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Trajectories of legumes insertion in farms: methodological framework for the analysis of long-term changes

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Summary

Despite their potential agronomic, economic and environmental benefits, legume crops are locked out of current agri-food systems in Europe. This paper provides a methodological framework to understand changes in legume cultivation in farms over long time periods. We formalise four distinct agronomic-coherence classes with regard to legumes in farms, based on the type of crop sequences and on quantitative indicators for the level of legumes insertion. We define farms' trajectories of change regarding legume crops as a succession of agronomic-coherence phases and transition periods. The framework is then used to formalise the trajectory of a mixed crop-livestock farm in Burgundy (France). Finally, we discuss the potential uses of this framework to understand the drivers and processes of change related to legumes on a larger sample of farms, and ultimately to promote and support legumes insertion in farms.

Key words: Legumes, farming systems, farm trajectories, farmer practices, crop diversification, transitions, change

Introduction

For the last three to six decades, the area cultivated with forage or grain legumes in Europe have been decreasing. More specifically, the area cultivated with grain legumes in the European Union, including soybean, pea and faba bean, decreased from 5.8 million hectares in 1961 to 1.8 million hectares in 2013: almost 70% of legume crop areas have disappeared in 50 years (Zander *et al.*, 2016). This situation is the result of multiple factors, among which the increasing structuration of supply-chains, accompanied by a simplification of cropping and farming systems and a specialisation of agricultural regions. The agri-food system as a whole is thus locked-in around major crops, while legume crops are marginalised (Magrini *et al.*, 2016). Yet, the potential benefits of increasing the part of legume crops in farming systems (Voisin *et al.*, 2014) seem more and more relevant in a context of increasing economic and climatic uncertainty impacting agricultural systems. From an environmental point of view, the symbiotic nitrogen fixation capacity of legumes represents

an alternative to synthesised nitrogen, thus reducing energy consumption and greenhouse gas emissions from its production and use. At the cropping system level, legumes can provide services to their following or associated crop, thus representing an agronomic and environmental asset for the farm (Preissel *et al.*, 2015). Finally, the carbohydrate and protein content of legumes gives them a good nutritional value for food and feed. The barriers and lock-ins at agri-food, territory and supply-chain level have been highlighted by various authors (Magrini *et al.*, 2016; Meynard *et al.*, 2013; Voisin *et al.*, 2014). However, these works did not study in detail the processes of modification of farming systems towards more legume cultivation. In this work, we aimed to provide a methodological framework for the dynamic, long-term analysis of the trajectories of change of farms who integrated legume crops in their cropping systems. This framework was constructed with a view to understanding the drivers of change and the levers that enable the farm's evolution over time. In this paper, we detail the contents of this methodological framework and provide an example of its application on a farm for the period 1990–2016.

Materials and Methods

General approach

In order to analyse the dynamics of change in legume crops insertion in farms over long time periods, we developed a method that draws on the concept of farm trajectories (Chantre *et al.*, 2015; Madelrieux *et al.*, 2002; Moulin *et al.*, 2008). Farms' trajectories, with regard to legume crops, are represented as a succession of “agronomic coherence phases” and transition periods. A coherence phase corresponds to a period in the history of the farm where the organisation, practices and decision rules for legume crops cultivation are stable. The transition periods that lead from one coherence phase to the next can extend over a variable period of time, and consist of more or less disruptive changes.

To build our analysis framework, we combined the conceptual background of farm trajectories with (i) available scientific literature on legumes (Jeuffroy *et al.*, 2015; Nemecek *et al.*, 2008; Schneider *et al.*, 2015; Voisin *et al.*, 2014) and (ii) the “Efficiency, Substitution, Redesign” (ESR) framework (Hill & MacRae, 1996). From this material, we classified crop sequences and levels of legumes insertion (step 1) in order to define a range of agronomic-coherence classes of farming systems with regard to legumes (step 2). We then tested this framework by representing the trajectory of a mixed crop-livestock farm in Burgundy from 1990–2016 (step 3). This procedure is summarised in Fig. 1 below.

