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Determining Factors and Trajectories Analysis to Support System Diversification: Mixed Orchard Animals and Mixed Orchard Vegetables Systems.

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Table of Contents

List of Tables and Figures

1. Introduction

The conventional agricultural production system requires the use of pesticides to ensure production in satisfactory quantity and quality, in line with market and consumers expectations. However, if the use of these products can bring benefits for agricultural production systems, it can also be the cause of negative effects on the human health and the environment and may incur costs to society. The implementation of European legislation towards a more "eco–friendly" agriculture as well as various national action plans may bring major changes to agricultural practices within the coming years (Lamine, 2011). In 2003, the CAP shifted from voluntary to mandatory integration of agri–environmental practices by introducing principles of cross–compliance. In parallel, since 2007 in France, a national and global effort to reduce use of chemical plant–protection inputs in French agriculture, named Ecophyto program, is implemented. Its main goal is to cut the nationwide use of pesticides by 50% in the space of ten years while at the same time maintaining agricultural production at a high level in both quality and quantity terms.

Despite the rise of these environmental issues and their recent translation into public policies, ecologization of agricultural practices is still difficult to implement at large scale due to "lock–in" effects in the socio–technical system. The socio–technical system can be defined as the whole stakeholders and organizations linked to the agricultural production, processing and distribution chain, plant variety breeding, research, technical consultancy, agricultural policies and civil society (Lamine et al., 2010). A "lock–in" effect can refer to a choice of technique production, of a product, a standard, or a paradigm, which become the reference in the whole socio–technical system. This choice has become such a standard that it seems difficult to change it, even if there are other alternatives that could be more effective, which limit the diffusion of innovations (Magrini and Triboulet, 2012). In the last decades, organic agriculture and Integrated Pest Management (IPM) have managed to spread among farmers, disregarding the socio–technical "lock–in" effect. Studying the adoption of more sustainable agricultural practices such organic agriculture or Integrated Pest Management might help in identifying the conditions for achieving a robust transition towards a more "eco–friendly" agriculture. Two kinds of studies have been made about adoption of organic agriculture and IPM: some based on the decisive factors and motivations behind the adoption and some others based on farmers' trajectories and their changes in conceptions and practices over time (Lamine, 2011).

The main motivations for organic agriculture conversion have been identified as: agronomic motivations such as soil quality, erosion limitation and products quality, ethical motivations, environmental motivations with the idea that organic agriculture can deal with pollution issues and economic motivations (Geniaux et al., 2010). On the other hand, decisive factors can be sorted in three categories: factors intrinsic at the producer such as the age, the education level or the agronomic experience, factors intrinsic at the farm such as the farm structure and its economic results and external factors such as market regulations or localization of the farm (Geniaux et al., 2010, Latruffe et al., 2013).

To describe the processes of transition and characterize the changes in the agricultural practices, a framework designed by Hill and Mac Rae (1995): the Efficiency–Substitution–Redesign framework has been regularly used by researchers. Its initial aim was to analyze the whole process of transition from conventional to sustainable agriculture (Hill and MacRae, 1995, Hill et al., 1999, Estevez et al., 2000). The Efficiency step consists on the use of decision support tools (detection kit diseases, epidemiological models, visual thresholds of treatment) and a curative use of pesticides instead of preventive ones (Lamine et al., 2009, Estevez et al., 2000, Sautereau et al., 2011). The Substitution step consists of replacing harmful chemical inputs by biopesticides or biological control practices (Estevez et al., 2000). However, these two strategies of pesticides use limitation do not fundamentally undermine the functioning of the cropping systems neither its design (Naverrete et al., 2011). Then, the Redesign step of Hill and Mac Rae's framework which involve a paradigm shift: recognize the causes of system unsustainability and prevent it by the transformation of system functions and structure to a more holistic way through the construction of diversified production systems instead of fighting these problems by the application of external inputs. Thus, diversity will promote interactions between components of the 'agro–eco–system', enhance natural regulation processes, and should therefore help sustaining fertility, productivity and resilience (Hill and MacRae, 1995, Penvern et al., 2012, Lamine, 2011).

Two main kinds of trajectories of organic agriculture conversion have been underlined: on one hand, a "direct" conversion where farmers decided to convert quite suddenly following a health–related incident or economic difficulties for example. On the other hand, a more progressive conversion where first tries of sustainable agricultural practices occurred long before the actual conversion to organic farming (Lamine et al., 2009, Lamine, 2011). By putting in parallel these types of trajectories with the "input substitution" and "system redesign" paradigms, Lamine stated that farmers with more direct trajectories had current practices which can be characterized as a substitution of conventional inputs by biological ones. This "substitution" step still enables reversibility to the transition. In the case of progressive trajectories, it was possible to highlight the three main steps of Hill and Mac Rae's framework (1995) and the implementation of a system redesign paradigm usually leads to more robust transition (Lamine et al., 2009, Lamine, 2011).

The analysis of farmers' trajectories in a context of shifting to a more sustainable practice underlined three phases in this shift: awareness raising, experimentation and adoption (Cerf et al., 2010). Awareness rising, or in other words, knowledge available for producers and their ability to "digest" it, is consequently an essential step in the shift to a more sustainable practice. In the field of agricultural knowledge and adoption of technical innovation by farmers, the paradigm during the last decades has been a downward transfer of knowledge from research to the farmers. This paradigm have also been called "top–down" approach (WorldBank, 2006, Chantre, 2011).

However, farmers do not rely exclusively on the results of agricultural research; they also use a much wider knowledge, based on their own experiences and on exchanges with other farmers and advisers (Doré et al., 2011, Petit et al., 2012). This leads to a new paradigm, also called "bottom–up" process, in which agricultural knowledge is a product of empirical knowledge from farmers or a product of a co–development process associating tightly researchers and farmers (Chantre, 2011). This "bottom–up" paradigm is not aiming at replacing the "top–down" paradigm: it can even help to enlarge current agronomic knowledge. Indeed, even in the absence of appropriate knowledge produced by research, farmers still managed to innovate to meet their needs in terms of productivity or environmental sensitivity. The experience–based knowledge they develop may therefore fill in some of the gaps in the research–produced agricultural knowledge (Doré et al., 2011). Technical advisors have to adapt to this new paradigm in which scientific knowledge is missing and in which farmers may be more qualified to provide knowledge (Cerf et al., 2010).

In French orchards, conventional system is mainly relying on monoculture and large amount of pesticides. Although representing a small percentage of the French utilized agricultural land (approximately 1%), orchards were estimated to use 21% of the total amount of pesticides sold in France and with treatment frequencies 10 times higher than in cereals systems (Sautereau et al., 2011). This massive use of pesticides in French orchards is partly due to the facts that fruit trees are perennial crops which create difficulties for breaking pests' life cycle with crop rotation systems. Moreover, retailers and consumers ask for cheap fruits without any imperfections which limit the pest level tolerance of producers (Sautereau et al., 2011, Lamine and Bellon, 2010). The use of these plant–protection products can bring benefits for agricultural production systems but it can also be the cause of negative effects on the human health and the environment and may incur costs to society. This high dependency on plant–protection products in orchards highlights a need for transition of orchard system towards less pesticides and more sustainability. Since 2008, the INRA (French National Institute for Agronomic Research) research unit "Ecodéveloppement" is animating a producers, technicians, advisors and researchers' network called "Sustainable Orchards". Its aim is to share knowledge, suggest and develop innovative practices or systems design for the shift of orchards towards more sustainability. After numerous field visits, technical and scientific background information and experience sharing, four prototypes of sustainable orchards have been defined including mixed orchard vegetables and mixed orchard animals systems. As Integrated Pest Management and organic farming in the last decades, mixed orchard systems may nowadays represent an interesting way of transition towards more sustainability. Crop diversification, at the plot or territory scale, represent a key factor in order to increase sustainability of agricultural production systems by promoting the reduction of inputs (water, pesticides, nitrogen fertilizer), the increased heterogeneity of habitat mosaics or the reduction of yield losses due to frequent returns of the same species (Meynard et al., 2015).

Mixed tree and crop systems are mainly deliberately designed to optimize the use of spatial, temporal and physical resources, by minimizing negative interactions such as competition while maximizing positive interactions between the components of the system (Jose et al., 2004). These positive interactions could take place either above ground or below ground. First, the presence of trees modify light interception by creating shade but also microclimate for the associated crop in terms of temperature, humidity and wind

(Smith et al., 2013, Jose et al., 2004). Second, orchard–vegetables combination is a potentially useful practice to reduce pest problems because this association may provide greater niche diversity and complexity than monocropping (Stamps and Linit, 1997). The increased of orchard plant diversity may affect insect communities living within the orchard, including orchard pests, disease vector arthropods but also pollinators, predatory and parasitoid arthropods, through an increase in the resource range, i.e. habitat, shelter and food. Focusing on belowground interactions, different soil strata occupation with trees and annual crops root systems may lead to higher efficiency in the use of soil resources such as water and nutrients (Schroth, 1998). Associated plant species in mixed tree–crop systems, with variations according to the tree species, develop vertically stratified root systems, leading to reduction in evapotranspiration under the trees increasing air and soil humidity for the associated crop, access to water and nutrients at depth and creation of a 'safety net' in which the tree roots absorb nutrients which have not been taken up by the shallower–rooted crops and have therefore been leached out of the topsoil (Schroth, 1998, Cannell et al., 1996, Jose et al., 2004). Thus by promoting a closed system with internal recycling of nutrients, nutrients are accessed from lower soil strata by tree roots and returned to the soil through leaf fall and dead roots, mixed tree–crop systems enhance soil organic matter levels, soil physical properties and reduce reliance on external inputs.

As in mixed orchard vegetables systems, mixed orchard–animals systems aim to optimize the use of spatial, temporal and physical resources, by minimizing negative interactions such as competition while maximizing positive interactions between the components of the system (Jose et al., 2004). These interactions can be classified into two categories: effects of the vegetal component (and its associated components such as soil, microclimate and biodiversity) on the animals and effects of the animals on the vegetal component. First, modification of the landscape and of the microclimate by trees provides many benefits for livestock such as providing shade and higher humidity levels for sensitive animals to heat stress, providing protection from the wind for the weakest animals and providing protection from aerial predators for poultry and consequently increase animals welfare (Pedersen et al., 2004, Smith et al., 2013). Reciprocally, grazing or ranging of animals under fruit trees can create positive interactions for the trees such as deposition of feces and urine which may be useful to plant development and to maintain soil fertility or reduction in pesticides and herbicides inputs (Sanderson et al., 2013, Bonaudo et al., 2014). In addition to their ability to control weed development in orchards, it has been shown that chickens and geese were able to reduce harvestmen (*Opiliones)*, polydrusus, apple saw fly (*Hoplocampa*) and pear midge (*Contarinia pyrivora*) population when put under fruits trees (Clark and Gage, 1997, Pedersen et al., 2004, Hilaire et al., 2001, Lavigne et al., 2012). Moreover, ingestion by poultry, sheep or pigs of leaves and damaged or over–ripe fruits left on the floor at the harvest may represent an efficient prophylactic measure against inoculums such as apple scab and that livestock trampling may destroyed vole tunnels (Häseli et al., 2000, Hilaire et al., 2001, Geddes and Kohl, 2009).

Beyond these agronomic and ecological benefits, a mixed orchard system has to be economically profitable to be adopted by producers. In other words, whether the primary objective of diversification is the land valorization, risk mitigation, response to short commercialization circuit demand by consumers, will of decreasing chemical inputs or increasing biodiversity (Dupraz, 1994, Malézieux et al., 2009, Cadillon et al., 2011) the productivity, market opportunities and ecosystem services must be higher than the constraints to attract producers towards a mixed orchards system. These constraints may be requirement for both orchards and vegetables or animals production knowledge, mechanization constraints, delay in fruit production start compare to conventional orchards, management of two harvest in the same plot, physical protection of young trees, adaptation of grazing and treatments etc.

The overall objective of this Master thesis is to give an overview of mixed orchard system producers' profiles, system design and trajectories to provide to producers and to future project holders, suitable references and support. In other words, what key elements or concepts may be extracted from previous experience of producers in mixed orchard system to provide them and to future project holders, a suitable support?
Following semi-structured interviews with technical advisors and producers, this Master thesis will first characterize the producers who implemented mixed orchard systems to identify which structural factors may have the most powerful influence on producers' implementation choices. Secondly, this Master thesis will identify producers' initial motivations, incentives and/or obstacles encountered during their pathways as well as system designs and agricultural practices implemented by the producers. While motivations and practices will be analyzed through the ESR framework in order to question the robustness of the diversification, this Master thesis will also highlight diversification trajectories of producers. Indeed, it can be assumed that combination of these elements may influence somehow or other the producer's trajectories. Finally, this Master thesis will reflect on the key elements which may be extracted from the previous results and on the knowledge production and support perspectives.

2. Methodology

2.1. Literature Analysis

As the amount of reference about mixed orchard systems seems low when writing the primary literature review[1], an analysis of the available scientific literature has been realized. The website Web of Knowledge was chosen because it gathers different scientific literature databases such as Web of Science, CAB or SciELO.

To evaluate the amount and the relevance of the scientific literature available for technical advisors and producers about mixed orchard systems, a succession of requests composed of key words and Boolean operators have been realized on Web of Knowledge database[2].

A literature analysis is an iterative process that follows the following step:

- Identification of key words from the research topic and the problematic associated,
- Creation of a request with the key words previously identified, specific punctuation and Booleans operators. As an example, “” requires terms in the exact order you type them, * replaces a string of characters, OR requires at least one of the terms joined by it to appear somewhere in the document and NEAR requires the term following it to occur within a certain proximity of the preceding word in the search.
- Reading of the results and selection of the relevant references.
- Refining of the request by addition of key words synonyms, addition of key words identified during the first reading of results or deletion of key words if they create too much “noise” or are “silent”. A key word that creates “noise” is a key word that leads to the identification of too many non-relevant references while a “silent” key word does not bring any results.
- Comparison of the new results with the previous ones to determine if the request’s modifications were useful.

Like all iterative process, this sequence can be repeated as many times as needed to obtain the desire result. The end of this process is consequently subjective and related to the objectives and time of each user. In this Master thesis, literature analysis was stopped when the number of references identified by the database stabilized itself and that the addition of new key words did not change this number.

Concerning mixed orchard animals systems, the first request *TS=((orchard* OR "fruit production" OR arboriculture) AND (animal OR chicken* OR poultry OR geese OR pig? OR sheep* OR "silvopastoral system*" OR grazing OR agroforest*))* gave 23710 results. This high number included many un–relevant references and has to be reduced. In the next requests, the terms “orchard meadows” or “horti–pastoral”, “organic fruit production” have been added trying to define at best the system. At the opposite, the term “agroforest*” and “sylvopastoral system” have been deleted from the requests because they were related to references about wood trees. The next step to reduce the amount of un–relevant results was to define more

[1] Cf. Appendix 1
[2] Cf. Appendix 2

precisely the kind of animals to take into account. As a matter of fact, in adding “farm and meat animals”, all the scientific articles talking about insects or birds for example have been removed: *TS=((orchard? OR "orchard meadow?" OR "fruit production" OR arboriculture) AND ("farm animal?" OR "meat animal?" OR "grazing animal?" OR chicken* OR poultry OR geese OR pig? OR sheep? OR grazing)).*

With 598 results remaining, the second issue was the high numbers of papers which referred to animals–trees interaction that did not specifically happened when the animals are physically present on the field such as the import of manure or poultry litter. To resolve this, these two words were excluded from the next request *TS= ((orchard? OR "orchard meadow?" OR "organic fruit production" OR arboriculture OR "fruit tree?") AND ("farm animal?" OR "meat animal?" OR "grazing animal?" OR broiler? OR chicken? OR poultry OR pig? OR sheep? OR "small ruminant*" OR grazing OR hortipastoral* OR "horti–pastoral*")) NOT TS= (manure OR "poultry litter").* Finally, the Boolean operator AND between the two parts of the request have been replaced by NEAR. This operator allows to select references that present both terms besides the NEAR in the same sentence or word juxtaposition. As a result, the amount of references was approximately divided by 10. Even with few results (57), a careful and individual analyze of each reference identified allow to keep only 21 were relevant references. The backlash of Boolean operator NEAR is references where the key words appeared through an enumeration, without especially being related to each other’s.

In the case of mixed orchard vegetables, a first request associated terms about orchard and fruit trees with terms about vegetables production *TS=((orchard? OR "fruit tree?") AND (vegetable* OR "market garden*")).* As a result, 1916 references were identified by the database, taking into account crop association in the same plot as well as presence of both productions at the farm scale. To only keep the first aspect, some localization related prepositions were added to the request such as “inter”, “under” or “between”. The number of amount sharply decreased to 49 but went back to 559 when the fruits and vegetables species were detailed. In the same time, the term “peach potato aphid” was excluded to avoid un–relevant references. Finally, the number of references stabilized at 43 when the localization related prepositions were replaced by terms such as “intercrop”, “multilayer crop” or ”multi–species system” *TS=((orchard? OR "fruit tree?" OR "fruit grow*" OR arboriculture OR apple* OR pear OR peach OR apricot OR plum) NEAR/5 (vegetable* OR "market garden*" OR lettuce? OR tomato* OR carrot* OR cabbage OR bean* OR pepper* OR zucchini OR eggplant OR onion* OR potato* OR radish OR melon OR squash) NEAR/5 ("intercrop*" OR interrow* OR "associated crop" OR "crop association" OR "mixed crop*" OR "multilayer crop*" OR "alley crop*" OR "row crop*" OR "combined crop*" OR permacultu* OR milpa OR "food forest*" OR "plant mixture" OR "crop mixture" OR "multispecies system*" OR "species mixture")) NOT TS=("peach potato aphid*" OR opuntia).* As for mixed orchard animals system, the youth of this system leads to a profusion of terms to describe it, which complicate the process of literature analysis.

2.2. Data Collection Process

As the literature analysis emphasized a lack of published references about mixed orchard systems, the logical follow-up is to collect information from the involved people themselves: technical advisors and producers.

The first phase of interviews occurred with technical advisors involved in the development and the support of these diversified systems. They were selected thanks to the literature analysis, by reading grey literature or by “word of mouth”. These technical advisors mainly acted as key informants to collect information about what exists in terms of knowledge and support for the producers and which non already identified producer can be interesting to interview.

The second phase occurred with producers already implementing in their farms these mixed orchard systems or producers willing to develop these kinds of systems in a short period of time. During the interviews, information about limiting and facilitating conditions encountered during the redesign process and about the diversity of redesign pathways and system model has been collected.

To identify these producers, a snowball sampling method or also called respondent driven sampling (RDS) method has been used. It consists in using key informant and/or documents to locate participants who in the course of their interviews may identify other persons to interview (Bernard, 2011).

Then the sample of producers has been ordered according to different criteria:

- having approximately the same amount of producers in both mixed systems,
- having approximately the same amount of producers already implementing these systems and willing to implement one in a few years,
- and having a diversity of producers’ profiles.

The localization of these producers has also been taken into account, the time available for interviews realization being limited.

As a result, the interviewed producers sample was composed of 20 producers. Among them, 9 were involved in a mixed orchard vegetables system: 1 had the project to implement such a system, 7 had already done it and 1 had stopped. Similarly, 14 producers were involved in a mixed orchard animals system: 12 producers having already implemented this system and 2 were willing to. It has to be noted that 3 producers had both a mixed orchard vegetables and a mixed orchard animal system in their farm.

Interviewed producers were localized in three different geographic areas among the French territory: half of the producers in the South–East region, 4 of them in the area of Toulouse (South West region) and the last 6 producers in the West region of France. These regions match with the ranking of the fruit production region in France. Indeed, South–East with Rhône–Alpes and PACA regions hold the first and third position in terms of orchard area with respectively 26 000 and 21 500 hectares of orchards. South–West are including Aquitaine, Midi Pyrenées and Languedoc Roussillon regions which respectively hold the second, fourth and fifth position in the ranking. Finally, West area includes Pays de la Loire region which is at the sixth position with 6000 hectare of orchards (AGRESTE 2014a).

