Crop diversification: obstacles and levers

Study of farms and supply chains

Synopsis of the study carried out by INRA
At the request of the ministries in charge of Agriculture and Ecology
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Synopsis of the study report

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Introduction: study context and objectives

The post-war agricultural revolution led to a significant intensification of French agriculture between the 1950s and the 1980s as a result of the development of mechanisation and the large-scale use of inputs. This intensification was accompanied by the progressive specialisation of farms. The specialisation process can be explained, in particular, by the increasingly technical skill necessary for each type of production (it is impossible to be at the cutting edge in all areas), but also by the quest to constantly boost work productivity in farming operations (greater diversity of production types can increase organisational difficulties). Furthermore, the parallel structuring of agro-industrial supply chains promoted a high level of geographic specialisation of agricultural systems (geographic separation between livestock and arable production, geographic concentration of processing industries), the aim being to more effectively control quality, volumes and supply logistics. Hence these broad trends in our agricultural production system gradually shaped our farming landscape, leading to sharp contrasts between different regions but less diversification within each one. This is particularly true since, within each of the specialised systems, the number of crops grown has also decreased: farmers have concentrated on the most profitable crops, using plant health products to reduce the detrimental effects of short rotations or monoculture.

The increased recognition of the negative external impacts associated with such specialized and intensive systems (pollution of local environments, greenhouse gas emissions, loss of biodiversity, etc.) are driving public authorities to consider the challenges involved in promoting a more sustainable form of agriculture. Several recent studies and expert reports conducted by INRA (French National Institute for Agricultural Research) at the request of the public authorities1, have highlighted crop diversification – meaning the diversification of the crops grown on a farm and/or in a landscape – as a lever to reduce the use of inputs from outside the farm - pesticides, fertilisers, water –, along with the environmental damage resulting from their excessive use. In other words, if the simplification of crop rotations is primarily based on the intensive use of inputs, greater diversification promoting biological regulation within arable ecosystems would appear to be preferable, in order to more firmly anchor agriculture in a sustainable production approach.

But, while French agriculture needs to become more sustainable, it also needs to remain competitive within the context of a global market economy. It is therefore essential to consider the economic benefits of greater crop diversification, and hence the market outlets that diversification crops can find, agro-industrial strategies, consumer demand and the technological innovations underpinning these. Consequently, the issue of greater diversification of arable land relates more broadly to our industrial choices, as well as our choices in terms of dietary habits and quality policy. The challenge is to combine diversification with the competitiveness of the agricultural and agro-industrial system.

Furthermore, it is necessary to be cautious, determining the relationship between a diversification of crop species and the associated environmental benefits, since not all types of diversification are necessarily virtuous in agronomic or environmental terms. Some diversification crops are demanding in terms of plant health treatments; rotations that have been inadequately thought out may exacerbate parasite problems or promote certain weed species. Diversification alone cannot address the environmental issues: it needs to be combined with an agronomic approach to cropping systems and adapted to the variety of local situations encountered.

However, promoting greater diversification in cropping systems may upset standard production systems and agro-industrial supply chains. Research is thus necessary to understand the mechanisms at work within farms and supply chains which act as obstacles to the development of crops that are currently marginal on French land. The levers for agronomic, economic or regulatory action that could potentially promote a transition towards a more sustainable form of agriculture need to be identified and assessed.

The objective of this study is to identify: i) the main obstacles to diversification of crops grown, at agro-industrial supply chain and farm level; ii) the levers that can be employed by the public authorities, in particular, to encourage these stakeholders to integrate greater crop diversity within their production system. However, the study does not aim to define which diversification crops French agriculture should develop or to demonstrate the virtues of any particular crop. The case studies that we conducted are only designed to reveal processes with a generic value.

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Understanding the obstacles to diversification and identifying the levers require the implementation of a cross-disciplinary analysis framework, integrating agronomy of practices and economy of supply chains. Justification of the theoretical framework adopted (lock-in theory and socio-technical transition theory), derived from an analysis of the international literature, forms the first part of this study. The literature demonstrates that technological trajectories are configured as a result of various self-reinforcement mechanisms, that serve to sort innovations and can significantly obstruct the development of certain innovative technologies where these would require a major change in the organisation of production systems (concept of "technological lock-in"). In other words, the literature suggests - and demonstrates on the basis of a few examples - that the adoption of alternative agricultural production practices, such as those based on greater diversification, comes up against the obstacle of a highly structured organisation of agricultural and agro-industrial production systems. The study therefore devotes significant space to an analysis of the organisation of production systems related to various diversification crops, in order to simultaneously identify the obstacles to their development, the conditions that are present in cases of successful diversification, and the levers that public authorities and agricultural stakeholders could use to support re-diversification.

The second part of the study is dedicated to a panorama of the obstacles and levers identified for twelve diversification crops. The study is based on an analysis of the scientific and technical literature, as well as interviews with experts from the world of agriculture. However, while this panorama provides an overview of the situation, it remains insufficient to guide actions since it does not provide an integrated picture of the connections between the various links in the chain liable to lead to the "technological lock-in" mentioned above. The third part of the report focuses on an in-depth study of all the production processes - in both agricultural and agro-industrial terms - for three crops selected on the basis of the contrasting organisations of their supply chains - pea, linseed and hemp. By highlighting the deeply rooted nature of the existing lock-ins, this third part makes it possible to come up with possible break-out strategies, which are presented in the conclusion.

This document is a synopsis, aimed at a broader audience, of the study report\(^2\), which provides a detailed account of the analyses performed and cites all the bibliographic references used. The study report, synopsis and a shorter communication document are available online on the INRA website.

Box 1. The simplification of cropping plans and rotations in France

Since the second half of the 20th century, a process of specialisation of farms and regions has been at work in French agriculture. Mixed arable and livestock farms, which were largely dominant in the past, have given way to specialised operations, focusing mainly on large-scale arable or livestock farming. This specialisation results from the combination of numerous factors: support for the prices of wheat and certain other major crops, reinforced after 1992 by premiums per hectare of cereals and oil and protein crops, the reduction in agricultural labour and the quest to make the work less hard, the artificialisation of environments made possible by drainage and the use of chemical inputs (mineral fertilisers, pesticides) explain the reduction in livestock activities in the regions most suitable for arable farming. Conversely, in other regions, the production of meat or milk has been concentrated around an efficient industrial system. As a result, a regional specialisation of production sectors and processing industries has gradually been constructed, the aim being to make the best use of soil capacities and climates wherever possible, but also to create agglomeration economies. Today, specialised cereal production dominates in the Paris Basin, Alsace or Aquitaine, whereas Western France (Brittany, Anjou, Normandy), which focuses on intensive livestock farming, often largely favours silage maize and monospecific grassland. Consequently, specialisation has gradually shaped agricultural landscapes, leading to sharp contrasts between different regions but less and less diversification within each one.

This trend seems likely to continue: today, the marked increase in cereal prices is tending to accelerate the process of abandonment of livestock activities by mixed farms; in addition, the elimination of milk quotas in 2015 is expected to speed up the concentration of production in the most competitive areas.

This regional specialisation is accompanied by a reduction in the number of crops grown and a shortening of rotations. For example, in arable zones, the surface areas of wheat and oilseed rape grown increased substantially between the 1980s and 2010. Conversely, pea, sunflower and maize surface areas have decreased. In the Seine Basin, the frequency of wheat monoculture and short rotations, such as oilseed rape-wheat-wheat, oilseed rape-wheat-barley or wheat-wheat-barley, has increased since the mid-1990s. Conversely, four-yearly rotations such as pea-wheat-sugar beet-wheat have often been replaced by shorter rotations. In France as a whole, maize monoculture accounts for around 6% of cultivated land and is particularly prevalent in Alsace (34%) and Aquitaine (49%). Wheat itself, which is traditionally preceded by other crops than cereals, is now preceded by a wheat in 17% of cases, promoting weeds and diseases endemic in this crop.

The evolution in alfalfa surface areas in the Seine Basin would appear to be particularly emblematic: in 1970, alfalfa was grown throughout the Basin (with surface areas of as much as 10 to 15% of the AA (agricultural area in use) locally); it was generally used in the farms where it was grown to feed livestock. In forty years, surface areas have fallen by almost 80% and now represent less than 1.5% of the AA of the Basin. Alfalfa has gradually become concentrated in the Champagne Crayeuse area, an arable area where the chalky soils with their high water content are favourable to high production yields per hectare. Drying plants set up in this region produce “pellets”, which are incorporated into livestock feeds sold to farmers from regions specialised in livestock farming.

The shortening of rotations increases problems related to soil-borne parasites and makes weed control difficult. Increasingly uniform cropping plans augment the risks of the development of airborne parasite populations (insects, cryptogamic leaf diseases). This process of specialisation would not be possible, therefore, without pesticides, which lessen the detrimental effects of short rotations or monoculture. For example, it can be noted that in the Seine Basin, the regions where there is the most oilseed rape are also those where each hectare of oilseed rape receives the greatest amount of plant health treatments.