Data acquisition

Study area and survey sample

Our study area consisted of two small French regions in western France (region of Chateaubriant) and eastern France (Langrois Plateau). In our work, we refer to them as zone P (as in “Pays de la Loire”) and zone B (as in “Burgundy”) respectively. These two regions are very different in terms of climate (resp. oceanic and continental) and soils (resp. silty and shallow soils), and thus in terms of yield variability.

The 27 sampled farms were a subset of 73 farms, with a view to representing the diversity of structures and productions, as well as legume practices, in the areas. The sample covered both organic and conventional farms, as well as arable and mixed farms. The main legume crops grown in these farms were alfalfa and pea (both regions), and lupin (zone P exclusively).

Interviews with farmers

Our interviews consisted of two series of in-depth semi-structured interviews. The objective of the first survey was to characterise each farming system of the sample in terms of (i) general structure, cropping systems, and technical management of legumes, and (ii) the broad history of legume

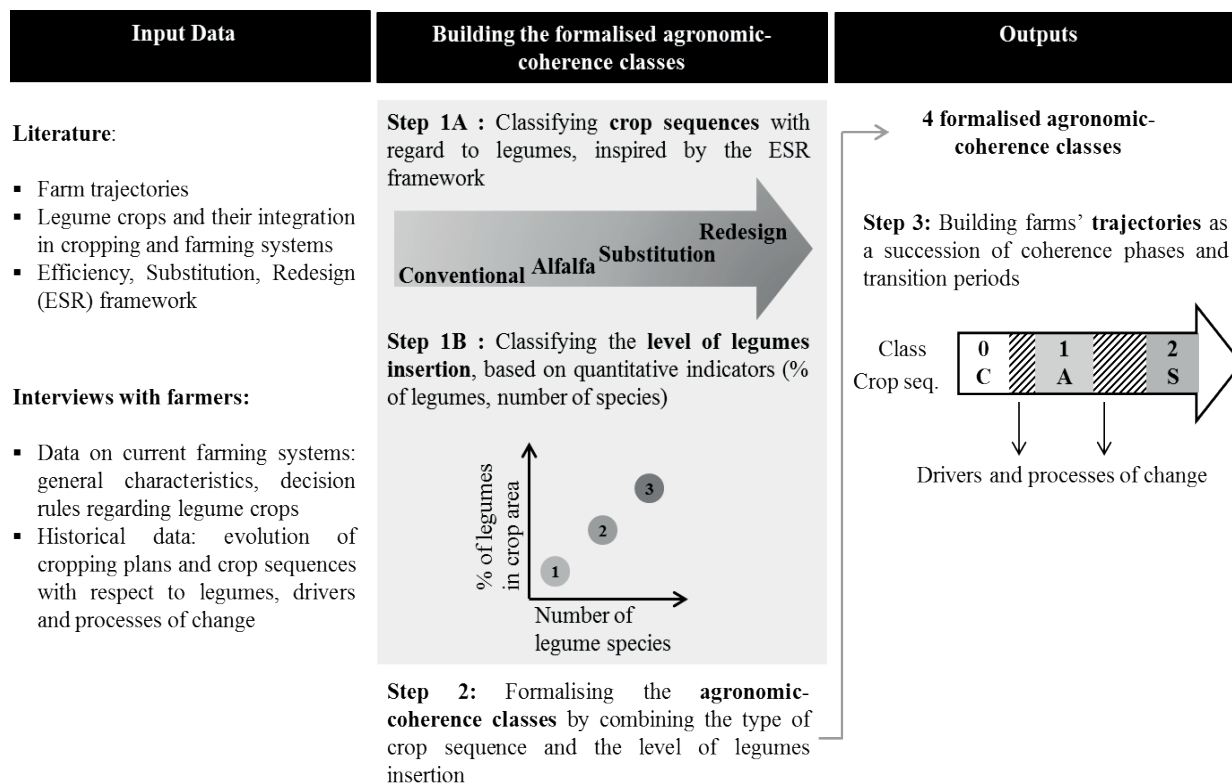


Fig. 1. General approach.

cultivation on the farm since 1990, in terms of crop sequences and practices. The data gathered from this first interview will be used to outline the trajectory of each farm with regard to legumes.