Setup dates of interviewed producers were, as planned, very diverse: values were ranging from 1983 to 2013. Specifically, interviewed producers were mainly producers either set up since more than 15 years ago (50% of the interviewees) or producers in their first years of production (30% of the producers). Following the same planned diversity, interviewed producers' UAA were ranging from 1 to 40 hectares with, on one hand, 35% of the interviewees (7/20) with less than 5ha and on the other hand, the same ratio of producers with 15ha or more. Then, interviewed producers were not distinguishable in terms of land structure and production standards. Only one producer on 20 interviewees had an agricultural land fragmented while more than 80% of them (17/20) had the organic farming certification.

The data collection process has been realized between March and the end of May with semi–structured interviews. With this method, the interviewer uses an 'interview guide'[3] which contains the main questions and topics that need to be covered during the conversation. The interviewer follows the guide, but is able to follow other trajectories in the conversation that may stray from the guide when he or she feels this is appropriate (Bernard, 2011). The producers' interview guide used in this Master thesis includes 5 main topics: farm description, explanation of the motivations to implement a mixed orchard system, description of the agricultural practices implemented following the diversification, global assessment and future perspectives. A time during the interviews was also dedicated to the drawing of a historical timeline resuming the key events and practices modification which happened on the farm.
This method of semi-structured interviews has been chosen because it enables the interviewer to have similar qualitative data. Moreover, thanks to the interview guide and unlike in structured interviews, it allows to tackle complex questions and issues.

A seminary was organized during the last month of the Master thesis with the participation of researchers, technicians, advisors, representative of the Agricultural Chamber and producers. The number of participants in each category was planned to be balanced but the number of producers was lower than expected, mainly because of harvest work. The goal of this seminary was to present the results of my Master thesis and to generate a discussion, a debate between all the stakeholders about how to support producers in mixed orchard systems.

2.3. Data Analysis

Interviews of both technical advisors and producers have been transcribed and analyzed through the Content Analysis methodology. The key step of this methodology is to choose what unit of analysis has to be taken into account. Several elements can be counted in Content Analysis such as words, themes, characters, etc.(Berg and Lune, 2014).

[3] Cf. Appendix 3

In this Master Thesis, the ideas and concept expressed by interviewees are essential to realize a qualitative analysis of their discourse: themes have consequently been chosen as the unit of analysis. Identification of potential analytic categories or themes has been made through a combination of inductive and deductive way. In other words, categories emerged directly from the interviewees' speech and were not pre–conceived nevertheless as the interviews were realized with an "interview guide", the categories mainly follow the structure of this guide.

These categories had to respect several key rules (Berelson, 1952):

- Homogeneity: A category has to merge similar ideas, concepts.
- Exhaustiveness: Each idea, relevant to the research question, quoted by an interviewee has to be categorized.
- Exclusivity: An idea, concept cannot be present in two different categories.
- Objectivity
- Relevance

The results of technical advisors' thematic analysis were presented through a vertical analysis highlighting which themes were quoted by an interviewee and a horizontal analysis highlighting which interviewee quoted a specific theme.

For producers' interviews, vertical analysis were also made in addition to the historical timeline drawings .These drawings were used as a basis to identify producers' trajectories and to determine what to place on the y-axis of these trajectories.

Then to combine qualitative and quantitative analysis, some of the identified categories were translated into variables and modalities and compiled into a database[4]. Some variables were deleted during this process of database creation because they were relevant for too few interviewees or because they did not bring useful information to the statistical analysis.

Different kinds of variables were differentiated according to the content analysis categories:

- Variables describing the farm and the producer: setup date, initial production before diversification, distribution circuits, certification, UAA, land structure, presence of a technical advisor and agricultural background.
- Variables describing the diversification process and project: date of diversification, system chosen, motivations, source of knowledge, length of the diversity during the season, proportion of land diversified, diversification ownership and practices adaptation.

From this database, a statistical multivariate analysis was implemented with the software R and the package FactomineR. First step was to analyze the database with descriptive statistical analysis such as mean, median or production of histograms. Then, Multiple Correspondence Analysis (MCA) and Hierarchical Clustering have been implemented on the different sets of variables. They are data analysis techniques for

[4] Cf. Appendix 4

nominal categorical data, used to detect and represent underlying structures in a data set. A Multiple Correspondence Analysis is to qualitative variables what Principal Component Analysis is to quantitative variables. It allows obtaining plots where it is possible to visually observe the distances between the categories of the qualitative variables. Indeed, the categories that have influenced the most the calculation of the axes are those that have the higher contributions and are located at the axis end on the plots. The Hierarchical Clustering is a classification method that aims to obtain, from the factors resulting from the ACM, the most coherent and homogeneous possible classes of individuals. The commonly used measure for judging the quality of a classification is the ratio of the interclass inertia on the total inertia of the cloud of individuals: the higher it is, the more the individuals gathered form homogeneous groups clearly differentiated from each other. Each individual can only be classified in one class at a time. The hierarchical tree or dendrogram resulting from the Hierarchical Clustering method helps us visualize the classification obtained.

To use these data analysis techniques, quantitative variables such as UAA or the date of setup were transposed in quantitative variables by creating classes. Thirdly, chisquare tests were realized on the clusters previously identified to highlight correlation between them.

Finally, a conceptual diagram was drawn to visualize which factors take into account in the data analysis and to presuppose the interactions between these factors (Figure 1). This diagram was also useful in the process of writing and structuring this Master thesis. As a result, the structure of the thesis follows this diagram with respectively sections about producer's profiles, motivations and external factors, system design and practices, self-evaluation and finally producers' trajectories which is a combination of these previous sections.

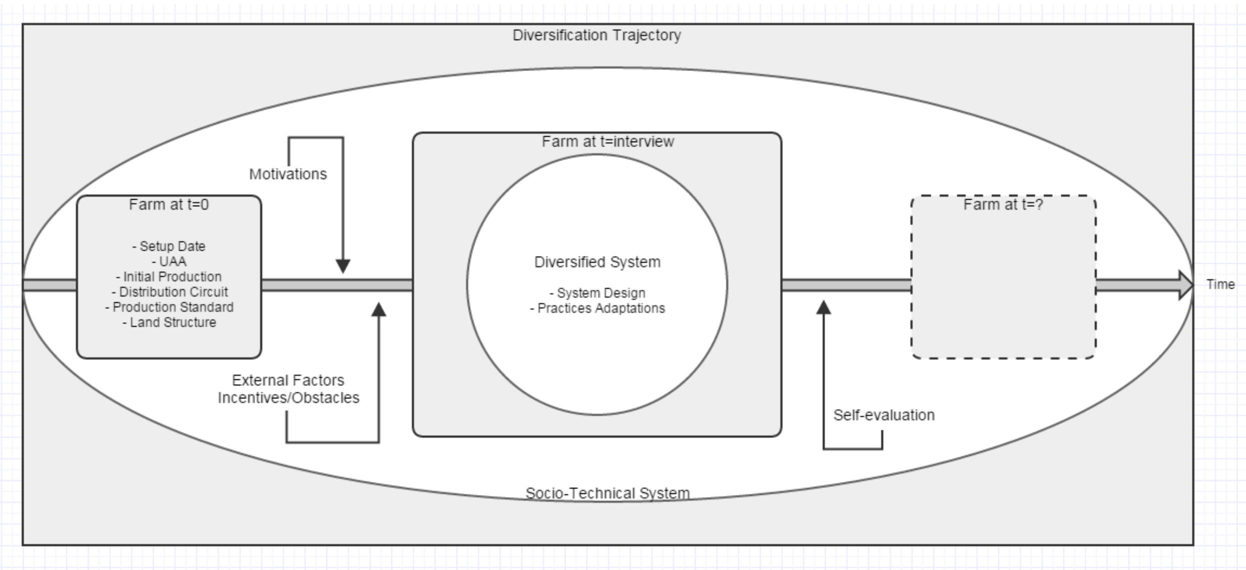

Figure 1: Conceptual Diagram

3. Results

3.1. A lack of suitable references for both producers and technical advisors

Mixed orchard systems implementations are currently driven by a growing interest from producers. These quotes from two different technical advisors underlined this phenomenon: "*Consistently there are many people interested by these things among the trainees.*" and "*I realize that there are more and more farmers interested by these systems*". To deal with producers' interest and to provide them suitable support, theoretical and practical knowledge is needed and this has been identified by the technical advisors as the main limit for now: 7 advisors interviewed on 8 identified a crucial lack of references about mixed orchard systems for both advisors and producers. Two technical advisors summarized this issue: "*A limiting condition is that someone who wants to implement a mixed orchard, he has to know that he will be alone. After some days of training session, he will know as much as the most advanced technicians on this subject*." "*To really promote the practice we need to be sure that there is a positive effect. And to recommend this practice we need to know which poultry, sheep or pig density is needed, at which stage of growth to really have a positive effect on such disease for example. If we had accurate knowledge on which animal, which density, which effect on which disease or pest … In this case we will be able to answer to producers' requests*."

The literature analysis confirmed technical advisors' statements by highlighting difficulties to find relevant information and/or references about mixed orchard systems within the scientific literature. Difficulties encountered in the process of analyzing the reference available on mixed orchard systems may be explained by two factors: First, the abundance of key words with multiple meaning. As an example, orchard may define commercial system, subsistence system or even a species of grass while swine may define the animal species or manure. Second, the difficulty to define with an exact expression or term these mixed orchard systems. Indeed, there is usually a time gap between the emergence of a new agricultural system and the stabilization of the key words used in the scientific literature to define it.

Another issue that arises in mixed orchard vegetables system is the existence of similar traditional system in tropical countries, which are unlike the temperate systems, well documented. When adding to the request tropical fruits and vegetables species such as banana, guava or maize, 231 references were found, approximately 200 more than before. However, even if these references are relevant, these traditional tropical systems may not be transposable because of temperate climatic conditions and also because of the shift from subsistence to industrialized agriculture. This phenomenon appears also in the case of mixed orchard animals systems: among the 21 relevant references identified, a large part focused on traditional tropical systems which aim to subsistence and not commercialization.

This acknowledgement of ignorance about mixed orchard systems from research or advisors emphasized the fact that the development of these systems is currently carried by the producers themselves. This "bottom–up" phenomenon where producers developed a system and subsequently drove research on this field opposes to a "top–down" phenomenon where research is carried on first to the implementation at large scale into producers' field. It resulted in the recent spread of experimentations to create references, training sessions and creation of producers' network to "*create bonds and dialogues, exchange and organize regional meetings on technical topics*".

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3.2. Technical advisors who identify benefits and limits for producers in mixed orchard systems

This Master thesis was realized in the scope of determining what kind of knowledge and support has to be provide to producers in mixed orchard systems and the future project holders. In this context, it is necessary to analyze what was the knowledge of research and technical structures about mixed orchards and producers who implemented these systems. As a matter of fact, these structures will be the ones to create knowledge and provide support to producers.

Each technical advisor or researcher interviewed during the first phase was already involved in a project related to mixed orchard systems. Among these projects, three categories have been distinguished: experimentations, creation of producers' network and training session.
These projects were all implemented in the last few years except for one: an experimentation which started in 2000 to evaluate the effects of chickens on pests in a peach orchard. "*At this time, people thought I was crazy. Indeed, at this time, reducing inputs was not as important as today*." This quote from the researcher responsible of the experimentation emphasized the precursory status of this experiment. Even today, some interviewees mentioned the difficulties to implement actions due to a lack of interest from the sectors stakeholders for these mixed orchards systems: "*We are still at the same step, we and the others organizations doing experimentations, we prove that things work or not and then when it is working, we need an interest from the stakeholders of the sector*."

In addition of meeting the growing interest of producers, organizations invested in these mixed orchard systems projects because they identified these systems as having beneficial interests for the producers (Figure 2).

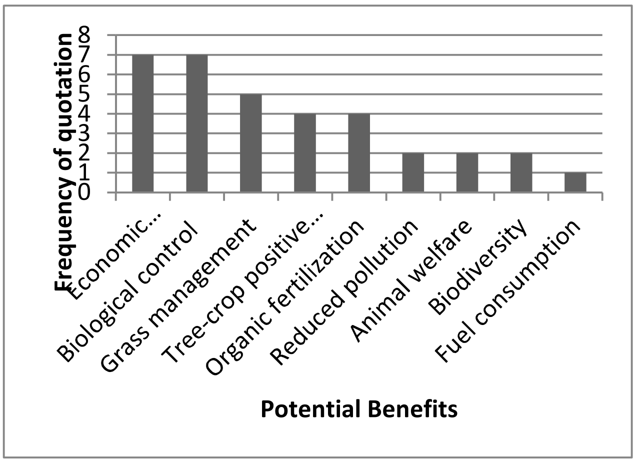

Figure 2: Potential Benefits Identified by Technical Advisors

Among the 8 advisors interviewed, 7 of them identified the potential economic benefit thanks to product diversification and the potential positive effect on pest management as the two main advantages of these mixed orchard systems. Indeed, according to the interviewees, production diversification could be a way to "*to mitigate climatic risks but also market risks*" and to bring additional revenue, especially in organic conversion context: "*Conversion in organic production represents easily a yield reduction of 50%, with a better price valuation but ... Any economic diversification is interesting*". The potential beneficial effect on pest management differs from mixed orchard vegetables and mixed orchard animals systems. In the first one, interviewees identified diversification as a way to "*increase diversity and heterogeneity in the plot*" and to use natural enemies "*by creation or maintenance of habitats*".

In the case of animal introduction, an interviewee summarized the potential advantages by saying: "*We supposed that we could introduce animals with prophylactic aim in relation to pest management. Sheep and scab for example, we supposed that the trampling, the feces may accelerate leaf litter decomposition and decrease scab inoculums. Trampling may also limit vole presence. Also maybe eating of worm infested fruits if poultry are introduced*." When in mixed orchard vegetable system, the aim is to create a balanced ecosystem, the main goal in mixed orchard animal system is to introduce a predator against specific pests. With 5 quotations on 8 interviewees, grass management in mixed orchard animals systems has also been identified as a potential advantage for producers. Indeed, introducing sheep or poultry into orchards may reduce the use of herbicides or fuel for mowing as said by two advisors: "*When you put chickens, it is worse than an herbicide, at the end there is no more grass*" and "*For grass mowing, we are sure that if we put sheep, they will graze so we avoid a mowing*". Concerning mixed orchard vegetables systems, another potential advantage has been mentioned by half of the interviewees: tree–crop positive interactions. Related to agroforestery concepts and potential benefits, it includes nutrients cycle "For me the advantage of such system is the recycling of the nutrients surplus under the annual crop. You do not need fertilization for the fruit trees: you use the nutrients excess from the annual crop" and microclimate effect for the annual crop "*Having a mitigated climate with the shadow effect, the reduced wind, the evapotranspiration too*". At first sight, it appears that mixed orchard animals benefits, and consequently potential producers' motivations, seem closer to Substitution practices. As a matter of fact, introduce domestic animals as pesticides and/or herbicides replacement may not lead to a system Redesign like the process of creating new habitats in mixed orchard vegetables systems.

However, as for all agricultural systems, interviewees also identified potential limiting factors that may hold back the willingness of some producers to implement such mixed systems and at a larger scale (Figure 3). Besides the lack of theoretical and practical knowledge for advisors and producers, three quarters of the interviewees highlighted the systems' dichotomy and the mechanization and workload constraints as the main limiting

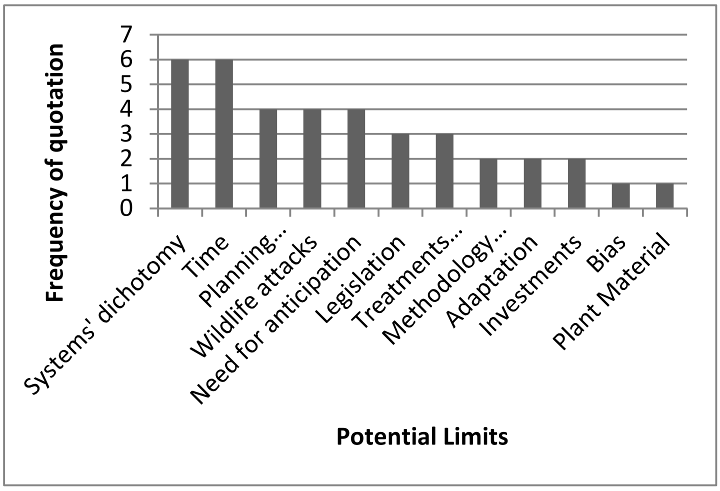

Figure 3: Potential Limiting Factors Identified by Technical Advisors

factors for both mixed orchard systems. Indeed, whether for mixed orchard vegetables or mixed orchard animals systems, "*Some producers tried because they understand the association interest but at the end it was too difficult to manage, it is another profession*" noted an interviewee.

Associate different productions raise also the issues of time: "*The drawback is the time. To be able to give an equal time to each production*" and of mechanization constraints: "*When you look at a vegetable producer, which faming tool will be compatible with fruit trees? The opposite is true too.*" "*Because there are many things that you cannot mechanize, you have to do it manually*". It has to be noticed that the issue of time may be divide in two different concepts: an additional workload when both productions request work on the same period of time and a time surcharge especially when animals request a permanent presence.

Introduction of animals into an orchard system and especially introduction of sheep can also be problematic in terms of treatment and grazing planning management. An interviewee rightly raised this issue saying: "*For shepherds it not always interesting because if the orchards has been mowed there is not enough grass. They also are afraid of chemical products. This implies that orchard treatments are not harmful for the animals. If the sheep die, it will be problematic.*" Moreover, approximately half of the interviewees identified legislation and especially sanitary regulations as a limiting factor like it is well explained in this quotation: "*Some producers introduced chickens or sheep but they stopped because it represented too much management, sanitary constraints, legislation.*"

Another limiting factor has been identified by half of the interviewee in the case of mixed orchard vegetables systems: the need for anticipation before implementation. Time is needed to conceive the project, choose the plant variety and to book them as two advisors said: "*You need to think in advance in terms of crop associations. What crop can I make under my trees?*" and "*The most important message is: anticipate for plant material, order the seedlings in advance, you can make the grafting but you need a training session first so anticipate*".

Despite the abundance of limiting factors identified by the interviewees, producers are currently implementing these mixed systems on their fields and a growing number of producers are willing to do the same. Interviewees noticed a producers' typology: first, mixed orchard vegetables systems seem to interest more producers coming from vegetables production with a main goal of diversifying the production "*For me one important aspect is that it is vegetables producer who are the most interested by mixed orchard vegetables. Vegetables producers seized this model because they are already diversified. Those in short distribution circuit wanted some sweet products in addition to their vegetables*". At the opposite, fruit growers seem the more interested by mixed orchard animals systems: "*The fruit growers are more interested by introducing animals in their orchards*". Moreover, some interviewees highlighted the high proportion of producers in setting up process within the producers interested by these systems because of a higher flexibility: "*Instead of conceive the project with separate plots, I see more and more young people* *who are setting up and want to mix crops, to make animals grazed under the trees, to put vegetables … This is something that you have to think in advance because after that, a fruit trees system is "frozen" for some years.".* The second phase of interviewees, focused on producers will allow to confirm or not this typology.

3.3. A multitude of producers' profiles

In the scope of providing suitable knowledge and support to producers who had implemented mixed orchard systems or are willing to, it is necessary to identify at whom technical structures are talking to. Indeed, technical structures have first to identify the characteristics of the producers who will receive their support and/or references. These characteristics will also be useful to position future project holders compared to producers already setup and give them suitable advices.

The significant proportion of producers in their first years of setting up corresponds with the producer's profile identified by the technical advisors (Figure 4). However, when distinguishing producers in mixed orchard vegetables system and those in mixed orchard animal system, another classification tendency can be identified. The first ones are mainly (5/9) in their first five years of production while the second ones are mainly producers setup since more than 10 years and even since more than 20 years for 7 of them. A hypothesis that can be stated is that producers in mixed orchard animals may be more experimented in terms of agricultural practices. They may have capitalized more practical knowledge from previous experiments and may have more "tools" available to react in case of issues in their mixed orchard animals system.

