Agricultural Systems 147 (2016) 87–97

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Co-design and assessment of cropping systems for developing crop-livestock integration at the territory level

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ARTICLE INFO

Article history:
Received 30 September 2015
Received in revised form 30 May 2016
Accepted 1 June 2016
Available online 7 June 2016

Keywords:
Crop-livestock integration
Participatory design
Water management
Landscape design

ABSTRACT

Agricultural systems face numerous sustainability challenges that require their ecological modernization. Strong changes in agricultural practices may require redesigning farming systems and involving local stakeholders in an agroecological transition. Development of Integrated Crop-Livestock Systems (ICLS) is a promising transition pathway. They can be developed at farm and territory levels by developing interactions between specialized farming systems. Designing ICLS at the territory level requires a systemic approach that considers social, technical and ecological issues from field and farm to territory levels. We present a participatory modeling approach for designing ICLS at the territory level in the Aveyron River basin (southwestern France), where arable farms experience significant sustainability issues due to intensive use of irrigation water and soil erosion, while livestock farms have significant feed self-sufficiency issues. We first quantified the amount of feed imported to livestock systems to determine the potential for local feed production. We designed alternative cropping systems with a group of arable farmers and technical advisors. The resulting options for change in land use and practices were simulated to assess the delivery of ecosystem services, socioeconomic performance and capacity to respond to water scarcity. The most promising option is the introduction of alfalfa into current cropping systems. This option reduces the use of inputs in cropping systems, in particular irrigation-water withdrawals, by up to 50% without decreasing socioeconomic performance. Ecosystem services, in particular soil fertility maintenance and biological regulation, could be enhanced. Technical practices can be modified with the support of local supply chains, but require further support from public policies.

1. Introduction

Agricultural systems face numerous sustainability challenges that require their ecological modernization, including major changes in technical practices and labor or supply-chain organization (Horlings and Marsden, 2011). Strong changes in agricultural practices may require redesigning farming systems (Hill, 1998) and involving local stakeholders in an agroecological transition (Duru et al., 2015; Caron et al., 2014).

The development of new interactions between crop and livestock enterprises can be a promising transition pathway. Integrated Crop-Livestock Systems (ICLS) have been studied in several contexts for their advantages for nutrient cycling (Russelle et al., 2007; Wilkins, 2008) and the provision of ecosystem services (ES) by enhancing agro-ecological processes (Dumont et al., 2013; Lemaire et al., 2014; Moraine et al., 2014a). Bell et al. (2011) show their benefits in productivity, soil fertility, and risk management regarding market and climate fluctuations. De Moraes et al. (2013) show that in Brazil, spatial crop-livestock integration among farms provides the opportunity for sustainable soil management through well-balanced crop-animal systems and the greatest profitability and stability of economic results for each farm. However, in intensive agricultural areas, such mixed farming systems have rapidly disappeared since the 1950s, mainly because of a decrease in the on-farm labor force and specialized supply chains and processing units (Peyraud et al., 2014). Resulting overspecialized farming systems led to landscape homogenization and often a decrease in soil fertility and an increase in crop pest proliferation, and pollution due to intensive chemical inputs and manure applications (Bell and Moore, 2012; Dumont et al., 2013; Russelle et al., 2007). Since the common belief is that livestock will not return to farms from which they disappeared (Lapierre, 2004; Wilkins, 2008), several authors analyze the potential of crop-livestock integration at local level through exchanges among specialized farms (Hendrickson et al., 2008; Lemaire, 2007; Wilkins, 2008). Here, the local level corresponds to the geographic area in which agricultural issues and natural resources are managed. It is the place where local stakeholders gather around common issues and where local decisions are made (Moraine et al., 2016; Duru et al., 2015; Nitschelm et al., 2015). Hereafter, it is called the 'territory-level'.

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http://dx.doi.org/10.1016/j.agsy.2016.06.002
0308-521X/

Accordingly, designing ICLS at the territory level requires accounting for interactions within and between the social system - socioeconomic structure and dynamics - and the ecological system - ecosystem structure and processes - i.e. designing new configurations of the entire social-ecological system (Moraine et al., 2016; Schouten et al., 2012).