A second interview will be necessary to validate the trajectory and to focus on the transition periods identified. For each process of change linked to legumes, we will carry out an in-depth analysis of the drivers and the learning processes involved.

Formalisation of agronomic coherence classes

Types of crop sequences (step 1A)

We outlined four main types of crop sequences corresponding to an increasing amount of legumes.

1. The “Conventional” (C) crop sequence refers to the current prevailing crop sequence found in conventional farms of the local area. For example, crop sequences in zone P are based on an alternation between ensiling maize and wheat, while in zone B they revolve around the rapeseed-wheat-barley sequence. This type of crop sequence can sometimes integrate a very small amount of legumes if their valorisation is higher than those of the main crops (see *Level of legumes insertion* below).
2. The “Alfalfa” (A) crop sequence refers to sequence C, extended by a temporary alfalfa grassland (usually 2 to 5 years) across at least a portion of the plots. Sometimes, a grain legume can also be included in the sequence on a small area.
3. The “Substitution” (resp. S1 and S2) crop sequences refer to a crop sequence in which an annual grain legume systematically replaces a cereal compared, respectively, to crop sequences C or A.
4. Finally, the “Redesign” (R) crop sequence refers to an elongated crop sequence within which forage and grain legume crops are integrated among numerous crops. In these crop sequences, practices regarding soil tillage, weeds and pest control, and fertilisation are significantly different from those of prevailing conventional cropping systems. Moreover, legume crops are often intercropped with other crops. Typical “Redesign” crop sequences consist of an alfalfa or sainfoin grassland followed by 4–5 years of cereals (wheat, barley, triticale, oat...) and protein crops (zone B), or in a mixed grassland (including alfalfa) renewed by maize-wheat-protein crop sequences (zone P).

Level of legumes insertion (step 1B)

We used two quantitative indicators to further characterise the level of legume insertion in farming systems: the percentage of legumes in the cropped area (i.e. the Utilised Agricultural Area excluding permanent grassland areas), and the number of legumes species cultivated. From these indicators, we defined four levels of legumes insertion:

1. A level “0” where no legumes are cultivated.
2. A low level of insertion where legumes represent less than 10% of the crop area and no more than one species is grown.
3. An intermediate level of insertion where one or two legume species are grown on 10–20% of the crop area.
4. A high level of insertion where two to five species of legumes are grown on more than 20% (and up to 50%) of the crop area.

Agronomic-coherence classes (step 2)

We defined four agronomic-coherence classes by crossing the type of crop sequence and the level of legume insertion described above (steps 1A and 1B). These classes represent the diversity of legumes cultivation in farms from our sample, and provide a framework for analysing farm trajectories.

Table 1. *Description of the formalised agronomic-coherence classes*

Class	Legume insertion	Crop sequence
0	None	C
1	Low	C or A
2	Intermediate	A or S
3	High	S or R

Building a farm trajectory (step 3)

We traced the trajectory of change of one of the farms from our sample by identifying the successive coherence phases encountered by the farmers from 1990–2016. We identified the type of crop sequences and the level of legume insertion associated with each agronomic-coherence phase in order to attribute a class to each of them. For one coherence phase, there can be several crop sequences found simultaneously in the farming system.

To further describe these phases, we characterised for each the types of legumes grown on the farm (forage and/or grain legumes) and their main use (on-farm consumption and/or sale). Then, for each transition period leading from one coherence phase to the next, we identified the drivers that triggered the changes in practices and management of legumes. These drivers can be either external to the farm (new market opportunities, price context...) or internal to the farm (change in the farmers’ strategy, evolution of the farm’s resources...).

Results

Description of the farm

The farm we analysed is a mixed crop-livestock farm located on the Plateau Langrois, in the French Burgundy region. In 2016, the farm’s Utilised Agricultural Area (UAA) was 440 hectares, and the herd consisted of 140 suckling cows and 100 ewes. The farm was jointly-run by three associates, and both crop and livestock productions benefited from the organic certification.

The farmers grew both forage and grain legumes, through (i) temporary grasslands intercropping either alfalfa and orchard grass (100 ha) or sainfoin and fescue (20 ha), and (ii) protein pea intercropped with barley or triticale (17 ha in total). All legumes were used for on-farm consumption by the livestock (Fig. 2).