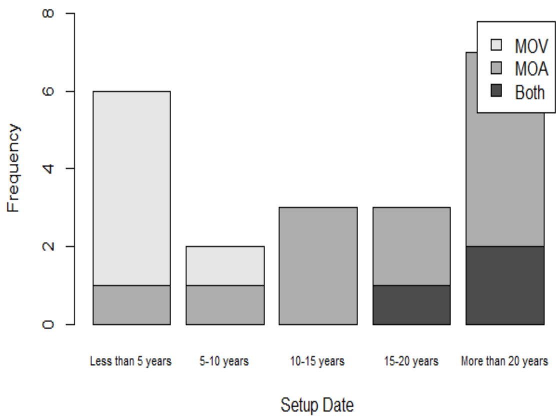

Figure 4: Sample Distribution according to Setup Date and the Diversified System (n=20)

When distinguishing producers in mixed orchard vegetables system and those in mixed orchard animal system, a dichotomy in UAA can be highlighted (Figure 5). The first ones do not have more than 10 hectares while the distribution of producers mixing fruit trees and animals in their fields is more even. However, this distribution is easily interpretable by the fact that vegetables production farms do not usually owns a large agricultural area. According to Agreste (2013), the national UAA average for vegetables specialized farms is 10,8 hectares. Moreover, the high

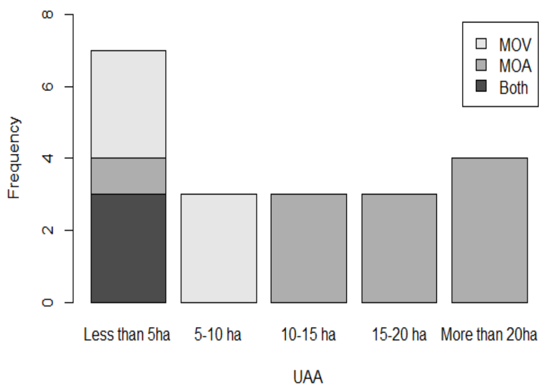

Figure 5: Sample Distribution according to UAA and the Diversified System (n=20)

proportion of large farms in mixed orchard animals systems may be explained by the need for producers with a self-sufficiency aim to have pasture or fodder for their animals.

The initial production of interviewees before diversification, in other words before the association of fruit trees and vegetables or fruit trees and breeding, has been sorted into 4 categories: breeding, orchard, vegetables and others. The “others” category includes all kind of agricultural production which is not part of the last three such as grassland, cereals, fallows etc.

This distribution highlights the fact that most (13/20) of the initial systems were orchards (Figure 6). This dominance of orchards among the initial systems of interviewed producers is especially true in the case of producers in mixed orchard animals system. This result confirms what have been previously said by technical advisors about the dominance of fruit tree growers through producers interested in mixed orchard animals systems. Knowing the producers’ initial production is essential in the process of providing suitable support. Indeed, a producer coming from an orchard system may not need support in fruit trees management as well as a breeder may not need training sessions about husbandry. The diversity of initial production among producers in mixed orchard systems consequently determine the diversity of knowledge, training sessions that the structures have to provide.

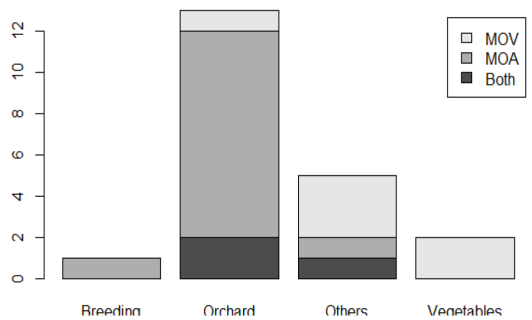

Figure 6: Sample Distribution according to Initial System and the Diversified System (n=20)

A Multiple Correspondence Analysis has been realized on structural data variables to identify discriminating and aggregation variables in order to identify a producers’ typology. However, some variables such as Demeter certification or Agricultural Family have been removed from the analysis due to a non-homogeneous distribution or due to too many missing data.

First the eigenvalues have been analyzed and it has been decided to keep two dimensions or axis to continue with the MCA. Indeed, the cumulative percentage of total variance explained by the two first dimensions is approximately 36%. The second step is to analyze the contribution of variables and their modalities on each axis to determine what is categorized by these dimensions (Figure 7). On the first dimension, “setup date inferior at 5 years”, “no wholesale distribution” and “other initial production” are opposed to “setup date superior at 20 years”, “wholesale distribution” and “orchard initial production”. It seems that this first dimension opposes, on one hand, new farmers selling their agricultural production in short marketing circuit and with a fallow or pasture initial system and on the other hand, farmers setup in orchard system since a long time, with a part of their production in a wholesale distribution circuit.

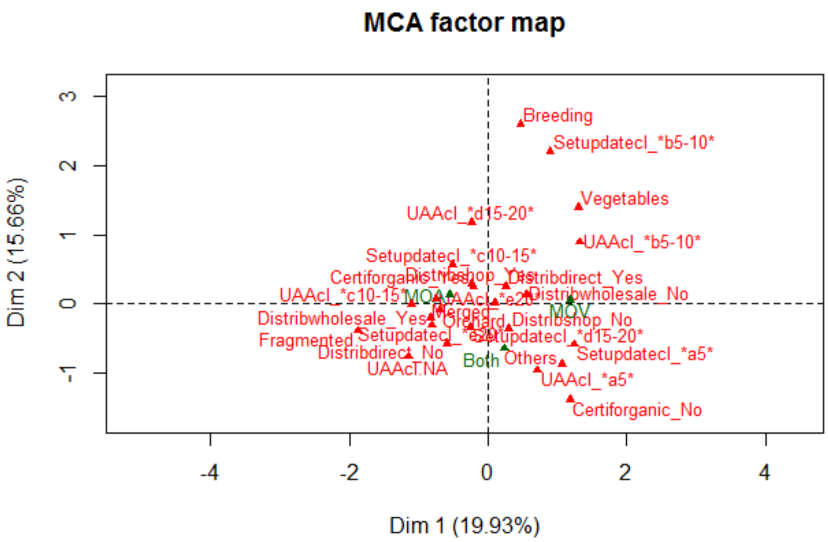

Figure 7: Modalities Contributions Map on Dimensions 1 and 2 of MCA Structural Data

A Hierarchical Clustering on Principal Components (HCPC) enables to visualize a producers' typology and the HCPC on this set of variables identified 3 clusters of producers (Figure 8).

Variables "Initial Production" and "Setup Date" and "UAA" are those which characterized the most the partition in these three clusters. When focusing on which variables and modalities characterized each cluster, the statistical analysis emphasized that the first one on the left gather producers, mainly in mixed orchard animals system, who diversified from an orchard system, with a large UAA and setup since 15 years or more. The second cluster gathers producers, mainly in mixed orchard vegetables system or having both systems, who setup since less than 5 years, on a small agricultural land previously in fallow or pasture. Finally, the third cluster mainly gathers producers who diversified their systems from a breeding or vegetables system.

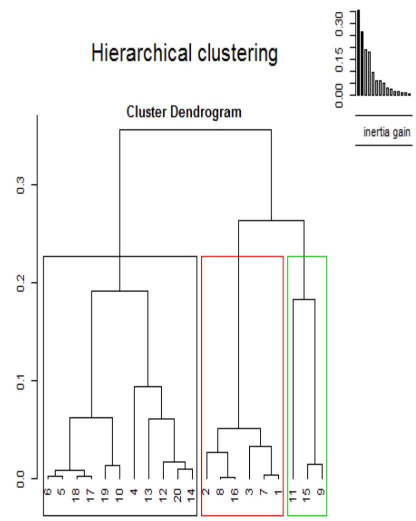

Figure 8: Cluster Dendogram of HCPC Structural Data

As a result, the distribution circuit related variables (wholesale, direct or producers' shop distribution) and especially the presence of a wholesale distribution which highly contributed to the MCA axis, did not act on the clustering process.

This typology of producers according to their structural data may have consequences on the support provided to them. Each cluster of producers may interact with stakeholders in two or even three sectors, stakeholders that the other producers may not be related to such as organic farming advisors for those with the certification, employees from a wholesale distribution center for those concerned by this kind of distribution circuit, sanitary administration for those with animals etc. Moreover, producers willing to implement a mixed orchard system may, according to the cluster they belong, will receive different kind of information, knowledge, advices which will influence their management practices of their diversified system. As a result, the diversity of knowledge and support received by the producers may leads to a diversity of mixed orchard system design.

3.4. Producers having multiple motivations to diversify theirs systems …

When asked why they have chosen to implement a mixed orchard system, whether with the association of fruit trees and animals or fruit trees and vegetables, interviewed producers' answers were diverse. However, initial motivations have to be distinguished from determining factors and positive benefits seen afterwards the diversification implementation. The latter will be described in a next part.

7 kinds of motivations have been quoted:

- Economic motivation represents the willingness to produce two agricultural products instead of one on the same area of land. Producers who have quoted this motivation wanted to earn a secondary income thanks to diversification or to make the initial investments such the land purchase profitable "*Meanwhile, I have to earn money and associate vegetables and fruit production seem to be a good idea. Land being very expensive, I cannot afford to only have fruit trees because of the time interval before they enter into production*".

- At the opposite, the motivation called "philosophical approach" related to producers who wanted to introduce a new kind of production but without necessarily an economic goal. It could be a will of creating a diversified ecosystem with plants and animals like for these two producers for example: "*I've always assumed that if the ecosystem gets more complex, it has more chances to balance itself.*" and "*I always wanted a mixed farm, with animals and plants*" or a will to mix trees and vegetables in a permacultural way of thinking.

- Pest management has also been quoted as a key motivation by producers. Creating new ecological niches by associating fruit trees and vegetables or using the predatory abilities of a domestic animal may help to deal with pests and to reduce pesticides use. These two quotations of producers, one in a mixed orchard vegetables system and the other in a mixed orchard animal system illustrate this biological control motivation: "*We are trying to bring a high biodiversity into the field to have natural regulations*" and "*We introduced sheep to deal with pest problems in the orchard*".

- Creating a microclimate under the trees canopy is also a motivation encountered in producers' discourses. This microclimate can be beneficial for both animals production "*I put trees to protect the hens during summer. In winter, this place is a wind corridor so I thought of trees for windbreaks*" and vegetables production "*The primary objective is to create a windbreak effect and to bring a different atmosphere on the plot*".

- Some producers quoted the planting of fruit trees as a way to create an enjoyable place to work. A vegetable producer who has planted rows of fruit trees in–between its vegetables summarized this idea: "*It creates a certain harmony, working in a better environment with shadows, shapes and vegetation is much nicer*". As for the "philosophical approach", this motivation was not previously identified by technical advisors.

- Another motivation, exclusively quoted by producers with mixed orchard animals systems or projects, is the grass management. Indeed, herbivorous domestic animals like sheep, horses or even geese are able to graze under the fruit trees and to replace the use of a mower: "*It's a bit ridiculous to mow grass when we know that there are animals that will love it*".

-Finally, the last motivation formulated by interviewed producers is the renewed nutrient cycling that is taking place in mixed orchard systems. According to the producers, this process may happen either in mixed orchard vegetables systems "*the idea is that trees will catch the leaching nitrogen from vegetables production. And at the end, nitrogen goes back in their branches, in their fruit and leaves which fall in autumn*" or in mixed orchard animals systems "*Even with few hens per square meter, there is a pollution and in this case there will be a nutrient exchange between the chickens and trees*".

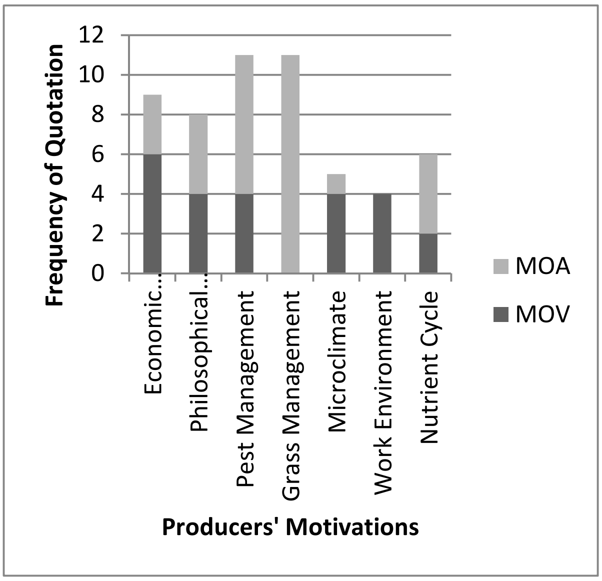

Figure 9: Producers' Motivations according to their Diversified System

When focusing on the quotation frequency (Figure 9), grass management, pest management and economic diversification are the main motivations raised by the interviewed producers with respectively 11, 11 and 9 producers on 20 quoting them. It has to be noticed that producers in mixed orchard vegetables system and those in mixed orchard animals system have not the same initial motivation to implement diversification on their farm. Indeed, if some motivation such as the philosophical approach is approximately evenly distributed among both systems, other motivations are exclusively quoted by producers in one kind of mixed orchard system. This is particularly the case for the grass management motivation which was quoted by 11 producers on the 14 in mixed orchard animals system and by none of the producers in mixed orchard vegetables system. The opposite situation also exists with the work environment motivation.

As previously stated in the technical advisors' interviews analysis, it may appear that producers' motivations in mixed orchard animals systems seem closer to Substitution practices. As a matter of fact, introduce domestic animals as pesticides and/or herbicides replacement may not lead to a system Redesign like the process of creating new habitats in mixed orchard vegetables systems.

A Multiple Correspondence Analysis has been realized on motivations related variables to see if producers can be gathered according to their motivations. First the eigenvalues have been analyzed and it has been decided to keep two dimensions or axis to continue with the MCA. Indeed, the cumulative percentage of total variance explained by the two first dimensions is approximately 61%. The second step is to analyze the contribution of variables and their modalities on each axis to determine what is categorized by these dimensions (Figure 10)

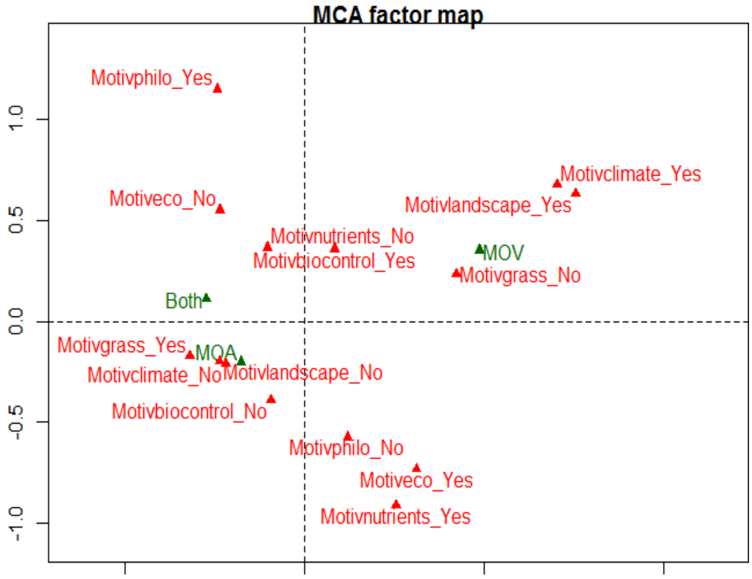

Figure 10: Modalities Contribution map on Dimensions 1 and 2 of MCA Motivations

On the first dimension, variables "landscape motivation", "climate motivation" and "grass motivation" are opposed. Thus, it seems that the first dimension opposes, on one hand, producers for whom main motivations are the microclimate and the improved work environment, and on the other hand, producers with the grass management as their main motivation. When the kind of mixed system is put in illustrative variable, the microclimate and landscape are connected to mixed orchard vegetables systems while grass motivation is linked to mixed orchard animals system. The second dimension seems to oppose on one hand, producers with economic motivations, willing to have an additional income, and on the other hand producers with a "philosophical" motivation such as willingness to have mixed productions, enjoyment of working with animals. The latter distinction is, for its part, independent from the system chosen by the producer.

A Hierarchical Clustering on Principal Components enables to visualize a producers' typology according to their motivations and the HCPC on this set of variables identified 4 clusters of producers (Figure 11). Variables "Motivation = philo", «Motivation = landscape" and "Motivation = climate" are those which characterize the most the partition in these four clusters. When focusing on which variables and modalities characterized each cluster, the statistical analysis shown that the first cluster on the left gather producers, mostly in mixed orchard vegetables system, who quoted a high number of motivations, especially those related to economic, climate and work environment.

These producers seem to have a more systemic idea for their system than those focusing only on one pest for example. The second cluster represents producers without an economic motivation but more with a philosophical approach. Then, the third cluster unites producers in mixed orchard animal system for whom their main motivations are grass management and nutrients.

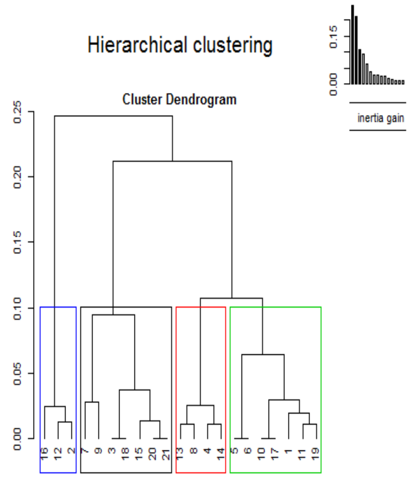

Figure 11: Cluster Dendogram of HCPC Motivations

3.5. But facing incentives and obstacles in their diversification pathways

Producers' motivations are a major factor in the process of system diversification. Indeed, they obviously influenced the decision of diversifying and the choice of the system, whether association of fruit trees and vegetables or fruit trees and animals, but they also highly influenced the agricultural practices implemented on these diversified systems. In addition to motivations, external factors may also play the role of incentives or obstacles and determine the decision of diversification and/or the time gap between the idea and its fulfillment. These incentives and obstacles present at the implementation phase have to be distinguished from limits and drawbacks which appear after some years. One of these external factors is the information about mixed orchard system available for producers. Under the word "information" is gathered references from readings, whether scientific or popularization literature, training sessions and knowledge acquired in the framework of a farmers' network.

In our interviewed producers' sample, almost all of them had access to at least one source of information about mixed orchard systems (Figure 12).

Only half of the producers used readings as a source of information while 18 producers on 20 found information, advices and references from formal and informal farmers' networks. This result illustrated well what have been noticed during the technical advisors interviews: there is a lack of scientific knowledge about these mixed orchard systems and consequently these latter are supported by producers themselves in a horizontal process.

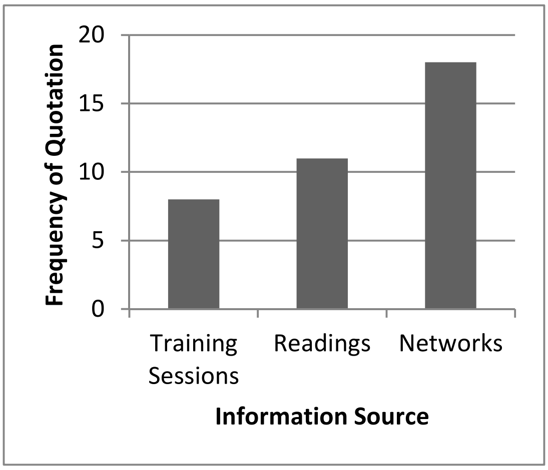

Figure 12: Sample Distribution according to the Information Source

Thus, the information availability may be characterized as an incentive or an obstacle, depending of the producers: while one say that the meeting with a technical advisor was a trigger *"I met a man from Agroof, he left me a DVD and quickly explained to me what agroforestry is and I thought: this is what to do!"*, others see the lack of information as an obstacle to their will "*We know nothing about that. If I had references about species or things like that, it will be a big step!*"

Many other external factors can act as incentive or obstacle of system diversification and these factors differed according to the mixed orchard system chosen by the producers. In mixed orchard vegetables systems, incentives may be a selling opportunity or a request from consumers "*Since the beginning the project is to add fruits into the consumers' basket, people are interested by this*" as well as a collateral effect from high land prices. In the case of an orchard implementation, producers may not be able to afford a non–productive time period and may be willing to produce something during this time "*The land is very expensive, I cannot afford to only have fruit trees before they start producing so associate them with vegetables seem a good idea*". In this case, diversification consequently leads to intensification in terms of productivity/hectares. Producers willing to implement a mixed orchard vegetables system may also face different obstacles such as regulations and difficulty in the choices and the availability of plant material. The first obstacles, regulations, may be related to treatments compatibility in the framework of an organic certification "*If I want to put copper on the fruit trees and there are salads under them, I cannot*" or related to production standards "*The PDO forbid the cultivation of another crop between the olive trees*".
Concerning mixed orchard animals systems, the main incentive may also be a request from consumers "*Egg production is very attractive in the organic sector; I can sell them in the 300 shops where I already sell my apples!*" However, except from difficulties in the choices and the availability of plant material and/or animals "*We do not know which species is suitable*", "*We went to Austria to buy the first sheep"*, obstacles encountered by producers are different from the other mixed orchard system. They could be funding difficulties "*We looked for funding but it was not easy. We had to delay tree planting because we did not have European funds*" or even non–adequate sector organization and regulation constraints "*When you want to do official breeding, there is a lot of administrative constraints, when you are a small structure is very difficult […] Breeding sector is not organized for small producers*".