This process of farm and regional specialisation poses a number of ecological problems: the low level of mineral element recycling (N, P, K, etc.) in farms leads to wasting of non-renewable resources and water (nitrate, phosphorus) and air pollution (ammonia, nitrous oxide); pesticides and their metabolites accumulate in soil and aquatic resources; a loss of biodiversity is observed in agricultural zones, related to the replacement of grassland by annual crops, the reduction in the diversity of habitats and the abundant use of pesticides; the local concentration of irrigated maize surface areas exacerbates water pressures. Finally, recent studies demonstrate that specialisation - and particularly the shortening of rotations - also contributes to the capping of arable yields being observed today.
1. The analysis framework and the study method

1.1. The analysis framework: technological lock-in and socio-technical transitions

The "technological lock-in" theory, developed in innovation economics, has identified a set of self-reinforcement lock-in mechanisms that can help us understand the potential obstacles and levers for a transition towards sustainable development (section 1.1.1). This theory coupled with a multi-level analysis of socio-technical transitions makes it possible to envisage levers for breaking out of the production system (section 1.1.2).

1.1.1. The technological lock-in concept and self-reinforcement mechanisms

- **The technological lock-in concept**

The example of the QWERTY keyboard illustrates the lock-in concept. This keyboard, in which the order of the letters was designed to slow down the typing speed of typists and therefore reduce key jamming in the typewriters in use at the end of the 19th century, remains the norm, despite other, more ergonomic and efficient keyboards - made possible by computer science - having been proposed (DVORAK keyboard, for example). This corresponds to the typical lock-in situation: despite the fact that a technology judged to be more effective exists, the initial technology remains the norm; it has become so standard for society that it appears to be difficult to change it. It should be specified that, in this analysis, the term "technology" refers to a broad definition: technological lock-in can apply to a choice of production technique, product, standard or paradigm, becoming a reference. Lock-in of a production system leads to a sorting process between innovations: those that are totally compatible with the standard technology have a chance of developing, while those that call into question either it, or the relationships between stakeholders as organised around the standard, have much less chance of developing (path dependency process).

In agriculture, numerous lock-in situations have been analysed, both internationally and in France. Hence, for example, the literature reports lock-in in the USA and Europe relative to the use of pesticides, slowing down or even preventing the development of alternative solutions, despite these being wanted by the majority of stakeholders contributing to the lock-in. Technological lock-in does not result from a deliberate strategy on the part of one or other stakeholder, but from self-reinforcement mechanisms created around a technological solution.

- **Self-reinforcement mechanisms**

To understand lock-in, the literature has identified several economic mechanisms that reinforce the initial choice of a technology. These "self-reinforcement" mechanisms have mainly been demonstrated via case studies. The main ones are: the increasing returns resulting from its adoption, technological compatibility, current knowledge and the organisational structure of the stakeholders involved.

Increasing returns refer to two types of interdependent effects: network effects and learning effects. Network effects help to reinforce the value of using a product or a technology linked to the increase in the number of users. Hence the increase in the number of specialised, input-intensive farmers promoted fine-tuning of knowledge in this sector, to the detriment of mixed arable and livestock farming or autonomous systems. In addition, the more widespread a technology becomes, the more complementary technologies develop, reinforcing its dominant position. These cumulative effects thereby increase the value of adopting the technology initially chosen.

Knowledge plays an important role in self-reinforcement, at different levels. Firstly, the training path of farmers and of those who provide an advisory service to them, have a strong influence on their capacity to use a given technology: individuals choose what appears to them to be the "best" option on the basis of what they know. This has led, for example, to farmers and agricultural advisers guiding production choices towards conventional agriculture, which remains the main paradigm disseminated in agricultural teaching and training. The core competencies of farmers and/or agro-industrial companies can therefore generate rigidities, limiting their capacities to innovate and change technology. In addition, the technical advice given to farmers is also incorporated within institutionalised relationships of strength that lock in the capacity to evolve knowledge towards alternative systems. Finally, the lack of practical knowledge of an alternative technology reduces the probability of its adoption.

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3 The bibliographic references used are indicated in the study report. The main thinkers behind this approach are the economists David and Arthur (in the 1980s), then Rip and Kemp (at the end of the 1990s). The authors having applied this approach to the agricultural sector in Europe include, in particular: G. Vanloqueren, P. Baret, P. Labarthe, C. Lamine, M. Fares, M.B. Magrini.
The literature concerning socio-technical regimes and the conceptual framework of the theory of transaction costs uncover another self-reinforcement mechanism, defined by the links structuring the stakeholders of a production sector, and suggest potential avenues for organising a “break-out”.

1.1.2. Transition theory: innovation niches and break-out

- **The socio-technical regime**

The development process of new production technologies is significantly influenced by its organisational and institutional frameworks. This means that while it is true that the process of adopting and disseminating innovations depends on its own characteristics, it also depends on those of the initial market, institutional factors and consumer habits. To understand these innovation dynamics via organisations, the analysis has to be focused on the “socio-technical” regime (term describing the interconnectedness of economic, social and technological aspects), which consists of “the rule-set or grammar embedded in a complex of [...] product characteristics, skills and procedures [...] all of them embedded in institutions and infrastructures” (definition proposed by Rip and Kemp, in 1998). This definition makes it clear that a regime consists in large part of a set of institutional routines used by the actors.

- **Innovation niches**

However, since a regime is not always totally uniform, innovation niches may appear, creating a space partially insulated from the normal functioning of the system and, in particular, from the processes that select markets and technological innovations. Such niches can then act as incubators for radical innovations. Operating with institutionally different norms and rules, niches permit learning and the construction of economic networks capable of supporting innovations, such as production and/or marketing chains. These niches constitute possible resources for a break-out and, to do this, need to form a structure in order to overcome the self-reinforcement effects of the standard socio-technical regime.

An explanatory model has been proposed, with three embedding levels, as part of a genuine “transition theory”. The landscape represents the upper level, composed of the institutions, social, political and cultural norms guiding the existing socio-technical regime. In principle, this level is the most stable and the most resistant to change, as a result of the interactions and links between the components forming this configuration. Consequently it imposes constraints on the management of change occurring at the lower levels, thereby generating self-reinforcement phenomena with respect to existing technological choices.

The socio-technical regime constitutes the intermediate level, where the interactions occur between these upper-level institutions and norms and the stakeholders involved. These interactions generate rules and procedures regulating the dominant socio-technical regime.

Niches represent the lower level, where radical innovations are created and organised - with the dominant socio-technical regime for its part producing incremental innovations. The partial insulation of niches enables the innovations to mature and, in some cases, spread. If a change in the landscape or the strategy of a key stakeholder (for example, the public authorities) drives a change in the standard regime, the radical innovation may spread beyond niches or the niches may expand: a new socio-technical regime can emerge in this case and the radical innovation ends up becoming the new technological standard. “Innovation niches” therefore open up opportunities for production systems to break out, via a form of “transition” related to a mechanism that gradually disseminates the radical innovation within the socio-technical regime. The conditions and incentives required for this transition then need to be understood. These can be analysed by referring to organisational theory, via the links structuring the relationships between the actors in the supply chains.

- **Innovation and organisational structure of supply chains**

The process underpinning the emergence of an innovation within a niche requires a minimum level of coordination between the stakeholders involved. Consequently, strong connections between the various producer and end-user networks must be established. Transaction cost theory provides a framework for analysing how economic stakeholders are coordinated within a supply chain, examining the vertical links between companies involved at the various stages in the production, processing and marketing of a product, and the horizontal links between companies involved at the same stage of the chain.

More specifically, coordination between the stakeholders at the various links in the chain can be understood in terms of the degree of its vertical integration. This degree of integration assesses whether the activities in the value chain for a given product are carried out by companies independent of one another or dependent via specific links, such as financial or ownership links, or long-term contractual links. Financial or ownership links define an ownership relationship and hence a set of decision-making and coordination rights. Similarly, contracts do not constitute straightforward coordination mechanisms defining prices and quantities: they also allocate decision-making power, in the same way as ownership rights. The choice of these coordination modes - integration (coordination via financial links) or quasi-integration (contractual coordination) - is

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crucial, since it determines the distribution of the value created within the supply chain and influences the strategies of all the actors involved in the supply chain. Indeed it is this value - and the way it is distributed - that defines the incentives for the implementation of technological innovations, be they process or product-related.

This summary of the relationships between the processes of innovation, lock-in and organisational structuring of the supply chain stakeholders within socio-technical regimes constitutes the main analysis framework used in the study.

1.2. Case analyses

Structured by the cross-disciplinary theoretical framework outlined above, the case studies aim to propose an analysis, with a generic value, of obstacles to diversification and levers that could be employed by both the public authorities and the various agricultural and agro-industrial stakeholders to promote it. This analysis was conducted in two phases:

- An inventory of the obstacles and levers mentioned in the literature and by experts on the basis of twelve examples of diversification crops. This inventory concerned the different links in the chains, upstream and downstream, (), taking into account the vertical coordination between upstream agricultural stakeholders such as varietal selection, farms and collecting agencies, and downstream stakeholders such as manufacturers, distributors and consumers. The analysis focused on the different links in a supply chain production subsystem (from agricultural supplies to distribution and consumption), and on its information subsystem (technical institutes, associations, research institutes, etc.). Given the limited nature of the sources used, none of these case studies claims to be exhaustive: only the panorama drawn up by the study of the twelve cases is relevant.

- An in-depth analysis of three diversification supply chains. The objective is to examine the supply chain from downstream to upstream in order to understand how its organisational structure impacts on the development of the crop on which it is based. The analysis focuses on all the production processes (at agricultural and agro-industrial level), the methods of coordination between the stakeholders involved (contracts, specifications, market structure) and their capacity to generate enough incentives to adopt the crop at the various links in the chain. The idea is to uncover any technological lock-ins and to understand their systemic nature. It is by understanding how the obstacles in these three case studies are linked together that action levers that are consistent with each other can be proposed.. The three supply chains selected - pea for animal nutrition, linseed and hemp - were chosen from the twelve examples examined in the panorama of obstacles and levers.