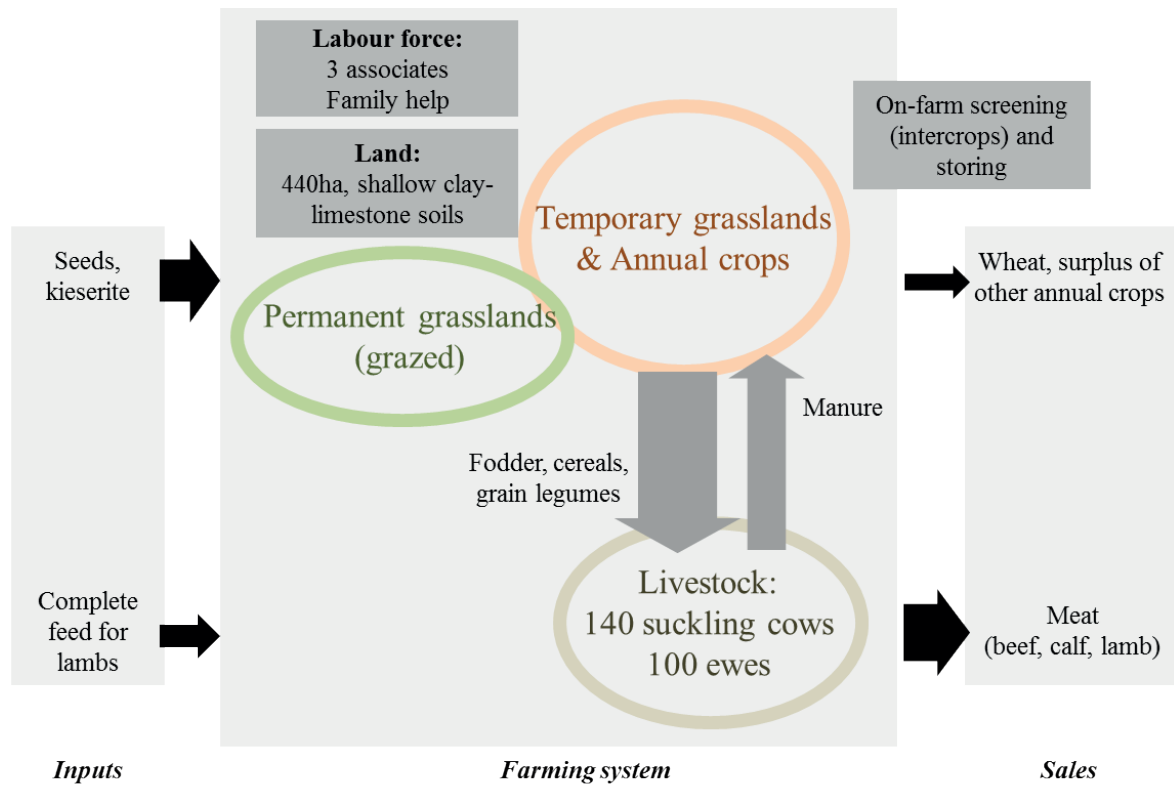


Fig. 2. Representation of the farming system in 2016.