These external factors, which act as incentives and obstacles, are linked to the upstream and downstream sector organization. As mixed orchard animals systems and mixed orchard vegetables systems do not involve the same sectors, fruits and breeding for the first one, fruits and vegetables for the second, external factors are different too. Obstacles, even if they are not numerous, may influence the way the producer will implement its mixed orchard system or may even make him give up the project. Indeed, producers may be tempted to implement a mixed orchard system based on Substitution practices rather than on a system Redesign to have the possibility to go back to a "classic" system. Some of these obstacles to the implementation and the development of mixed orchard system may be removed or at least decreased with a suitable producer's support. Creation of references, of farmers' networks, advices in the species and varieties choices, support through the process of funding search may enter into the scope of action of technical advisors and the structures they belong to.

3.6. A multitude of system (re)design related to the diversification

While interviewees' setup date underlined two tendencies among interviewed producers: producers in their farms since more than 15 years and producers in their first years of production, the date of diversification implementation do not follow this dichotomy (Figure 13). More than half of the interviewees (11 producers on 20) have implemented a mixed orchard system in the last 10 years. Moreover, among these 11 producers, the implementation of a mixed orchard happened in the last 5 years for 9 of them. These numbers highlighted the fact that the spreading of these mixed orchard system among farmers is a recent phenomenon. When distinguishing producers in mixed orchard vegetables system and those in mixed orchard animals system, 6 producers associating fruit trees and vegetables on 8 have started the process of diversification implementation during the last ten years. More specifically, these 6 producers diversified their systems during the last 5 years while distribution of producers associating fruit trees and husbandry is more even. Moreover, when focusing on the time interval between the producer setup date and the diversification start, half of the producers have diversified their system in their 5 first years of production (Figure 14).

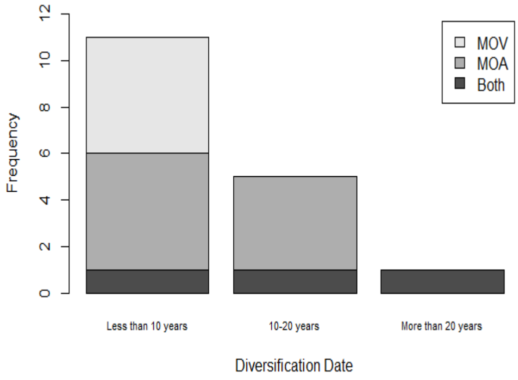

Figure 13: Distribution according to the Date of Diversification and the Diversified System (n=17)

Consequently, a tendency that can be highlighted from these numbers is that producers may not necessarily wait until stabilization and cost–effectiveness of their system before diversification. Indeed, it can be assumed that the implementation of a mixed orchard system requires investments, new agricultural practices and even new machinery: a phase of transition consequently seems necessary. This relatively short transition phase observed highlights a risk–taking behavior from interviewed producers. Then, support from technical advisors and the organizations associated may deal with this risk–taking behavior and this by two ways. First, make this risk–taking behavior of producers profitable and collect references, data, and knowledge from producers who already implement a mixed orchard system. Secondly, all this new knowledge acquired must be pass to producers willing to implement such a system.

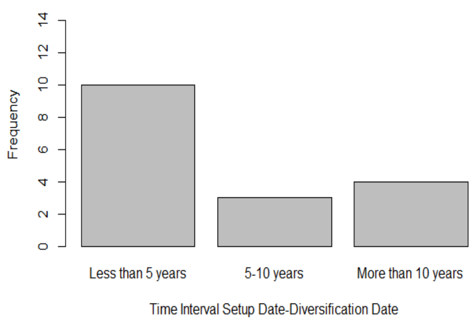

Figure 14: Sample Distribution according to the Time Interval between Setup Date and Diversification Date (n=17)

If the diversification process is quite recent for most of the interviewed producers, the technical choices and agricultural practices related to this diversification highly differs from a producer to another and between mixed orchard animals and mixed orchard vegetables system as well.

Concerning mixed orchard vegetables systems, design diversity can be characterized with the following criteria:

- Distance between fruits trees and consequently the space available to grow vegetables. This distance turned out to be highly variable according to the motivations or objectives of the producers and ranged from 3m to 40m. In the latter case, such a high distance between rows of trees was explained by the producer as a precautionary approach: "*I did a spaced grid with rows at 40m from each other's. If in 10 years, it satisfies me and I want to densify more, I will but I keep this time of reflection because I do not want to plant and having to pull everything in 10 years because it is too dense*".

This distance is also representative of the production hierarchization that may happen in mixed orchard system: the priority can be put by producers on fruit production "*There is 4m between peach trees and 6m between plums ones, it is approximately the distance recommended in a fruit trees specialized farm* […] *I could have put 1m supplementary but I wanted to have 100 trees and I built the grid as in a monoculture orchard*" or on vegetables production "*These trees rows are spaced 20m apart, there is space because we are vegetables growers prior than fruit trees growers*".

- Diversity within fruit trees is also varied. Vegetables could grow under a unique fruit tree species such as olives tree "*Since two years, we are producing vegetables between olives trees rows*" or under various fruit trees species such as with the interviewee system "*In terms of trees species, there is cherry, peach, apricot, pear, apple and plum. And among these, there are 3-4 varieties by species*".

- The "life expectancy" of the mixed orchard vegetables system depicts another criterion of diversity among producers. For example, two producers of the sample will reduce the percentage of vegetables production under fruit trees to only keep an orchard system*:"In the future, when trees will be bigger, vegetables production will be reduced"*.

In the case of mixed orchard animals systems, a high diversity of system design can also be identified:

- The first criterion of diversity among interviewed producers is the animal species and the amount of these species in the farms. Animal species grazing into orchards could be sheep, pigs, cows, horses, donkey, chickens and other poultry. Sheep and poultry are the main animal species encountered: 9 interviewed producers on the 14 with a mixed orchard animal system have sheep grazing under their fruit trees and 6 on 14 have poultry which may include chickens, geese or ducks. These animals species can be the only one into the orchard or may coexist in the orchard like at this interviewee's farm "*I have twenty horses, about fifteen sheep, between 10 and 30 pigs, it depends, a hundred chickens, 150 poultry including the chickens, geese, ducks ... Also 4 cows, a donkey and it must be all*". In the process of identifying producers' trajectories, this criterion may be a suitable indicator of the diversification level within a mixed orchard animal system.

- The animal introduction into orchards can also differ in terms of grazing duration. This latter can be of a few months, mainly during winter time to avoid tree damages like with this producer example: "*I implement a rotational grazing, when there is vegetation on trees, I do not put them there. They are grazing on plots where I have no trees from early March until mid–July*". The animals, mainly poultry species but in some case sheep and pigs, may also grazed into the orchard during the whole year whether or not there is vegetation and fruit on the trees.

- Another criterion of diversity among producers in mixed orchard animals system is the animal ownership. Producers may associate themselves with a nearby breeder and let him use orchards as a pasture "*Every winter, he comes with 400 sheep*" or producers may buy their own sheep. This association with a nearby breeder concerns 3 producers and is sometimes requested by producers not willing to deal with their own animals: "*Ideally, it would be that we find someone, a breeder who is willing to bring us sheep from time to time.*"

Agricultural practices related to the diversified systems can also be considered as adaptations of previous practices in a "classical" system such as vegetables or fruit monoculture or, in other words, as a Redesign of a "classic" agricultural system. These adaptations can occur through different agricultural practices: fertilization, tree management, pesticides use, turnover and buildings arrangement (Figure 15).

However, not all components of the agricultural system were adapted and producers did not adapt the same components according to their previous system and practices. Vegetables turnover is a suitable example: some of the producers reasoned the vegetables turnover according to the presence of the fruit trees canopy "*If there are vegetables that fear the wind, for example, I will put them between the trees. And if there are vegetables that like the wind, like garlic for example, I'll put them in open plots. It is the same for salads in summer which like to have a bit of freshness; we will put them under the trees*" whereas other producers do not reason the vegetables turnover except in terms of commercialization "*The turnover is made rather to be in line with what the customers want than according to production problems*". Fertilization practices followed the same scheme with producers adapting the amount of nutrients they spread on their fields "*I adapt it but not in a scientific way: this year, I applied lower doses because it is a year of alternation and because there was sheep during winter.*" and producers not adapting their fertilization practices "*I do the same as before, sheep are just recycling what they are eating*".

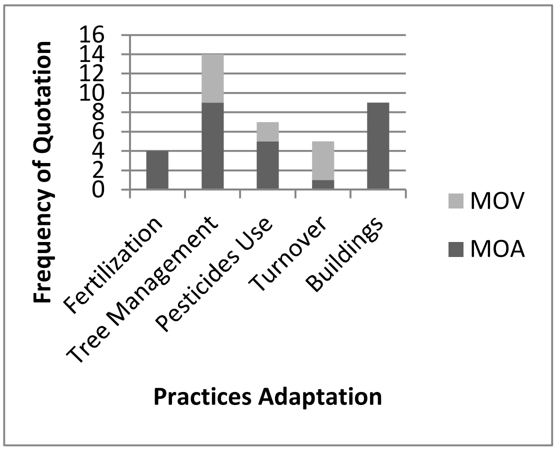

Figure 15: Adaptation according to the Diversified System

Practices adaptations may also differ from producers according to the mixed orchard system they have chosen to implement. Whereas some adaptations such as tree management are approximately evenly distributed among producers in both mixed orchard systems, some others are exclusively applied in one system. The adaptation “buildings” for example, is only applied by producers in mixed orchard animals systems who had to build fences and shelters to keep their animals close–by and to protect some parts of the fields. Moreover, mixed orchard animals systems seem to imply more practices adaptations for the producers than a mixed orchard vegetables system. Indeed, in addition to the adaptations related to fertilization, tree management and buildings previously quoted, pesticides use is also an agricultural practice influenced by the association of animals and fruit trees. Producers quoted this phenomenon: “*The first issue with sheep is copper application. So I use very few amount of copper, highly fractionated*”.

When analyzing these practices adaptations in the scope of the Efficiency–Substitution–Redesign framework, it may seem that the highest amount of practices adaptation applied in mixed orchard animals system bring it closer to a Redesign process. This may remain as a hypothesis because some adaptations such as adaptation in fertilization and pesticides may just be part of the Efficiency or Substitution step, keeping the system away from a Redesign. On the other hand, practices which seem to be a part of a Substitution process such as replacing a mower by sheep may finally be part of a Redesign process when the producers adapt other practices in order to manage correctly the first one.

As a result, agricultural practices implemented by producers in their diversified systems are diverse and related to different knowledge: field layout, (phyto)sanitary issues, management production, commercialization etc. The support that may bring technical advisors or scientific research will necessarily take into account this “multidisciplinary” approach.

A Multiple Correspondence Analysis has been realized on the variables related to the design and practices within the diversified system. The starting date of diversification and the kind of system chosen have been put as illustrative variables. First the eigenvalues have been analyzed and it has been decided to keep two dimensions or axis to continue with the MCA. Indeed, the cumulative percentage of total variance explained by the two first dimensions is approximately 46%. The second step is to analyze the contribution of variables and their modalities on each axis to determine what is categorized by these dimensions (Figure 16). On the first dimension, producers with a temporary diversification that is not belonging to them and who adapt their fertilization practices are opposed to those with a permanent and personal diversification who do not adapt their fertilization practices. It seems that the first dimension opposes, on one hand, producers associated with a nearby breeder to let sheep graze during winter time and on the other hand, producers having implementing by their own the diversification during the whole year, whether by introduction of animals or by association of fruit trees and vegetables.

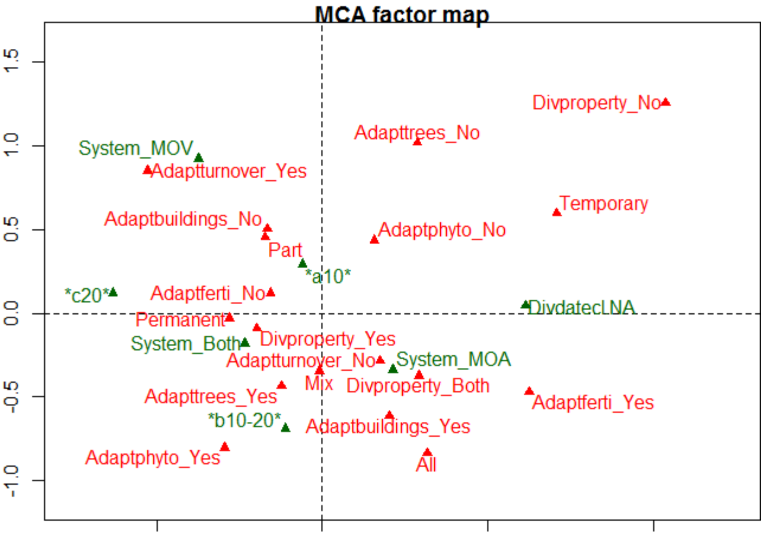

Figure 16: Modalities Contribution Map to Dimensions 1 and 2 of MCA Practices

The second dimension seems to oppose producers who diversified only a part of their farm without necessarily adapt their pesticides and tree management practices on one hand and producers who diversified their whole agricultural land while adapting their practices at the same time.

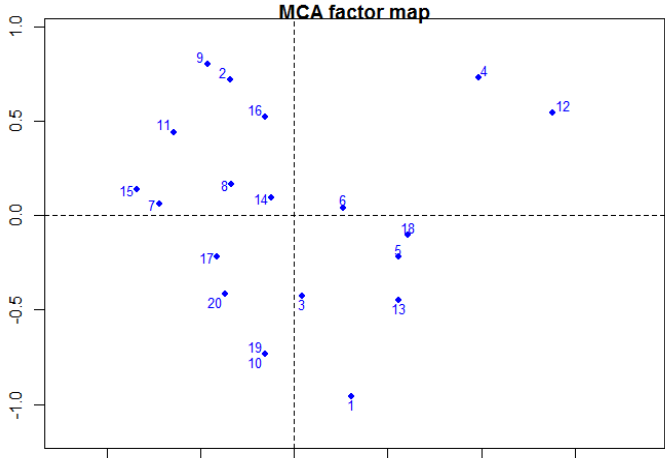

Figure 17: Individuals Scatterplot of MCA Practices

The individuals' scatterplot may allow identifying a first classification tendency among producers according to their diversifed system and their agricultural practices related (Figure 17). Producers 4 and 12 seem to be distinct producers whereas the others producers seem more homogeneous. When looking for details into the database, producers 4 and 12 are the only ones, in mixed orchard animals system, to be associated with a breeder and to have sheep grazing their orchards during winter time. This cluster localized on the right of the first axis match with the previous interpretation of this dimension.

A Hierarchical Clustering on Principal Components is necessary to reinforce or not these first tendencies of classification (Figure 18). As a result, the HCPC partly confirmed it: 3 clusters of producers were created, some of them similar to those previously identified. For example, at the producers 4 and 12 previously identified were added the producers 6 and 18. The key variable which has been used to create this cluster, the one in the middle on the figure, is the temporary aspect of the diversification and more precisely the fact that this diversification is only present in winter time during the sheep grazing time. The second identified cluster, on the right of the figure, has been mainly characterized by the modalities land proportion=all and adaptbuildings=yes. This cluster essentially gathers producers in mixed orchard animal system, animals being present on their whole agricultural land and who invests in buildings such as fences or shelters.

Finally, the third cluster is mainly characterized by the modalities land proportion=part, adaptbuilding=no and adaptturnover=yes. It unites producers, essentially in mixed orchard vegetables system, who usually own a part of their agricultural land non–diversified for monoculture fruit or vegetable production, adapt their vegetables turnover to the fruit trees presence and do not invest in buildings. It has to be noticed that only the variable "diversification duration" which have two modalities (temporary and permanent) was used to characterize both a dimension in the MCA and a cluster in the HCPC.

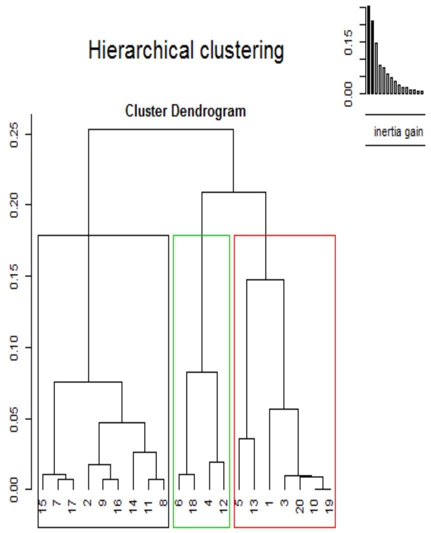

Figure 18: Cluster Dendogram of HCPC Practices

A chi-square test has been realized to see if the practices' clusters are correlated to the motivations' clusters. The result is a p–value of 0.09348 which is higher than 0.05; motivations and practices consequently seem to be not correlated. This result may be explained by the fact that agricultural practices are not only the result of producers' motivations. Indeed, they can be influenced by structural constraints, commercial outlets or even non-suitable machinery.

3.7. An empiric evaluation of the mixed orchard systems by the producers themselves

Besides initial motivations and determining factors that influence producers to diversify their systems and the way they implement and manage this diversification, producers may, after some years of working in their diversified systems, identified benefits and limits to their systems. It has to be noticed that in both mixed orchard systems, producers do not use indicators to evaluate their systems: they based their conclusions on empirical observations.

A high variety of benefits of having mixed orchard systems were identified by producers themselves. The majority of benefits corresponds to the initial motivations of producers but some of them were unexpected by them which may help to promote the development of these mixed orchard systems. However, many benefits were quoted by few producers only. This could be explained by the high diversity in producers' profiles and motivation. Each producer, according to what he wanted when he implemented a mixed orchard system, will focus on different results, whether positive or negative. This phenomenon may also influence the way research and technical advisors will produce references. If the references created focused on a sole potential benefit of having a mixed orchard system, producers focusing on another ones will not feel concerned by these references.

Benefits identified by producers themselves highly differ according to the mixed orchard system (Figure 21). Some of them such as improvement in biological control, quoted by 9 producers on 20, affects both producers in mixed orchard vegetables system and producers in mixed orchard animal system as these producers' quotations prove it: "*chickens highly influenced pest pressure: there was no codling moth while we had hens in the orchard*." and "*I have seen a potential positive effect for the trees: by having a diversified vegetables production under them, we had a high variety of insects that inevitably came over and predators are among these insects*". In the same way, a positive effect on soil was quoted by 3 producers on 20, whether in mixed orchard animals or vegetables system: "*I think that there is an effect for the soil too: catching the leached nutrients*" and "*We saw an effect on the soil quality, sheep and geese as well played a role in this*".

When focusing on the amount of benefits that may be identified by a sole producer, it seems that producers in mixed orchard animals system are more prolific than those in mixed orchard vegetables system when asking to identify positive aspects. This result may be explained by the fact that the majority of producers in mixed orchard vegetables system (6/8) start their diversification process during the last 5 years. Indeed, they may not have the necessary hindsight to judge the results of their system. Moreover, some producers in mixed orchard vegetables system are aiming long term and "invisible" benefits without suitable indicators such as microclimate or nutrient cycle.