1.2.1. Panorama of the obstacles and levers mentioned with respect to twelve diversification crops

The twelve diversification crops were chosen to develop an overall understanding of the obstacles and levers to diversification on the basis of a range of cases, rather than to promote the development of one or other crop. These twelve crops studied are: hemp, beans, flax and linseed, lupin, alfalfa, mustard, pea, chick pea, soybean, sorghum and sunflower (in northern regions only for the latter). These crops are currently marginal in terms of surface area, whereas outlets would exist in France for their development, if they replaced either other crops or imports. There are agronomic references for all these species, which could be used to support their development. Most of these crops are relatively low-input.

Technical journals (Cultivar, La France Agricole, Perspectives Agricoles, Réussir-Grandes Cultures) and the websites of agricultural technical institutes were consulted for each crop, in addition to the few scientific articles that are available. Around thirty experts from a variety of institutions (Table 1) were questioned - on average three specialists per crop.

The interviews were conducted as follows:
- questions concerning the professional positioning of the expert (functions, diversification crops in the list in which they are specialised, etc.);
- a semi-directive interview on obstacles to the development of these crops, at farm and supply chain level;
- for the main obstacles identified during the interview, questions concerning the proposed levers that can be employed by public authorities and supply chain stakeholders that could, in the expert's opinion, promote the development of these crops.
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1.2.2. In-depth analysis of the operation of three supply chains

The analysis conducted on the twelve cases made it possible to formulate hypotheses concerning the relationship between obstacles to diversification and the organisational structure of the supply chains, and to select three supply chains corresponding to different degrees of vertical organisation for more in-depth studies.

The first of these studies concerns the pea and more specifically analyses why this crop has not managed to play a greater role in the animal nutrition sector, despite its agronomic benefits and nutritional qualities. The second study focuses on linseed, a crop which, unlike pea, benefits on the animal nutrition market, from a specific quality label promoted by an ad hoc supply chain created in the 2000s; this case demonstrates how the coordination system set up by stakeholders in this supply chain has supported its development. The third study is dedicated to hemp and the various industrial outlets for the fibre that have developed recently. The latter two cases highlight how the introduction of quality labels on the market promotes the granting of additional added value for goods produced using these diversification crops.

The analysis consisted of two components: one dedicated to an analysis of the organisational structure of the supply chains, the other to integration of the diversification crops into cropping systems and farms. While the study of the “twelve cases” was based on the diagnosis made by a limited number of experts, the in-depth study is supported by surveys among the socio-economic stakeholders in these three supply chains and a sample of farmers.

- At supply chain level

The purpose of the interviews in this in-depth analysis was to understand how the supply chains are organised. The objective was i) to accurately describe the various coordination modes, tools, methods and knowledge constructing the relationships between the supply chain stakeholders and ii) to analyse the efficiency of these mechanisms.

Transaction cost theory is the scientific approach employed to understand this structuring and organisation of the supply chains. It characterises the mode of organisation of a supply chain on the basis of how the stakeholders involved are coordinated. The aim is then to understand the mechanisms governing these exchanges: exchange of products (contractual relationships, market operation, specifications, etc.) and exchange of information (networks and coordination structures, market and production monitoring, etc.).

To identify and characterise these modes of coordination between stakeholders, the study defined an analysis grid for the various relationships, with information provided by representatives of the various links in the chain (seed companies, farmers, storage centres, processors, distributors, associations, technical institutes, design offices, etc.) during semi-directive and open interviews. These interviews were carried out in order to gather i) information about the approaches implemented, such as the history of negotiations relative to setting up a production contract, ii) information explaining exchange and production processes, such as clarification of formulation strategies in the animal nutrition sector, iii) quantitative data for example, volumes of raw materials exchanged under contract, and iv) qualitative data such as quality criteria described in specifications. The clarification and formalisation of these links between stakeholders gave rise to relatively long interviews,
focusing on i) technical information such as technical characteristics related to storage of a harvested product, ii) strategic elements such as decision-making processes leading to the exploration of a market, and iii) organisational information, for example types of contracts set up with a supplier. In particular, these interviews made it possible to identify the organisational structure of interactions on the plant raw material market, determined by different types of links.

- **At farm level**

The part of the study dedicated to the twelve diversification crops demonstrated that obstacles to crop diversification at farm level operate on different scales - field or farm, related to the economic and regulatory context - and result from constraints of different types: existence of, and access to, knowledge and technical innovations, management strategies and constraints in terms of farm resources (land, labour, equipment), economic opportunities and associated risks. It is therefore essential to take into account the factors that guide farmers’ decisions when attempting to understand the obstacles to diversification of cropping plans and rotations and when seeking levers for action.

The surveys were conducted among farmers who had diversified their cropping system by introducing one or more of the three focus crops in the in-depth study. The aim was understand:
- the factors leading to diversification on an individual level;
- the obstacles encountered during the diversification process;
- the way farmers, by hierarchising the various assets and constraints related to these diversification crops, assess their benefit within the cropping system and decide to maintain or abandon them;
- the way that, from their point of view, supply chains organise themselves to overcome these constraints.

A series of interviews was held among around thirty farmers who had diversified their cropping plans by adding pea in the Eure-et-Loir area, linseed in the Eure and Ile-et-Vilaine areas and hemp in the Aube and Vendée areas. Without aiming to obtain exhaustive or representative information, these interviews revealed variability in behaviour in a diversity of agronomic and economic contexts. These analyses were put into perspective using data obtained from centres of reference (technical institutes, management centres, etc.). Coordination between the approaches at farm and supply chain levels was facilitated by the fact that the majority of farmers interviewed had commercial relationships with the companies (cooperatives, processors) surveyed in the supply chain approach.
2. The obstacles and levers identified for twelve diversification crops

With the exception of the sunflower, which is only a diversification crop in the northern half of France, the twelve crops studied (Box 2) are marginal in terms of surface area compared to the major French annual crops, but there is a high level of variability between these crops in terms of their current surface area (Figure 1) and their trends (surface areas decreasing, relative expansion or highly fluctuating). These crops also differ with respect to market outlets, which concern a variable number of markets, each different in terms of size, vitality or opportunities. Some of these crops are concerned by large, highly competitive markets for “standard” agricultural raw materials (production of livestock feed, in particular), whereas others correspond to niche markets in the human nutrition sector (condiment mustard, chick pea, soybean, etc.), eco-construction sector (hemp, flax) or animal feed sector (linseed oil). In addition, these crops present varied agronomic requirements and agro-ecological benefits, which combine to make them attractive to varying degrees to farmers and downstream stakeholders.

The obstacles and levers on the basis of these twelve cases are presented from the upstream production stage to the downstream stage, namely:

- the seed and agricultural supplies sector, which provides access to some of the production factors required for a given crop;
- agricultural production, i.e. the farms that may introduce these crops into their cropping plans and rotations;
- the harvest crop collection and storage sector (private operators and cooperatives) guarantee raw material flows in terms of both space (geographical organisation of collection and storage) and time (scheduling of transfers from upstream to downstream, stabilisation and homogenisation of batches) It therefore plays a major role in structuring the supply and its capacity to respond to downstream demand, and in the cropping plan choices of farmers;
- the processing and distribution sector. This mainly involves actors in the agrifood sector, who play a key role in structuring the supply chain and access to the market (consumers). By focusing on certain environmental or consumer health concerns, their product differentiation strategy leads to the creation of new outlets that may promote the use of diversification crops.

2.1. Obstacles and levers at seed and agricultural supplies industry level

The more widespread a crop is in a region, the greater the investment in the selection of varieties suitable for the characteristics of this region and in other agricultural supplies, such as plant health products or agricultural machinery. Conversely, crops for which the surface areas remain marginal and that are unlikely to offer a good return on investment do not benefit from significant plant breeding efforts, or trials and coordination structures equivalent to those of dominant crops.

![Figure 1. Evolution in surface areas (ha), in mainland France, for 9 of the 12 crops](image)
### Box 2. The twelve diversification crops studied

#### Pea

The pea was the main crop to benefit from the “protein plan” introduced at the end of the 1970s, but pea surface areas fell gradually from 740,000 ha in 1994 to 100,000 ha in 2009, following the dismantling of this support policy in the early 1990s. This was caused by the onset of climate scenarios unfavourable to production, as well as by serious plant health problems due to the soil-borne fungus *Aphanomyces*. These factors have had a significant impact on the attractiveness of pea in cropping plans, along with its competitiveness on the animal nutrition market, the main outlet for the crop. Competing against the cereal-soybean meal pairing in feed formulas, pea has become an “adjustment variable”, both for farmers, who nonetheless recognise its agro-environmental benefits (improvement of soil structure, nitrogen supply, etc.), and for livestock feed manufacturers, who only incorporate it into their formulas occasionally, depending on certain market conditions. A new outlet is currently developing in the human nutrition market, which offers greater added value.

A second protein plan launched in 2010 led to a temporary increase in surface areas, to 250,000 ha in 2010, before a further fall. While pea remains the main arable legume, its falling popularity is a broader reflection of the gradual loss of manufacturers’ interest in protein crops, in spite of the fact that the agro-environmental aspects of these crops are still a focus of interest for research institutes and public authorities.

