Designing and assessing climate-smart cropping systems in temperate and tropical agriculture

P. Debaeke\textsuperscript{1}, S. Pellerin\textsuperscript{1}, E. Scopel\textsuperscript{2}

\textsuperscript{1}INRA \textsuperscript{2}CIRAD
Climate change variability & trends

Impacts on crop production

Impacts on pests & diseases

Impacts on natural resources (water)

Adaptation through Cropping Systems

2. Mitigation through Cropping Systems

3. Trade-offs

4. Design

GHG emissions

C storage

Perception by farmers

resilience resource-use efficiency

vulnerability (exposure, sensitivity, adaptive management)

1. Mitigation through Cropping Systems

GHG emissions

C storage

Perception by farmers
Cropping System

ACTORS
Multi-goals Multi-criteria

LEVELS
Field Farm Landscape Region

Uncertainty & risk management Adaptive strategy Decisional & information system

PRACTICES
Crops & varieties Crop management Crop sequences

Yield Quality Stability Resource allocation Diversification Net Income Environment Markets Land use Policy

Multi-goals Multi-criteria

Resource allocation Diversification Net Income

Environment Markets Land use Policy
### 1. Mitigation options involving cropping systems

<table>
<thead>
<tr>
<th>Levers</th>
<th>Technical options</th>
<th>Expected effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>N fertilisation</td>
<td>More legumes in crop rotations, Adjust N mineral fertiliser application rates &amp; dates, make better use of organic fertiliser, use nitrification inhibitors, incorporate fertilisers (to reduce losses)</td>
<td>↘ N2O</td>
</tr>
<tr>
<td>Soil tillage</td>
<td>Reduce tillage (direct seeding, occasional tillage, shallow tillage)</td>
<td>↘ CO2 (fuel)</td>
</tr>
<tr>
<td>Cover crops and residue management</td>
<td>More cover crops in arable cropping systems, in vineyards and orchards, Grass buffer strips</td>
<td>↗ C storage</td>
</tr>
<tr>
<td>Trees in agrosystems</td>
<td>Agroforestry (low planting density) (Re)-planting field hedgerows</td>
<td>↗ C storage</td>
</tr>
<tr>
<td>Grassland management</td>
<td>Extend the grazing period, increase the lifespan of temporary grazing, extensify the most intensive grasslands, make unproductive grasslands more intensive</td>
<td>↗ C storage</td>
</tr>
<tr>
<td>Paddy rice management</td>
<td>Promote aeration of rice-growing soil to reduce fermentation reactions: reduce the depth of paddy fields, empty them several times a year,...</td>
<td>↘ CH4</td>
</tr>
</tbody>
</table>
In temperate, intensive agricultural contexts a major part of the cost-effective abatement potential is related to N management

A recent advanced study by INRA on French agriculture (Pellerin et al., 2013)

26 proposed technical measures to reduce agricultural GHG emissions:

• Calculation of the abatement potential (Mtons of CO$_2$e avoided per year)
• Calculation of the cost to the farmer (€ per ton of CO$_2$e avoided)

► 26% of the cumulated abatement potential was related to N management (N fertilization, legumes, cover crops,...)

https://www6.paris.inra.fr/depe/Projets/Agriculture-et-GES
Most measures targeting a reduction of N$_2$O emissions were characterised by a negative cost (input savings, no yield losses) → “win-win measures”

However, the assessment of their potential abatement was characterized by a very high uncertainty.
Management practices that increase effectively SOC are based on:

- a reduction of mineralisation rate (e.g. reduced tillage)

- an increase of C inputs in soils (e.g. organic fertilisers, cover crops, agroforestry…)

Total France (2030): 30% abatement potential
Recent meta-analyses have shown that additional C storage is not always observed under reduced tillage.

Changes in soil C stocks depend on:
- biomass production (and subsequent C inputs as crop residues) under reduced tillage
- climatic context (more C storage under dry conditions)

Even where no additional C storage is observed, reduced tillage reduces GHG emissions thanks to less energy consumption.
## 2. Adaptation options involving cropping systems

<table>
<thead>
<tr>
<th>Levers</th>
<th>Technical options</th>
</tr>
</thead>
</table>
| **Crop species & varieties** | • (stress escape) more appropriate thermal time and vernalization requirements  
                                 • (stress tolerance) increased tolerance to heat shock, drought, low temperature, emergent pests and diseases...  
                                 • (stress avoidance) lower water needs, optimal water use pattern  |
| **Crop management**           | • (escape) shifting sowing date to escape water and thermal stresses  
                                 • (avoidance) nutrient applications, planting density and spatial arrangements (e.g. skip row) adjusted to precipitation patterns and yield goals  
                                 • (attenuation) supplementary/deficit irrigation if available  
                                 • (conservation) soil tillage and residue management to maximize soil water storage, reduce evaporation, runoff and erosion  |
| **Cropping pattern**          | • Diversify crops & cultivars to increase resilience (rotation, landscape); variety mixtures and intercropping; agroforestry; flexible systems  |
| **Information & decision system** | • Use seasonal weather forecasting; model-based decision support systems (DSS)  |
Observed adaptation responses as reported by survey respondents (50 experts) for individual environmental zones in Europe