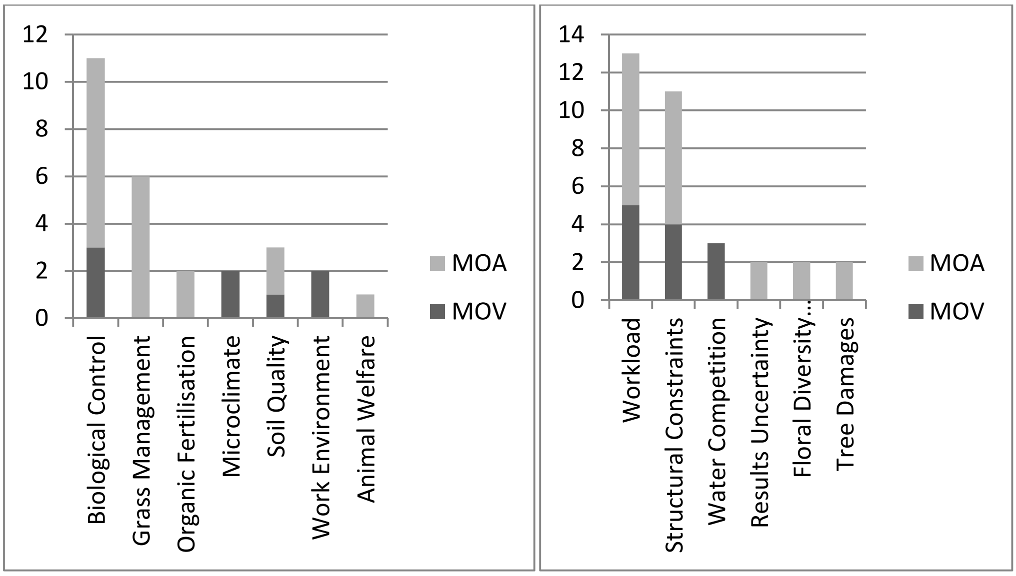

Figure 19: Benefits and Limits Observed by Producers according to the Diversified System

As for incentives and benefits, limits identified by producers and presented in the Figure 19 have to be distinguished from obstacles previously detailed. Indeed, the first ones are negative results observed by producers after some years of practice in their mixed orchard systems while the second ones are external factors acting as obstacles in the first phase of diversification implementation. The two main limits identified by producers are time surcharge or workload and structural constraints and are observed by both producers in mixed orchard animal system and producers in mixed orchard vegetables system.

Mixing two different productions into one agricultural system increase the workload, in other words, the time of work needed to manage these two productions. This additional workload can be characterized differently according to the mixed orchard diversified system. In mixed orchard animals system, having to manage animals and fruit trees in the same time may imply a continuous presence of the producer on his farm "*In theory, it's wonderful to have animals in orchards but actually, it is a permanent constraint*" and/or an additional work when managing fences "*It requires work: install enclosures and uninstall them regularly, daily in some periods*". In mixed orchard vegetables systems, the additional work time is often problematic when it comes at the same period than the "work peak" related to the second production "*the main issue is that the work on trees is often at the same time that the work on vegetables*". For producers who diversified from an already implemented system, whether it was an orchard system, a breeding system or a vegetable one, a limit may be the adaptation of the initial system to the new practices applied. Previous tree pruning, irrigation system or net height may create difficulties to increase and manage diversification on the fields.

Then some limits are specific to one kind of mixed orchard system. In mixed orchard vegetables systems, producers identified water competition as an important limit. Some of the producers even had to adapt their vegetables turnover to deal with this phenomenon "*I started to reduce vegetables production under almond trees because I saw that they were too greedy and it was difficult to manage irrigation*". Three more limits have been identified by producers in mixed orchards animals systems: tree damages especially by sheep, decrease in floral diversity "*sheep are still in the orchard so there not too many flowers*" and results uncertainty. The latter one means that producers observed a positive phenomenon but are not able to determine if the association of trees and animals is the reason of this positive phenomenon "*I tried to evolve on many things. I have seen an improvement in the recent years but I am not sure that is linked to the animals*".

3.8. A combination which leads to various trajectories.

Acknowledging limits in their diversified systems may lead producers to adapt their practices and system over time. As a result, their "systems' trajectories" evolved in different ways according to which limits they have identified, their objectives and how they have modified their systems to deal with the latter ones.

In mixed orchard animals systems, two kinds of trajectories have been highlighted among producers: "trial and error" trajectory and "gradual" trajectory (Figure 20).

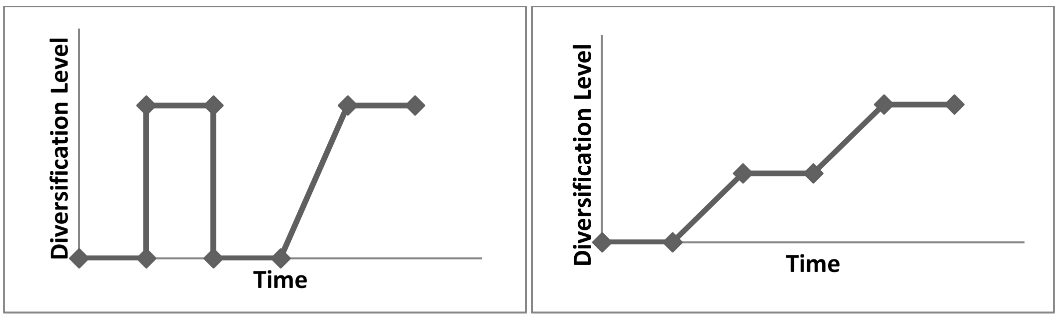

Figure 20: Trajectories Diagrams

On these trajectories diagrams created in analyzing trajectories of each producer in mixed orchard animal systems, the diversification level integrate both the number of animal species under the fruit trees and the number of animals in each species. Indeed, in the “trial–error” trajectory, the first phase of the curve corresponds to an animal introduction which did not match the producer needs and/or had too much drawbacks. The second phase corresponds to another introduction of animal, often another species, with a gradual increase in the number of animals. However, even if between these two phases, the diversification level went back to zero, producers earned experience, knowledge on which they built up the second phase of diversification. In the case of a “gradual” trajectory, the diversification level, in other words the number of animal species under the fruit trees and the number of animals in each species, increase gradually over time, without a decrease phase.

Chi-square tests have been realized to determine if these kinds of trajectories are related to some motivations’ clusters and/or practices’ clusters. The results were a p–value of 0.4518 between motivations’ clusters and trajectories and a p–value of 0.2552 between practices’ clusters and trajectories. None of these p–value were lower than 0.05 so it seems that there is no correlation between motivations, practices and trajectories. This result must not be interpreted as a strict non correlation between motivations, practices and trajectories. This correlation was clearly expressed by producers during the interviews and can be feel through the qualitative analysis.

In mixed orchard vegetable systems, the majority of producers’ trajectories seemed constant, without any increase or decrease in the diversification level. Two hypotheses can explain this result: first, 6 producers on the nine in mixed orchard vegetables systems have diversified their system in the last five years and are not yet in a phase of fruits production in the case of an orchard plantation. Due to this system’s youth and to the lack of one production, producers may not have the enough hindsight to evaluate their system and modify it. The second hypothesis is that producers’ motivations include long–term and hardly appreciable phenomenon such as a renewed nitrogen cycle. Indeed, without a time gap to observe positive or negative effect and without simple” indicators” to evaluate these effects, no modification is made on the system and the trajectory remains constant.

4. Discussion

4.1. Determining factors and trajectories extracted from the diversity

Previous results have shown a high variability of initial situations, motivations and systems design among producers in mixed orchard vegetables and mixed orchard animals systems. Then, the issue that arises is how to extract from this diversity some concepts, key points or even advices that may be generalizable and useful to as many producers as possible. The “target” recipients of these advices may be project holders or producers with less innovative agricultural systems who may not be willing to implement a mixed orchard system in the coming years. Once again, support has to adapt to the producers’ profiles and will and be as diverse as them.

When looking at the initial situations among interviewed producers, it may seem that three structural factors have the most powerful influence on the choice of a mixed orchard system: the initial production, the distribution circuit and the UAA.

In mixed orchard vegetables systems, the initial production or, in other words, the way the plot is arranged before the diversification can determine the amount of diversification and even the future of it. Indeed, the space between tree rows highly influences the revenue related to vegetables growing in determining the amount of vegetables that can grow and the duration during which vegetable growing can happen. A producer with narrow tree rows for example, may be forced to give up vegetables growing under the trees after some years and may find his revenue through another production. As a result, one key element that can be extracted from this assessment and shared with producers willing to implement a mixed orchard vegetable system is to adapt the distance between tree rows to their production goals. In the same way, mixed orchard vegetables systems may be difficult to implement from an existing orchard, especially if arranged as a monoculture and intensive one.

In addition to the initial production, the distribution circuit is also a decisive factor in mixed orchard systems. This interaction between agricultural system and distribution may be emphasized in two different ways: first, some technical choices such as species choices, production standard or practices choices influence products final quality and their commercial outlet. Second, some distribution circuit and their related specifications guide the practices implemented on the farm (Petit, 2013). In mixed orchard systems, both interactions can be identified: on one hand, as 17 producers interviewed on 20 owned the organic certification, products had different commercial outlet compared to conventional ones. On the other hand, producers selling a part of their production to wholesale companies (7/20) received strict guidelines about species choices and production amount.

The distribution circuit is consequently a decisive factor in mixed orchard system and especially in mixed orchard vegetables systems. Indeed, in the case of a producer planting fruit trees in his plot, vegetable growing become vital to earn revenue during the non–productive years of the fruit trees. However, we saw that producers in mixed orchard vegetables systems are mainly setup on small areas, less than 5 hectares for the majority of them. Producing enough vegetables in such a small surface to provide a wholesale distribution circuit seems unrealizable; direct distribution appears at the better solution. Moreover, having a dual production may represent an advantage to have access to direct distribution circuits such as CSA. In terms of replicability to producers willing to implement such a system, it seems that without a large area of vegetable growing in addition to the diversified plot to ensure enough production, direct distribution may represent the only suitable circuit.

In mixed orchard animals systems, it is more difficult to identify structural factors that can be used as guidelines or advices for producers willing to implement such a system. The economic hierarchization of the productions may be an explanation of this phenomenon. As a matter of fact, in mixed orchard vegetables systems, vegetables production is often the main source of revenue: factors influencing this production such as the space available and the commercial outlets are consequently essential. In the majority of mixed orchard animals systems encountered, animals do not represent an actual source of income, even if some producers sell their animals products such as eggs or sheep meat. If it is sometimes a choice of the producer not to consider animals as an economically valuable production, others producers are willing to earn a secondary income from animal production but are stopped by an unsuitable sector organization. This development limits imposed by the downstream part of the sector do not only concerns mixed orchard systems: it has also been identified as an obstacle to organic farming conversion (Latruffe et al., 2013). However, it can be assumed that the UAA may be considered as a decisive structural factor for producers in mixed orchard animals systems and may be anticipated for project holders. If the producer plan to have domestic animals grazing under fruit trees only during winter time, additional pasture lands are necessary. In the same way, producers who are in a self-sufficiency logic may plan to have cereal or fodder plots.

In accordance with what have been identified about motivations to organic farming conversion, initial motivations of producers in mixed orchard systems may nearly be sorted in economic, agronomic and ethical motivations. These motivations were not evenly distributed among producers: two-thirds of the producers in mixed orchard vegetables systems quoted the economic motivation while only 3 on 20 producers in mixed orchard animals system quote it. This distinction may be explained, as for the decisive structural factors, by the fact that the animal production do not represent an actual source of income for the majority of the producers. Another tendency can be underlined from these initial motivation when analyzed through the scope of the Efficiency-Substitution-Redesign framework: producers in mixed orchard animal system seem to state motivations closer to Substitution practices such as introduce domestic animals as pesticides and/or herbicides replacement. On the other hand, the ones in mixed orchard vegetables system stated motivations which may lead to a system Redesign like the process of creating new habitats or a renewed microclimate. Does it mean that the diversification which occurred in mixed orchard vegetables system is more robust? A sole motivation analysis is not enough to validate this assumption. Indeed, it does not integrate the complexity of farmer’s motivation and their integration into the socio-technical system: interests and motivations of the socio-technical system stakeholders (farmers, down-stream operators, support structures, public authorities, agro-supply firms, etc.) do not necessarily align, at least not in the short term (Meynard et al., 2012). Moreover, producers' motivations are generally analyzed after the transition or conversion and motivations which are given a few years after may not be those that would have been expressed if asked at the really beginning (Lamine and Bellon, 2009).

As shown in the previous results, a high diversity of system designs and agricultural practices, some adapted from non–diversified systems, are implemented by producers. The framework Efficiency-Substitution-Redesign framework (Hill and MacRae, 1995) is one of the possible approach to analyze these agricultural practices and their consequences on the system. However, as said in the results, the distinction between a Substitution practice and a Redesign related practice is often ambiguous. As an example, introduction of sheep to replace a mower or introduction of chicken as a "natural pesticide" against codling moth may seem at first Substitution practices but may also be closely linked to a system Redesign. As a matter of fact, if the introduction of these animals leads to a high number of adaptations such as reduction in fertilization and pesticides doses, fences building, growing of cereals to feed them, etc., the agricultural system may be considered as redesigned. This ambiguity about how to identify these steps (E, S and R) and how they may be combined by producers have already been identified (Navarrete et al., 2011).

Lamine (2011) identified that organic farming producers with more direct conversion trajectories had current practices which can be characterized as Substitution while producers with gradual trajectories were more often in a Redesign step which lead to a more robust transition. Can such assumption be made about producers in mixed orchard systems? Does the previously identified "trial-error" trajectory involve Substitution practices while the "gradual" one is leading to a Redesign? Does the "gradual" trajectory consequently more robust? At first sight, it may be assumed that producers associated with a breeder to have sheep grazing during winter time are using the animals' introduction as a Substitution practice. In accordance with Lamine (2011), these producers may also easily stop this association and come back to a classic orchard system: the diversification is consequently less robust. However, except this particular case, it is more difficult to draw such parallel for the other producers' agricultural practices and trajectories. An issue that arises is the characterization of Lamine producers' trajectories: direct trajectories for transition to organic farming which lasts less than 3 years and progressive for transition to organic farming which lasts 3-20 years, with antecedents such as use of biological control while in conventional (Lamine, 2011). If in the case of an organic farming conversion, a sequence of practices modification have to be made to achieve the transition. Only one practice, introduction of vegetables or animals under fruit trees, have to be realized to shift from a "classic" agricultural system to a mixed orchard system. In other words, what have been represented when drawing the trajectories is different: on one hand, the shift duration from a conventional system to an organic one and on the other hand, the evolution of the diversification level once the diversified system is implemented (Figure 21).

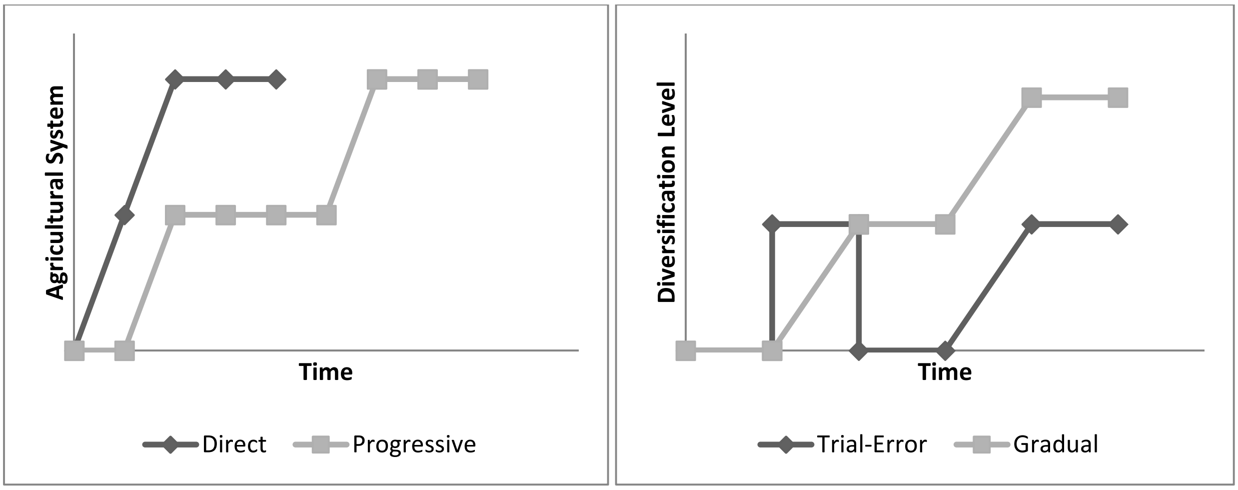

Figure 21: Comparison of producers' trajectories from Lamine (2011) and the ones drawn in this Master Thesis

This difference in terms of factors taken into account leads to difficulties to proceed at a parallel trajectories analysis through the scope of the ESR framework. Another analytical framework may be more suitable: the concept of "technical leap" theorized by Petit (2013) in her thesis. In this framework, a transition leads to practices modification or even practices abandonment and can be characterized as a "technical leap". Moreover, these "technical leaps" may have different amplitude according to the producers' initial situation and the objectives (Petit, 2013) .Contrary to Lamine (2011) who analyze the progressiveness between two fixed states (conventional and organic agriculture), this concept of technical leap amplitude is closer to the diversification level expressed in this Master thesis's trajectories. Indeed, the amplitude in the diversification level was empirically measured through a combination of the number of animal species and the number of animals in each species. Although not as objective as the way Petit measured technical leaps' amplitude, it allows to confirm one of her thesis' hypothesis which is that the high diversity of transition process may be sorted thanks to this framework. As a result, the thesis of Petit (2013) allows a relatively validation of the trajectory identification process used in this Master thesis but the trajectories' analysis is limited by the few numbers of producers and the lack of identified trajectory for producers in mixed orchard vegetables system.

4.2. Knowledge production and producers' support perspectives

Multiple determining factors, acting as incentives or obstacles can influence the producers' choices and implementation of mixed orchard systems. As an example, the initial system managed by the producer before the diversification and consequently plot arrangement, producer's knowledge and skills is one of these determining factors. However, a farm cannot be considered as an autonomous system operating in an isolated way: it takes place into the global functioning of a socio–technical system. The socio–technical system includes the whole stakeholders and organizations linked to the agricultural production, processing and distribution chain, plant variety breeding, research, technical consultancy, agricultural policies and civil society (Lamine et al., 2010). Research and producers' support are part of this socio–technical system and

consequently influence, in a positive or a negative way, producers along their choices of implementation and management.
Producers’ support is currently facing a shift in its paradigm: formerly focus on the diffusion of knowledge from research and technical structures to group of producers, farmers are now not only considered as receivers but as source of knowledge (Compagnone et al., 2009). This shift from a top–down to a horizontal then bottom–up process is particularly present in the case of mixed orchard systems in which a lack of scientific references have been acknowledged. More specifically, the horizontal process represents a phase in which producers shared and exchanged knowledge exclusively between them before that research and technical structures make profitable this producers’ knowledge to create references.

One of the main issues in knowledge production is the time gap between the knowledge production in itself and its application in the field by the producers. Without major consequences for producers in the case of a top–down knowledge production process, it can be problematic in mixed orchard systems. Whereas in the first case producers receive knowledge previously experimented and validated from research and technical structures, producers in mixed orchard systems implement their systems without formal knowledge diffusion, research and technical structures implementing experimentations as a second step. This time lag leads to a high risk taking behavior by producers, exacerbated by the innovative aspect of these mixed orchard systems. The concept of “technical leap” of Petit (2013) in case of transition to another agricultural system, supposed by its etymology this concept of risk. Previous results have shown that even with a knowledge gap about mixed orchard systems, as acknowledged by technical advisors and producers themselves and a high risk hypothesis, producers are more and more willing to implement their kind of mixed systems in their farms. Some of these producers, got over these limits, implemented a mixed orchard system and adapted it with fails and/or success. The practical and local knowledge acquired by these producers, based on their own experiences and on exchanges with other producers, should serve as the basis of the bottom–up knowledge production process. Indeed, according to Doré et al. (2011), farmers have to be considered as lay experts: experts because of their experience–based knowledge and lay because this knowledge is limited in scope. In the same way, producers willing to experiment are sometimes considered as “experienced practitioners” who possess a tacit knowledge based on long-term and reflected experience (Baars, 2011). Baars (2011) stated also that the externalization of this tacit and somehow hidden knowledge was particularly relevant in the development of innovative practices.