#### Beans

Bean surfaces, which were less than 20,000 ha in the early 2000s, increased significantly thereafter, exceeding 150,000 ha in 2010, following the development of an outlet in Egypt for human nutrition and driven by community and French aids for protein crops. However, the growth in surface areas is irregular, primarily due to fluctuations in cereal prices and bean yields. The export market, aimed at human nutrition, accounts for over 50% of total volumes. Cooperatives and merchants are very active on this market, relatively profitable compared to the domestic animal feed market, which only represents a third of the outlets.

As a leguminous crop, beans are grown as a starter crop in arable systems, particularly in Northern France, which is well suited to spring varieties. Winter varieties account for smaller surface areas, in Western and South-Western France. The crop is tolerant of the *Aphanomyces* fungus and it is easier to harvest than pea, so it can be considered in fields where the pea is not recommended.

#### Lupin

Lupin presents some of the same agro-ecological benefits as legumes. The crop is considered to be technical, primarily due to the lack of agronomic references, but also to the lack of approved plant health products. It generally requires little chemical treatment, but weed control is difficult. Its growing area is limited to soils with a neutral or acidic pH.

The nutritional composition of its seeds mean that is of major interest for animal nutrition applications (35-40% protein), but its use by livestock feed manufacturers is limited due to the low volumes available and the presence of xylose polymers in the seed, which cannot be digested by monogastric animals. However, lupin is used in niche markets with a higher added value: in animal feeds via thermo-extrusion; in human nutrition for use as flour.

For many years stable at 5,000 ha, the lupin surface area (mainly sweet white lupin with large seeds) increased in the 2000s to as much as 14,000 ha in 2002 (under the effect of the CAP) before stabilising at 6,000 ha in 2010, for a production of 29,000 t. Despite its environmental and nutritional benefits, it is a crop in which there is little investment on the part of research and professional stakeholders, with the exception of one large French cooperative, which has filed a flour processing patent for the “gluten-free” human nutrition market.

#### Chick pea

Despite being well represented and a lucrative outlet in the human nutrition sector (canning industry, couscous, chickpea flour, etc.), most of the chick pea consumed in France is imported. Chick pea is considered to be a useful diversification crop from an agro-environmental and economic point of view, but its cultivation is nonetheless characterised by a technological gap in terms of crop protection (control of anthracnosis, Heliothis armigera) and the construction of agronomic references.

Limited to the Midi-Pyrénées and Languedoc-Roussillon regions, the crop has been the subject of development initiatives by farmer groups. But the problem of anthracnosis and the lack of technical support for these groups led to the crop being abandoned in the early 2000s.

Very recently, however, initiatives appear to be starting up again, in particular with the development of an additional outlet in the region and the involvement of downstream stakeholders. Research is necessary to support an increase in surface areas, limited to 4,500 ha in 2010.

#### Soybean
Crop diversification: obstacles and levers

CAP support for soybean crops led to a dedicated surface area of almost 120,000 ha in 2002, before the implementation of decoupling measures that triggered a gradual reduction up until 2009. Interest in soybean was subsequently renewed for a variety of reasons: i) the development of new outlets in human nutrition, with highly contract-based supply chains offering interesting financial returns for farmers, and in animal nutrition, with the use of roasted or extruded beans; ii) changes in specifications for organic farming, where feed derived from organic farming products for the cattle sector involved the use of organic soybean cake, and iii) the potential agro-environmental benefits of the crop, such as its use in irrigated maize zones, and as an alternative to maize and oilseed rape in some regions affected by plant health problems on these crops. As much as 51,000 ha of the crop were grown in 2010, of which 33,500 ha were in the South-West, a region with a strong focus on human nutrition, and 17,500 ha in Eastern France, more traditionally oriented towards animal nutrition.

Soybean is a crop offering interesting development potential, raising the hopes of stakeholders in the supply chain with respect to variety section and agronomic research, in particular. Cultivated dry (mainly in the East) or irrigated (mainly in the South-West), soybean can represent at least 10% of the cropping plan of farmers in these areas.

Alfalfa

Alfalfa offers a number of environmental benefits (absence of nitrogen fertilisation, erosion prevention, weed control, maintenance of biodiversity, etc.); it is a very good previous crop that improves the soil structure, leaves residual nitrogen and facilitates the management of green cover. This crop therefore presents an interesting environmental balance.

Alfalfa is above all produced and used in livestock farms (which grow 75% of pure alfalfa surface areas and 100% of combined alfalfa surface areas). Drying for the production of “alfalfa pellets” used in livestock feed (either directly by the farmer or incorporated in compound feeds) is the main market outlet. Accounting for around 10,000 producers over a total surface area of 75,000 ha, dried alfalfa production (750,000 t per year) is mainly aimed at the domestic market (85%).

Today, the drying sector is having to face some economic challenges, particularly in terms of energy costs to operate industrial facilities, as well as plant supply costs (withdrawal of drying aid, transport costs). Highly concentrated in the Champagne-Ardenne region, dried alfalfa production has been affected by the closure of several industrial units. The stakeholders in the sector are therefore supporting projects aimed at alternative processing and use methods, partly the focus of debate concerning the evolution of the French production system.

Flax

Previously distributed throughout France, today flax is primarily grown along the English Channel coast, where the mild, wet climate is particularly suitable for dew retting of the flax, a tricky step (dependent on weather conditions) required for the extraction of the fibres during the scutching phase. The thirty or so processing plants (agricultural scutching cooperatives or private scutching operations), which are concentrated in this area, generally use specific equipment to harvest the flax. Up until 2011 the sector benefited from aid, but this has now been withdrawn. Europe is the world’s leading flax producer (far ahead of China), with France ahead of the field with 55,000 ha in 2011 (and a maximum of 80,000 ha in 2004).

The main outlet for the sector is export to China for the textile industry. The short fibres, which are much more expensive, are traditionally destined for the papermaking industry, where they are in competition with wood fibres, hence the value of projects implemented to develop new uses, such as composite materials for the car industry. The shives (flax waste) and dust, by-products of the pulping process, are used as a combustible and fertiliser, respectively. The seeds of flax, considered to be a sub-product, are sometimes used as seed or in oil.

Linseed

Linseed, cultivated using specific varieties and a completely different management technique than that used for flax fibre, can be grown over a wide area, thanks to the winter and spring varieties that exist. It is mainly to be found in Western France and covers an area of 10 to 20,000 ha, depending on the years.

Previously used to produce oil employed in a variety of different industries (used in paints for its drying properties, cosmetics, inks, etc.) and partially in animal nutrition (oil or cake as a dietary supplement), linseed is now destined almost exclusively for animal nutrition uses, with the development of a quality supply chain based on the use of thermo-extruded linseed in animal feeds and promoting the nutritional properties of the seed (high omega 3 content).

Sunflower

Very well represented in the early 1990s, sunflower growing has continued in the South-Western quarter of France (Midi-Pyrénées and Poitou-Charentes mainly), but has significantly decreased in central France (Centre, Pays de la Loire and Bourgogne regions). Nationally, it remains the most common arable crop after cereals, maize and oilseed rape, with almost 750,000 ha in 2010.

Sunflower offers the advantage of requiring few inputs and less water than maize (less than 4% of French sunflower surface areas are irrigated, compared to 40% of maize surface areas). In addition, it can be grown as a secondary crop, a practice that is still marginal but which appears to be of interest in Southern France in irrigated systems.
A dozen crushing plants throughout the country process 90% of the sunflower produced in order to extract the oil, mainly used in human nutrition (the most consumed oil in France), whereas oil cake, with a relatively high protein content and no antinutritional factors, is used in animal nutrition, particularly for beef cattle. Its incorporation in feed is limited, however, due to its low lysine content and its high cellulose content. Less than 10% of production is used as whole seeds (confectionery sunflower seed, bird feed).

Since the 2000s, oil sunflower crops (varieties with a specific fatty acid composition) have developed significantly via contracts to address the specific requirements of human nutrition and, especially, industry (biodiesel, biolubricants); today, it accounts for more than half of national production.

**Mustard**

Historically present in the Burgundy region of France, brown mustard (condiment) practically disappeared in the middle of the 20th century, due to competition with oilseed rape (both are Brassicaceae) in cropping plans and competition with Canadian mustard seed to supply Dijon mustard manufacturing plants.

Today it is commonly used throughout France as a fallow period crop (white mustard mainly, but also brown mustard) because of its nematode control properties and the speed with which it becomes established, making it an effective catch crop. Mustard is much less present in France as a cash crop for the condiment market. A spring crop generally sown in the autumn, it is better suited to high temperatures than oilseed rape but more sensitive to frost and could therefore be grown over a wide area.

The French sector developed significantly in the 1990s, thanks particularly to local stakeholders (producer associations, storage centres, manufacturers, Chamber of Agriculture, research centres, etc.) who coordinated the organisation of production and the definition of prices. It was also helped by the creation of “Moutarde de Bourgogne” (Burgundy Mustard) PGI (protected geographical indication). Research into varieties has benefited from the rise in its use as a catch crop. The surface areas, less than 300 ha at the end of the 1990s, have now increased to over 5,000 ha, mainly on the Dijon plain. France still imports more than two thirds of its requirements from Canada.