Farm trajectory with regard to legumes

Representation of the trajectory

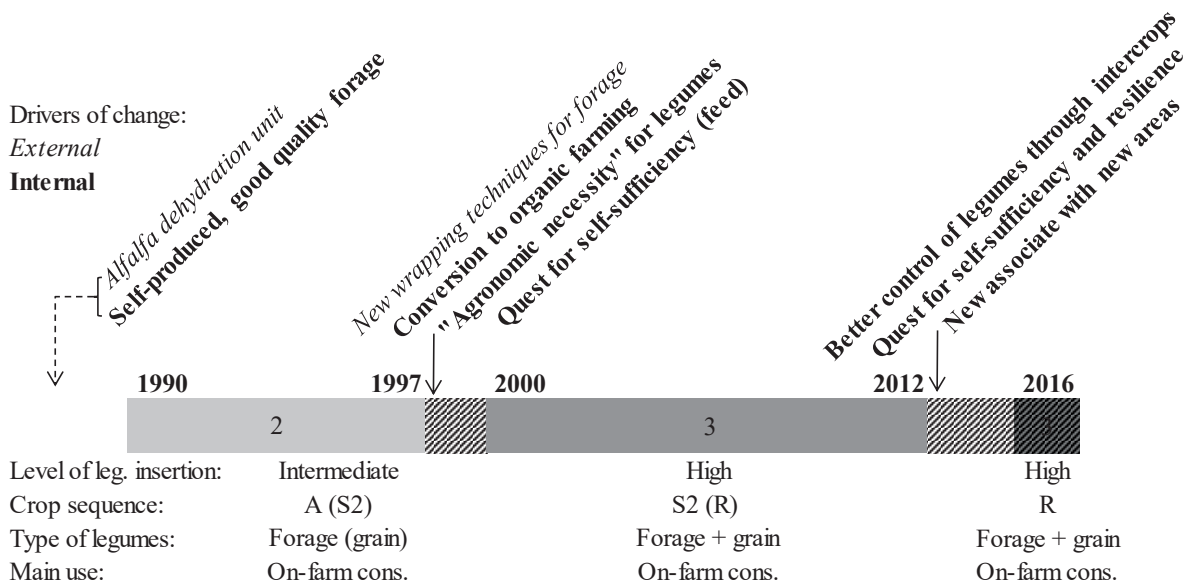


Fig. 3. Farm trajectory.

From 1990 to 1997: an initial system based on alfalfa

In 1990, alfalfa was the only legume grown on the farm and represented around 15% of the UAA. Farmers had started cultivating mixed temporary grasslands of alfalfa and orchard grass in the 80s as fodder for their livestock (cows, sheep and pigs at the time). The trigger for cultivating alfalfa was the creation of a dehydration unit in the area, enabling them to benefit from a good quality forage and easy harvest (the harvest was taken care of by the dehydration unit). The farmers tried cultivating sainfoin (as an alternative forage to alfalfa) and protein pea in the years 1992–1995 but gave up these crops because the yields were not satisfactory.

From 1998 to 2012: conversion to organic farming and quest for self-sufficiency in feed

In 1998, the farm started its conversion to organic agriculture. Meanwhile, the size of the herd was increasing. As a consequence, the farmers raised the area of alfalfa-orchard grass grasslands to 40 ha, that is, 33% of their UAA. At the same time, they stopped dehydrating alfalfa and instead began to harvest, wrap and store it themselves. This was made possible by the arrival of new wrapping techniques and material in the local area. They also started cultivating forage pea intercropped with triticale (4 ha), and faba bean as a sole crop (2 ha) to incorporate in the livestock's ration.

Around 2005, a new associate joined the farm. The total UAA and livestock size increased, triggering a growth of alfalfa areas. Faba beans were replaced by winter protein peas because fungal diseases had been observed on the crop. However, these changes did not modify the general coherence of the farming system.

From 2012 to 2016: conversion of new land, use of intercrops, and quest for longer crop sequences

From 2012, a third associate joined the farm, bringing with him new land. As a result, the farm UAA doubled from 220 ha to 440 ha. Meanwhile, the ovine and bovine herds had kept growing progressively in numbers. Thus, the alfalfa area doubled (100 ha), replacing rapeseed as a crop sequence starter, and ensilage maize as forage, in the new areas (previously under conventional farming).

The new associate also brought new ideas, and triggered changes in crop sequences and in the management of legumes. Sainfoin was cultivated again, this time intercropped with fescue instead of a sole crop. Since the crop was more successful than previously, the farmers increased the sainfoin area up to 20 ha. These temporary grasslands, combined with grazing on the permanent grasslands, ensured that the self-sufficiency of the livestock in forage was maintained.

The farmers also experimented with faba bean, lentil and protein pea on small surfaces. Lentil and faba bean were deemed unsuccessful, but the protein pea worked well when intercropped with barley. As a consequence, the farmers increased its area to 6 ha, then 14 ha, incorporating these new crops in the livestock's ration.

