FRUIT-TREES IN AGROFORESTRY SYSTEMS - REVIEW AND PROSPECTS FOR THE TEMPERATE AND MEDITERRANEAN ZONES

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Introduction

Monocropping has proved its high performance under optimized conditions such as the provision of external resources. However these systems perform poorly when inputs are reduced (Altieri et al. 2015). Agroforestry belongs to the multiple cropping paradigm using plant interactions to increase or at least to maintain crop production with lower inputs and to enhance ecological services (Gaba et al. 2015). It is mostly based on full intercropping or relay cropping depending on if plants are grown together during their whole-growing cycle or a part of it, respectively (Parrotta et al. 2015).

The focus of this paper is on how fruit-trees can be integrated in agroforestry systems (AFS) in the temperate and Mediterranean zones. We will first show the contrasted situations between the tropics and the temperate and Mediterranean zones. We will then present the main biological and agronomic specificities of fruit-trees compared to annual crops and timber-trees. We will conclude on the interest and challenges of AFS structured around timber- and fruit-trees.

Fruit-trees are under-represented in agroforestry systems in the temperate and Mediterranean zones

A majority of AFS are found in the tropics and sub-tropics where fruit-trees constitute an important component of agroforestry systems (Nair 1991). In these contexts, the interactions between the characteristics of AFS and the behavior of fruit-trees receive an increasing interest for crops such as coffee (e.g., shade *versus* productivity; Cerdan et al. 2012) and cocoa (e.g., spatial structure and biodiversity *versus* productivity (Deheuvels et al. 2012) or pests and diseases (Gidoin et al. 2014)).

In temperate Europe, fruit-trees have been traditionally cultivated in AFS known as “Joualles” and “Verger haute tige” in France (Dupraz and Liagre 2011) or “streuobst” in Germany (Herzog 1998). These systems dated back from the 17th century and reached their peak during the 1930s (Herzog 1998). Production was mostly oriented towards family consumption and the possible surplus of fruit was sold to neighboring cities (Herzog 1998). It is likely between the two world wars, along with a generalized specialization of all production systems in agriculture, that the increasing demand for fruits entailed the disintegration of these fruit-tree-based AFS and fruit hedges, and the emergence of orchard systems precursors of modern intensive orchards, mechanized crop and fodder production (Herzog 1998). At the same time, traditional fruit-tree-based AFS were considered as not profitable by the European Economic Community and 1998-statistics indicated that these systems use of the whole agricultural land ranges from 0% (Ireland) to 5.4% (Spain) mostly as silvopastoral systems (Herzog 1998; Nair 1991). The strong reduction in the number of cultivars accompanied these evolutions. For example, in Germany, it is estimated that the traditional streuobst systems hosted a high genetic diversity with ca. 1400 apple cultivars which were robusts and well adapted to the local pedoclimatic conditions (Herzog 1998) whereas in the current monocropping system 52% of apple production is covered by only five cultivars (Garming 2013).

Nowadays, a majority of research works developed on fruit-trees are based on monocropping systems, with ca. 5% of all published articles dealing with fruit-trees in AFS and no significant trend over the recent years (**Figure 1**). However, the economic and ecological interests of traditional systems integrating agroforestry practices are documented on fruit-trees such as walnut (e.g., Mary et al. 1998). In the same time, there is a growing interest for agroecological orchards not only in terms of sustainability especially with regards to the control of pests and diseases (Simon et al. 2015) but also in terms of economic efficiency (Duru et al. 2015). In this context, there is a need to develop more fundamental and applied research on the design and performances of temperate and Mediterranean AFS integrating fruit-trees.

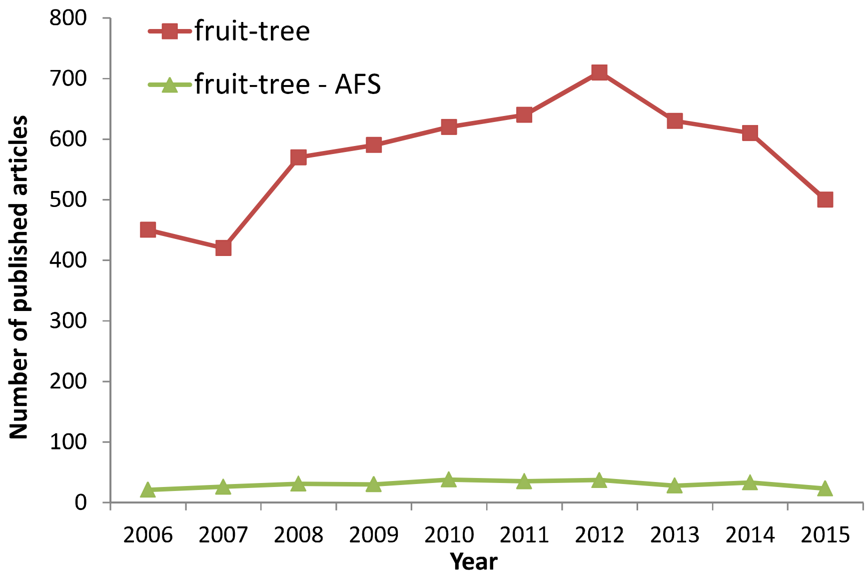

Figure 1: Annual frequency of published articles with topic “fruit-tree - AFS” (i.e., “fruit-tree” combined with “agroforestry” or “agroecosystem” or “agrosystem” or “silvoarable system” or “alley cropping system”) and with topic “fruit-tree” alone, from 2006 to 2015, in all document types and all Web of Science (WOS) categories (access, January 2016).

