Session 3 - Cover crops, legumes and emissions at rotation scale

Chair: Charles Rice
Co-chair: Elizabeth Pattey

Key note lecture - Bob Rees

Short oral presentations:
- Marie-Hélène Jeuffroy, Pierre Cellier
- Xiaoxi Li
- Alberto Sanz-Cobeña
Key note lecture

Cover crops, legumes and N$_2$O emissions at rotation scale

Bob Rees, SRUC, UK

Soyabean production

![Graph showing soybean production over time.](https://via.placeholder.com/150)

FAOSTAT 2013
Global grain legume production

FAOSTAT 2013
Global fertiliser use and $N_2O$ emissions

- **X-axis:** Global fertiliser N use (Millions t)
- **Y-axis:** Global fertiliser N use (Millions t) and Tg $N_2O$
- **Legend:**
  - Red line: Fertiliser N
  - Green line: N2O emissions

FAO stat
The contribution of N fixation to \( N_2O \) emissions

- Clover grown in an atmosphere labelled with \(^{15}\)N\(_2\)
- Allows direct measurement of N fixation and \( N_2O \) produced from recently fixed N

Carter and Ambus, 2006; NCA 74;13-26
Summary

• Legumes are a vital global component of agricultural systems and their low N₂O emissions would appear to offer mitigation potential.

• The use of legumes for N₂O mitigation can be economically favourable, but supportive policies would probably be necessary to promote wider adoption.

• Emissions of N₂O from crop residues and cover crops is poorly understood, and likely to be influenced by residue quality and management.
Short presentation

Introducing pea crop in arable crop successions: an efficient way to decrease greenhouse gas emissions from cropping systems

Marie-Hélène JEUFFROY, Pierre CELLIER
INRA, France
Context

- \( \text{N}_2\text{O} \) emissions in the European cropping systems are mainly linked with the use of mineral nitrogen fertilizers.
- Decreasing the use of \( \text{N} \) fertilizers without reducing crop production is allowed by introducing legumes in cropping systems. Among them, pea is the most grown legume in Europe.
- Yet, the effect of legumes on \( \text{N}_2\text{O} \) emissions is still debated in the literature (Rochette & Janzen, 2005) due to:
  - Possible \( \text{N}_2\text{O} \) emissions during the \( \text{N}_2 \) fixing process
  - Their residue, rich in Nitrogen
  - The large amount of \( \text{N} \) rhizodeposition in the soil
- Few data on \( \text{N}_2\text{O} \) emissions on pea are available, especially in comparison with other crops grown in the same conditions, while emissions vary with climate, soil characteristics, the cropping system considered.
Aims

• to quantify N$_2$O emissions from a pea crop in comparison with wheat and oilseed-rape crops, fertilized or not, during spring

• To quantify N$_2$O emissions during autumn, after a pea crop, a wheat crop or an oilseed rape crop

• To quantify N$_2$O emissions in various rotations
Material and Methods

3 years field experiment

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>Wheat (N/no N)</td>
<td>OilSeedRape</td>
<td>Wheat (N/no N)</td>
</tr>
<tr>
<td>or Barley</td>
<td>Wheat (N/no N)</td>
<td>Pea</td>
<td>OilSeedRape</td>
</tr>
<tr>
<td></td>
<td>Wheat (N/no N)</td>
<td>Pea</td>
<td>Wheat (N/no N)</td>
</tr>
<tr>
<td></td>
<td>Wheat (N/no N)</td>
<td>Wheat (N/no N)</td>
<td>OilSeedRape</td>
</tr>
<tr>
<td></td>
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<td>Wheat (N/no N)</td>
<td>Wheat (N/no N)</td>
</tr>
<tr>
<td></td>
<td>OilSeedRape</td>
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<td>OilSeedRape</td>
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</tr>
<tr>
<td></td>
<td>Pea</td>
<td>Wheat (N/no N)</td>
<td>Wheat (N/no N)</td>
</tr>
</tbody>
</table>

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

→ Comparison of crops, preceding crops and rotations
Material and Methods

Crops are grown on a same field → similar soil and weather conditions for N₂O emissions

3 years of measurements

N₂O measurement with static chambers (6 per treatment)

- Every month during the crop cycle; twice a week in the two weeks following a N fertilizer application

- Measurement of N₂O in the chamber at closure of the chamber, and 45 min, 90 min, and 135 min later

→ 20 measurements in spring and 10 measurements in autumn, in average.