**Sorghum**

Sorghum cultivation developed in the 1970s in South-Western France. Thanks to the development of earlier varieties, its growing zone then expanded northwards (Rhone valley, Ouest-Atlantique (Western France and Atlantic Coast). Peaking at 100,000 ha in the early 1990s, the surface areas then gradually decreased, replaced by sunflower, maize and compulsory set-aside, before gradually stabilising at around 50,000 ha.

The main outlets for French sorghum grain are export to Spain for animal fodder (pig farming), the Benelux countries for bird feed and to supply livestock feed manufacturers on the domestic market. It is a useful substitute for maize in animal feeds because of its similar nutritional characteristics but is of little interest to livestock feed manufacturers owing to its low and dispersed production. Its development potential is however estimated at 100,000 ha, and its lower input requirements are said to make it a competitive option in cropping plans in place of non-irrigated sunflower and irrigated maize.

**Hemp**

French hemp surface areas fluctuate around the 8,000-ha mark (with a maximum of 12,000 ha reached in 2009). Used in the past in the manufacture of ropes, the main outlet for the hemp straw produced in the Aube basin - a traditional hemp-growing area - for the past thirty years has been the papermaking industry. The development of biomaterials (insulating panels, hemp concrete, composite materials for the car industry, etc.), based on the techno-economic or environmental performances of hemp – a low- input crop – has led to the emergence of new production basins organised around processing plants. These promising outlets could lead to a significant growth in surface areas but competition with existing materials in these sectors (for example glass wool for insulating panels) is a factor. Hempseed is considered to be a by-product of the straw and in some areas is mainly used in animal nutrition (bird feed) and human nutrition (oil).
2.1.1. The lack of research into varieties

The low availability of certified seeds and, in particular, the limited range of varieties, are obstacles mentioned by most of the experts questioned, for the majority of diversification crops (lupin, hemp, linseed, soybean, mustard, chick pea). The marginal surface areas of these crops do not encourage plant breeders to invest in them. This situation promotes the use of farm-saved seeds (i.e. seeds produced on the farm itself), making investment in these crops even riskier for plant breeders. However, the extent and intensity of research in the field of variety selection, along with the number and type of structures involved upstream of production, appear to be variable depending on the crops. Among the twelve crops studied, three situations can be identified, depending primarily on the investment of public and private sectors and their relationships.

- Private research with little support from public research

There is little, no longer or no public research in certain “marginal” crops, but some private stakeholders, who have invested in specific outlets, are still or once again carrying out research. For example, although research into the lupin (Figure 2) has become marginal at the INRA, the Terrena cooperative, which controls the niche market for lupin flour used in the bakery sector, has maintained the selection activities of its Jouffray-Drillaud subsidiary for this crop. For chick pea, only two varieties are currently listed in the French catalogue (and only one of these is grown) and the problems related to anthracnosis still have no technical solution. However, there is an upsurge in interest in the crop: the Arterris cooperative, which has signed supply contracts with a manufacturer, is reinvesting in upstream research into chick pea and formulating certain requests to public research bodies, concerning, in particular, support for the selection and ecophysiology of the crop. For mustard, the selection of condiment varieties for a niche sector in Burgundy is now being sustained by the catch crop outlet, which is more recent and concerns a much more extensive area and market.

- Continued public and private support for research into struggling crops: a wager for the future

For crops such as pea, soybean and sorghum, although surface areas under cultivation are falling or struggling to stabilise, considerable research into varietal improvement, relative to the size of the supply chain, is continuing. So, for example, despite the reduction in pea crop surface areas, new varieties continue to be listed relatively regularly (Figure 3). Pea selection is the subject of significant coordination between public and private research.

The benefits of these crops in environmental and economic terms (reduced input use, in particular) are leading some stakeholders to wager on a higher demand in the future. In addition, some new outlets are opening up for these crops, such as the use of pea for protein extraction or the use of “organic“ soybean meal in cattle feed for organic farming.

Finally, these crops benefit from significant expertise within research institutes (French and international) and technical institutes, along with networks that remain operational today. Soybean, pea and sorghum are still included in the agronomic trials conducted by technical institutes, where new varieties are assessed.
The development of new markets is driving and boosting research into certain crops and leading to the construction of networks and structures bringing together institutional and private stakeholders. This is the case for linseed and hemp, in particular.

The discovery of the nutritional properties of linseed and the development of the Bleu-Blanc-Cœur quality label supply chain (see Chapter 3) have revived interest in this crop (Figure 4). The first studies on the effects of linseed-based feed on animals and the quality of their products, were undertaken by private actors. Integrating the crop within the strategies of several seed companies and technical institutes and developing research into linseed are also supported by a high level of interaction between the public and private sectors, via the LINEA economic interest group, in particular. On the French linseed market, the INRA and LINEA are leaders in the co-breeding of varieties, three of which account for 90% of the winter variety seed market.

Despite their development, varietal research into these crops continues to run into difficulties. This is partly due to downstream market segmentation, as the criteria for genetic improvement can differ according to the outlet. Coordination between the profession and research is therefore essential in order to reach a consensus as to which strategic directions plant selection should take. For hemp, the diversity of outlets for fibres and seeds multiplies the selection criteria (fibre content, fibre quality, oil content, yield, etc.), for which inter-trade bodies appear to have difficulty defining priorities. Competition between production areas and the recent arrival of new developers in the insulating panel manufacturing sector (CAVAC, EURALIS) make coordination between the professions a delicate exercise, appearing to create obstacles to the construction of a consensus regarding varietal improvement. As a result, selection work is focusing mainly on “conventional” criteria, such as straw yield.

2.1.2. The low level of investment in the approval of plant health products and agronomic trials

- The cost of approval

For the majority of diversification crops, few approved plant health products are available. The approval procedure is relatively complex and hence costly, dissuading plant health companies from investing in niche sectors, where possibilities for recouping costs are limited. For chick pea, for instance, only one herbicide is currently authorised and no effective products are available to control anthracnosis, a disease that nonetheless caused the fall in production in the early 2000s in Southern France. No herbicides have been approved for lupin, although effective products do exist (approved for cereals).

- The lack of agronomic trial networks

The experts consulted consider the inclusion of diversification crops in the trial networks of technical institutes to be an essential prerequisite for the development of these crops. The lack of technico-economic references constitutes a relatively large obstacle to farmers and agricultural advisers. For protein crops, for example, studies focus mainly on pea and, to a lesser extent, on beans; few studies concern lupin, despite its agronomic and nutritional benefits, and few references and little technical support have been developed for this crop outside the Terrena cooperative's production area. For linseed, the lack of support from "conventional" structures has led operators investing in the crop to develop training schemes, not only for farmers, but for advisers from cooperatives in the collection areas concerned and for agricultural contractors too.

The experts consulted highlight the fact that the lack of technical references and advisers' poor knowledge of these crops may explain the failures encountered in hemp cultivation (wrongly considered to be a plant that “grows anywhere”) or chick pea cultivation (jeopardised by the spread of anthracnosis). According to the experts, the lack of technical support, at both Chamber of Agriculture and cooperative level, along with the lack of references available, highlights the inadequate investment in the Research-Development-Advice system for diversification crops.
2.2. Obstacles and levers at farm level

These obstacles concern the availability of technical and agronomic knowledge at field scale, the compatibility between diversification and the farmer's objectives and constraints, and the influence of the economic and regulatory context on farmer decisions. It should be noted that the issue of the climate limits of growing areas have not been incorporated into the study; only those regions in which the production conditions for the crop under consideration are met have been examined.

2.2.1. On a field scale: the need to acquire technical expertise when introducing a new crop

- Lack of knowledge and references concerning crop management

Today, farmers and technical advisers are fully conversant with management techniques for the dominant crops in France (wheat, grain maize, barley, oilseed rape). In contrast, certain diversification crops are less well mastered from a technical point of view and/or confronted with as yet unresolved problems. This may be a source of failure and hence abandonment of the crop. Pest control, in particular, is a prime example.

Very often, a crop (re)introduced into an area on a small scale presents few plant health problems due to the absence in the region of pests specific to the said crop. This is the case for sorghum, for example, which is relatively little developed in France and not subject to any major insect or disease problems. Conversely, a crop that is not very abundant in an area may become the sole target of certain polyphagous pests during certain periods: isolated sunflower fields can, for example, suffer significant damage from birds at emergence and harvest; spring mustard, which flowers at a different time from oilseed rape, is subject to significant pressure from pollen beetles, a flower bud pest. Introducing a crop into a region can thus introduce risks that differ from those encountered in zones where the crop is more prevalent. Not anticipating these risks can lead to significant crop damage, liable to discourage the farmers affected.

The absence of plant health products that are effective against a disease, pest or weed is frequently mentioned by farmers as an obstacle to the adoption of a diversification crop. In addition to the problem, already cited, of lupin crop weed control (which requires farmers to use non-approved products or abandon the crop), several other examples are cited.

- The fungus *Aphanomyces euteiches*, which causes root rot in pea, can lead to significant yield losses. The pathogen, against which no plant health products or resistant varieties exist, is common in French soils and spread significantly in the 1990s as a result of pea being planted too frequently within the rotation in fields. However, adhering to the recommended rotation return time (5-6 years) alone is insufficient to control this risk since *Aphanomyces* can persist in the soil for a period much longer than 6 years. According to the UNIP (French national inter-professional union for protein-rich plants), the only way to control this risk reliably is to perform a test to measure the infectious potential of the soil, in order to avoid using fields where the infestation level is too high. This risk is often cited as an obstacle by farmers, but few of them (5%) use the tool capable of assessing it. It is also recommended that preference be given to winter pea, as it is much less vulnerable than spring varieties, which are nonetheless the most commonly used. At present, no varieties resistant to *Aphanomyces* exist, but partially resistant varieties are in the process of being developed.

