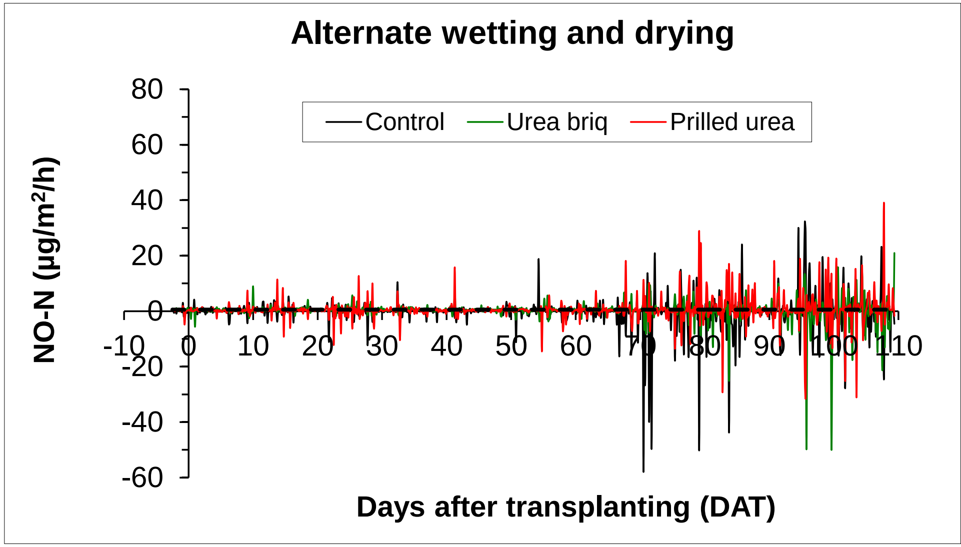
15
10
5
0
-5
-10
0
10
20
30
40
50
60
70
80
Days after transplanting (DAT)

NO: Aman 2013


Continuous standing water
NO-N (µg/m²/h)
80
60
40
20
0
-20
-40
-60
-10
0
10
20
30
40
50
60
70
80
90
100
110
Control
Urea briq
Prilled urea
Days after transplanting (DAT)


Alternate wetting and drying
NO-N (µg/m²/h)
80
60
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0
-20
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-60
-10
0
10
20
30
40
50
60
70
80
90
100
110
Control
Urea briq
Prilled urea
Days after transplanting (DAT)

Conclusions

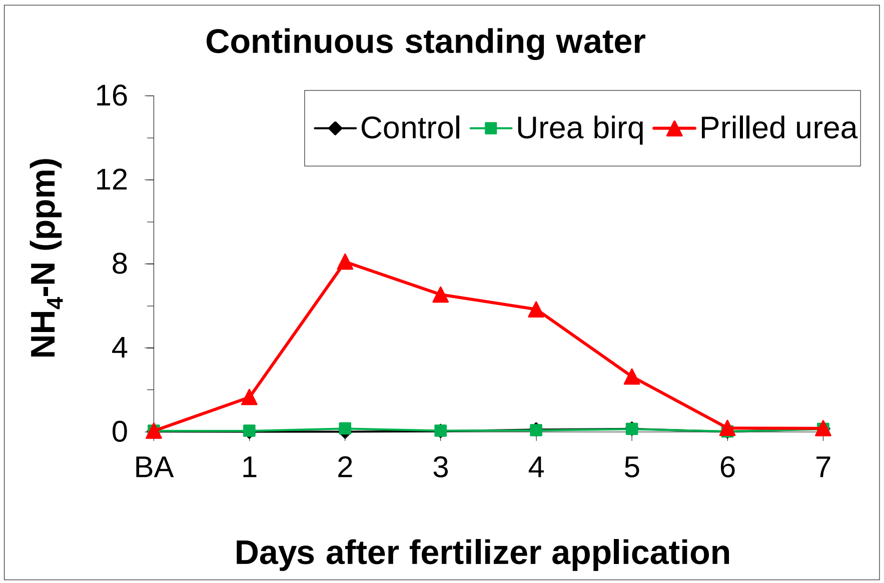
- N_2O and NO emissions are negligible under CSW, while significant emissions occurred under AWD.