Biological and horticultural specificities of fruit-trees

Growing fruit-trees in AFS requires taking into account three main aspects.

1) ***Genetics of the plant material*** - In the last decades, whatever the species, fruit-tree breeding programs have poorly considered tree hardiness. As a consequence, available cultivars in monocropping orchards are generally pest- and disease- susceptible and are heavily sprayed with pesticides (e.g., apple, Parisi et al. 2014). This could be a bottleneck to develop mix cropping with fruit-trees since pesticides are registered per pest and crop.
2) ***The fruit-tree as a composite entity*** - Contrary to timber-trees usually propagated by seeds or cuttings, most temperate fruit-trees are planted as composite entities with the cultivar bearing the desired fruits (most of the aerial part) grafted on a rootstock (root system). The rootstock is used to control the intrinsic vigor of the tree, its growth habit and fruiting precocity. It is also used to adapt the cultivar to unfavorable abiotic and biotic environmental conditions. Although planting own-rooted fruit-tree cultivars, i.e., with more vigor, could be interesting in contexts of competition for light and nutrients (e.g., apple, Maguylo and Lauri 2007), the genetic variability of both the cultivar and rootstock are efficient means to precisely adapt the plant material to growing conditions.
3) ***Tree management*** - Once the tree is planted, training and pruning techniques are essential to drive tree growth and fruiting year after year. These manipulations of tree architecture have two objectives: to give a shape to the tree to optimize light interception in relation to the planting design and to balance vegetative growth and fruiting to ensure regular fruit production (e.g., apple, Lauri and Laurens 2005).

Integrating fruit-trees in temperate and Mediterranean agroforestry systems

In the AFS predominant in the temperate zone, plants are structured in two spatial strata with timber-trees, nut-trees or fruit-trees in the upper stratum and herbaceous crops in the lower stratum (e.g., apple trees combined with soybean and peanut; Gao et al. 2013).

We propose that, similarly to what is commonly observed in tropical AFS, an original timber-tree-based AFS could be enriched with fruit-trees in an intermediate vertical stratum (**Table 1**). However, developing 3(or more)-strata AFS structured around fruit-trees and timber- or nut-trees directly addresses how ecosystem services are managed, especially the hierarchy among provisioning (fruit yield) and other ecosystem services such as regulation of pests and diseases.

Table 1: AFS ideotypes integrating fruit-trees.

	3 (or more) vertical strata	2 vertical strata	Life-cycle
Upper stratum (10m and above)	Timber-tree, nut-tree (walnut…)	-----------	30 years or more
Medium (3 to 4.5m)	Fruit-tree (possibly trellised in row design) In the timber-tree row and/or In the cropping alley	Fruit-tree (possibly trellised in row design)	15-25 years
Lower (up to 2m)	Cereals and associated rotation Vegetables, annuals/perennial grasses, Fruit bushes	Cereals and associated rotation Vegetables, annuals/perennial grasses, Fruit bushes	1 to 5 years

In such context, the interest but also the challenges of timber- and fruit-tree based AFS lie in the following aspects:

1) **Fruit production –** Increasing plant diversity in an AFS increases competition for light. The ability of fruit-trees to grow under the shade of timber- or nut-trees depends partly on the phenology of all the species, and for a given species of the cultivar. Interactions between the environment and the characteristics of the fruit-tree may not only affect fruit yield but also the visual appearance of the fruit. Further, how the fruit-tree based AFS, compared to the monocropping systems, affects the Land Equivalent Ratio (LER) but also labor efficiency warrant more studies.
2) **AFS microclimate and plant ecophysiology –** In the Mediterranean area, fruit-trees may be subjected to an excess of solar radiation during summer with known deleterious effects on fruit quality and leaf functioning (photooxydative damage). In such micro-climatic condition, the use of timber- or nut-trees for shade may be a good alternative to shade nets that are commonly used in monocropping orchards.
3) **Biocontrol of pests and diseases –** Designing annual and perennial plant assemblages can be a way to foster both bottom-up and top-down processes in the food web, as well as barriers and dilution effects, to control pests and diseases and to decrease pesticide use (Simon et al., 2015).

Ongoing and planned projects at INRA, France, in collaboration with other academic and applied research organizations and growers aim to enhance the scientific knowledge of fruit-tree-based AFS, and further to improve the design of these systems and to evaluate their productivity and economic viability. Apart from research investigations conducted on the aerial (e.g., light) and the subterranean (e.g., water, nutrients) compartments of the various plants under the paradigm of competition or facilitation (e.g., Moustakas et al. 2013), two main aspects need to be considered. Firstly, although the vertical stratification of the trees, timber- or nut-trees and fruit-trees, is related to the architectural characteristics of the species (Table 1), their horizontal distribution needs to be adapted to the growth patterns of the species (e.g., alternating rows of timber- and fruit-trees vs. planted in the same row). Secondly, the temporal resolution of the AFS also has to be investigated whether all species are planted in the same year or in consecutive years, possibly including a dynamic planting density scenario with the removal of some trees depending on competitions among plants.

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