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Co-design and multicriteria assessment of low-input cropping systems in the South-West of France: a 8-years experimentation with farmers

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Introduction
Food production in the last decades has been greatly increased thanks to intensification of agriculture but this intensification also led to numerous undesirable environmental impacts such as biodiversity loss, soil degradation, and soil, water, air, and food contamination by pesticides (Foley et al., 2005; MEA, 2005). Moreover, in many cases, economical performances of intensive cropping systems (CS) decreased that weakens the sustainability of farms. In the South-West of France, two main traditional CS could be identified: a rainfed durum wheat-sunflower CS and a maize monoculture CS (mainly irrigated). The main objective of this study was to evaluate the sustainability of CS designed as alternatives of these two traditional CS that aimed at reducing the negative externalities of agriculture while answering specific objectives of the involved farmers.

Table 1. Main characteristics of the 8 farms involved in the study.

<table>
<thead>
<tr>
<th>Site (department number)</th>
<th>Soil type</th>
<th>Initial CS</th>
<th>Alternative CS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm 1 (09)</td>
<td>Silt – Clay silt</td>
<td>MS monoculture</td>
<td>MS → MS → SF → SW → SB → SW</td>
</tr>
<tr>
<td>Farm 2 (31)</td>
<td>Silty with coarse elements, hydromorphic</td>
<td>M monoculture</td>
<td>M → SW → SB</td>
</tr>
<tr>
<td>Farm 3 (65)</td>
<td>Silt with coarse elements</td>
<td>M monoculture</td>
<td>M → SF → SW → SB → SW</td>
</tr>
<tr>
<td>Farm 4 (65)</td>
<td>Silt with coarse elements, hydromorphic</td>
<td>M monoculture</td>
<td>M → SB → SW</td>
</tr>
<tr>
<td>Farm 5 (31)</td>
<td>Silt with coarse elements, hydromorphic</td>
<td>M → SW</td>
<td>M → SW → CS → SW → RS → SW</td>
</tr>
<tr>
<td>Farm 6 (31)</td>
<td>Calcareous clay on hillsides</td>
<td>DW → SF</td>
<td>DW → SF → SW → SG</td>
</tr>
<tr>
<td>Farm 7 (46)</td>
<td>Calcareous clay on hillsides</td>
<td>RS → SW → B</td>
<td>RS → SW → SF → B</td>
</tr>
<tr>
<td>Farm 8 (81)</td>
<td>Calcareous clay on hillsides</td>
<td>DW → SF → SW → SF</td>
<td>DW → SG → SB → SW → SF → FB → SW → SF</td>
</tr>
</tbody>
</table>

Materials and methods
Workshops, mixing farmers, advisers and scientists, were organized in 2009 and 2010 in order to (i) identify strengths and weaknesses of initial CS; (ii) design alternative CS (based on formalized decision rules) in order to answer to common and specific objectives; (iii) define/choose the indicators to monitor the performances and, after an ex-ante assessment (iv) experiment and perform an ex-post evaluation of the designed CS for each involved farm (Papy, 2001; Debaeke et al., 2009). A 8-farms network was involved in this 8-years study (2010-2017) (Table 1). The main indicators chosen to monitor performances are mentioned in Table 2.