+ agronomic measurements (N in soil, SWC, yield, …)
Pea vs. other crops (case of spring 2008)

- A high variability in N₂O emissions across the spring
- Fertilized crops (W and OSR) have higher emissions than unfertilized wheat
- The emissions on pea are similar to those of unfertilized wheat
- The same results were observed during the three years
No effect of the nature of the previous crop on N$_2$O emissions in autumn, even though mineral N conc. was higher in the soil after the pea crop.
Comparison of crops
(cumulated values from January to July)

Daily average N2O emissions in spring

→ An effect of the year (due to the weather when N fertilizer was applied)
→ A strong difference on pea, with emissions lower than that over fertilized wheat or oilseed rape, but similar to unfertilized wheat, whatever the year
Comparison of rotations

N20 emissions cumulated on 3 years

→ A strong effect of the rotation on the cumulated N\textsubscript{2}O 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

17-19 March 2014  Workshop "Experimental databases and model of N\textsubscript{2}O emissions by croplands: do we have what is needed to explore mitigation options?"

P = Pea
OR = Oilseed Rape
W = Wheat
W\textsubscript{0} = unfertilized Wheat
Conclusion and perspectives

✓ This study provided new data on N$_2$O emissions on grain legumes and at rotation scale

✓ In the field, N$_2$O emissions were very low on pea, during the crop and the intercrop. No effect could be observed during the following crop

✓ These results are in agreement with the IPCC reference, which does not take into account N$_2$O emissions from N$_2$ fixation

✓ The introduction of one pea crop in a 3-year rotation could allow a reduction of more than 20% of N$_2$O emissions!

✓ The effect of GHG budget should be larger, when accounting for the energy saved from not using industrial fertilizers

In a near future, we will use models in order to simulate the daily emissions, to be able to make a better integration of N$_2$O emission along the season.
Nitrous oxide emissions from crop rotations including wheat, oilseed rape and dry peas

M. H. Jeuffroy\textsuperscript{1,2}, E. Baranger\textsuperscript{1,2}, B. Carrouée\textsuperscript{3}, E. de Chezelles\textsuperscript{1,2}, M. Gosme\textsuperscript{1,2}, C. Hénault\textsuperscript{4}, A. Schneider\textsuperscript{3}, and P. Cellier\textsuperscript{5,6}

Study funded by the Ministry of Agriculture

Workshop "Experimental databases and model of N\textsubscript{2}O emissions by croplands: do we have what is needed to explore mitigation options?"
Short presentation

Nitrous oxide emissions from an organic cropping system as affected by catch crop type and management

Xiaoxi Li, Aarhus Univ., Denmark
Søren O. Petersen, Peter Sørensen
Jørgen E. Olesen
Organic farming and CC

- **Expanding** in Denmark: >6%, double by 2020
- **No manure** input from conventional sources, 2022
- How to **sustain N inputs** and **higher yields** with **less GHG emissions** in organic farming?
- Increasing interest in using CC as biogas feedstock
- **Hypothesis**: a) LBCC, more N, higher risk of N$_2$O, lower yield-specific emissions; b) Harvest CC can reduce soil N$_2$O emissions
Experimental design

- **Factor I** -- 5 CC types + 1 no CC control
  1. CL  Red clover  sown in May 2012
  2. GC  Ryegrass/clover
  3. WV  Winter vetch  sown in Aug 2012
  4. FR  Fodder radish
  5. GR  Ryegrass
  6. CO  Control without CC

- **Factor II** -- 2 management
  H - autumn harvest  end Oct 2012
  U - spring incorporation  late Apr 2013

Spring barley: Apr – Aug 2013

and model of N2O emissions by croplands: 'e mitigation options?
**LBCC can give substantial C and N input**