Olesen et al. (2011), Eur. J. Agron
# 3. Some trade-offs in cropping system design

<table>
<thead>
<tr>
<th></th>
<th>Adaptation</th>
<th>Mitigation</th>
<th>Food Production</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>reduce N2O</td>
<td>increase SOC</td>
<td></td>
</tr>
<tr>
<td>Reduce the use of mineral N</td>
<td>+ (W)</td>
<td>+</td>
<td>o/-</td>
</tr>
<tr>
<td>fertilizer</td>
<td></td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>No till and mulching</td>
<td>+ (W)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Legumes in crop rotations</td>
<td>- (W)</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>Catch crops, multiple cropping</td>
<td>- (W)</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Agroforestry, intercropping</td>
<td>+(T), -(W)</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Bioenergy crops</td>
<td>/o (W)</td>
<td>0</td>
<td>o/-</td>
</tr>
</tbody>
</table>

Temperature (T)  
Water (W)  
Impact : +, o, -
Some benefits of conservation agriculture in the tropics

Run off

\[ y = e^{3.3x} \\
R^2 = 0.66 \]

Nutrient cycling

\[ y = 0.66x + 13.23 \\
R^2 = 0.94, P<0.01 \]

Mulch of crop residue (amount)

Soil erosion

Weeds

Soil C


A case-study of multiple trade-offs: rainfed rice in Madagascar (hillsides)

Biomass production

Grazing

Residue burial

+++

Mulching

Mineralization

Sowing dates

+++

SOC

Available soil water

+++}

Cultivars

Water balance

+++
Rainfed rice in Madagascar: livestock as a priority

- Biomass production
- Grazing
- Residue burial
- Mulching
- Sowing dates
- Available soil water
- Cultivars
- Water balance
1. Diagnosis
Objectives
Constraints

2. Cropping
system (CS)
design

3. Multi-
criteria
assessment

4. Designing CS
Assessment with a multi-
attribute qualitative method
from Pelzer et al. (2012)
### Methods for designing cropping systems in the context of climate change

<table>
<thead>
<tr>
<th>Method</th>
<th>New variables to assess (e.g. N\textsubscript{2}O)</th>
<th>Multiple solutions to explore</th>
<th>More uncertainty to consider</th>
<th>Actors to involve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cropping system experiments</td>
<td>+++</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Simulation &amp; optimization studies (in silico)</td>
<td>++</td>
<td>+++</td>
<td>+++</td>
<td>+</td>
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<tr>
<td>Prototyping methods</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Participatory modelling (games)</td>
<td>+</td>
<td>++</td>
<td>++</td>
<td>+++</td>
</tr>
</tbody>
</table>

Coupled with assessment methods (indicators, multi-criteria decision-aid)
CropSyst model implemented within the BioMA modelling platform of the European Commission (JRC): e.g. wheat

Donatelli et al. (2012), IEMSs

Simulation studies concluded to successful adaptation but:

- A subset of adaptation measures: sowing dates and hypothetical varieties

- Decision rules, feasibility (workable days) and resource availability (water) are not considered

- Some important limiting factors are omitted: e.g. invasive pests and diseases
Simulation models for assessing and designing cropping systems with a CSA perspective

- Crop models generally do not consider yield impacts from extreme frost and heat events (Barlow et al., 2015). Intercomparison of crop models (e.g. AgMip) revealed uncertainties in simulating yield under CO2 and high temperatures (Asseng et al., 2013);
- Major CS models (e.g CropSyst, DSSAT, EPIC, Stics...) can theoretically simulate a wide range of adaptation options at field level (e.g conservation agriculture with residue management and minimum tillage) but plurispecific stands still need new modelling achievements;
- The ability of simulation models to account for the effect of cropping systems on N₂O emissions must be better assessed;
- Some progress is also expected concerning the emergence, incidence and damage of weeds, pests and diseases under future agriculture (only a few contributions)
Hybrid design methods have been developed combining both participation and research based-models (via serious games) in order to develop the adaptive capacity of farmers on real-world challenges. 


Collective workshops
Summary

• Cropping systems offer numerous actionnable options for CSA
• Multiple trade-offs to consider when designing cropping systems for CSA objectives
• A range of methods for designing and assessing CS (based on multicriteria decision-aid) that could be combined
• Underlying simulation models have to be completed to widen the set of options to explore
• Farm constraints should be considered explicitly when testing the adaptation and mitigation solutions
Thank you for your attention!