- Hemp has practically no diseases or pests, except for a parasitic plant - broomrape - which can only be controlled using preventive agronomic methods, such as leaving a rotation return time of 5-6 years or stopping hemp once broomrape has appeared. Today, the plant selection process is focused on resistance of the crop to broomrape; the sector does not want to develop a plant health solution, as the aim is to preserve hemp's image as a "pesticide-free" crop.

- For beans, the outlets in the human nutrition and seed sectors require good control of a pest, the bean weevil (maximum of 1 to 3% of beans affected). Insecticides exist but are often judged to be ineffective. Arvalis and the UNIP developed a decision-making tool in 2008 for controlling weevils in fields, called Bruchi-LIS®, intended for storage centres and Chambers of Agriculture. The tool enables insecticide treatments to be precisely positioned according to the bean development stage, the weather conditions and products and enables risky situations to be targeted. But to be effective, the control strategy has to be simultaneously implemented by all growers in a production area, since weevils move around a great deal.

Beyond the real difficulties involved in controlling certain pests, one of the obstacles to the introduction of a diversification crop appears to be the difficulty in managing without a chemical safety net. Other solutions exist, but these are very little used, perhaps because they are still little known or because they are based on temporal (agronomic principles in terms of the rotation) and spatial (collective management on a regional scale) approaches that are more complex to implement. Paradoxically, pest control in diversification plans is considered to be an obstacle to their development, even though it is one of the reasons for seeking to diversify cropping plans and rotations from an agronomic and environmental point of view.

Furthermore, to grow certain diversification crops successfully, techniques that are unusual for conventional crops have to be learned and mastered. For example, planting lupin or flax requires a specific type of soil tillage and growing certain legumes (alfalfa, soybean, lupin) in new fields requires inoculation of nitrogen-fixing symbiotic bacteria specific to the crop. For many
of the crops, harvesting is a trickier operation, representing a source of stress. For example, despite varietal improvements in terms of pea stem strength, harvesting is still difficult when the crop is not standing upright. Dual harvesting of seeds and straw for linseed and hemp is also "technical" and mastered to varying degrees depending on the production area. The experts indicate that these specific technical characteristics are sources of concern for farmers who have just adopted the crops but that they are no longer problematic once the learning phase has been completed.

For these diversification crops, numerous questions remain unanswered. Even for pea, for which references are available, the experts stress that yields may be very low with no explanation, with no identified climatic or plant health problems. This lack of clarity with respect to sources of yield variations also appears to be an obstacle to the development of other crops (linseed, lupin, beans, etc.). The inability to identify the reasons for a failure can further reinforce rejection of the crop, sometimes for several years.

- **A lack of knowledge and references relative to the agronomic benefits of diversification, and the "carry-over" and cumulative effects of diversification crops**

Knowledge of the effects of the crop on the next one - known as "carry-over" effects – varies considerably depending on the diversification crops concerned. Of the twelve cases examined, the most documented crop is pea: numerous references exist concerning its effect on the yields and nitrogen fertilisation of subsequent crops. However, this effect has mainly been studied on wheat as the next crop; only recently has the pea-oilseed rotation (which is still rare) been analysed. For other crops, such as lupin, for example, references are lacking in Europe concerning the benefits of the crop on subsequent crops. As for the other effects of adding an extra crop to the rotation (breaking the cycle of diseases and pests, green cover management, soil structure, etc.), these are difficult to assess and their economic benefits are very difficult to quantify accurately.

The economic benefits of diversification crops on a rotation scale could be an argument in their favour, but these are rarely highlighted in communication aimed at farmers. Economic profit margin calculations in the context of crop choice advice are often performed on a crop-by-crop basis without taking into account previous crop “carry-over” effects, rather than at a rotation scale. This fact has already been highlighted in the Ecophyto R&D report and the "Pea-Oilseed Rape-Wheat" study conducted by the CasDar (**Compte d’affectation spéciale pour le Développement agricole et rural** - French special fund for agricultural and rural development); it is also mentioned as an obstacle to diversification by several of the agricultural advisers surveyed. For spring pea, the UNIP demonstrated that its introduction into crop rotations including several successive wheat crops can improve profitability at a rotation scale, despite the lower annual gross profit margin of pea. This improvement, due to an increased yield for the next wheat crop (+8.1 q/ha compared to a wheat-wheat rotation according to the CasDar "Wheat-Oilseed rape-Wheat" study), could be even greater if farmers adjusted their input levels - and particularly nitrogen fertilisation - in accordance with the technical recommendations available.

While several experts identified the low availability of references concerning the “carry-over” and cumulative effects of diversification crops as an obstacle to their development, a bibliometric analysis of the technical publications (Box 3) reveals that sometimes extensive yet often incomplete knowledge does exist, but its quality is highly variable depending on the crops. For some crops, such as pea, alfalfa or linseed, the “carry-over” effects are well known and comparisons of margins on results obtained over several years are widely disseminated, highlighting the economic benefits of introducing the diversification crop. For other crops, knowledge of the “carry-over” effects and margins on rotation remains very sparse, however, and inadequately supported by quantitative data. Overall, more than half of the technical publications concerning diversification crops do not tackle the issue of their effects over several years, whereas this is an important aspect for farmers.

- **Still patchy dissemination and local creation of references**

Locally, the dissemination of agronomic references concerning diversification crops is poor since technical advisers, whose areas of expertise are often limited to dominant crops, still know little about them. As long as the collection of a diversification crop remains marginal, storage centres do not invest in training their technicians in the management of the crop in question. However, diversification strategies initiated or supported by cooperatives have been accompanied by technician training (for example the CAVAC agricultural cooperative for hemp, Vegam for linseed, InVivo for the development of "Premium sorghum", etc.). For alfalfa, since most technicians from storage centres or Chambers of Agriculture lack the relevant knowledge, a technical service is provided by **Coop de France Luzerne Déshydratation** concerning the main collection areas of drying plants.
Box 3. Analysis of the information disseminated to farmers concerning the “carry-over” and long-term effects of crop diversification

During the interviews, several experts mentioned the availability of key information as one of the major obstacles to crop diversification. On the one hand, this lack of information concerns the "carry-over" and cumulative effects of diversification crops, which are considered to be little known, little or inadequately disseminated and, on the other, it concerns comparisons of profit margins, often performed on an annual, crop-by-crop scale, rather than on a rotation scale. It thus appears that the information available to farmers makes it difficult for them to construct medium to long-term crop rotations. To test this hypothesis, a bibliometric study was conducted on a set of data obtained from the internet and the farming press (covering the years 2009 to 2012), in order to gain a snapshot of the information available and readily accessible to farmers concerning these diversification crops.

The internet resources explored are the websites of the relevant technical institutes (Arvalis – Institut du végétal (Plant Institute), CETIOM, ITL, UNIP) as well as all the documents published by these bodies over the period 2009-2012 and available online. These institutes regularly disseminate information concerning diversification crops, particularly for nine of the twelve studied. For alfalfa, the information disseminated by Coop de France Déshydratation was also analysed. The farming press was studied via four national monthly (Cultivar, Perspectives Agricoles and Réussir Grandes Cultures) or weekly (La France Agricole) publications liable to circulate information about the twelve crops. A total of 220 references, including 180 articles (farming press articles and dated texts) and 40 special reports (online special reports on websites, brochures, press reports) were selected and analysed.

A variable amount of references depending on the diversification crop

Numerous references are available for the majority of leguminous and protein crops: pea (42 documents), leguminous/protein crops (38), alfalfa (17), beans (15), soybean (13). They are also numerous for sorghum (23) and linseed (11), but less so for other crops: lupin (2), sunflower (6), hemp (4), flax (5). No references were found for chick pea and mustard as a cash crop - however, the latter is often examined as a fallow period cover crop. Few articles (9) focus primarily on the diversification of cropping plans and rotations, but more (29) examine a specific crop and cover this theme ("Assolement : le sorgho a encore une carte à jouer" ("Cropping plan: sorghum still has a card to play") for example).

Pea, sorghum and hemp have a relatively large number of references dedicated to them compared to their surface area (at different levels, however, for the three crops), in contrast with sunflower, flax and mustard, for example. For flax and mustard, this low level of information dissemination at a national level can be related to the highly regionalised nature of these supply chains and hence information that is doubtless passed on by other routes (cooperatives, Chambers of agriculture, local technical press, etc.).

“Carry-over” effects that are often mentioned but not always quantified

The “carry-over” effects of diversification crops on environmental conditions are mentioned in 100 references out of a total of 220. These usually concern effects on pest populations (in 40% of references) and nitrogen fertilisation of the next crop (37%), and, less frequently, effects on soil structure (23%) (Figure 5). These effects are quantified in 38 of the 100 references: all of these quantify the carry-over effect on nitrogen fertilisation and, more rarely, the reduction of herbicide use on the next crop. The effect on nitrogen fertilisation of the next crop is mentioned and quantified for all the legumes, except lupin, and mentioned but not quantified for linseed and sorghum. This effect is always positive (possible reduction in nitrogen fertilisation of next crop) except for sorghum, which, according to these references, led to a higher amount of nitrogen fertiliser being applied to the next crop.

