AGROFORESTRY: NEW CHALLENGE FOR FIELD CROP BREEDING?

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Introduction

Agroforestry (AF) as a design including field crops and trees is largely studied with more than 22000 articles (period 1970-2015), referenced in WOS[1], that contained the two keywords "Agroforestry" and "Crop". However, when adding the keyword "Breeding", the number of articles falls to less than 1700 **(figure 1)** and the entire majority concerns the breeding of the trees. Very few concern field crops and if any, the main aim is the evaluation of some varieties in AF systems (Singh et al., 2015; Mishra et al., 2010; Sirohi et al., 2012; Tiwari et al., 2012), and not real breeding.

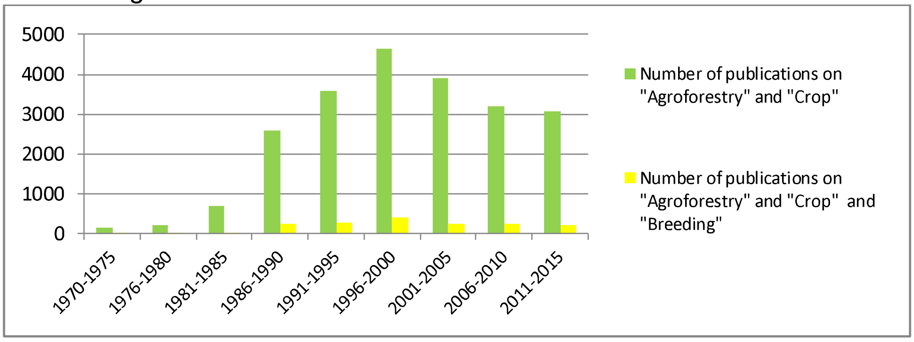

Figure 1: number of publications in the Web Of Science

Farmers deplore that the crop varieties they grow are not adapted to their AF systems because no selection is made under these conditions. There is an urgent need to breed for AF.

How the association tree-crop may modify the way of thinking plant improvement?

Referring to the Millennium Ecosystem Assessment, the main benefits of agroforestry concern the four types of ecosystem services: (i) Supporting (nutrient cycling, soil formation, primary production), (ii) Provisioning (food, wood and fiber), (iii) Regulating (climate regulation, flood regulation, disease regulation, water purification) and (iv) Cultural services (aesthetic, spiritual, educational, recreational) (MEA, 2005). When zooming on the ecosystem services offered by the trees to the associated crops, Supporting and Regulating services have to be considered. Regarding also the facilitation and competition effects on shoots and roots between tree and crop, it may allow to elaborate an efficient breeding strategy, i.e to choose the relevant breeding criteria and to rethink the way of breeding.

1- Breeding criteria for field crops associated to trees

- **Shade tolerance**

A great number of studies report that the tree shade, by reducing the photosynthetically active radiation (PAR) intercepted by crops, leads to a decrease in yield. The reduction of PAR increases with the time (22% lower during wheat flowering, 56 % at maturity) (Li et al., 2008) and the yield of cereal can decreased by more than 50% (Dufour et al., 2013). The varieties proposed to farmers are all bred under full sun and therefore they are not the best adapted to shade conditions. The first step to assess breeding criteria for shade tolerance is to determine if it exists a genetic variability in the target crop for the following traits: (i) plant and leaf shape that are able to capture more light, (ii) photoperiodic need, (iii) radiation use efficiency (RUE), (vi) phenology. Theoretically, wheat yield potential could increase by genetically improving RUE (Molero et al., 2015). And phenology of crop should also be studied to better match the period of unshaded.

- **Soil Nutrient contribution**

Agroforestry Systems promote a permanent input of litter that increases the organic matter content of the soil and therefore of the microbial community (Araujo et al., 2012). Besides the contribution to soil organic matter from senesced roots, living roots release exudates. Root-

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induced changes to the chemical environment of the rhizosphere are crucial to the nutrient acquisition of many plant species and include modifications to pH, reduction/oxidation conditions, complexation of metals and enzyme activity (Hinsinger et al., 2003). Molecules contained in tree root exudates influence the development of Arbuscular mycorrhizal fungi (AMF). AMF constitute a key functional group that favors short-lived crops growth by improving plant nutrition and protecting plants from stresses (Shukla et al., 2012).
Breeding strategies must take into account functional traits like the ability of some crop varieties to increase their own AMF colonization when associated with trees. And it is therefore necessary to analyze the potential genetic variability for root exudates that favor mycorrhization. These traits have never or very few been studied in formal breeding, compared to nitrogen use efficiency (NUE) that is currently one of the main aim in formal plant breeding program.