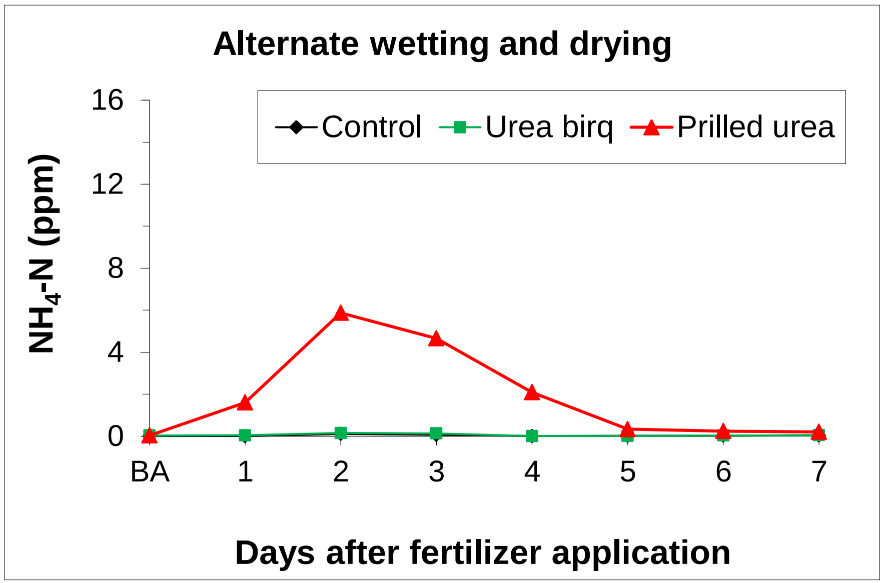
- However, emissions peaks appeared after broadcast application of urea but not from deep placement.

- Deep placement increased emissions under AWD.

- Ongoing *Boro (Dry season)* trials will provide crucial information on effect of AWD and N management on emissions.

Ammonium-N in floodwater





Experimental databases and model of N_2O emissions by croplands
Do we have what is needed to explore mitigation options?

Concluding remarks

N_2O emissions by agricultural soils

- Complex, not fully elucidated underlying processes
- Very small fluxes, highly variables in space and time
- Numerous shortcomings about measurement techniques
- Remaining knowledge gaps (e.g. N_2O consumption,multiple processes…)
- Progresses are expected from new tools (isotopes, molecular biology,…)
- Better understanding of underlying processes will probably help to improve models so that they better account for the effect of management practices, but it remains debatable

Effect of agricultural practices on N_2O emissions and levers for mitigation

- This question has received attention from agronomists only recently
- The metrics which is used to compare agricultural practices is a key issue (area-scaled N_2O? Yield-scale N_2O?,…)
- Important to have complete N budget data and other GHG. Important to consider (multi)year round measurements
- Some levers for mitigation have been clearly identified (reduce N excess, legumes, cover crops,…).
- Need for synthetic papers, for the most widely studied practices (*e.g.* N fertilisation)
- Some techniques, which may offer levers for mitigation in the mid-term, need further studies (e.g. fertiliser placement, biochars, liming, …)
- The biodegradation of organic products (crop residues, manure) and associated N_2O emissions must be better understood
- The effect of highly disturbing management practices (land use change) or events (freeze-thaw) must be quantified
- We need more studies in dryland contexts
- There is a strong need to design and assess cropping systems with a multicriteria approach (not only GHG but also crop production, reduced use of pesticides,…)

Models

- Models are definitely an appropriate tool
  - to decipher the relative effects of soil properties, climate, agricultural management practices;
  - to interpret and compare data from different experiments;
  - to make prediction
- They don't work so bad
- Process based model (e.g. DNDC, Daycent, Stics,…) successfully simulate the effect of several key agricultural practices, although not always the accurate temporal dynamic. Clarify how they do the job ?
- We should not fear model failure
- Could we still improve synergy between data collection and modelling efforts in a win-win process
  - For experimentalists: Better interpretation of their results
  - For modellers: Model evaluation in a wider range of contexts
  - But intermediate variables should be measured (e.g. NO_3^-, NO_2^-, WFPS) and how model account for the effect of management practices must be made more transparent
- Models don't simulate long term, cumulative effects of cropping systems on important variables (pH, soil porosity,…)
- Upscaling at large scale (which is the relevant scale for policy making) is an important objective

What will happen now?

- Workshop 2 will start just after. The key word is model intercomparison.
- Ppt presentation will be available on the GRA website (if authors agree for that)

Thanks to

The key-note speakers and authors of oral presentations and posters for their contributions

Chairs and co-chairs

Members of the scientific and organisation committee

INRA and Ademe for financial support

Fiona and Lénaic for practical organisation

All of you for active participation in discussions