<table>
<thead>
<tr>
<th>Catch crop type</th>
<th>Dry matter (Mg ha(^{-1}))</th>
<th>Top/root ratio</th>
<th>N content (%)</th>
<th>Total N (kg ha(^{-1}))</th>
<th>Top/root N ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Top</td>
<td>Root*</td>
<td>Top</td>
<td>Root</td>
<td>Top</td>
</tr>
<tr>
<td>LBCC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red clover</td>
<td>1.9 a</td>
<td>1.4 a</td>
<td>1.5 a</td>
<td></td>
<td>3.4 a</td>
</tr>
<tr>
<td>Grass / clover</td>
<td>1.9 a</td>
<td>1.2 a</td>
<td>1.5 a</td>
<td></td>
<td>3.2 ab</td>
</tr>
<tr>
<td>Winter vetch</td>
<td>1.7 ab</td>
<td>1.2 a</td>
<td>1.4 a</td>
<td></td>
<td>4.0 a</td>
</tr>
<tr>
<td>Non-LBCC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fodder radish</td>
<td>1.7 ab</td>
<td>1.3 a</td>
<td>1.2 a</td>
<td></td>
<td>2.4 b</td>
</tr>
<tr>
<td>LBCC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ryegrass</td>
<td>1.3 b</td>
<td>1.3 a</td>
<td>1.0 a</td>
<td></td>
<td>2.5 b</td>
</tr>
<tr>
<td>Weeds</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control (no CC)</td>
<td>1.4 ab</td>
<td></td>
<td></td>
<td></td>
<td>2.2 b</td>
</tr>
</tbody>
</table>

* Root (0-20 cm), >40% of DM, >33% of total N

17-19 March 2014 Workshop "Experimental databases and model of N₂O emissions by croplands: do we have what is needed to explore mitigation options?"
Different seasonal N$_2$O emission patterns

<table>
<thead>
<tr>
<th></th>
<th>Red clover</th>
<th>Grass/clover</th>
<th>Winter vetch</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>Autumn</td>
<td>Winter</td>
<td>Spring</td>
</tr>
<tr>
<td>Plough</td>
<td>20 cm</td>
<td>H</td>
<td>U</td>
</tr>
</tbody>
</table>

For LBCC:

- Red clover
- Grass/clover
- Winter vetch

For Non-LBCC:

- Fodder radish
- Ryegrass
- Control

130 µg N m$^{-2}$ h$^{-1}$
Mineral N increase after incorporation, differs among CC

**Soil NO$_3$**

**WFPS**

**Plough 20 cm**

17-19 March 2014 Workshop "Experimental databases and model of N2O emissions by croplands: do we have what is needed to explore mitigation options?"
Higher yield of barley in LBCC and non-harvest plots

Grain yield

<table>
<thead>
<tr>
<th>Plot Type</th>
<th>Treatment</th>
<th>Grain Yield (Mg ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LBCC</td>
<td>Early harvest (H)</td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>Left untouched (U)</td>
<td>a</td>
</tr>
<tr>
<td>Non-LBCC</td>
<td>Early harvest (H)</td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>Left untouched (U)</td>
<td>a</td>
</tr>
</tbody>
</table>

Grain N yield

<table>
<thead>
<tr>
<th>Plot Type</th>
<th>Treatment</th>
<th>Grain N Yield (kg N ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LBCC</td>
<td>Early harvest (H)</td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>Left untouched (U)</td>
<td>a</td>
</tr>
<tr>
<td>Non-LBCC</td>
<td>Early harvest (H)</td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>Left untouched (U)</td>
<td>a</td>
</tr>
</tbody>
</table>
Conclusions

- LBCC did increase the crop yield, but will not necessarily increase annual or yield-specific N\textsubscript{2}O emissions.
- Harvest of CC may reduce crop yield (i.e. WV), unless the harvested N is recycled to the field in manure of digested biomass; little effect on total N\textsubscript{2}O emissions.
- Long-term study (dif soil, climate & management), micro-scale soil process study and simulation study will help elucidate how LBCC can benefit a sustainable organic farming system.
Short presentation

Implications of introducing cover crops in a maize cropping system: N uptake, NO$_3^-$ and N$_2$O losses

Alberto Sanz-Cobeña,
Technical University of Madrid, Spain
Cover crops

• Crops introduced to cover the soil within the period in which this is not protected by the main crop.

• Aiming to increase the sustainability of the cropping system

Benefits:
- Control of soil erosion
- Control of weeds, pests and diseases
- Improvement of crop quality
- Nutrients recycling
- Reducing nitrate leaching
Spring | Summer | Autumn | Winter | Spring | Summer
---|---|---|---|---|---
Cash crop: Maize

**RAINFALL**

Intercrop period: Fallow

Inorganic N (NO$_3^-$, NH$_4^+$..)

Nitrate Leached

AQUIFER
Cash crop: Maize

Intercrop period: Catch crop

Inorganic N (NO$_3^-$, NH$_4^+$..)

Organic Nitrogen

Nitrate Leached

AQUIFER
Field experiments

- 2006 -2010 in CC (barley, vetch and rape)-maize rotation.
- Objectives:
  
  **Intercrop period (autumn-winter)**
  
  - To study the effect of CC over N uptake, NO$_3^-$ leaching and GHG emissions (only in 2009-2010).

