Evaluation and design of multispecies cropping systems with perennials: are current methods applicable?

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1 Introduction

Mixing simultaneous crops, including perennials is repeatedly mentioned as a way towards ecological intensification in agricultural fields (Malézieux *et al.*, 2009). Research on these systems has developed recently and show that this mixing is not a silver bullet: practices have to be adapted locally in order to build on synergies and minimize tradeoffs between diverging functions, productions and services. For example, the introduction of shade trees in coffee plantations has contrasting effects on disease regulation, depending on the location, on the disease considered, or even on the epidemiological stage of the disease (Bedimo *et al.,* 2012). The same difficulties arise when considering the use efficiency of water or of nutrients. These requirements for local adaptations make the outscaling of innovations relatively difficult: the same cover crop in vineyard can have positive outcome on grape production in a location, and a negative outcome in another one, due to climatic or soil differences (Ripoche *et al.*, 2010).

Moreover, these systems usually rely on various products that enter into different value chains and are delivered at different time scales; the systems, due to the inclusion of perennials, have to be planned on the long term, with low transformability; as they are supposed to provide services as well as goods, their evaluation is complex, relying on multiple indicators.

Methods for cropping system evaluation and design have been developed for annual systems principally. Do they apply to cropping systems with perennials, are adaptation required or do we need to develop new methods?

2 Existing methods and their applicability to multispecies cropping systems with perennials

We discuss the applicability to these systems of common methods developed for the design of simple and annual cropping systems, based on several temperate and tropical case studies (Table 1).

Table 1: case studies selected for each method

Method used for the design / Systems	Prototyping	Participatory diagnosis of current systems	Modelling/simulations
Tropical Agroforestry	Design of two long term coffee agroforestry experiments with experts (Haggar et al., 2011)	Design of agroforestry systems based on the study of trade offs between Ecosystem Services, (Notaro*et al.,* this congress),	Modeling for the design of coffee based agroforestry systems, (Meylan et al., 2014)
Temperate agroforestry	Design of pesticide-free agroforestry system without pesticides with experts (Grandgirard et al., 2014)	*Commercial agroforestry systems in temperate regions are too scarce to allow for meaningful diagnosis*	Virtual experiments to identify optimal tree density and organization in the field (Talbot, 2011)
Mediterranean grapevine	A prototyping method for the re-design of intensive perennial systems: the case of vineyards in France (Metral*et al.*, this congress)		Cropping system design for including cover crop in vineyards (Ripoche et al., 2010)

A first approach is prototyping, based on the integration of general and local knowledge to elaborate hypotheses on the factors influencing the performances to be improved and build solutions according to these hypotheses (Lançon *et al.*, 2007). These methods apply well to complex systems, as the expert knowledge mobilized is often integrative, as shown in vineyards (Metral *et al.*, this congress) or in trees/arable crops systems (Castel *et al.*, 2013; Grandgirard *et al.*, 2014)

in France. However, the evaluation and iterative design improvement of the resulting prototypes is problematic, as it relies on long lasting experimentation with results only validated locally (Stamps and Linit, 1999). Some experiments have been set, both in tropical regions and in EU and the US, which design were usually decided following this method. Few of them have already produced the expected results (Haggar *et al.*, 2011). The timing of the iterative adjustment of prototypes is always problematic in these perennial systems.
A second approach is based on diagnosis of existing cropping systems. The objective is to identify and rank environment and cropping system variables related to performance variation, and then to identify leeways and stepwise improvements through participatory research (Doré *et al.,* 1997). Many experiences of complex cropping system design rely on related methods. However this method requires an important number of commercial fields, implemented since long time enough, which might result difficult particularly in case of poorly disseminated complex systems. This is particularly true in vineyards in Europe, where monocropping has been the rule, particularly with the advent of mechanization. It is still very common in tropical agroforestry, where research has followed, rather than preceded, these practices. Millions of hectares of coffee or cocoa plantation are managed as agroforestry systems, and the potential of these methods for innovation is great (Notaro *et al.*, this congress).
The third set of methods relies on simulations with numerical models, to evaluate or design new combinations of practices that better fulfill a limited number of objectives. This method allows the exploration of very numerous solutions to select those that satisfy best the criteria; it can be used with stakeholders (Martin *et al.*, 2013). Models simulating multiple species and perennial cropping system are relatively scarce. Moreover, these models have a narrow validity domain: for example, they rely on strong hypotheses on soil exploration by the roots of mixed species, which can be hardly transposed to new environmental conditions. When used in collaboration with farmers, these models have proved very useful to explore scenarios and trigger new, more precise questions and hypotheses from participants (Meylan *et al.*, 2014). The recent uptake in silvoarable temperate agroforestry systems (STAFS) (about 3000 ha planted each year in France since 2012) was stimulated by the publicity about some key features of STAFS that were NOT measured on the field, but produced by simulating STAFS with process-based numerical models (i.e. high Land Equivalent Ratio (Talbot 2011); deep nitrate capture (Adriannarisoa *et al.*, 2015); good light transmission (Molto and Dupraz, 2014); enhanced resilience to extreme weather event (Schuller *et al.*, 2015)). Waiting for field experiments to deliver the same outputs would have required decades. Nevertheless, there is a need to refine and validate the modelling tools that were used in order to avoid stakeholders to take wrong decisions for wrong reasons

