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Stephane Bellon, Joel Fauriel, Jean-Louis Hemptinne, Laurent Jamar, Pierre-Eric Lauri, M. Lateur, Gilles Libourel, Sylvaine S. Simon

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Bellon S.[1], Fauriel J.[1], Hemptine J.-L.[2], Jamar L[3]., Lauri P.E .[4], Lateur M.[3], Libourel G.[5], Simon S.[6]

[1]INRA UR 767 Site Agroparc 84914 Avignon Cedex 9, France (bellon@avignon.inra.fr)
[2] ENFA, UMR CNRS 5174 BP 22687, 31326 Castanet-Tolosan Cedex, France
[3] CRA-W, Dept. of biocontrol and plant genetic resources 5030 Gembloux, Belgium
[4] INRA UMR DAP-AFEF Avenue Agropolis 34 398 Montpellier cedex, France
[5] GRAB Maison de la bio – Agroparc- BP 1222 - 84 911 Avignon cedex 9, France
[6] INRA UERI Gotheron 26320 Saint-Marcel-lès-Valence France

INTRODUCTION

The design issue is explicitly raised in several proposals aiming at "ecologizing" horticulture. Due to a recurrent use of pesticides, fruit production is at stake; albeit some approaches such as Integrated Pest Management (IPM) and biological control contribute to fulfill the objectives of integrated or organic fruit production (Lescourret and Sauphanor, 2008). What can be learned from such production models in order to design orchards less dependent from external inputs to achieve plant protection? We present the first results of a working group including agricultural scientists, ecologists, extension workers and fruit producers. This group enables to share scattered knowledge and skills into a co-design approach. This approach is consistent with frameworks issuing from expert-based knowledge and system prototyping. However, such proposals have not been implemented in fruit production: as perennial crops and multi-strata systems, orchards create complex designs to be modulated for agronomic purposes.

MATERIALS AND METHODS

Based on transition pathways towards sustainable agriculture, a framework was derived from the field of crop protection and extended to food systems (Hill, 1985). This framework discerns three types of innovations: (i) increase the efficiency of practices in order to reduce the use of costly, scarce and environmentally damaging inputs; (ii) substitute conventional inputs with alternative practices and biological methods; (iii) redesign an agroecosystem so that it functions on the basis of a wider set of ecological processes. It was used as a guide for orchards eco-design. The approach of our working group was to (i) define the expected properties of a sustainable orchard, (ii) identify and combine the bio-technical components of an ecologically-based orchard redesign, (iii) propose relevant criteria to assess the performances of such orchards.

RESULTS AND DISCUSSION

Three targeted properties for such orchards are: self-sufficiency, through minimizing external inputs and maximizing the use of natural resources; connectivity among vegetation layers to enhance beneficials; adaptability and reversibility in management options. Components for orchard redesign were identified, based on participants' practical and methodological experience.

Currently, a few number of apple cultivars are commercially grown in the world and practically all of them are highly susceptible to scab which is the most serious apple disease. Therefore the main breeding programmes are focused on scab resistance. Monogenic sources of resistance, specifically the *Vf* gene, were the most used by the breeders. However, the breakdown of *Vf* resistance by at least three scab races emphasizes the importance to broaden the genetic diversity of scab resistance including quantitative resistance. Very different selection pressures occurred in the past that created a large diversity of apple cultivars. Many of these were grown formerly in extensive high stem standard trees orchards and expressed too many unexploited quantitative traits. Interesting traits were such as: high tolerance to most diseases, long natural maintenance ability, low fertilizer requirements, diversity of tree architecture …Rescue surveys pointed out that many landraces are still present in old orchards or gardens and may be used either as cultivated varieties or as parent in breeding programmes (Lateur, 2003). Non-chemical sanitation practices against apple scab have been first reasoned in the frame of the orchard eco-design: (i) the inoculum reduction by leaf litter management in the previous autumn and/or the following early spring, (ii) the respect and the use of antagonists suppressing conidial and ascospore productions, (iii) the mixed apple cultivars orchards and (iv) sheep or birds breeding integrations. Besides, various environmentally safe methods were discussed in order to reduce the amount of fungicides applied in orchards including strategies involving spraying during the infection process (Jamar *et al*., 2008), screenings of alternative control input and new adapted sprayers for treatment applications.

In the multiscale paradigm we define the tree itself is likely to be a first and key step to design. Beginning with seminal research works developed on apple in the 1960's at INRA France, a large amount of studies have shown that tree architecture and fruiting behaviour are related in many ways (Lauri *et al*., 2009). Indeed a low branching density is generally related to higher branch length which is in turn positively related to higher regularity of fruiting. These features which vary greatly among apple genotypes also indicated new training and pruning strategies. A high canopy porosity obtained through precise pruning cuts (spur extinction) is proposed as a way to better control branching density, return-bloom and fruit quality. Tree architecture management also impacts pest and disease epidemics indicating innovative, albeit partial, ways to control bio-aggressors in the orchard. We propose to focus on the following orchard traits and management to enhance ecosystem functions: (i) decrease the spatial monotony (linear arrangements) of orchard systems and increase boundary effects; (ii) emphasise a functional multi-strata design, i.e. through the introduction of a missing bush layer; (iii) increase plant diversity within and outside the orchard; (iv) pay specific attention to the soil organic status and to the role of scavengers at the basis of food-webs.

Fruit production patterns enhancing orchards' nutritional and environmental performances are thus identified. A relationship appears between tree vigor – as determined by training and pruning strategies – and fruit quality. Low-input fertilization practices entail higher concentrations in secondary metabolites (Fauriel *et al*., 2007). Organic fruit production patterns are candidate for such performances. However, their productivity is still too low for the current marketing standards.

Partnerships among actors involved in a redesign process enabled us to identify research topics: relationships between training systems and pest and disease pressure; consistency between crop protection efficiency and ecological value of orchards; relevant levels of organization (spatial and temporal) to promote such orchards and their integration into sustainable food systems.

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