Figure 5. Number of references mentioning ‘carry-over’ effects concerning a given crop or practice (fallow period cover crop or prolongation of rotation) in particular
The effect on the yield of the next crop is mentioned in 49 of the 220 references, and concerns all the crops except hemp and sorghum. For these crops (flax, pea, lupin, soybean, alfalfa, sunflower) except for beans, the figures are available (Figure 6). In 60% of cases, the next crop considered is a straw cereal and the increase in yield is compared to the yield obtained following a straw cereal; for pea the next crop considered is oilseed rape in some cases.

Figure 6. Number of references mentioning and quantifying the effect of diversification crops on the yield of the next crop

An evaluation of economic benefits that varies depending on the time scale considered

A quarter of the references mention the economic profitability of the crops. The measurements used are generally the profit margin (gross margin generally, semi-direct or semi-net including the cost of depreciation of the equipment and more rarely labour) or only the level of costs, sometimes the gross product or the added value. The scale is over several years in almost half of the cases (Table 2), indicating the economic benefits of introducing a diversification crop on the rotation, on the next crop or on the cropping plan (taking "carry-over" effects into account). However, the multi-year quantitative data concern almost uniquely pea, alfalfa and linseed.

Table 2. Percentage of references evaluating the economic benefits of diversification as a function of the time-scale considered

| Benefits of the diversification crop evaluated over the crop year solely | 51% |
| Benefits of the diversification crop taking into account its effects on the next crop | 24% |
| Benefits of the diversification crop taking into account its effects at rotation level | 25% |

The annual evaluation of the economic benefits of diversification crops reveals varied results (Figure 7): they are judged to be less beneficial than other crops in almost half the cases, particularly when these comparisons are supported by figures. The comparisons are usually given relative to wheat, and also to oilseed rape in certain cases. However, the references evaluating the economic benefits at a multi-year scale are less often quantified but always indicate a positive effect of introducing the diversification crop.

Figure 7. Percentage of references mentioning or quantifying the economic benefits of diversification as a function of the time-scale considered (annual or multi-year) and the conclusion reached (positive effect, negative effect or not indicated)
However, while important references have been developed in traditional diversification crop production areas, these remain inadequately disseminated at national level, apparently due to competition between different regions. Work has to be carried out on developing local references in order to take into account the specific soil and climate characteristics of each area, and greater coordination and reference-sharing between different areas would be useful if we want to promote diversification.

At present, new tools are being developed to design diversified rotations (Box 4). These tools appear to be meeting with a certain level of success among organisations that have tested them, but are still too recent to estimate their influence. They are useful to help structure the analysis of interactions between crops in a rotation, but their parameters still require fine-tuning, with the addition of crops for which there are few references.

**Box 4. Two tools for the design and evaluation of cropping systems**

_Persyst_ is a simulation tool developed by the INRA, aimed at operators in the field (agricultural advisers, watershed managers): it is used to evaluate the agronomic and environmental performance of cropping systems on the basis of reference management techniques and hence to assess the impact of introducing a new crop into the rotation. At present, its parameters have only been set for the Bourgogne and Eure-et-Loir regions, on the basis of information provided by local experts, and it is in the process of being rolled out with the cooperation of the various R&D bodies.

The _Stephy_ guide was produced following studies conducted by CORPEN (the French steering committee for environmentally-friendly farming practices) and the Joint Technological Network for "Innovative Cropping Systems" (RMT SdCi, created in 2007, which brings together research, development and training). It was sent to Chambers of Agriculture and Technical Institutes and is designed to provide information to assist the design of cropping systems that are more economical in terms of plant health product use, based particularly on lengthening crop rotations. It will soon be supplemented by the Agro-PEPS collaborative web tool, a technical information and exchange tool developed by RMT SdCi and aimed mainly at farmers, agricultural advisers and teachers.

- **Farmer learning dynamics to be taken into account**

Although the rapid increase in oilseed rape surface areas over the past few decades demonstrates farmers’ capacity to adopt new crops quickly, a learning process has to be implemented that focuses on these crops. Various studies have demonstrated the importance of information-sharing between farmers and collective dynamics in terms of the adoption of new practices, for example, a switch to conservation farming, organic farming or integrated production. Group activity and the testimonies of those who have tested innovations help to consolidate changes in practices. Experience acquires the status of a credible new reference because it comes from a colleague; it supplements the technical references that result from experimental systems, whose on-farm feasibility can always be called into question. Experts note the importance of “lead” farmers on the ground, who can have greater influence than the advisers.

But learning by experience takes time, often requiring several seasons. However, experts highlight the major impact of a poor harvest on abandonment of a crop. It appears that for the majority of farmers, more than one or two failures (weather-related failures, harvesting problems, for example) following the introduction of a new crop will not be tolerated. In addition, a failure with a diversification crop will appear to have more impact than for a conventional crop: several experts highlight the fact that farmers frequently plant new crops (especially if they are reputed to be hardy) in their low-potential fields. However, they more readily accept poor harvests for a known crop (the field will be blamed for the poor result) than for a new crop (which will be blamed for the failure).

Hence, the successful introduction of a new crop in an area requires that its cultivation be well mastered from a technical point of view in order to reduce the risks of under-performance from the very first years. A lower than expected yield can discourage producers, especially if it cannot be explained: the experts highlight the fact that farmers and advisers often lack the capacity to diagnose the variability of local performance in order to understand failures. Farmers must also be given enough time to consolidate their knowledge of the new crop by sharing their actual experiences as well as experimental references. Methodological and financial support for the construction and evaluation of this experience in the field would doubtless be an interesting lever.

**2.2.2. At farm scale, crop choice guided by adaptation to the farm’s internal constraints**

- **Constraints related to fields and cropping plans**

Land quality and, in particular, the characteristics of fields judged to be “poor” or “difficult” (stony topsoil, or soil with a low water reserve or water-logged soil, etc.), can reduce the range of possible crops, particularly for spring crops, which could be difficult to plant at the end of the winter or suffer from dry weather in the spring. Some plants require specific soil characteristics, such as lupin, which can only be grown in soil with high limestone content.
The return time on the same field can make some diversification crops difficult to integrate into rotations. To limit plant health risks, a return time of variable length is recommended for each crop depending on the type of pests concerned and the sensitivity of the particular crop. Linseed, hemp, and alfalfa have particularly long recommended return times (6-7 years for linseed, 5 to 7 years for hemp depending on sources...). It is therefore necessary to incorporate these crops within rotations that are already long, or to limit the proportion they represent in the total agricultural area in use so that the crop does not return too frequently on the same field. Shorter return times may pose a problem in zones with very short rotations. In the Tarn and Lauragais areas, for example, farmers introduced chick pea into short cereal-sunflower rotations, returning it to a field every 2 or 3 years in order to exploit its effect on the yield of the next crop; failure to comply with the recommended return time (4 years) led to significant damage caused by anthracnosis, after which chick pea was abandoned in this zone for around ten years. The return time must also take into account the other crops in the rotation belonging to the same botanical family or sensitive to the same pests. The recommendation to sow a Brassicaceae only every 4-5 years, because of high disease and insect pest pressure, leads to mustard being introduced as a substitute for oilseed rape rather than prolonging the rotation.

The multi-year character of alfalfa can also be an obstacle to its introduction since it takes up the use of fields, thereby reducing the flexibility of the system. Conversely, perennial crops can be useful to make use of fields that are too small or far away.

- **Constraints and opportunities related to water resources**

In 2010, irrigation was practised on 40% of grain and seed maize surface areas, 51% of soybean surface areas, 18% of sorghum surface areas and 4% of sunflower surface areas (Agreste). Introducing crops into rotations that demand little water reduces water requirements at farm and area level, and makes it possible to use soils with a low useful water reserve. Crops such as chick pea (the legume that best tolerates water shortages), pea, soybean and sorghum can be a good alternative to maize, which has the disadvantage of requiring the most water during periods when water levels are at their lowest. Soybean - and pea even more so - require less water than maize (Figure 8). In addition, spring pea offers the advantage of requiring the most water in late spring, in contrast with maize and soybean which require their water later on; introducing this crop into the cropping plan can therefore facilitate water management at farm scale.

In general, winter sowing leads to deeper rooting and hence better resistance to droughts than spring sowing. So the arrival (in 1995) of winter varieties has made it possible to grow linseed in regions more exposed to summertime water stress as a result of soils with lower water reserves (Centre, Poitou-Charentes, Pays-de-Loire, Bourgogne, etc.).

The fact that certain crops (such as alfalfa, for example) make good use of water supplies can be an advantage for their development in farms with an irrigation system. In contrast, water restrictions on irrigated land could lead either to diversification of cropping rotations, via the incorporation of crops with low water requirements, or, conversely, to simplification, via the elimination of the crops with the highest water requirements.

- **Constraints in terms of equipment and storage**

Some crops require specific sowing and/or harvesting equipment. This constraint implies either an investment on the part of the farmer, or organisation within the production area: between farmers (shared equipment within a machinery-sharing cooperative) or with agricultural contractors (contract for sowing or harvesting) or with downstream companies (harvesting handled by the processor), which can lead to organisational constraints for the farmer.