Both sainfoin and protein pea were a means for farmers to set up longer crop sequences, to grow more cereals between two grasslands and to have alfalfa return less often. More generally, the diversity of grain and legume crops ensures that they are not only self-sufficient for feeding their livestock, but also resilient: they adapt the livestock's ration each year depending on the crops' respective yields.

Discussion and Conclusion

From individual trajectories to a typology of pathways

Using our framework of agronomic-coherence classes, we were able to represent the evolution of legume crops in the crop sequences and the strategy of a French mixed crop-livestock farm. We observed that many small, continuous changes occurred in the farmers' practices, but the concept of farm trajectory and coherence phases was used to identify the more substantial changes, that questioned the farm's strategy regarding legumes.

In the future, this framework and methodology will be applied to a larger set of farms in two French regions (27 farms in the two zones presented). Based on the literature on transitions in farms (Lamine & Bellon, 2009; Petit & Aubry, 2014), we expect to obtain a diversity of individual trajectories if we take into account: the number of coherence phases farmers go through during their trajectory; how long these phases last; the extent of the changes involved in the passage from one coherence phase to the next.

The analysis of these farm trajectories should enable us to group together farms that went through comparable transitional pathways (Chantre *et al.*, 2015) with regard to legume crops.

Multiple drivers of change

In our example, the changes implemented in the cultivation and management of legume crops were related to various drivers. These drivers were mainly, at the farm level, the management of livestock, the consideration of the agronomic benefits of legumes, and the availability of land and labour resources. Outside of the farm, the drivers of change were mostly linked to the availability of material and services at the territorial level (dehydration unit, wrapping material for fodder).

We hypothesise that this is a specific situation: in particular, the fact that few drivers of change were external to the farm is probably linked to the nature of the farm. Indeed, the farm we studied is a mixed farm where the main source of income is the meat and where the cropping system is oriented toward feeding the herd. We expect drivers to be more varied across our sample. Literature suggests that the structuration of markets and supply chains and the regulatory context (Meynard *et al.*, 2017), as well as changes in the farmers' management choices (Darnhofer *et al.*, 2010; Mawois *et al.*, 2012; Navarrete & Le Bail, 2007), will be major drivers of change for legume cultivation.

Importance of taking into account the processes of change

We observed that some changes in legumes cultivation on the farm didn't last: faba bean, sainfoin and lentil crops, for example, were all experimented with at some time but abandoned (at least for a few years) because the farmers were not satisfied by the crops' performance. The difficulties encountered in weed, pest or harvest management led either to a substitution of the crop by an "equivalent" legume crop (faba bean replaced by protein pea) or to the suspension of the crop. Thus, triggering the change was not enough: the way in which the changes were executed, and the learning processes associated with a new crop or a new practice, were essential for the success of legumes insertion. This is consistent with the work of Cerf *et al.* (2010) who distinguish, in the process of change, the initiation phase (triggering the change), the experimentation phase, and the adoption (or discontinuance) of the change that is a result of the forms of experimentation carried out.

In our example, farmers almost always implemented a new crop or a new practice on a small area of their farm to judge if it was successful, and adjust it if necessary, before expanding the change to a larger area. Moreover, they called upon both advisory services (Chambre d'Agriculture and local cooperative) and their peers (colleagues, farmers' groups dedicated to organic farming or to mixed crop-livestock farms) to share experiences, to help them improve their farming system and to support them in the implementation of changes. We thus hypothesise, in line with the literature on learning processes (Chantre *et al.*, 2015; Chantre & Cardona, 2014), that farmers' behaviour, when they face problems in the management of new crops or new practices, is key for the success or failure of the changes they experiment; and that a combination of individual and group forms of experiences, such as was carried out by the farm in our example, leads to more success in the implementation of changes.

Research perspectives

To test these hypotheses, we will analyse the data from two series of interviews carried out with a sample of 27 farms in our two study areas: we wish to understand if certain drivers and processes of change are linked with certain pathways of change, and to identify the drivers and processes of change, or combination thereof, which permit the insertion or increase of legume crops in farms. This should inspire the way public policies, advisory and extension services support farms toward more legume insertion, and the redesign of their farming systems in general.

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