To deal with this lay expertise and the requests of producers in terms of knowledge, three points of view are currently emerging from research and support stakeholders:

- First, make profitable the risks taken by producers in implementing their mixed orchard systems and the knowledge consequently acquired while managing it. In other words, evaluate the results and the performances of these already existing systems to create references. According to the will of some producers and technical advisors, these references may be accessible through a “resource bank” sorting environmental, economic and agronomic results by productions, climate, soil types, etc.

The main issue is the choice of an evaluation method and the indicators associated. Producers and technical advisors are facing more than 2000 indicators coming from more than 100 evaluation methods (Bockstaller, 2013). Bockstaller (2013) defined also some questions to answer before choosing an evaluation method such as: What is the need of an evaluation? For whom the results will be useful? What do we want to evaluate? At which scales? What will be the technical constraints (time, money, skills, etc.)?

Two issues arise in the case of mixed orchard systems: the time available for the evaluation realization and the choice of the criterion to evaluate. In the previous results, workload have been identified by producers as one of the main limits, performance evaluation must consequently be easy and quick to not encroach on the time dedicated to fruit trees, vegetables or animals. The second issue is linked to the complexity of these systems: take every aspect into account will represent a huge amount of work and too many indicators to follow. The question which arises is: may it be better to follow generic indicators to have a global overview of the system’s performances or may it be better to select some very precise indicators while setting aside some others?

However, if the creation of references is promoted by some technical advisors and some producers themselves, others have a more contrasted point of view about it. Indeed, the issue raised by the ones perplexed about references is how to create references generalizable and transposable from such a variability of producers’ situations? Meynard et al. (2012) stated that due to the diversity of stakeholders and producers’ situations, a universal ideal farming system cannot exist. Support in a context of farming systems Redesign has to prepare for a diversity of solutions, but also and above all, to help the producers and other stakeholders to build their own systems, to adapt these systems to their own situation, relying on their own knowledge.

- Consequently, the second point of view among research and support structures is to compile producers’ testimonies with their own context, trajectories, success, failures without trying to generalize. Interested producers may be able to draw some parallels with their own situation and to select the practices they can apply in their farms. Rather than depend on concepts of reproducibility, generalization or causal explanation, the core of a case study or testimonies approach is locality, holism, specificity, or even singularity (Baars, 2011). As said previously when analyzing technical advisors’ interviewees, projects in favor of mixed orchard systems started quite recently and do not provide results yet. For now, collect producers’ testimonies and spread them through technical literature is one of the main action of support.

- Third, mixed orchard systems are related to a wide range of practices, from field design to breeding, involved a multitude of disciplines and stakeholders. In this context, it seems difficult to find a technical advisor skilled in all practices and sectors. Consequently, the “classic top–down” producers’ support where a technical advisor provide knowledge, technical diagnostic and expertise have been replaced by a principle of network facilitation (Albaladejo et al., 2009). As seen in the previous results, producers have multiple profiles, motivations and agricultural practices. Moreover, they are in touch with different stakeholders according to their productions, distribution circuit, etc. If this diversity may be problematic in the case of generic knowledge or references, the diversity is the key and the wealth of a successful network. In the case of mixed orchard systems, networks already exist as 18 interviewed producers on 20 quoted them as a source of information. These networks may be formal like the one called « Sustainable Orchards" facilitated by INRA since 2008 or informal such as chats with neighbors or at market places. If formal networks may allow knowledge diffusion and may attract more producers thanks to the structure influence, it is more difficult for informal networks. The Environmental and Economic Interest Groups (GIEE), created in 2014 in the framework of the French Agroecological Project may be a solution to give more influence to informal networks. These groups, recognized by the French State, gather producers who engage themselves in a project to modify or consolidate their practices with economic, environmental and social goals. To promote the development of these dynamics and to guarantee the sustainability, recognition and valuation of their new practices, producers will have to create partnerships and share their results with sector and territory stakeholders.

4.3. Methodology limits

The producers' sample have been deliberately conceived to be as diversified as possible in order to encounter different producers' motivations, practices and trajectories. By doing so, a high diversity of producers have been met, somehow "atypical" for some of them.

As 13 on 20 producers interviewed started their diversification process from a fruit tree system, orchards has been considered as the system of reference to compare interviewees' structural data to the national average ones. These national data are collected with surveys each 10 years by the French Ministry of Agriculture and the more recent ones are from 2010.

Three main characteristics can be compared between interviewed producers' structural data and the national ones: UAA, organic certification and marketing channels. First, the national UAA mean for specialized fruit production farms is 19ha whereas in our producers' sample, the UAA mean is 12ha with a median at 10,5ha which mean that half of the interviewees have less than 10,5ha of UAA (AGRESTE 2013). Second, national data stated that 11% of the 53000 orchards in France are certified organic agriculture (AGRESTE, 2013). In the producers' sample, this ratio ranged up to 85% with 17 producers out of 20. Finally, national data shown that one third of French orchards commercialize their production through short marketing channels (AGRESTE, 2013). Producers in our sample are above this ratio with 70% of them using direct selling such as CSA or markets and with 55% of them selling their fruits through local producers' shops.

The comparison of these three structural data: UAA, organic certification and marketing channels, highlights the fact that the producers' sample is not representative of the national French orchard. Indeed, in our sample, diversification process, whether in mixed orchard animal or mixed orchard vegetables system, happened on small, organic and with direct distribution circuit farms.

If the diversity of producers' profiles, even non representative of the national French producer's profile, and the wealth of information are essential to a qualitative analysis, it could be problematic for a quantitative and statistical analysis. As a matter of fact, the process of clustering may be distorted by a non–homogeneous distribution of modalities into a variable.

The producers' sample has also been distorted by the identification process of the producers. The latter ones have mainly been identified thanks to technical advisors who knew them or thought that they may be interested and interesting. As a result, it is "always" the same producers that are identified and considered as interesting because they are already involved with technical structures or because they are using their innovative practices as a way of marketing. This leads to a phenomenon of "overgrazing" at these producers' farms and to exclusion of producers that may be interested and interesting as well, maybe even more, but who are not identified. The difficulties of producers' identification when using research or technical structures relationship is not a recent phenomenon: in 1982-1983, French government started a sequence of reflections and debate about future perspectives of the French agriculture (Etats Généraux du Développement Agricole). These discussions enabled to highlight a high heterogeneity in the French agriculture and that at this time only 55% of the producers had regular contacts with support structures (Colson, 1986).

In the case of innovative agricultural systems such as mixed orchard ones, the issue is that it may be these producers, absent from the research and technical relationship, that mostly implement these innovative systems. A similar phenomenon has been highlighted in a Master thesis of 2014 focused on pest protection strategies in a Prunus species shift context. Producers who had less relationship with technical and/or support structure and networks were the ones implementing most alternative and innovative agricultural practices (Kouchner, 2014).

If the high variability in producers' initial situation, motivations, practices and trajectories have make difficult the statistical clustering process, the low number of interviewed producers (20) may have disturb the obtaining of robust statistical results. As an example, the chi-square tests realized on the motivations, practices and trajectories producers' clusters have shown no correlation between them. With a more homogeneous modalities distribution and/or a higher number of interviewed producers, these results may have been different. Given the importance of the factors size and homogeneity of the sample, a higher number of interviewees would ideally have been realized. However, the realization of these interviewees and the results analysis would have required much more time that a 6 months internship. Moreover, the realization of the interviewees via a close ended questionnaire to save time will exclude the wealth of the producers' discourse and significantly reduced the qualitative analysis.

Another limit due to the methodology chosen is the fact that the producers' answers are dependent on the way the questionnaire was written and on how the interview took place. Indeed, even with semi–structured interviewees, in which the producer is relatively free to talk about everything, some subjects may be ignored or botched whether due to the producer that willingly or not skipped the subject or to the interviewer that forgot a question or did not enough revitalize the discussion. Redoing an interviewee with the same interlocutors, the same questionnaire but with a different context may provide different results. It is why for some researchers, due to the way the data are collected and analyzed, a qualitative analysis is more “subjective” than a quantitative one. However, quantitative analysis is not perfectly objective either. When using a framework as R to realize MCA and HCPC, the choice of which variables will be descriptive or illustrative or the choice of the number of clusters for example, are left to the framework user according to what he expects as results.

Another issue aroused during the interviewees: initially, it was planned to draw the producers’ trajectories with the producers themselves, asking them to fill a historical timeline of their farm with all the structural and practices modification and the related dates. This exercise was difficult to realize with the producers and the timeline and trajectories were finally draw afterwards in extracting the relevant information from the interview’s transcriptions. Different hypothesis may explain the difficulties encountered during this process timeline conception with the producers: First, some producers may not remember the exact date of an event, the implementation of a new practice etc. A solution may be to not ask for precise date but to place the event in the timeline according to other events already written. Second, producers may not think to quote some system modifications because they happened so gradually that boundaries between the previous and actual system are ambiguous.

5. Conclusion

In a context of pesticides use reduction and agriculture ecologization, "innovative" orchard systems such as mixed orchard vegetables and mixed orchard animals systems are arousing producers and researchers curiosity.

Through semi–structured interviews with producers who had implemented such systems or are willing to, this Master thesis give an overview of their profiles, motivations, agricultural practices and trajectories.

As previously identified in studies focused on conversion to organic farming, the shift to a more sustainable agricultural system may be motivated by economic, agronomic and ethical reasons. These initial motivations as well as the wide range of agricultural practices and system designs highly influence their trajectories. The latter may be sorted in two types according to the "technical leap" amplitude implemented by producers when modifying their diversification level: trial–error and gradual trajectories. Detailed through the scope of the Efficiency-Substitution-Redesign framework, distinction between Substitution practices and the ones belonging to a system Redesign is ambiguous as well as the distinction between reversible and robust trajectories. A hypothesis may still be stated: a practice, which at first sight is a Substitution practice, may be part of a system Redesign process when associated with many other practices modification in the agricultural system.

This master thesis highlighted also the diversity of determining factors that can influence the producers' choices and implementation of mixed orchard vegetables and mixed orchard animals. The initial system managed by the producer before the diversification and consequently plot arrangement, producer's knowledge and skills is one determining factor. However, these determining factors cannot be considered only at the scale of the farm, farm being an integral part of a much wider socio–technical system including the whole stakeholders and organizations linked to the agricultural production, processing and distribution chain, plant variety breeding, research, technical consultancy, agricultural policies and civil society. If the distribution circuit and downstream regulations, especially sanitary regulations, are key factors to be considered, the knowledge and support available for producers remains decisive.

Despite an acknowledged lack of scientific references for both technical advisors and producers on these specific mixed orchard systems, producers, in a risk–taking behavior, dare to implement such systems, confronting the issues they may encounter. To deal with this situation, research and technical structures are facing two solutions, which may be combined for a higher efficiency:

Firstly, evaluate agronomic, economic and environmental performances of already implemented mixed orchards systems to create references transposable to future project holders. Different structures and projects such as the Smart Casdar (a national fund for agricultural research) are currently working on this references creation process and are dealing with the issue of suitable indicators choice. Secondly, considering the difficulty for technical structures to have qualified employees in each sector (fruit, animal and/or vegetables production), the advisor profession is shifting to a network facilitator profession. Networks, whether formal or informal, are a place to share and exchange producers' knowledge, experiences and advices. At the opposite of references which aim suitable and relevant results for as many producers as possible, knowledge shared in networks is specific at one farm context and must be adapted. The issue raised by these networks creation is the integration of many producers and representatives of each sector. Indeed, and especially in the case of mixed orchard animals systems, producers emphasized a non-suitable breeding sector organization unable to deal with their systems characteristics. Consequently, more projects have to be implemented in the next years to integrate breeding sector stakeholders in the discussions and even modify some regulations.

List of References

Agence Bio. 2014. La Bio dans les territoires. Fiches filières 2014.

Agreste. 2013. Structure des exploitations fruitières et légumières. Évolutions entre les recensements agricoles de 2000 et 2010. Agreste Les Dossiers 16:11-53.

Agreste. 2014a. Inventaire des vergers 2013

Agreste. 2014b. Enquête sur les pratiques phytosanitaires en arboriculture 2012. Agreste Les Dossiers 22:9.

Association Française d'Agroforesterie. 2008. L'Agroforesterie en France. Agroforesteries 1:7-10.

Association Française d'Agroforesterie. N.d. Agroforesterie et maraichage: produire et protéger.

Albaladejo, C., Girard, N. & Labatut, J. 2009. Du conseil agricole à l'animation d'un réseau d'apprentissage: le cas des safraniers du Quercy. *COMPAGNONE C., AURICOSTE C., LEMERY B., Conseil et Développement en agriculture. Quelles nouvelles pratiques*.

Baars, T. 2011. Experiential science; towards an integration of implicit and reflected practitioner-expert knowledge in the scientific development of organic farming. *Journal of agricultural and environmental ethics,* 24**,** 601-628.

Berelson, B. 1952. Content analysis in communication research.

Berg, B. L. & Lune, H. 2014. *Qualitative Research Methods for the Social Sciences,* Pearson Education, Limited.

Bernard, H. R. 2011. *Research methods in anthropology: Qualitative and quantitative approaches,* Rowman Altamira.

Bockstaller, C. 2013. Evaluation agri-environnementale et choix des indicateurs: acquis, enjeux et pistes.

Bonaudo, T., Bendahan, A. B., Sabatier, R., Ryschawy, J., Bellon, S., Leger, F., Magda, D. & Tichit, M. 2014. Agroecological principles for the redesign of integrated crop–livestock systems. *European Journal of Agronomy,* 57**,** 43-51.

Brown, M. W. 2012. Role of biodiversity in integrated fruit production in eastern North American orchards. *Agricultural and Forest Entomology,* 14**,** 89-99.

Cadillon, A., Fourrié, L. & Coulombel, A. 2011. Système multi-espèces: des arbres fruitiers et des PPAM pour améliorer la production légumière. *Alter Agri: bimestriel des agricultures alternatives,* 110**,** 29-31.

Cannell, M., Van Noordwijk, M. & Ong, C. K. 1996. The central agroforestry hypothesis: the trees must acquire resources that the crop would not otherwise acquire. *Agroforestry systems,* 34**,** 27-31.

Cerf, M., Omon, B., Chantre, E., Guillot, M., Le Bail, M., Lamine, C. & Olry, P. 2010. Vers des systèmes économes en intrants: quelles trajectoires et quel accompagnement pour les producteurs en grandes cultures.

Chantre, E. 2011. *Apprentissages des agriculteurs vers la réduction d'intrants en grandes cultures: Cas de la Champagne Berrichonne dans les années 1985-2010.* AgroParisTech.

Clark, M. S. & Gage, S. H. 1997. The effects of free-range domestic birds on the abundance of epigeic predators and earthworms. *Applied Soil Ecology,* 5**,** 255-260.

Colson, F. 1986. Le développement agricole face à la diversité de l'agriculture française. *Économie rurale,* 172**,** 3-9.

Compagnone, C., Auricoste, C. & Lémery, B. 2009. *Conseil et développement en agriculture: quelles nouvelles pratiques?,* Editions Quae.

Coulon, F., Dupraz, C., Liagre, F. & Pointereau, P. 2000. Étude des pratiques agroforestières associant des arbres fruitiers de haute tige à des cultures ou des pâtures.

Dawkins, M. S., Cook, P. A., Whittingham, M. J., Mansell, K. A. & Harper, A. E. 2003. What makes free-range broiler chickens range? In situ measurement of habitat preference. *Animal behaviour,* 66**,** 151-160.

Doré, T., Makowski, D., Malézieux, E., Munier-Jolain, N., Tchamitchian, M. & Tittonell, P. 2011. Facing up to the paradigm of ecological intensification in agronomy: revisiting methods, concepts and knowledge. *European Journal of Agronomy,* 34**,** 197-210.

Dupraz, C. 1994. Les associations d'arbres et de cultures intercalaires annuelles sous climat tempéré. *Rev. For. Fr,* 46**,** 72-83.

Eichhorn, M. P., Paris, P., Herzog, F., Incoll, L. D., Liagre, F., Mantzanas, K., Mayus, M., Moreno, G., Papanastasis, V. P., Pilbeam, D. J., Pisanelli, A. & Dupraz, C. 2006. Silvoarable systems in europe - past, present and future prospects. *Agroforestry Systems,* 67**,** 29-50.

Estevez, B., Domon, G. & Lucas, E. 2000. Le modele ESR (efficacite-substitution-reconceptualisation), un modele d'analyse pour l'evaluation de l'agriculture durable applicable al'evaluation de la strategie phytosanitaire au Quebec. *Courrier de l'Environnement de l'INRA*.

Geddes, P. & Kohl, R. 2009. Shropshire sheep control weeds in orchards. *Pesticides News*, 3-4.

Geniaux, G., Latruffe, L., Lepoutre, J., Mzoughi, N., Napoléone, C., Nauges, C., Sainte-Beuve, J. & Sautereau, N. 2010. Les déterminants de la conversion à l'agriculture biologique: une revue de la littérature économique.

Hilaire, C., Mathieu, V., Joly, T. & Mirabito, L. 2001. Red label chickens, a selective natural enemy in peach orchards. *Infos Ctifl (France)*.

Hill, S. B. & MacRae, R. J. 1995. Conceptual framework for the transition from conventional to sustainable agriculture. *Journal of sustainable agriculture,* 7**,** 81-87.

Hill, S. B., Vincent, C. & Chouinard, G. 1999. Evolving ecosystems approaches to fruit insect pest management. *Agriculture, ecosystems & environment,* 73**,** 107-110.

Häseli, A., Weibel, F., Brunner, H. & Müller, W. 2000. La culture biologique des vergers haute tige. FIBL.

IBIS 2010. Prés-vergers.

IDELE 2012. Des vergers, des vignobles, des brebis et des hommes. Témoignages d'éleveurs ovins d'Aquitaine conciliant cultures pérennes et surfaces fourragères. *Collection Théma.* Institut de l'Elevage.

Jose, S., Gillespie, A. & Pallardy, S. 2004. Interspecific interactions in temperate agroforestry. *New Vistas in Agroforestry.* Springer.

Karki, U. & Goodman, M. S. 2010. Cattle distribution and behavior in southern-pine silvopasture versus open-pasture. *Agroforestry systems,* 78**,** 159-168.

Kouchner, C. 2014. *Analyse des stratégies de protection dans un contexte de changement d'espèce fruitière Prunus en Rhône-Alpes : mise en perspective par rapport aux trajectoires d'exploitation et influences du système socio-technique.* Master Thesis, AgroParisTech.

Lamine, C. 2011. Transition pathways towards a robust ecologization of agriculture and the need for system redesign. Cases from organic farming and IPM. *Journal of rural studies,* 27**,** 209-219.

Lamine, C. & Bellon, S. 2009. Conversion to organic farming: a multidimensional research object at the crossroads of agricultural and social sciences. A review. *Agronomy for sustainable development,* 29**,** 97-112.

Lamine, C. & Bellon, S. 2010. *Transitions vers l'agriculture biologique*, Educagri Editions.

Lamine, C., Meynard, J.-M., Bui, S. & Messéan, A. 2010. Réductions d'intrants: des changements techniques, et après? Effets de verrouillage et voies d'évolution à l'échelle du système agri-alimentaire. *Innovations agronomiques,* 8**,** 121-134.

Lamine, C., Meynard, J. M., Perrot, N. & Bellon, S. 2009. Analyse des formes de transition vers des agricultures plus écologiques: les cas de l'Agriculture Biologique et de la Protection Intégrée. *Innovations agronomiques,* 4**,** 483-493.

Latruffe, L., Nauges, C., Allaire, G., Cahuzac, E., Garapin, A., Lemarié, S. & Poméon, T. 2013. Freins et incitations au développement de l'agriculture biologique en France: une analyse à plusieurs niveaux.

