Webinar III - Climate Smart Agriculture
Loss of Biodiversity and the Uncertainties associated with Climate Change

Soil biodiversity a major challenge for the multiperformance of agroecological systems

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INRAE

Wednesday 27 May, 2020
Current intensive conventional agricultural systems are not sustainable

- **Increase of inputs:** fossil energy, fertilizers, pesticides, water
- **Resource erosion:**
  - Arable lands (desertification, salinization, soil sealing,...) with soils being not renewable at our human time scale
  - Biodiversity
  - Water: quantity and quality
- **Global change to which agriculture contributes but also to which agriculture is submitted.**

**Agricultural systems should:**

- **Provide food of adequate quantity and quality**
  - Prevalence of people undernourished (822 Mo - 2018) = 10.8%
  - Malnutrition: ‘Hidden Hunger’ 2 Ma
  - Increase of the world population: 7.79 Md, 2030 ~ 8.5, 2050 ~ 9.7 Md
- **Contribute to climate mitigation**
- **Preserve resources:** soil, water, biodiversity

➡ **Move from intensive conventional agriculture to ecological intensification with agroecology**


- **Agroecology:** Apply ecological concepts and principles to optimize interactions for a sustainable that (i) support food production and food security and nutrition and (ii) deliver ecosystem services including climate mitigation. [http://www.fao.org/agroecology/overview/eg/](http://www.fao.org/agroecology/overview/eg/)
Agroecological transition

Conventional agricultural systems

Paradigm shift: Harness biodiversity and biotic interactions

Going back to the roots: the microbial ecology of the rhizosphere

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Living soils

- Huge quantity of organisms
  - Fauna: 1-5 T/ha
  - Fungi: 3.5 T/ha
  - Bacteria: 1.5 T/ha

- Fantastic diversity

Soil biodiversity delivers a range of ecosystem services.
Soil biodiversity is submitted to major threats


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Soil biodiversity is submitted to major threats

Potential threats to soil biodiversity

To preserve and value soil biodiversity, it is necessary to better know it....
This requires a better knowledge in:

- Soil biodiversity
- Relationships between soil biodiversity-functions-ecosystem services
- Impact of the variety of environmental situations
Soil microbial diversity: fantastic methodological developments

First scientific international journals
1957
First handbook Brock
1966
Development of growing media
1970
Development of biochemistry and molecular biology
1974-76
Extraction nucleic acids from environment
1980
High-throughput sequencing
1990
Metagenomic
2000
Metatranscriptomics
2010
2020

Cost per Raw Megabase of DNA Sequence

Adapted from Maron et al. 2007. Microbiol. Ecol.

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Soil microbial diversity: Diagnosis

Molecular biomass

Bacterial diversity

Strong impact of the soil type
Significant impact of the land use

Predictive model
\[ Y = \beta_0 + \sum (\beta_j X_j + \beta_j X_j^2) + \sum \beta_j X_j X_k + \epsilon \]

threshold value
reference value

Dequiedt et al., 2011 Glob Ecol Biogeogr

Ranjard et al., 2013 Nature Com

Horrigue et al., 2016 Ecol Indic

Terrat et al., 2017 Plos One

Courtesy of L. Ranjard INRAE Dijon
The question of how such loss of biological diversity will alter the functioning of ecosystems and their ability to provide society with the goods and services needed to prosper (Cardinal et al. Nature 2012)

Courtesy of Van der Heijden, Agroscope, Zurich

Relations between biodiversity and functioning

Carbon cycle – Mineralization

Mineralization SOM = f (Microbial diversity)


Courtesy of P.-A. Maron, INRAE Dijon
Relations between biodiversity and functioning

Expression of each function under changing environmental conditions

- Low diversity
- High diversity

Environmental conditions

Expression of a range of functions

- $R^2 = 0.56$
- $P < 0.001$

Agroecology can play an important role in building resilience and adapting to climate change. [http://www.fao.org/agroecology/overview/eg/]

Wagg et al. 2014. PNAS 111:5266-5270
Agroecology: Steering microbial communities for productivity and food quality

Benefits
- nutrition
- health

Costs
- rhizodeposits

Feedback loop

$O_2$

$CO_2$

$N_2$

$N_2$ fixation

Arbuscular Mycorrhiza

Root hair

Bacterial nodule

Mucilage

Nutrition

Health

Fixation
Agroecology: Steering microbial communities for productivity and food quality

Iron dynamics impact crop productivity and quality

1. Plant nutrition: [Fe]
   - Influence of soil properties
   - Rhizodeposits
   - Selection of microbial populations adapted to iron stress

2. Production of siderophores with high affinity for iron
   - Iron nutrition
   - Growth
   - Microbial antagonism
   - Plant health

3. Promotion of plant growth and health
   - FeEDTA FeSid


Courtesy of S. Mazurier, INRAE Dijon

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Agroecology: Steering microbial communities for productivity and food quality

Promoting nitrogen fixation

104 pea accessions inoculated with a mixture of 5 *Rhizobium* strains

High variability of the number of nodules and the composition of Rhizobia in nodules according to the pea accession

Agroecology: Steering microbial communities for productivity and food quality

Crop associations increase productivity and food quality

Grain content in AA and Fe

Grain content in AA and Fe

Courtesy of B. Pivato, INRAE Dijon

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17/28
Recruitment by wheat roots infected by *Gaeumannomyces graminis* var. *tritici* of antibiotic producers leading to take-all decline in all soils tested.

