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Design of innovative orchards: proposal of an adapted conceptual framework  
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1 Introduction

System experiments are a developing approach to address complex questions such as the design and management of sustainable cropping systems. If the general framework of system experiments is well documented and adapted to iteratively design annual cropping systems (Debaeke et al., 2009), specificities of other crops are not always considered with possible limits at using the approach. As perennial and multi-layer systems that produce fresh fruit, orchards are complex agroecosystems that require specific design and management over space and time. The present work analyzed two contrasted system experiments aiming at decreasing pesticide use in temperate (apple) and Mediterranean/tropical (citrus) fruit productions. Our aim was to examine similarities and differences, and to propose a conceptual framework for designing innovative orchards.

2 Materials and methods

A crossed analysis was used to identify general aims, methodology used to design, type of levers combined to decrease pesticide use and related processes, and nature of outputs of the two studied system experiments (Table 1, Fig. 1).

Table 1. Main outlines of the two studied experiment systems.

<table>
<thead>
<tr>
<th></th>
<th>Apple (Simon et al., 2011)</th>
<th>Citrus (Le Bellec et al., 2012)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research program</td>
<td>BioREco</td>
<td>ECOFRUT followed by Agrum’Aide</td>
</tr>
<tr>
<td>Location</td>
<td>South-East France</td>
<td>Reunion Island (France)</td>
</tr>
<tr>
<td>Orchard type</td>
<td>System experiment</td>
<td>Growers’orchard network</td>
</tr>
<tr>
<td>Study period</td>
<td>2005-2015</td>
<td>2010-2018</td>
</tr>
<tr>
<td>General aim / target pests</td>
<td>Pesticide use decrease / insects, diseases, weeds</td>
<td>Pesticide use decrease / insects and weeds</td>
</tr>
<tr>
<td>Methodology to design orchards</td>
<td>Mix of prototyping &amp; step by step approach based on scientific knowledge and experience</td>
<td>Step by step approach</td>
</tr>
<tr>
<td>Main levers used to decrease pesticide use (see also Fig. 1)</td>
<td>Low-susceptibility cultivar &amp; combining of several methods</td>
<td>Weeds management with or without introduction of cover crop</td>
</tr>
<tr>
<td>Main processes at stake and practices to control pests</td>
<td>Bottom-up and top-down processes &amp; direct measures</td>
<td>Bottom-up and top-down processes &amp; direct measures</td>
</tr>
<tr>
<td>Main outputs</td>
<td>Important pesticide decrease(45-60%) when all levers are combined &amp; information of damage risk available</td>
<td>Important pesticide decrease (30 % and more) when the growers are implicated as co-designers of the cropping system <a href="http://cosaq.cirad.fr/projets/agrum-aide">http://cosaq.cirad.fr/projets/agrum-aide</a></td>
</tr>
</tbody>
</table>

Fig. 1. Main levers combined to (re-)design apple and citrus orchard systems to manage orchard pests. Levers refer to broad non-exclusive groups of levers according to their nature and/or mode of action; Orchard reconception combines all types of levers.
3 Results – Discussion: Spatial and temporal design of innovative orchards towards more sustainability

This cross-analysis outlined (Table 2) three main aspects:
- The young unproductive stage of the orchard that can last for 2 to 5 years according to fruit species and cultivar requires careful management as the development and yield of the adult tree is building up during this stage.
- The permanency of the crop constrains the management of soil fertility: some practices are no more possible (e.g. legume crops in the rotation), fertilizing and ground cover management differentiate between tree rows and alleys.
- The longevity of the crop constrains decision making: a pest can be damageable in the present but also in the following seasons as many serious pests can complete their lifecycle in the orchard and build up important populations or inoculum across years. This is especially true in tropical areas where there is no dormant season. Conversely, the permanency of the orchard habitats facilitates the planting or sowing of plant assemblages (e.g. ground covers, lining hedgerows) to enhance conservation biocontrol and/or compete weeds, provided non-disruptive practices are applied.

Table 2. Specificities of the design and management of orchard systems compared to rotational systems.

<table>
<thead>
<tr>
<th>Rotational cropping systems</th>
<th>Orchard systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cropping system design</td>
<td>One-layer annual crops, no woody crop</td>
</tr>
<tr>
<td>Cropping system lifetime</td>
<td>Seasonal crops in the rotation with some exceptions (e.g. alfalfa)</td>
</tr>
<tr>
<td>Fertilization and soil management</td>
<td>Whole-field fertilizer supply</td>
</tr>
<tr>
<td>Soil cover and crop management</td>
<td>Successive crops</td>
</tr>
<tr>
<td>Weed management</td>
<td>Long-term decisional management</td>
</tr>
<tr>
<td>Pest and disease management</td>
<td>Pest/disease lifecycle broken by crop sequences</td>
</tr>
<tr>
<td>Natural enemies management</td>
<td>Scarce permanent resources and habitat unless semi-natural habitats are present</td>
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</table>

4 Conclusions

Because of their longevity, orchards permit to foster both bottom-up and top-down processes in the food chain. Therefore, they offer opportunities to redesign the cropping system within space and time (Fig. 2), and to enhance ecosystem services such as pest and weed control through the management of cultivated and companion plants (Thies et al., 2003; Tscharntke et al., 2007). In such perennial cropping systems requiring intensive and long-term management, interactions among the orchard life stages, spatial and functional dimensions and practices need to be explicitly considered to optimize the efficiency of the system as a whole. Such complexity in the re-design requires knowledge from many stakeholders in the food system (growers, advisors, scientists…). Co-design also requires more and renewed interactions among these stakeholders with the aim of building capacity in participatory approach appropriation, and for growers in the design of their own orchard and decisional system (Le Bellec et al., 2012; Lauri, 2014).

Fig. 2. General framework: main dimensions to consider when designing orchard systems.

References