Table 2. List of selected indicators for cropping system performance assessment.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Criteria</th>
<th>Indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic</td>
<td>Profitability</td>
<td>Semi net margin (SNM) at rotation level (€/ha)</td>
</tr>
<tr>
<td>Economic</td>
<td>Weed management</td>
<td>Weed abundance in the field</td>
</tr>
<tr>
<td>Economic</td>
<td>Dependency on external inputs</td>
<td>Input use efficiency</td>
</tr>
<tr>
<td>Economic</td>
<td>Productivity</td>
<td>Energetic yield (MJ)</td>
</tr>
<tr>
<td>Environmental</td>
<td>Water quality (pesticide)</td>
<td>Treatment Frequency Index (TFI)</td>
</tr>
<tr>
<td>Environmental</td>
<td>Water quality (pesticide)</td>
<td>I-phy</td>
</tr>
<tr>
<td>Environmental</td>
<td>Water quality (pesticide)</td>
<td>Number of toxic pesticides for aquatic systems</td>
</tr>
<tr>
<td>Environmental</td>
<td>Water quality (nitrate)</td>
<td>Nitrogen indicator (NI)</td>
</tr>
<tr>
<td>Environmental</td>
<td>Water quantity</td>
<td>Irrigation amount (m³/ha)</td>
</tr>
<tr>
<td>Environmental</td>
<td>Soil quality</td>
<td>Organic matter indicator (IMO)</td>
</tr>
<tr>
<td>Environmental</td>
<td>Soil quality</td>
<td>Length of bare soil period (%)</td>
</tr>
<tr>
<td>Environmental</td>
<td>Fossil energy</td>
<td>Total fuel consumption at CS level (MJ/ha)</td>
</tr>
<tr>
<td>Environmental</td>
<td>Climate change mitigation</td>
<td>GHG emission (equivalent t CO₂/ha)</td>
</tr>
<tr>
<td>Social</td>
<td>Farmers’ quality of life</td>
<td>Labor time (h/ha)</td>
</tr>
<tr>
<td>Social</td>
<td>Farmers’ quality of life</td>
<td>Workload distribution (h/ha/month)</td>
</tr>
<tr>
<td>Social</td>
<td>Farmer and public health</td>
<td>Number of pesticide applications</td>
</tr>
</tbody>
</table>
Furthermore, in order to test the robustness of cropping systems, 8 crop price scenarios, chosen over the period 2007-2014, were applied and a comparison between the economic performances of the initial CS and the alternative CS was made.

Results and discussion

Crop diversification was found to enhance CS economical performances if associated with rigorous control of the mechanization loads (Fig.1a). In most cases, diversification led to a better distribution of workload during the year allowing the development of high added value production (such as vegetables with direct selling). Selected indicators illustrated that diversification could lead to lower environmental impacts (Table 3), except if seed production (with high pesticide use) was integrated in the CS.

For the project DiverIMPACTS, further investigations are performed with economical stakeholders to increase economical performances of diversified CS. In parallel, a multicriteria assessment (using the indicator list of DiverIMPACTS) of the initial (mainly maize monoculture) and diversified CS of the 20 farms involved in the Case Study 5 has started and should strengthen conclusions on the effects of crop diversification on the sustainability of South-West of France farms.

Table 3. Multicriteria assessment of alternative CS (selected indicators from the list of Table 2)

<table>
<thead>
<tr>
<th>SNM</th>
<th>TFI</th>
<th>NI</th>
<th>GHG</th>
<th>Labor time</th>
<th>Farmer satisfaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm 1</td>
<td>-35%</td>
<td>-39%</td>
<td>+43%</td>
<td>-21 %</td>
<td>-67 %</td>
</tr>
<tr>
<td>Farm 2</td>
<td>+46%</td>
<td>-62%</td>
<td>0%</td>
<td>0%</td>
<td>-72%</td>
</tr>
<tr>
<td>Farm 3</td>
<td>-10%</td>
<td>-16%</td>
<td>0%</td>
<td>-17%</td>
<td>-37%</td>
</tr>
<tr>
<td>Farm 4</td>
<td>+189%</td>
<td>+25%</td>
<td>+156%</td>
<td>-62%</td>
<td>-45%</td>
</tr>
<tr>
<td>Farm 5</td>
<td>+72%</td>
<td>+71%</td>
<td>+15%</td>
<td>-17%</td>
<td>0%</td>
</tr>
<tr>
<td>Farm 6</td>
<td>-20%</td>
<td>-48%</td>
<td>+32%</td>
<td>+24%</td>
<td>+25%</td>
</tr>
<tr>
<td>Farm 7</td>
<td>-35%</td>
<td>+10%</td>
<td>+24%</td>
<td>-30%</td>
<td>0%</td>
</tr>
<tr>
<td>Farm 8</td>
<td>+5%</td>
<td>-43%</td>
<td>+47%</td>
<td>-43%</td>
<td>+10%</td>
</tr>
</tbody>
</table>

References