*Mendes et al. 2011. Science 332:1097-1100*
Soil Organic Matter

Feedback loop

Costs

Benefits

Storage atm. [CO₂]

Mineralisation

Minerals (N,P,..)

O₂

CO₂

N₂

atm. [CO₂]

Agroecology: Steering microbial communities for climate regulation

N₂ fixation

Bacterial nodules

Root hair

Arbuscular Mycorrhiza

Mucilage

Nutrition

Health

Costs rhizodeposits
Agroecology: Steering microbial communities for climate regulation

Banerjee et al. 2019. ISME J
Agroecology: Steering microbial communities for climate regulation

Tune SOM mineralization to plant nutrition to maximizing plant nutrition & soil C sequestration


Courtesy of S. Fontaine, INRAE Clermont-Ferrand

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Soil Organic Matter

Mineralisation
Minerals (N,P,..)

$\text{CO}_2$ atm. [CO$_2$]

Storage

$\text{CO}_2$ atm. [CO$_2$]

$\text{O}_2$

$\text{N}_2$

$\text{N}_2\text{O}$

Feedback loop

Costs
- rhizodeposits

Benefits
- nutrition
- health

Agroecology: Steering microbial communities for climate mitigation

$\text{N}_2$ fixation

Arbuscular Mycorrhiza

Bacterial nodule

Root hair

Mucilage

Nutrition

Health
Agroecology: Steering microbial communities for climate mitigation

Nitrogen cycle – Denitrification

Spatial distribution of the denitrifiers

Negative correlation between the % of bacteria capable to reduce $N_2O$ and the $N_2O/(N_2O+N_2)$

Courtesy of L. Philippot INRAE Dijon

### Multi-Performance of Agroecology in Practice

An annual growth rate of 0.4% in the soil carbon stocks, or 4% per year, in the first 30-40 cm of soil, would significantly reduce the CO₂ concentration in the atmosphere related to human activities. 

[https://www.4p1000.org/](https://www.4p1000.org/)

### Potential for Additional Carbon Storage in Arable Cropping Systems

*Assessed by a modelling approach at a fine spatial-scale resolution (≈1 km²)*

<table>
<thead>
<tr>
<th>Land use</th>
<th>Additional C storage 0-30 cm soil layer</th>
<th>Potential additional C storage at the national level 0-30 cm soil layer</th>
<th>Relative yearly increase of soil C stocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arable cropping systems</td>
<td>Kg C/ha/an</td>
<td>Mha</td>
<td>Mt C/year</td>
</tr>
<tr>
<td>Expansion of cover crops</td>
<td>+126</td>
<td>16.03</td>
<td>+2.019</td>
</tr>
<tr>
<td>No tillage</td>
<td>+60</td>
<td>11.29</td>
<td>+0.677</td>
</tr>
<tr>
<td>New carbon inputs</td>
<td>+61</td>
<td>4.21</td>
<td>+0.257</td>
</tr>
<tr>
<td>Expansion of temporary grasslands</td>
<td>+114</td>
<td>6.63</td>
<td>+0.756</td>
</tr>
<tr>
<td>Agroforestry</td>
<td>+207</td>
<td>5.33</td>
<td>+1.102</td>
</tr>
<tr>
<td>Hedges</td>
<td>+17</td>
<td>8.83</td>
<td>+0.150</td>
</tr>
<tr>
<td>Total for croplands</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>+4.960</td>
</tr>
</tbody>
</table>

*Assessed by a modelling approach at a fine spatial-scale resolution (≈1 km²)*

### Clay Content and Initial Soil C Stock Value

*Courtesy of S. Pellerin, INRAE Bordeaux*
Multiperformance of agroecology in practice
Effect of integrated weed management in cropping systems on N2O emissions from soils

<table>
<thead>
<tr>
<th>Crop system</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of system</td>
<td>Reference</td>
<td>IWM</td>
<td>IWM</td>
<td>IWM</td>
</tr>
<tr>
<td>Specific agricultural practices</td>
<td>Conventional</td>
<td>Minimum tillage, Plowing, harrowing, mechanical weeding excluded</td>
<td>Mechanical weeding excluded, Tillage allowed when necessary</td>
<td>Mechanical weeding and plowing allowed</td>
</tr>
<tr>
<td>Treatment frequency index</td>
<td>2,4</td>
<td>2,0</td>
<td>1,4</td>
<td>0</td>
</tr>
<tr>
<td>Plowing frequency</td>
<td>1 / year</td>
<td>-</td>
<td>0.4 / year</td>
<td>0.5 / year</td>
</tr>
<tr>
<td>Crop Rotation</td>
<td>Wheat/barley/rape</td>
<td>diversified</td>
<td>diversified</td>
<td>diversified</td>
</tr>
<tr>
<td>Cumul (g N-N₂O ha⁻¹)</td>
<td>326 ± 168c</td>
<td>5226 ± 670a</td>
<td>177 ± 172c</td>
<td>777 ± 177b</td>
</tr>
</tbody>
</table>

No significant relationships between N2O emissions and microbial community composition and activity were identified. The most important factors controlling the intensity of N₂O emissions:


Courtesy of C. Henault & B. Nicolardot, INRAE, AgroSup, Dijon
Territorial Initiative: Dijon Sustainable Agri-Food 2030
Linking farmers, food process-distribution, and end-users to promote local agroecology, transformation, distribution and consumption for a better food and environment quality, and a stronger social cohesion.
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For further information…..

https://www.globalsustainableagriculture.org/