  **Maize crop period (spring-summer)**
  
  - To study the effect of (previous) planted CCs over maize N uptake and NO$_3^-$ leaching.
  
  - To study the effect of incorporating CC residues (i.e. green manure from previous CC) to the soil over mineral N and GHG emissions (N$_2$O, CO$_2$, CH$_4$).
• **Experimental design**

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
<th>Year</th>
<th>Event</th>
<th>Year</th>
<th>Event</th>
<th>Year</th>
<th>Event</th>
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<td></td>
</tr>
<tr>
<td>Cover crops</td>
<td>Maize</td>
<td>Cover crops</td>
<td>Maize</td>
<td>Cover crops</td>
<td>Maize</td>
<td>Cover crops</td>
<td>Maize</td>
</tr>
</tbody>
</table>

**Cover Crop period 2009-10**

Maize harvest (29th September)

Gliphosate application (18th March)

Cover crop incorporation (12th April)

1st N fertilization 140 kg N ha\(^{-1}\) (NH\(_4\)NO\(_3\)) (27th May)

Maize harvest (7th October)

**Maize Crop period 2010**

Cover crop broadcast (5th October)

P and K Fertilization (120 kg ha\(^{-1}\))

Maize sowing (13th April)

2nd N fertilization 70 kg N ha\(^{-1}\) (NH\(_4\)NO\(_3\)) (29th June)

- Soil: moisture, temp., N\(_{\text{MIN}}\) (NH\(_4\)\(^+\) + NO\(_3\)^-) (0.2 m depth).
- Maize: yield, aerial biomass, N uptake.
- GHG: N\(_2\)O, CO\(_2\), CH\(_4\).
- Drainage & NO\(_3\)^- leached.
- Weather conditions (air temp., pp, ET\(_0\), etc.)
Results: maize yield

<table>
<thead>
<tr>
<th>Year</th>
<th>Treat.</th>
<th>Biomass (kg dm ha⁻¹)</th>
<th>N Concentration (%)</th>
<th>N Content (kg N ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Grain</td>
<td>Total plant</td>
<td>Grain</td>
</tr>
<tr>
<td></td>
<td>Vetch</td>
<td>14546</td>
<td>24129</td>
<td>1.16</td>
</tr>
<tr>
<td>2007</td>
<td>Barley</td>
<td>14922</td>
<td>25243</td>
<td>1.20</td>
</tr>
<tr>
<td></td>
<td>Fallow</td>
<td>14351</td>
<td>24646</td>
<td>1.22</td>
</tr>
<tr>
<td></td>
<td>Vetch</td>
<td>11590</td>
<td>22195</td>
<td>1.36</td>
</tr>
<tr>
<td>2008</td>
<td>Barley</td>
<td>11708</td>
<td>21805</td>
<td>1.30</td>
</tr>
<tr>
<td></td>
<td>Fallow</td>
<td>11438</td>
<td>22281</td>
<td>1.30</td>
</tr>
<tr>
<td></td>
<td>Vetch</td>
<td>11831</td>
<td>22477</td>
<td>1.35</td>
</tr>
<tr>
<td>2009</td>
<td>Barley</td>
<td>9796</td>
<td>18792</td>
<td>1.35</td>
</tr>
<tr>
<td></td>
<td>Fallow</td>
<td>8446</td>
<td>17115</td>
<td>1.35</td>
</tr>
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</table>

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<table>
<thead>
<tr>
<th>Year</th>
<th>Treatment</th>
<th>Year</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NS</td>
<td></td>
<td>NS</td>
</tr>
</tbody>
</table>