3 Conclusions

We conclude that the existing methods are applicable to multispecies cropping systems with perennials. However, the particular features of these cropping systems highlight the drawbacks of each of them. Therefore, combining these approaches, where and when it is possible, should be preferred. Whatever the method, evaluation of the new systems requires new indicators development, to account for the multiple productions with very different timescales and serving varying objectives. Development of simple and effective sets of indicators adapted to these systems is a powerful tool to boost the design realm, for practitioners and researchers alike.

References

Andrianarisoa, K.S., Dufour, L., Bienaime, S., Zeller, B. and Dupraz, C., 2015. The introduction of hybrid walnut trees (Juglans nigra x regia cv. NG23) into cropland reduces soil mineral N content in autumn in southern France. Agroforestry Systems, accepted for publication.
Bedimo, J.A.M., Dufour, B.P., Cilas, C., Avelino, J., 2012. Effects of shade trees on Coffea Arabica pests and diseases. Cah Agr 21, 89-97.
Castel, L., Sieffert, A., Warlop, F., Tchamitchian, M., 2013. Participative co-design of innovative agricultural systems mixing fruit trees and annual crops. DINABIO congress, 10-12 November 2013, Tours, France.
Doré, T., Sébillotte, M., Meynard, J., 1997. A diagnostic method for assessing regional variations in crop yield. Agr Syst 54, 169-188.
Grandgirard, D., Oheix S., Lançon L., Liagre F., Dupraz C., Mézière D., Poulain J.L., Wartelle R., 2014. SCA0PEST, a pesticide-free agroforestry cropping system: ex-ante performance evaluation. In: EURAF (Editor),2nd European Agroforestry Conference. 4-6 June 2014, Cottbus, Germany.
Haggar, J., Barrios, M., Bolaños, M., Merlo, M., Moraga, P., Munguia, M., Ponce, A., Romero, S., Soto, G., Staver, C., Virginio, E., 2011. Coffee agroecosystem performance under full sun, shade, conventional and organic management regimes in Central America. Agrofor Syst 82, 285-301
Lançon, J., Wery, J., Rapidel, B., Angokaye, M., Gérardeaux, E., Gaborel, C., Ballo, D., Fadegnon, B., 2007. An improved methodology for integrated crop management systems. Agron Sustain Dev 27, 101-110.
Malézieux, E., Crozat, Y., Dupraz, C., Laurans, M., Makowski, D., Ozier-Lafontaine, H., Rapidel, B., de Tourdonnet, S., Valantin-Morison, M., 2009. Mixing plant species in cropping systems: concepts, tools and models. A review. Agron Sustain Dev 29, 43-62.
Martin, G., Martin-Clouaire, R., Duru, M., 2013. Farming system design to feed the changing world. A review. Agron Sustain Dev 33, 131-149
Metral R., Lafond D., Gary C., Mero A., Metay A., Wery J., 2012. “How to design and experiment new cropping systems with low pesticide inputs for perennial crops: framework development and application to vineyards”. ESA Congress 2012 (Helsinki)
Meylan, L., Sibelet, N., Gary, C., Rapidel, B., 2014. Combining a numerical model with farmer participation for the design of sustainable and practical agroforestry systems. IIIrd World Congress of Agroforestry. ICRAF, Delhi, India, 10-14 Feb 2014.
Molto, Q. and Dupraz, C., 2014. Is light competition between trees and crops a limiting factor for agroforestry systems at high latitudes? In: EURAF (Editor), 2nd European Agroforestry Conference. European Agroforestry Federation, Cottbus, Germany, pp. 257
Ripoche, A., Celette, F., Cinna, J.P., Gary, C., 2010. Design of intercrop management plans to fulfil production and environmental objectives in vineyards. Eur J Agron 32, 30-39
Schuller, A., Gosme, M., Talbot, G. and Dupraz, C., 2015. A model-based assessment of the adaptation of Mediterranean agroforestry systems to climate change (Poster). In: Cirad-Inra (Editor), Climate-Smart Agriculture, Montpellier
Stamps, W.T., Linit, M.J., 1999. The problem of experimental design in temperate agroforestry. Agroforestry Systems 44, 187-196.
Talbot, G., 2011. L'intégration spatiale et temporelle des compétitions pour l'eau et la lumière dans un système agroforestiers noyers-céréales permet-elle d'en comprendre la productivité?, Université de Montpellier 2, 281 pp.