Lavigne, A., Dumbardon-Martial, E. & Lavigne, C. 2012. Les volailles pour un contrôle biologique des adventices dans les vergers. *Fruits,* 67**,** 341-351.

Magrini, M.-B. & Triboulet, P. 2012. Transition agroécologique, innovation et effets de verrouillage: le rôle de la structure organisationnelle des filières. *Cahiers Agricultures,* 21**,** 34-45.

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. *Agronomy for Sustainable Development,* 29**,** 43-62.

Meynard, J.-M., Charlier, A., Charrier, F., Fares, M. h., Le Bail, M., Magrini, M.-B. & Messéan, A. 2015. La diversification des cultures: comment la promouvoir? *Notes et études socio-économiques.* CENTRE D'ÉTUDES ET DE PROSPECTIVE - SERVICE DE LA STATISTIQUE ET DE LA PROSPECTIVE

Meynard, J.-M., Dedieu, B. & Bos, A. B. 2012. Re-design and co-design of farming systems. An overview of methods and practices. *Farming Systems Research into the 21st century: The new dynamic.* Springer.

Navarrete, M., Bellon, S., Geniaux, G., Lamine, C., Penvern, S., Sautereau, N. & Tchamitchian, M. 2011. L'écologisation des pratiques en arboriculture et maraîchage. Enjeux et perspectives de recherches.

Naverrete, M., Bellon, S., Geniaux, G., Lamine, C., Penvern, S., Sautereau, N. & Tchamitchian, M. 2011. L'écologisation des pratiques en arboriculture et maraîchage. Enjeux et perspectives de recherches.

Newman, S. 1986. A pear and vegetable interculture system: land equivalent ratio, light use efficiency and productivity. *Experimental agriculture,* 22**,** 383-392.

Pedersen, H. L., Olsen, A., Horsted, K., Korsgaard, M. & Pedersen, B. Combined production of broilers and fruits. Proceedings 11th International Conference on Cultivation technique and Phytopathological problems in Organic Fruit-Growing, 2004. 131-136.

Penvern, S., Simon, S., Bellon, S., Alaphilippe, A., Lateur, M., Lauri, P. E., Dapena, E., Jamar, L., Hemptinne, J. L. & Warlop, F. 2012. *Sustainable orchards' redesign: at the crossroads of multiple approaches*.

Petit, C. 2013. *Transitions des exploitations agricoles vers l'agriculture biologique dans un territoire: approche par les interactions entre systèmes techniques et de commercialisation. Application aux aires d'alimentation de captages en Île-de-France.* AgroParisTech.

Petit, M., Reau, R., Dumas, M., Moraine, M., Omon, B. & Josse, S. 2012. Mise au point de systèmes de culture innovants par un réseau d'agriculteurs et production de ressources pour le conseil. *Innovations agronomiques,* 20**,** 79-100.

Pottier, L., Sagot, E. & Rodriguez, A. 2002. Pâturage hivernal de la brebis, effets sur la prairie et les performances animales.

Ridier, A. & Kephaliacos, C. 2006. Modélisation de la diversification des exploitations agricoles. Application aux élevages laitiers combinés à des vergers en agroforesterie/Modelling diversified production systems: a case study of dairy farms combined with agroforestry orchards. *Ingénieries***,** 47-61.

Sanderson, M. A., Archer, D., Hendrickson, J., Kronberg, S., Liebig, M., Nichols, K., Schmer, M., Tanaka, D. & Aguilar, J. 2013. Diversification and ecosystem services for conservation agriculture: Outcomes from pastures and integrated crop–livestock systems. *Renewable agriculture and food systems,* 28**,** 129-144.

Sauphanor, B., Simon, S., Boisneau, C., Capowiez, Y., Rieux, R., Bouvier, J.-C., Defrance, H., Picard, C. & Toubon, J.-F. 2009. Protection phytosanitaire et biodiversité en agriculture biologique. Le cas des vergers de pommiers. *Innovations agronomiques,* 4**,** 217-228.

Sautereau, N., Penvern, S., Petitgenet, M., Fauriel, J. & Bellon, S. 2011. Concilier des performances pour une agriculture durable-L'agriculture biologique comme prototype.

Schroth, G. 1998. A review of belowground interactions in agroforestry, focussing on mechanisms and management options. *Agroforestry systems,* 43**,** 5-34.

Smith, J., Pearce, B. D. & Wolfe, M. S. 2013. Reconciling productivity with protection of the environment: Is temperate agroforestry the answer? *Renewable Agriculture and Food Systems,* 28**,** 80-92.

Stamps, W. & Linit, M. 1997. Plant diversity and arthropod communities: implications for temperate agroforestry. *Agroforestry Systems,* 39**,** 73-89.

WorldBank 2006. *Enhancing Agricultural Innovation: How to go Beyond the Strengthening of Research Systems,* The World Bank Washington, DC, USA.

Table of Appendices

Appendix 1: Literature Review

- **"Lock–in" effect**

The conventional agricultural production system requires the use of pesticides to ensure production in satisfactory quantity and quality, in line with market and consumers expectations. However, if the use of these products can bring benefits for agricultural production systems, these can be the cause of negative effects on the human health and the environment and may incur costs to society The implementation of European legislation towards a more "eco–friendly" agriculture as well as various national action plans may bring major changes to agricultural practices within the coming years (Lamine, 2011). Indeed, in 2003, the CAP shifted from voluntary to mandatory integration of agri–environmental practices by introducing principles of cross–compliance. In parallel, since 2007 in France, a national and global effort to reduce use of chemical plant–protection inputs in French agriculture, named Ecophyto program, is implemented. Its main goal is to cut the nationwide use of pesticides by 50% in the space of ten years, if possible while at the same time maintaining agricultural production at a high level in both quality and quantity terms. To achieve this objective, French government implemented different kind of actions: dissemination as widely as possible among users and their advisers information on known techniques for economic use of plant protection products, improvement of the information given to farmers in real time on the distribution of crop diseases and pests with a goal of improve the targeting of treatment, training sessions to ensure that every actor in the chain is fully competent in relation to plant protection inputs, promotion of agricultural research into crops that require less chemical protection and communication of results of that research to the widest possible audience.

Despite the rise of these environmental issues and their recent translation into public policies, ecologization of agricultural practices is still difficult to implement at large scale due to a "lock–in" effect in the socio–technical system. The socio–technical system can be defined as the whole stakeholders and organizations linked to the agricultural production, processing and distribution chain, plant variety breeding, research, technical consultancy, agricultural policies and civil society (Lamine et al., 2010). A "lock–in" effect can refer to a choice of technique production, of a product, a standard, or a paradigm, which become the reference in the whole socio–technical system. This choice has become such a standard that it seems difficult to change it, even if there are other alternatives that could be more effective which limit the diffusion of innovations (Magrini and Triboulet, 2012). The persistence of a "lock–in" effect is mainly due to self–reinforcement mechanisms as explained by Magrini and Triboulet (2012). First, increase in the number of a practice users enhance the knowledge produced about this practice and contribute to increase in yields, encouraging farmers to continue with this practice. Second, this practice became the main paradigm in agricultural education and knowledge of technical advisors which strongly influence farmers' ability to choice and use an alternative practice. Finally, the agricultural sector and especially the contractual relationship between stakeholders may limit farmers' tendency to shift to another practice. It is indeed difficult to imagine a farmer shifting its production system if he does not find a financial counterpart that reinforces it in this shifting choice (Magrini and Triboulet, 2012).

- **Case study of conversion to organic agriculture and Integrated Pest Management**

In the last decades, Organic agriculture and Integrated Pest Management (IPM) have managed to spread among farmers, disregarding the socio–technical "lock–in" effect. Studying the adoption of these more sustainable agricultural practices might help in identifying the conditions for achieving a robust transition toward a more "eco–friendly" agriculture, transition that most farmers will probably have to make in the future. Two kinds of studies have been made about adoption of organic agriculture and IPM: some based on the decisive factors and motivations behind the adoption and some others based on farmers' trajectories and their changes in conceptions and practices over time (Lamine, 2011).

Géniaux et al. (2010), stated that the organic agriculture conversion is a complex decision where interact not only farm characteristics, the agricultural sector and its market rules, distribution networks, agricultural policy, the cost and the conditions of the organic certification, but also the characteristics of the farmers, their agricultural past experiences, their education and their sensitivity to environmental issues. It should be noted that among these complex interactions, motivations and decisive factors have to be differentiate. Following a literature review, the main motivations for organic agriculture conversion are: agronomic motivations such as soil quality, erosion limitation and products quality, ethical motivations, environmental motivations with the idea that organic agriculture can deal with pollution issues and economic motivations (Geniaux et al., 2010). On the other hand, decisive factors can be sorted in three categories: factors intrinsic at the producer such as the age, the education level or the agronomic experience, factors intrinsic at the farm such as the farm structure and its economic results and factors external such as market regulations or localization of the farm (Geniaux et al., 2010, Latruffe et al., 2013).

According to Lamine (2009), studies focused on motivations and decisive factors are centered on the "why" of the adoption of more sustainable agricultural practices whereas an approach in terms of trajectories enables to track the complexity of the factors and background that led the farmers where they are today. In others words, it centered on "how we come" to the adoption or conversion. To describe the processes of transition and characterize the changes in the agricultural practices, a framework designed by Hill and Mac Rae (1995): the Efficiency–Substitution–Redesign framework has been used. It has been created to analyze the whole process of transition from conventional to sustainable agriculture but it was mainly used in pest management (Hill and MacRae, 1995, Hill et al., 1999, Estevez et al., 2000). The Efficiency step consists on the use of decision support tools (detection kit diseases, epidemiological models, visual thresholds of treatment) and a curative use of pesticides instead of a preventive one (Lamine et al., 2009, Estevez et al., 2000, Sautereau et al., 2011). The Substitution step consists of replacing harmful chemical inputs by bio pesticides or biological control practices (Estevez et al., 2000). However, these two strategies of pesticides use limitation do not fundamentally undermine the functioning of the cropping systems neither its design (Naverrete et al., 2011). The ecological relevance of these two strategies is also put into question: on one hand, a limited use of environmentally harmful chemical inputs and on the other hand, alternative inputs with minor but still existing environmental effect (Sautereau et al., 2011, Estevez et al., 2000). Indeed, it has been observed an increased resistance phenomenon of codling moth toward the granulosis virus

(CpGV), which is one of the main tool in organic fruit production to fight against this pest (Sauphanor et al., 2009).

The key may be in the Redesign step of Hill and Mac Rae's framework which involve a paradigm shift: recognize the causes of system unsustainability and prevent it by the transformation of system functions and structure to a more holistic way through the construction of diversified production systems instead of fighting these problems by the application of external inputs. Thus, diversity will promote interactions between components of the 'agro–eco–system', enhance natural regulation processes, and therefore help sustaining fertility, productivity and resilience (Hill and MacRae, 1995, Penvern et al., 2012, Lamine, 2011). Hill and Mac Rae (1995) summarize this by writing: *"The redesign stage is achieved when the causes of the problems are recognized, and thereby prevented, being solved internally by site and time–specific design and management approaches instead of by the application of external inputs. By making the farm more ecologically and economically diverse, greater resource self–reliance and resilience are achieved"*.

Two main kinds of trajectories of organic agriculture conversion have been highlighted: on one hand, a "direct" conversion where farmers decided to convert quite suddenly following a health–related incident or economic difficulties for example. On the other hand, a more progressive conversion where first tries of sustainable agricultural practices occurred long before the actual conversion to organic farming (Lamine et al., 2009, Lamine, 2011). By putting in parallel these types of trajectories with the "input substitution" and "system redesign" paradigms, Lamine stated that farmers with more direct trajectories (5 out of 12 producers interviewed) had current practices which can be characterized as a substitution of conventional inputs by biological ones. This "substitution" step still enables reversibility to the transition. In the case of progressive trajectories (7 out of the 12 producers), it was possible to highlight the three main steps of Hill and Mac Rae's framework (1995): a phase of input reduction or efficiency (E) while still in conventional agriculture, a phase of substitution (S) where some chemical inputs are replaced by biological ones and a phase of system redesign (R) in which they are still in. The implementation of a system redesign paradigm usually leads to more robust transition (Lamine et al., 2009, Lamine, 2011).

Lamine (2011) identified three main sets of conditions for having robust transition process toward ecologization of agriculture: antecedents along farmers' trajectories, inclusion of food distribution and consumption practices and collective dynamics. First, antecedents along farmers' trajectories may be reduction in inputs, introduction of alternative crop protection methods or other environmentally friendly practices prior the transition process, the organic farming conversion in the case study of Lamine. These prior experiences provide a practical basis for a progressive change in farmers' conceptions. Second, the inclusion of food distribution and consumption practices in the conception of these transitions means that all the stakeholders of the sector have to be part of this transition process: producing with more sustainable and environmentally friendly practices in a system driven by product aspect and standardization due to the "consumer demand" for perfect and regular products is nearly impossible (Lamine, 2011). Then, collective dynamics, involvement in networks, enables producers in a transition process to clearly define the practices they already had, to compare their practices and results to the others producers, to learn from the experience of others, to talk about their technical impasses and seek solutions. As a result, these collective dynamics make transition more robust and less reversible (Lamine et al., 2009).

- **Producers' support**

The analysis of farmers' trajectories in a context of shifting to a more sustainable practice presented three phases in this shift: awareness raising, experimentation and adoption. Experimentation allows the farmers to assess feasibility and time required of the practice and can be realized on variable space and time (Cerf et al., 2010). In the field study of agricultural knowledge production and adoption of technical innovation by farmers, the paradigm during the last decades has been a downward transfer of knowledge from research to the farmers. This paradigm have also been called "top–down" approach (WorldBank, 2006, Chantre, 2011). Technical advisors refer to it as "technical support" in which they disseminate the latest scientific and technical knowledge to farmers (Cerf et al., 2010).

However, farmers do not rely exclusively on the results of agricultural research; they also use a much wider knowledge, based on their own experiences and on exchanges with other farmers and advisers (Doré et al., 2011, Petit et al., 2012). This leads to a new paradigm, also called "bottom–up" process, in which agricultural knowledge is a product of empirical knowledge form farmers or a product of a co–development process associating tightly researchers and farmers (Chantre, 2011). This "bottom–up" paradigm is not aiming at replacing the "top–down" paradigm: it can even help to enlarge current agronomic knowledge. Indeed, even in the absence of appropriate knowledge produced by research, farmers still managed to innovate to meet their needs in terms of productivity or environmental sensitivity. The experience–based knowledge they develop can therefore fill in some of the gaps in the research–produced agricultural knowledge (Doré et al., 2011). Technical advisors have to adapt to this new paradigm in which scientific knowledge is missing and in which farmers may know more than them. To do it, they implement sharing tools like farmers networks and substitute scientific knowledge by farmers' knowledge based on personal experimentations (Cerf et al., 2010).

- **Context of French fruit production**

In 2013, fruits orchards represented approximately 122 000 hectares on the French territory (Agreste 2014a). More than one quarter of this area was dedicated in 2010 to apple production which is consequently the first fruit produced in France just before nuts, plums and apricots (Agreste 2013). Although representing a small percentage of the French Utilized Agricultural Land (approximately 1%), orchards were estimated to use 21% of the total amount of pesticides sold in France and with treatment frequencies 10 times higher than in cereals systems (Sautereau et al., 2011).

This massive use of pesticides in French orchards is mainly due to agronomic and socio–economic aspects. First, fruit trees are perennial crops which create difficulties for breaking pests' life cycle with crop rotation systems. Secondly, retailers and consumers ask for cheap fruits without any imperfections which limit the pest level tolerance of producers and accentuate the systematic use of pesticides (Sautereau et al., 2011, Lamine and Bellon, 2010).

Even if organic fruits production in France represented 20 000 hectares (approximately 16% of French orchards) in 2012, the mean number of pesticides treatments remained high: approximately 35 treatments for apple production, between 10 and 20 for the other fruits production (Agence Bio 2014, Agreste 2014b). According to Lamine and Bellon (2010) and many other studies, pesticides have an economic, environmental and social cost not only for the producer but for all the society. The high dependency on pesticides use in orchards and particularly in apple production highlights the need for a transition of orchard system toward more sustainability.

Nowadays two prototypes of diversified orchard systems are arousing farmers, technicians and scientist's curiosity: mixed orchards–vegetables and mixed orchards–animals systems. Considering their complexity and the "models" diversity found in these systems, few references have yet been published about these diversified orchard systems. However, as they associate trees with crop or animals components, their main principles, potential benefits and limits could be related to those of agroforestry and integrated crop–livestock systems.

- **Mixed Orchards Vegetables Systems**

Mixed tree and crop systems are mainly deliberately designed to optimize the use of spatial, temporal and physical resources, by minimizing negative interactions such as competition while maximizing positive interactions between the components of the system (Jose et al., 2004). A central hypothesis in mixed tree and crop systems is that productivity is higher compared to monocropping systems due to complementary interactions, either above ground or below ground, in resource–capture (Smith et al., 2013).

The presence of trees modify light interception but also microclimate for the associated crop in terms of temperature, humidity and wind (Smith et al., 2013, Jose et al., 2004). However, consequences of these modifications differ with the flora's development cycles. If trees and crops such as vegetables develop at different times of the year, annual total yield (total biomass) of the plot will increase due to the higher efficiency in light use. Indeed, the vegetables will be able to grow through winter and spring before the trees come into leaf, taking advantage of the whole light (Cannell et al., 1996, Eichhorn et al., 2006). If trees and crops develop at the same time, the situation became more complex. On one hand, trees limit the speed of the wind and increase the humidity around them by their own transpiration. Thus, it helps to limit the temperature falls and protect underlying crops from heat stress or drying by reducing their evapotranspiration (Association Française d'Agroforesterie, n.d.). On the other hand, shade created by the trees can also be identified as a factor of reduced yield (Jose et al., 2004). However, this negative response to shading may depend on the carbon fixation pathway of the associated crop: unlike C4 species such as maize or sorghum, C3 species, like vegetables grown in temperate climate, maintain a constant photosynthetic rate from 50% to 100% of full sunlight (Jose et al., 2004). Thus, in mixed orchards–vegetables systems, C3 vegetables species will mainly take advantage of this microclimate modification created by the trees.

Orchard–vegetables combination is a potentially useful practice to reduce pest problems because this association may provide greater niche diversity and complexity than monocropping (Stamps and Linit, 1997). The improvement of orchard plant diversity may affect insect communities living within the orchard, including orchard pests, disease vector arthropods but also pollinators, predatory and parasitoid arthropods, through an increase in the resource range, i.e. habitat, shelter and food. Indeed, Brown (2012) compared biodiversity levels and their effects on pest pressure, yields and pesticides use between apple and peach trees monoculture plots, polyculture fruit trees plot (apple, pear, peach and cherry combined in a stratified pattern) and with or without companion plants between the tree rows. Results showed that more predatory insects were present in polyculture plots and that the most diverse treatment (polyculture combined with companion plants) had the greatest proportion of both herbivores and predators. The study concluded that the creation of a biologically diverse orchard can produce high quality fruit without sacrificing yield, no effects on performance of the apple and peach trees were observed, while also reducing insecticide use (Brown, 2012). In 2010, Simon et al. looked at 30 case studies on the effects of increased orchard plant diversity (flower strips, plant cover, bushes, hedgerows or even interplant fruit trees) on pest control. In more than half of these case studies, the effect on pest control was positive which emphasized the fact that plant diversity manipulations generally aimed at favoring either predator or parasitoid beneficial species .

