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Review

How does research address the design of innovative agricultural production systems at the farm level? A review

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ABSTRACT

In trying to respond to societal demands for sustainable development, farming systems worldwide face a range of environmental, technical and economic challenges. These challenges call for renewed methodologies that can be used to support farmers in designing innovative agricultural production systems at the farm level. This paper aims to analyze the various methods described in scientific literature. The review is based on the analysis of 80 reference papers published in international scientific journals between 1999 and 2010. We focused in particular on the purpose of the research, which fell into two broad categories: "design" and "design support". We also examined the use of models to represent production systems and to evaluate *ex-ante* the impact of innovations on these systems' functioning and performance. In so doing, we developed a classification system to organize the studies into five sub-categories according to the type of methodology followed, namely: prototyping and design modelling for design orientated studies; participation, support modelling and advisory for design-support orientated studies. We found that very few studies attempt to address the three main components of an innovation process in agricultural production systems (biotechnical processes, farm management, and advisory services) within a single research framework. We therefore developed such a framework by connecting the design and design support orientations together with biotechnical research and conducting integrated research both at farm and advisory service levels.

Contents

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1. Introduction

Farming systems worldwide are facing a combination of challenges posed by irregular production levels, fluctuating input and output prices, and growing concerns over the impact of agricultural activities on the environment. Demographic trends and rising energy costs are likely to further complicate the situation in the future. The capital-intensive agricultural model widely diffused in western countries has revealed some limitations. In a number of developing countries, particularly in Africa, small-scale farmers have not adopted the model for various reasons, both internal (e.g. lack of cash or labor resource for instance) and external (e.g. lack of input supply, low market prices). The model's impact on the natural environment and human health also is coming under increasing debate. Lastly, the model's oil-based techniques, including mechanization, will become increasingly expensive as oil reserves are depleted.

Agricultural research is addressing these challenges by searching for more environmentally-friendly cropping and livestock systems that are based on renewable resources, natural processes, and biodiversity conservation while enabling a high level of productivity to be achieved in order to feed a growing world population (Conway, 1997; Doré et al., 2011; Keating et al., 2010). The research is intended to propose innovations that farmers would be able to implement. However, the innovations often involve critical elements of farm operations, and their implementation may lead to systemic change that results in the partial or total redesign of a production system (Bellon et al., 2007). For example the introduction of zero-tillage associated with permanent mulch, as is proposed in conservation agriculture, may affect animal feeding, manure management, use of animal traction, and labor management, particularly in smallholder crop-livestock farms (Altieri, 2002; Giller et al., 2009).

The implementation of systemic innovations ultimately has to be considered at the farm level. This is the level where farmers' decisions regarding the selection of activities, the allocation of resources between crop and livestock productions, and the management of production processes determine their farms' impact on both the quantity and quality of agricultural products available to consumers and on the natural environment. This implementation process is complex due to the interrelationships between the various elements of a production system, interactions between the different levels of decisions, the impact of stochastic events, and the diversity of farms and farmers in a given area. It is risky, time-consuming, and costly for farmers to individually test such innovations on their own through a trial and error process. An alternative is for trusted farm advisors to provide support by evaluating *ex-ante* the potential consequences of systemic innovation on the structure, functioning and performances of a farm.

This paper aims to investigate how agricultural research addresses the design of innovative production systems at the farm level. It is based on a review of various methods described in scientific literature, with a specific focus on the purpose of the research and the use of models. Given the wealth of material available on the subject, the objective was not to be exhaustive, but rather to define methodological guidelines for researchers involved in the process of supporting farmers in designing their production systems. As such, this work complements recent review papers on the role of decision support systems in agriculture (McCown, 2002), the assessment of innovations at the farm level using bioeconomic models (Janssen and van Ittersum, 2007), "virtual world" simulation methodology (Woodward et al., 2008), and planning models dedicated to agri-food supply chains (Ahumada and Villalobos, 2009). Section 2 describes the conceptual framework which guided the selection and the analysis of the articles reviewed. Section 3 describes how the various methods found were classified into five main categories. Based on these results an integrated research framework is then proposed to improve the efficiency of research to ultimately support farmers' design processes.

2. Conceptual background

An agricultural production system is defined as a combination of cropping/livestock systems at the farm level which use labor, land, equipment, knowledge and capital resources over time and space to produce goods, consumed by the household or marketed outside the farm, and ecosystem services (Boiffin et al., 2004). Its management includes a range of decisions taken on interconnected time scales: strategic (several years), tactical (seasonal), and operational (daily/weekly); and on different spatial scales, for example intra-field (pasture or irrigation units), field, area per crop, and farm (Le Gal et al., 2010a). Decisions are made by farmers based on objectives and various types of determining factors (environmental, technical, economic and cultural). This review focuses on the tactical/strategic decisions made at the farm level, which are affected by, and shape the design of, systemic innovations.

Design consists of an intentional process of change that involves: (i) existing knowledge, (ii) the use of possible modelling tools based on the generic properties of the object/system to be designed, (iii) new knowledge produced during the process, and (iv) a range of innovative proposals that are not defined *a priori* (Le Masson et al., 2006). When these proposals consist of new techniques, farmers may test them in practice; when they consist of new ways

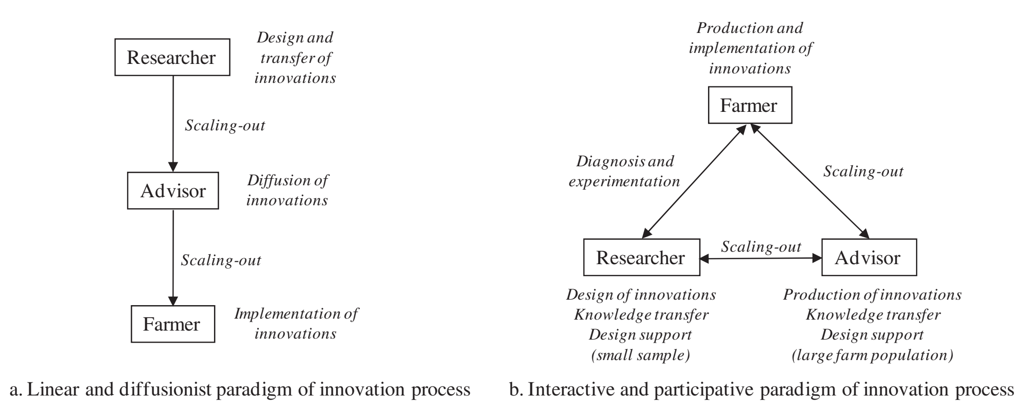

Fig. 1. Schematic representation of two innovation process paradigms including farmers, advisors and researchers. The concept of «innovation» includes both new technologies and new ways of organizing and managing production systems. In paradigm (b) researchers and advisors carry out similar tasks but at different scales, which requires an efficient scaling-out process.