Managing changes in such social-ecological systems requires combining innovative ideas in technical and organizational domains at farm, supply-chain and landscape levels. McGranahan (2014) suggests developing scenarios of change that consider stakeholders' real constraints to favor innovations in practice. Cash et al. (2003) highlight that producing useful scientific knowledge (e.g. when designing agricultural systems) requires ensuring that outcomes of participatory research be salient (i.e. questions are similar to stakeholders' issues of concern), credible (i.e. data, knowledge and references are scientifically valid and locally suitable), and legitimate (i.e. the diversity of ideas is represented and discussed by an appropriate panel of stakeholders). Jordan et al. (2011) identify Multi-Stakeholder Landscape Design for Communicative Learning as a solution to deal with barriers to methodological challenges of credibility, legitimacy and saliency. Etienne (2010) developed a participatory methodology called “companion modeling” to design collective-management solutions for natural resource management based on local and scientific knowledge. All of these approaches combine qualitative and quantitative analysis and assessment of investigated systems as well as integrate stakeholders' knowledge to design sustainable and achievable innovative systems (Pahl-Wostl and Hare, 2004).

This article explores the possibility of designing new cropping systems (CS), i.e. crop rotations and associated technical practices, to promote crop-livestock integration at the territory level. These CS have to be feasible from a technical point of view and consistent with sustainable soil and crop management. More specifically, our study aims to illustrate the potential of designing more sustainable CS, i.e. less dependent on inputs and enhancing diverse ecosystem services, by developing local supply chains linking crop and livestock systems within the same territory. The main objective is to elaborate on the potential interest in and impacts of developing crop-livestock interactions at the territory level and the required participatory methodology to design context-adapted options for change. The design method involves farmers and supply chain stakeholders from specialized crop and livestock areas in the Aveyron River basin (southwestern France). In an initial step, we design and implement a participatory diagnosis of current sustainability issues in agricultural systems. Then we estimate the potential demand of products by livestock farms and design alternative CS to meet these requirements. Finally, we estimate the potential area and production of these alternative CS and analyze their sustainability through multicriteria assessment including criteria on environmental impacts, ecosystem services, social and economic performances and local challenges. The results are discussed in terms of sustainability of the designed alternatives and strengths and limits of the method.

2. Materials and methods

2.1. Case study: the Aveyron River basin and the crop-livestock integration issue

The territory was first described in Moraine et al. (2014b) on the basis of a participatory diagnosis, with specific focus on sustainability issues in farming systems and opportunities to develop crop-livestock interactions. The Aveyron River, located in the South West of France, is 300 km long and runs from hills to lowland plains. Farming differs greatly between the upland Ségala sub-region (upstream) and the lowland “Plain of Montauban” sub-region (downstream) due to natural constraints. This case study presents an interesting gradient of livestock-to-crop specialized farming systems in a relatively small area. “Lowland” and “upland” farm communities are not strongly connected but occasional exchanges and collaboration exist, e.g. forage exchange when severe drought occurs. Main features of the study area, main production and sustainability issues are summarized in Table 1.

The Aveyron watershed experiences recurring and significant water shortages due to irrigation: water demand from agriculture is greater than its availability (Murgue et al., 2015). Across the watershed (1560 km^2), the annual water deficit is estimated at 7–12 million m^3, depending on the annual climate. As a consequence, irrigation is frequently restricted, which implies tensions and harsh negotiations between agricultural representatives and local government services in charge of aquatic ecosystem protection (Debril and Therond, 2012; Mazzega et al., 2014). Mean volumes withdrawn for irrigation each year reach approximately 18 hm^3, which represents 80% of the agricultural withdrawals of the entire Aveyron River basin.

Moraine et al. (2014b) demonstrated that local stakeholders have two main challenges:

(1) increasing self-sufficiency of upland livestock systems in both energy and protein needs and (2) diversifying lowland CS to ensure soil fertility and reduce qualitative and quantitative impacts on water resources. Both issues were analyzed, first by characterizing animal feed inputs regularly imported into the Ségala sub-region, then, based on these results, by designing cropping and farming systems that respond to livestock system requirements with a group of lowland crop farmers.

Table 1
Presentation of the case study sub-regions. UAA: Utilized Agricultural Area.

Sub-region	Uplands – Ségala sub-region	Lowlands – Plain of Montauban
Landscape and agricultural characteristics	Hills and plateau around 600 m above sea level; 130,400 ha UAA Permanent grasslands: 25% UAA Temporary grasslands: 50% UAA Cereal crops: 18% UAA Forage crops: 7% UAA	Plain with flat fields and deep soils 40,000 ha UAA, of which around 10,000 ha is irrigated
Main production	2455 farms: Beef cattle: 40% Dairy cattle: 30% Dairy sheep: 10% Meat sheep: 10% Others: dairy goats, pigs	On alluvial terraces and “boulbènes” (loamy hydromorphic soils): maize monoculture On hilly clayey-calcareous slopes: sunflower-wheat crop rotations Other production: Fruit trees and vegetables
Sustainability issues	High dependence on imported fodder and soybean Water pollution due to high animal density	Water deficit Water quality (nitrate and pesticide pollution) Soil erosion Soil fertility