Note: Treatment: NS
### Results: N uptake by the maize crop

<table>
<thead>
<tr>
<th>Year</th>
<th>Treat.</th>
<th>Grain 15N concentration (%)</th>
<th>Biomass 15N concentration (%)</th>
<th>Grain 15N recovered (kg N ha(^{-1}))</th>
<th>Biomass 15N recovered (kg N ha(^{-1}))</th>
<th>Total 15N recovered (kg N ha(^{-1}))</th>
<th>NRF (% N)</th>
<th>NOS (kg N ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>Vetch</td>
<td>1.10</td>
<td>1.07</td>
<td>66.9</td>
<td>17.2</td>
<td>84.1</td>
<td>40.0</td>
<td>129.4</td>
</tr>
<tr>
<td></td>
<td>Barley</td>
<td>1.18</td>
<td>1.18</td>
<td>79.2</td>
<td>17.7</td>
<td>97.0</td>
<td>46.2</td>
<td>122.1</td>
</tr>
<tr>
<td></td>
<td>Bare fallow</td>
<td>1.13</td>
<td>1.10</td>
<td>77.8</td>
<td>20.9</td>
<td>98.7</td>
<td>47.0</td>
<td>124.2</td>
</tr>
<tr>
<td>2008</td>
<td>Vetch</td>
<td>1.17 (b)</td>
<td>1.19 (b)</td>
<td>69.1</td>
<td>29.8</td>
<td>99.0</td>
<td>47.1</td>
<td>124.6 (a)</td>
</tr>
<tr>
<td></td>
<td>Barley</td>
<td>1.27 (a)</td>
<td>1.29 (a)</td>
<td>77.0</td>
<td>30.6</td>
<td>107.6</td>
<td>51.2</td>
<td>102.0 (b)</td>
</tr>
<tr>
<td></td>
<td>Bare fallow</td>
<td>1.29 (a)</td>
<td>1.29 (a)</td>
<td>73.7</td>
<td>30.4</td>
<td>104.1</td>
<td>49.6</td>
<td>104.7 (b)</td>
</tr>
<tr>
<td>2009</td>
<td>Vetch</td>
<td>1.16 (b)</td>
<td>1.19 (b)</td>
<td>68.2</td>
<td>31.9</td>
<td>100.1</td>
<td>47.7</td>
<td>129.9 (a)</td>
</tr>
<tr>
<td></td>
<td>Barley</td>
<td>1.29 (a)</td>
<td>1.33 (a)</td>
<td>62.4</td>
<td>31.5</td>
<td>93.9</td>
<td>44.7</td>
<td>98.3 (b)</td>
</tr>
<tr>
<td></td>
<td>Bare fallow</td>
<td>1.23 (ab)</td>
<td>1.29 (a)</td>
<td>53.5</td>
<td>31.2</td>
<td>84.8</td>
<td>40.4</td>
<td>87.7 (b)</td>
</tr>
</tbody>
</table>

**Year** *p* values: NS

**Treatment** *p* values: NS

N from the fertilizer

N from organic sources
Results: Nitrate leaching

- Lower drainage in CC plots than in fallow.
- 80% of drainage in periods with CCs.
- Vetch: more N in soil without increase in leached NO$_3^-$.
- Barley: Immediate reduction in leached NO$_3^-$ (no BNF & larger development).

Gabriel et al., 2012
Results: $N_2O$ emissions  

Cumulative $N_2O$ intercrop period (2010)

VT > BF > RP ≈ BA > C

Sanz-Cobena et al., 2014
**Results: N$_2$O emissions**

**Cumulative N$_2$O crop period**

- **Low emissions (IPCC):** denitrification + leaching + N uptake by crop

- **Bare fallow:**
  - C/N low: N immobilization. Lower N$_2$O losses.
  - C/N high: labile OC release. Higher N$_2$O (denitrification)

- **Control:**

Bar chart showing:
- **N-N$_2$O (mg/m$^2$)**
- **- cover crop residue**
- **+ cover crop residue**

Comparison of emissions across different treatments:
- Bare fallow
- Barley
- Vetch
- Rape
- Control
Conclusions

1. Replacing fallow by CCs in the intercrop period reduced N leaching without significantly decreasing maize yield.
2. Most of NO$_3^-$ losses (e.g. 80%) occurred in the CCs period although NO$_3^-$ concentrations fluctuated within the experimental period.
3. CCs reduced N leached, recirculated N and increased the N available in the upper soil layers.
4. Ba showed the highest efficiency as CC, reducing leaching and NO$_3^-$ concentration. However, Vt increased the N content in upper soil layers.
5. Vt highest N$_2$O emission (75% >Control) in the intercrop period.
6. Fertilization of maize increased N$_2$O losses in all cases.
7. Only the incorporation of Rp and Ba residues increased N$_2$O emission (40 y 17%).
8. Total N$_2$O < than expected in fertilized crops (0.09 EF< IPCC$_{2007}$ EF=1.00).
Remarks for modelling

• CCs in the intercrop period:
  – Effect of legumes over N2O losses
  – Effect of CC type over water balance (drainage)

• CCs as green manures:
  – N mineralization rates
  – Effect of CC types
  – N2O uptake
References

Thanks for your attention!

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