Another central hypothesis in mixed tree–crop systems is that occupation of different soil strata with their respective root systems may lead to higher efficiency in the use of soil resources such as water and nutrients (Schroth, 1998)(Schroth, 1998)(Schroth, 1998). Although many researchers have reported the highest tree–root density within the top 30cm of soil, highlighting the potential competition between trees and associated crops, Schroth (1998) suggested that plants themselves tend to avoid excessive root competition by spatial segregation. As a consequence, associated plant species in mixed tree–crop systems develop vertically stratified root systems, leading to complementarity in the use of soil resources. This situation of vertically stratified root systems is likely to occur in mixed orchard–vegetables because fruit trees, and particularly apple trees, possess highly plastic root systems which readily respond to changes in their growth conditions (Schroth, 1998)(Schroth, 1998)(Schroth, 1998). Once this stratification is created, the tree–crop combination should enables a better use of the available water and nutrients by reducing evapotranspiration under the trees increasing air and soil humidity for the associated crop, by accessing water and nutrients at depth and by creating a ‘safety net’ in which the tree roots absorb nutrients which have not been taken up by the shallower–rooted crops and have therefore been leached out of the topsoil (Schroth, 1998, Cannell et al., 1996, Jose et al., 2004).

By promoting a closed system with internal recycling of nutrients (nutrients are accessed from lower soil strata by tree roots and returned to the soil through leaf fall and dead roots) mixed tree–crop systems enhance soil organic matter levels, soil physical properties and reduce reliance on external inputs. Thus, several studies have recorded higher microbial diversity and increased enzyme activity in mixed tree–crop systems attributable to higher litter quality and quantity than in monocropping systems (Cannell et al., 1996, Smith et al., 2013).

Beyond agronomic and ecological benefits, a mixed orchard vegetables system has to be economically profitable to be adopted by producers. As said previously, mixed tree and crop systems aim at optimize the use of spatial, temporal and physical resources by producing different goods in the same plot and during the same period of time. This optimization strategy could be the result of different process and producer's choices: valorization of limited land available, search for income stability and risk mitigation, response to short commercialization circuit demand by consumers, will of decreasing chemical inputs or increasing biodiversity … (Dupraz, 1994, Malézieux et al., 2009, Cadillon et al., 2011). Each kind of approach should result in distinct priorities and objectives for the design and the management of mixed orchard–vegetable system. However, to be economically profitable, the productivity, market opportunities and ecosystem services must be higher than the constraints linked to a mixed orchards–vegetables system such as requirement for both orchards and vegetables production knowledge, mechanization constraints, delay in fruit production start compare to conventional orchards, management of two harvest in the same plot … (Coulon et al., 2000)

While ecosystem services are difficult to assess, even if there has been recently considerable interest in placing a monetary value on the delivery of these ecosystem services, productivity of a mixed tree–crop system can be easily calculated with the land equivalent ratio (LER). It compares the yields obtained by growing two or more species together in a mixed system with yields obtained by growing the same crops as monocropping. A LER greater than 1 indicates that mixed systems are advantageous, whereas a LER less than 1 shows a yield disadvantage (Smith et al., 2013, Malézieux et al., 2009). In mixed orchard–vegetables system, studies usually showed advantageous LER such as in this experiment from a pear orchard/radish system with mean LER of 1.2 over the 60-year rotation (Newman, 1986)(Newman, 1986)(Newman, 1986)(Newman, 1986)(Newman, 1986)(Newman, 1986)(Newman, 1986)(Newman, 1986)(Newman, 1986)(Newman, 1986)(Newman, 1986)(Newman, 1986)(Newman, 1986)(Newman, 1986)(Newman, 1986)(Newman, 1986)(Newman, 1986)(Newman, 1986)(Newman, 1986).

- **Mixed Orchard Animals Systems**

As in mixed tree–crop systems, mixed orchard–animals systems aimed to optimize the use of spatial, temporal and physical resources, by minimizing negative interactions such as competition while maximizing positive interactions between the components of the system (Jose et al., 2004). These interactions can be classified into two categories: effects of the vegetal component (and its associated components such as soil, microclimate, biodiversity …) on the animals and effects of the animals on the vegetal component. This dichotomy highlights two paradigms widespread among farmers in mixed orchard–animals systems: fruit producers willing to integrate animals under their trees and breeders willing to make their animals grazed under trees.

Modification of the landscape and of the microclimate by trees provides many benefits for livestock (Smith et al., 2013). As an example, cattle are particularly sensitive to heat stress and by providing shade and higher humidity levels, trees can reduce the energy needed for regulating cattle body temperatures, and so result in higher feed conversion and weight gain. In the same way, during cooler months, trees provide valuable protection from the wind for livestock, particularly for the weakest animals such as new–born or freshly shorn sheep (Smith et al., 2013). Some livestock species such as gallinaceous birds originally lived in forests where they can hide for predatory birds under trees. Fruit trees in orchards could consequently offer protection from aerial predators and increase poultry welfare (Pedersen et al., 2004, Smith et al., 2013). Some studies observed ranging behavior in commercial free–range broiler systems and found that the number of birds going outside and their dissemination was positively or negatively correlated with the percentage tree cover on the range (Dawkins et al., 2003, Hilaire et al., 2001).

In mixed orchards–animals systems, using space under fruit trees as a complementary pasture can extend the annual grazing cycle of livestock or enable a better grazing rotation (IDELE, 2012). Indeed, it has been showed that sheep winter grazing lead to animal performances similar, if not better, than those obtained by sheep in winter sheepfold. This use of winter grass allows a reduction of 70% of winter forage need for the producer (Pottier et al., 2002). In the same way, livestock can valorize some by–products and crop residues that are not suitable for human consumption such as fruits fell on the ground or leaves after pruning. This valorization can also reduce the cost of feeding livestock for the producer (Bonaudo et al., 2014, Sanderson et al., 2013).

The grazing or ranging of animals in orchards leads to deposition of feces and urine that can be used for beneficial plant development and to maintain soil fertility (Sanderson et al., 2013, Bonaudo et al., 2014). It has been showed that thanks to the modification in microclimate, cattle dispersion in a pasture under trees is higher than in an open grassland which enables a uniform nutrient cycling within the system (Karki and Goodman, 2010).

Effectiveness of poultry to deal with pests and weeds in orchards has also been analyzed and the results were mainly positive. Indeed, it has been shown that chickens and geese were able to reduce spider, harvestmen, polydrusus, apple saw fly and pear midge population when put under fruits trees. No population reduction was observed for ground beetle, rove beetle and forficula which can be explained by the nocturnal activity pattern of these pests (Clark and Gage, 1997, Pedersen et al., 2004, Hilaire et al., 2001). Concerning weeds, poultry and particularly geese have been recognized as a promising method for controlling weeds in orchards but leading to an increased proportion of unpalatable species in the herbaceous cover (Lavigne et al., 2012). Not only poultry has been identified as efficient to control weeds in orchards: it has been studied that the grazing of Shropshires sheep, a Britain’s breed which do not strip bark from the trees, kept the ground vegetation tidy and short and made routine mowing unnecessary (Geddes and Kohl, 2009). Moreover, it has been shown that ingestion by poultry, sheep or pigs of leaves and damaged or over–ripe fruits left on the floor at the harvest represent an efficient prophylactic measure against inoculums such as apple scab and that livestock trampling may destroyed vole tunnels (Häseli et al., 2000, Hilaire et al., 2001, Geddes and Kohl, 2009). Integration of animal under the cover of fruit trees is consequently a promising practice to reduce pesticides and herbicides inputs. However more research still has to be done to analyze and deal with potential side effects such as soil compaction or fruit contamination by feces.

As for mixed orchard–vegetables, mixed orchard–animals systems have to be economically profitable to be adopted by producers. Once again, this profitability is the result of a balance between productivity, market opportunities and ecosystem services on one hand and constraints linked to this specific system on the other hand. These constraints could be: need of knowledge in both breeding and fruit production, delay in fruit production start, mechanization constraints, physical protection of young trees, adaptation of grazing and treatments or harvest planning … (Lamine and Bellon, 2010, Coulon et al., 2000, Häseli et al., 2000). Few researchers have studied the profitability of mixed orchards–animals systems and in France or Switzerland these studies focused on “pré–vergers”, a traditional system combining apple production and cattle. They concluded that lower fruit yields compared to apple monoculture systems, 10-15 tons per hectare compared to 25-100 tons per hectare (IBIS, 2010), is compensated by two phenomenon: market opportunities with higher prices for apple production such as organic label, “pré–verger” labels or AOP/IGP appellations on one hand and higher productivity per unit of land on the other hand (Coulon et al., 2000, Ridier and Kephaliacos, 2006, Häseli et al., 2000). Indeed, in the same way as Land Equivalent Ratio calculation method, it has been studied that by producing fruits, milk or meat and even sometimes wood on the same plot, total productivity is higher of 6-15% than the same productions in monocropping systems (IBIS, 2010).

Appendix 2: World Of Knowledge Database Requests

Requests	Number of Results	Request's Modifications
Mixed Orchard Animals Systems		
TS=((orchard* OR "fruit production" OR arboriculture) AND (animal OR chicken* OR poultry OR geese OR pig? OR sheep* OR "silvopastoral system*" OR grazing OR agroforest*))	23710	
TS=((orchard? OR **"orchard meadow?"** OR "fruit production" OR arboriculture) AND (animal OR chicken* OR poultry OR geese OR pig? OR sheep* OR "silvopastoral system*" OR grazing))	17074	Addition and/or suppression of terms to describe the system
TS=((orchard? OR "orchard meadow?" OR "fruit production" OR arboriculture) AND **("farm animal?" OR "meat animal?" OR "grazing animal?"** OR chicken* OR poultry OR geese OR pig? OR sheep? OR grazing))	598	Addition of terms to define the kind of animals to take into account
TS=((orchard? OR "orchard meadow?" **OR "organic fruit production"** OR arboriculture) AND ("farm animal?" OR "meat animal?" OR "grazing animal?" OR chicken* OR poultry OR geese OR pig? OR sheep? OR grazing **OR hortipastoral* OR "horti-pastoral*"**))	464	Addition of terms to describe the system
TS=((orchard? OR "orchard meadow?" OR "organic fruit production" OR arboriculture **OR "fruit tree?"**) AND ("farm animal?" OR "meat animal?" OR "grazing animal?" **OR broiler?** OR chicken? OR poultry OR pig? OR sheep? **OR "small ruminant*"** OR grazing OR hortipastoral* OR "horti-pastoral*")) **NOT TS=(manure OR "poultry litter")**	543	Addition of terms to describe the system Addition of terms to define the kind of animals to take into account Exclusion of literature related to manure and poultry litter
TS=((orchard? OR "orchard meadow?" OR "organic fruit production" OR arboriculture OR "fruit tree?") **NEAR/2** ("farm animal?" OR "meat animal?" OR "grazing animal?" OR broiler? OR chicken? OR poultry OR pig? OR sheep? OR "small ruminant*" OR grazing OR hortipastoral* OR "horti-pastoral*")) NOT TS=(manure OR "poultry litter")	57	
Mixed Orchard Vegetables Systems		
TS=((orchard? OR "fruit tree?") AND (vegetable* OR "market garden*"))	1916	
TS=((orchard? OR "fruit tree?") NEAR/5 (vegetable* OR "market garden*") NEAR/5 **("inter*" OR "inside" OR**	49	Addition of localization related prepositions

"between" OR "under" OR "associated*" OR combin* OR mix*))		
TS=((orchard? OR "fruit tree?" OR arboriculture **OR apple* OR pear OR peach OR apricot OR plum**) NEAR/5 (vegetable* OR "market garden*" **OR lettuce? OR tomato* OR carrot* OR cabbage OR bean* OR pepper* OR zucchini OR eggplant OR onion* OR potato* OR radish**) NEAR/5 ("intercrop*" OR interrow* OR "inside" OR "between" OR "under" OR "associated*" OR combin* OR mix*)) **NOT TS=("peach potato aphid*")**	424	Addition of fruits and vegetables species names
TS=((orchard? OR "fruit tree?" OR "fruit grow*" OR arboriculture OR apple* OR pear OR peach OR apricot OR plum) NEAR/5 (vegetable* OR "market garden*" OR lettuce? OR tomato* OR carrot* OR cabbage OR bean* OR pepper* OR zucchini OR eggplant OR onion* OR potato* OR radish OR melon OR squash) NEAR/5 **("intercrop*" OR interrow* OR "associated crop" OR "crop association" OR "mixed crop*" OR "multilayer crop*" OR "alley crop*" OR "row crop*" OR "combined crop*" OR permacultu* OR milpa OR "food forest*" OR "plant mixture" OR "crop mixture" OR "multispecies system*" OR "species mixture"))** NOT TS=("peach potato aphid*" OR opuntia)	43	Replacement of localization related prepositions by terms to define the system
TS=((orchard? OR "fruit tree?" OR "fruit grow*" OR arboriculture OR apple* OR pear OR peach OR apricot OR plum **OR banana OR guava OR coco* OR pineapple**) NEAR/5 (vegetable* OR "market garden*" OR lettuce? OR tomato* OR carrot* OR cabbage OR bean* OR pepper* OR zucchini OR eggplant OR onion* OR potato* OR radish OR melon OR squash **OR corn OR maize**) NEAR/5 ("intercrop*" OR interrow* OR "associated crop" OR "crop association" OR "mixed crop*" OR "multilayer crop*" OR "alley crop*" OR "row crop*" OR "combined crop*" OR permacultu* **OR milpa** OR "food forest*" OR "plant mixture" OR "crop mixture" OR "multispecies system*" OR "species mixture" OR agroforestr*)) NOT TS=("peach potato aphid*" OR opuntia)	231	Addition of tropical species names

Appendix 3: Interview Guides

Interview Guide – Technical Advisors

Interviewee introduction ->

Information to collect:
Name
Role, tasks into the organization

"Can you introduce yourself and present your tasks into the organization?"

Projects implemented by the organization to promote and develop mixed orchard systems ->

Information to collect:
List of projects
Genesis
Scale
Partnership
Financing

"What are the different projects implemented by the organization to support development of mixed orchard systems?"

Relationship with producers ->

Information to collect:
Number of request from producers
Evolution of this number
Reason of this evolution
Answer to these requests

"Do you receive requests from producers with mixed orchard systems projects or plots?" "Have you noticed an evolution in the numbers of these requests?" "How do you explain this evolution?"

"What kind of support can you provide to a producer who request advices?"

Opinions about mixed orchard systems ->

Information to collect:
Benefits from mixed orchard systems
Motivation/ Objectives of producers when they implement mixed orchard systems
Obstacles/ Limiting conditions encountered by producers
Drawbacks of mixed orchard systems

Technical advisors and producers' network ->

Information to collect:
Knowledge about other projects implemented in France to promote and develop mixed orchard systems
Existence of a partnership with these projects
List of technical advisors or producers that might be of interest to interview

Interview Guide – Producers (Project)

Introductory speech: Objectives of these interviews + Recording agreement.

Farm and Farmer Description ->

Information to collect:

Farmer in setup process / Farmer already having a farm

Farm status (EARL, GAEC …) / Who is taking decisions?

Setup Date

UAA / Merged or fragmented land?

Main productions

Workload / Labour force / Pluriactivity

Distribution

Certification

Innovative practices already experimented in the past years?

Timeline of the farm / Key events

"Can you describe your farm and its historical background?"

Project Description -> What is the project? Which incentives, motivations? Which source of information?

Information to collect:

Since when this project exists?

Motivations/ Incentives

On which field? Empty/Vegetables crops/Orchard?

Which technical choices? Breed/Rotation/Density/Management/Pruning …

Why these technical choices? Which source of information?

Expected consequences of these choices on workload, field management, distribution …

"Can you explain your project of diversification?"

"Why do you want to implement such a system?"

"How do you imagine this implementation?"

"Where did you find the information about this system?"

Obstacles/Constraints ->

Information to collect:

Obstacles encountered

Reasons of non implementation

« What are the constraints that limit the system implementation?"

"How can you solve these problems?"

INTERVIEW GUIDE – PRODUCERS

Introductory speech: Objectives of these interviews + Recording agreement.

Farm and Farmer Description ->

Information to collect:

Farm status (EARL, GAEC …) / Who is taking decisions?

Setup Date

UAA / Merged or fragmented land?

Main productions

Workload / Labour force / Pluriactivity

Distribution

Certification

Innovative practices already experimented in the past years?

"Can you describe your farm and its historical background?"

Timeline of the farm / Key events (Size of the farm, production shift, certification, distribution …)

Initial production

Date of diversification

Diversified System Description -> What is it? Which incentives, motivations? Which source of information?

Information to collect:

Motivations/ Incentives

On which field? Empty/Vegetables crops/Orchard?

Which technical choices? Breed/Rotation/Density/Management/Pruning …

Why these technical choices? Which source of information?

Consequences of these choices on workload, field management, distribution …

"Can you describe your diversified system at the time of its implementation?"

"Why did you want to implement such a system?"

"Where did you find the information about this system?"

Evolution of this Diversified System -> Which change and why?

Information to collect:

Date of the change

Reason of the evolution

New technical choice implemented

Why these new technical choices? Which source of information?

Outcomes of the Diversified System and Perspectives ->

Information to collect:

Outcomes (positive and negative) of the implementation of a diversified system

Perspectives / Future projects

"What are the outcomes of the implementation of this diversified system on your farm?"

"Do you have any projects for the future? How do you see your farm in a few years?"

Appendix 4: Variables Database

Variable	Transcription	Modalities
Variables related to the farm		
Length of time since setup	Setupdatecl	<5, 5-10, 10-15, 15-20, >20
Initial production before diversification	Initialprod	Orchard, Breeding, Vegetables, Others
Wholesale distribution circuit	Distribwholesale	Yes, No
Direct distribution circuit	Distribdirect	Yes, No
Shops distribution circuit	Distribshop	Yes, No
Organic certification	Certiforganic	Yes, No
Demeter certification	Certifdemeter	Yes, No
Nature et Progrès certification	Certifnature	Yes, No
UAA	UAAcl	<5, 5-10, 10-15, 15-20, >20
Land structure	Landstructure	Merged, Fragmented
Variables related to the producer		
Advices from a technical advisor	TechnicalAdvisor	Yes, No
Advices from a network	Network	Yes, No
Producer coming from a farmers' family	Agrifamily	Yes, No
Agricultural Training	Agritraining	Yes, No
Length of time since diversification	Divdatecl	<10, 10-20, >20
Timegap between setup date and diversification date	Deltasetupdivcl	<5, 5-10, >10
Diversified system chosen	System	MOA, MOV, Both
Variables related to motivations		
Economic motivation	Motiveco	Yes, No
Philosophical approach	Motivphilo	Yes, No
Microclimate creation	Motivclimate	Yes, No
Work environment	Motivlandscape	Yes, No
Grass management	Motivgrass	Yes, No
Nutrient cycle	Motivnutrients	Yes, No
Variables related to the information source		
Knowledge about diversified systems from training sessions	Knowledgetraining	Yes, No
Knowledge about diversified systems from readings	Knowledgereadings	Yes, No
Knowledge about diversified systems from formal or informal networks	Knowledgenetwork	Yes, No
Variables related to the agricultural practices		
Temporality of the diversification	Divduration	Permanent, Temporary
Ownership of the diversification	Divproperty	Yes, No, Both
Proportion of land diversified	Landproportion	All, Part
Fertilization practices adaptation	Adaptferti	Yes, No
Tree management practices adaptation	Adapttrees	Yes, No
Pesticides use practices adaptation	Adaptphyto	Yes, No
Turnover practices adaptation	Adaptturnover	Yes, No
Farm's buildings adaptation	Adaptbuildings	Yes, No

Abstract

Fruit production is one of the largest users of pesticides among the agricultural productions, leading to detrimental effects for environment quality and human health. In a context of pesticides use reduction and agriculture ecologization, mixed orchard animals and mixed orchard vegetables systems are arousing curiosity of both producers and researchers.

Through a sequence of semi-structured interviews with technical advisors and producers in mixed orchard system, an overview of producers' profiles, motivations, system design and trajectories have been realized. Thus, the question that aroused was: What key elements may be extracted from these producers' personal experiences to provide a suitable support to producers and future project holders?

The interviews highlighted a high diversity of producers' profiles, motivations and system design which consequently influence producers' trajectories. Among this diversity, decisive factors in the implementation choices of a mixed orchard system have been identified such as the UAA, the initial production, the distribution circuit and the lack of suitable knowledge and support available.

To deal with this acknowledged lack, research and technical structures are facing two options: references creation by on-farm agronomic, economic and environmental performances evaluation and formal or informal networks animation.

Key words: Orchard, Diversification, Husbandry, Vegetables, Support, Knowledge Production

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