- **Soil Water contribution**

A fundamental hypothesis of agroforestry is that different plant forms such as trees and crops occupy different soil strata with their root systems when grown in association. It leads to a degree of complementarity in their use of soil resources and especially of water. For this reason, rooting depth and the vertical distribution of root systems are of particular interest for agroforestry. Response to root management must be regarded as a clear breeding aim. The crops have to develop their root system when those of the trees are already established. So, it could be interesting to look after varieties that have a shallower root system with relevant lateral root spread in the topsoil. Parameters of root competitiveness, such as root length density, mycorrhization and flexibility in response to water and nutrient patches in the soil, have to be considered for predicting the outcome of interspecific root interactions (Schroth, 1999). These traits must be combined with the usual WUE (Water use efficiency) trait in AF plant breeding programs.
Several authors have emphasized the critical role of arbuscular mycorrhizal fungi (AMF) in improving the ionic content and water parameters in hosts plants including sorghum (Augé et al., 2015), and barley (Tao et al., 2014). A meta-analysis (Meddich, 2015) conducted on 460 studies shows that across all host and symbiont combinations under all soil moisture conditions, AMF plants have shown 24 % higher stomatal conductance than nonmycorrhizal controls. This influence has been even more pronounced under severe drought, with over four times the promotion observed with ample water. Colonization by native AMF has produced the largest promotion.

- **Microclimate adaptation**

Planted in alignment or in hedges, the trees can influence the components of microclimate at different scales. Trees play on two essential elements: radiation and air flow. They contribute to decrease daily amplitude of air (2.5 to 8°C) (Lott et al., 2009) and of soil temperature (5°C) (Van Noordwijk et al., 2014) and to play a role of windbreak. Wind may stimulate photosynthesis and increase yields in crop plants, while in different circumstances it retards growths or occasions physical damage (Grace, 1977). It seems therefore relevant to screen the crop genetic diversity under different situations of wind and temperature.

- **Pests and Diseases resistance**

Even though the effects of agroforestry on pest abundance and plant damage in annual cropping systems are not well known, some studies provide examples of reduction in pests with the use of AF (Girma, Rao, & Sithanantham 2000; Ogol et al., 1999). This can be explain by lower populations of specialist herbivores in AF systems that contained both host and non-host plants, and by an increased abundance of predators, crop auxiliaries and parasitoids (Schroth et al., 2000).
However, there are also instances where agroforestry has led to an increase in pest abundance. High nutrient availability in AFS could lower carbon-nutrient ratios and also reduce the plant defense systems. The effect of agroforestry on pests and diseases does not only depend on crop type, but also on factors such as pest identity, microclimate, and the microclimatic preferences of the pest (Schroth et al., 2000; Pumarino et al., 2015). Therefore these traits must be evaluated in several situations.

- **Weed competition**

Shading by trees could contribute to weed control (Nestel and Altieri, 1992) as the improvement in soil nutrient availability (Barrios et al., 1998; Sileshi et al., 2008). Allelopathic effects of litter (including root) extracts and rhizospheric soil of agroforestry trees on the root growth of crops and other tree species have often been detected under controlled conditions (Ramamoorthy and Paliwal, 1993). But in the field it is still rather obscure as it is notoriously difficult to distinguish from other, soil-root and root-root interactions. In some studies, higher weed diversity has been shown to be associated with a higher proportion of insect-pollinated species thereby extending food potential for other groups of organisms and creating a source of complexity for the agro-ecosystem (Kuussaari et al., 2011; Tscharntke et al., 2011).

Breeding for this trait means to firstly screen the germplasm/varieties of field crops for both allelopathic potential and allelopathic response and to valorize it.

2- How to breed for Agroforestry?

Formal breeding methods were not always suitable to address the very large diversity of both environmental conditions and end-users needs. This large diversity is frequently encountered in AF Systems. Participatory plant breeding (PPB) methods represent alternatives aimed to improve local adaptation breeding, to promote genetic diversity, to empower farmers and rural communities. The term PPB refers to a set of breeding methods usually distinguished by the objectives (functional or process approach), institutional context (farmer-led or formal-led), forms of interaction between farmers and breeders (consultative, collaborative or collegial), location of breeding (centralized or decentralized), and stage of farmer's participation in the breeding scheme (participatory varietal selection or participatory plant breeding). Few PPB programs for AF are running at this time, but they are powerful to catch the diversity of the AF systems and to share knowledges between all the participants (Tiwaria et al., 2009; Desclaux and Nolot, 2014).

Conclusion

Most often, breeding for Agroforestry is only seen as breeding for shade. But this is a very reducing way of thinking if only taking into account the constraints while ignoring the numerous benefits of the trees.

A systemic approach should be largely more relevant than an analytic one, because interactions are much greater in AF systems than in mono-cropping systems.

As a main difference with respect to conventional field crop breeding, breeding for AF obliges to consider traits influencing agroecological structure and function as important as- or more important than- the classical targeted traits such as yield or quality. Among these traits, shoots traits (growth form, leaf shape, photosynthetic rate, displaced phenology, etc…) and roots traits (shape, type of exudates, mycorrhization, etc..) must be highlighted. Some of them have even been counter bred in formal breeding. AF contributes to change perception of plant improvement towards an ecologic manner. Taking into account key concepts from community ecology –namely niche differentiation, facilitation, competition - and translating these into a breeding framework is necessary. Therefore, referring to the etymology, the term oikosbreeding should be used for AF breeding, in order to emphasize that it's necessary to take into account habitat of plants and the whole ecosystem. So, what must be considered is not only 'response' traits i.e. how plant responses to environmental stimuli, but also 'effect' traits i.e. how plants influence ecosystem function (Lavorel and Garnier, 2002). Moreover, the way of breeding must change to integrate the great diversity of AF practices and outlets. Including farmers, collectors, processors, consumers in a Participatory plant breeding program will lead to higher adapted varieties to AF.

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