While sorghum and the protein crops considered in the study can be cultivated using the same machinery as cereals, sunflower requires a single seed drill and harvesting equipment that non-maize-growing farms do not have. Likewise, hemp requires specific harvesting machinery. In traditional hemp-growing areas (structured around the Chanvrière de l’Aube, Interval Eurochanvre and PDM Industries), farmers are responsible for harvesting and generally perform it themselves using their own machinery (combine harvester to collect the grain, then a mower for the straw). The organisation is completely different in new production areas (around Euralis and CAVAC), where harvesting is conducted by agricultural contractors contracted by cooperatives and invoiced to the farmer. It appears to be easier for farmers to begin growing hemp in an area where it is possible to subcontract harvesting operations. However, the quest to achieve a return on significant investments can have the positive result of encouraging greater long-term commitment on the part of farmers.

When a farmer sells his crop to a broker or merchant, he is obliged to store it. This constraint represents an obstacle to diversification since it requires access to as many storage units as crops harvested over the same period. It is also an

![Figure 8. Total water requirements of crops and average contribution of irrigation to meet these needs in French irrigated systems](Source: UNIP-ITCF, INRA-SupAgro Montpellier)
obstacle to crops for which storage is the most difficult, such as linseed, for instance. On-farm storage may also be made compulsory or encouraged by cooperatives (case of hemp for Chanvrière de l’Aube and CAVAC).

- **Labour and labour time**

Agricultural labour per hectare of agricultural area in use is tending to decrease: hence, for example, it fell by 18% between 2000 and 2010 in farms specialising in major arable crops. However, it may be assumed that increasing the number of different crops in the cropping plan tends to increase the labour time per hectare (follow-up, rinsing and adjustment of equipment, administrative tasks, etc.). A simulation study demonstrated that cropping plans including the largest number of crops do indeed demand the most labour, but the difference is small, at around 0.5 hours per hectare per year.

In situations of mixed arable and livestock farms or multiple activities, farmers may be encouraged to simplify their cropping system or, conversely, to incorporate crops that are not very demanding in order to be able to devote more time to their livestock or to their second activity. Crops such as hemp are particularly appreciated in these cases since they require few treatments and hence few hours of labour.

Introducing a new crop into the cropping plan can lead to an accentuation in peak labour periods or, conversely, a more even spread of labour over the year. These effects can be an advantage or a disadvantage, depending on the farmer’s priorities. Some prefer to group tasks together to avoid the need to get out and clean machinery several times or to free up certain periods, whereas others prefer to spread the work load in order to occupy available labour. However, the increasing use of agricultural contractors is changing the issue of labour peaks.

2.2.3. The economic context of the farm

- **A choice in an uncertain context**

Optimising the income, which is considered to be one of the major factors when choosing cropping rotations, becomes more difficult in situations of uncertainty. Against a background of highly variable prices and increasing climatic uncertainties, to which can be added a lack of knowledge of the long-term benefits (in terms of the rotation) of diversification, producers are encouraged to take a short-term view. When the prices of the main crops are high, farmers favour these crops, even if the prices of diversification crops are also rising; they are more likely to consider the issue of diversification when prices are low.

- **Spreading the risks by diversifying?**

Diversification of the cropping plan reduces the risks related to raw material price fluctuations and weather or health-related failures in a given year. This aspect is mentioned by management centres (CER-France) as one of the solutions for coping with price volatility.

However, management centres state that they notice that many farmers appear to consider their cropping plan on the basis of prices and market principles, rather than on technical and economic reasoning incorporating the effects of crop rotations. “Entrepreneurial” farmers, who account for 10 to 20% of the farming population and are on the increase, have strategies founded on adjustment to the market and are willing to take risks. This “opportunistic” attitude requires a high level of flexibility of cropping systems, permitting “reactive” production choices to be made in response to price or weather contexts. This approach can penalise perennial or multi-year crops such as alfalfa, but also facilitate the adoption of “diversification” crops that are not very demanding in terms of natural resources and involve few constraints in terms of their incorporation into rotations.

Contracting can partially reduce uncertainties and support a long-term approach. In some contracts, prices are set or index-linked in advance, offering security for the farmer (linseed, brown mustard in Bourgogne). Some crops, such as pea, are subject to few price fluctuations, even when grown without a contract. However, even in situations in which there are few price fluctuations, the variability of yields for the new crop remains a source of risk, particularly during the learning phase when management techniques are not yet fully mastered.
2.3. Obstacles and levers at collection and storage level

The choice of crops to be planted is generally a joint decision by producers and collecting agencies, with the latter able to influence their partners. For cooperatives, the main parameter guiding these strategic choices is the profitability of crops, which depends primarily on the volumes to be collected and the market price. This profitability requirement has led cooperatives to adopt strategies based on economies of scale throughout the agricultural region. However these volume strategies generate obstacles to the adoption of diversification crops, related in particular to the low number of collections and their logistical costs. Hence the experts highlight the fact that cooperatives only collect certain diversification crops (particularly pea) to fulfill their commitment to their members. To these logistical problems can be added the specific technological characteristics of these crops; agricultural advice that is too closely linked to the dominant crop system is incapable of offering solutions to help master these.

2.3.1. The trend towards specialisation focusing on dominant crops

The gradual deregulation of CAP intervention mechanisms has gradually led to the development of a competitive agricultural raw materials market, driving cooperatives to favour crops with profitable prices and a familiar market, in which trends can be anticipated. In addition, the strategy of operators is to market high volumes bringing greater market power to a small number of crops, rather than low volumes of a large number of crops, leading to significant specialisation of production systems. This volume strategy is reinforced for crops with higher per-hectare yields. Whereas a hectare of milling wheat in 2006 could produce an average of 7 tonnes of grain, sold at a price of €135/t, a hectare of pea produced 4 tonnes, sold at €150/t. With such a marked difference in revenue - to the tune of €345/ha in favour of wheat - commercial logic leads storage centres to give priority to volume strategies based on crops such as wheat. Hence, for example, the collection system of the Dijon Céréales group, which brings together 12 cooperatives, primarily focuses on cereals (80%) and oilseed rape (10%).

Cooperative unions, such as InVivo, have organised genuine market analysis services aimed at cooperatives. These services focus primarily on the markets of dominant crops, in which France specialises. Since diversification crops do not benefit from networks and expertise of this type, the lack of support available to storage centres to market these crops can represent a not insignificant obstacle.

Finally, these economies of scale strategies have been accentuated by the cooperative merger-acquisition trend, leading to the creation of large groups bringing together thousands of producers over extensive areas. These developments, which are accompanying processes of agricultural production standardisation, may, according to some experts, have further reinforced the “selection” of dominant crops, to the detriment of crops that have become marginal today. However, this observation needs to be qualified, since some large groups are also present on niche markets, exploiting diversification crops (Terrena for lupin, Dijon Céréales for mustard or Arterris for chick pea, for example).

2.3.2. Logistical problems: costs and organisation

Collection and storage operations generate various costs (fuel, machinery, etc.), the control of which is judged to be essential by these operators. At cooperative level, cost reduction strategies, which go hand-in-hand with economy of scale strategies, once again place diversification crops in an unfavourable position in terms of competing with dominant crops. Several “logistical” obstacles to the development of diversification crops exist.

- Geographic dispersal crop collection

Apart from localised farmer group initiatives organised for the production of a crop (chick pea, hemp for certain regions), diversification crops are generally geographically widely dispersed throughout a given collection area. For example, in the hemp production area in South-Western France, some straw producers are located several tens of kilometres from the pulping plant. The large distances between fields induce high logistical costs compared to the tonnage collected. In the absence of a diversification crop development strategy (pea, lupin, beans, sorghum), the organisation of their collection is
secondary for storage centres. Their storage may also be secondary, and the mixing of heterogeneous batches and crops (protein crops, in particular) within the same silo is common practice, making any quality initiative for these crops difficult.

Cooperatives wishing to develop certain crops have implemented a variety of different strategies to overcome these logistical problems. One option consists in offering a per-tonne premium as an incentive to encourage farmers to deliver their crop to the silo themselves. This strategy, which implies that farmers possess their own transportation equipment, is implemented, in particular, by the Vegam cooperative for linseed. Another option consists in trying to group production geographically, rallying the support of farmers whose farms are relatively close to one another: this is the strategy developed by Cavac for hemp straw, for example.

- **Competition between crops for the organisation of labour and silo availability**

The harvesting period for diversification crops sometimes overlaps with that of dominant crops, which can be problematic in terms of the organisation of labour on the farm, as well as for collection. In South-Western France, for example, sorghum is harvested at approximately the same time as maize, which generally takes priority when it comes to allocating transport and storage resources.

Silo availability is frequently mentioned as a major obstacle to the development of diversification crops. This is because, since the volumes are relatively low, storage centres often have to allocate a storage unit with a much higher capacity, as the specialisation of agricultural systems has tended to encourage investment in large silos, which are not profitable with low volumes. The desire to free up silo space for dominant crops, which are given priority, may lead cooperatives to quickly "get rid of" stored marginal crops. These are therefore sold soon after harvest - and hence often not at the best price - and are consequently under-valued. Logistical problems also seem to be a source of under-valuation by the market of bean varieties selected for their absence of antinutritional factors (ANFs): in fact, the experts stress that, in order to limit logistical costs, many storage centres do not sort bean batches and mix varieties with and without ANFs.

On-farm storage also involves investment costs (silo) and opportunity costs (using these silos for marginal crops rather than to store dominant crops pending better sales conditions). In addition, some cooperatives are reluctant to reincorporate into their silos batches stored on the farm, where they have not benefited from the same storage conditions (quality monitoring).

Hence the logistical and organisational capacities of storage centres, as well as farmers, are very important factors in cropping plan choices and the integration or otherwise of diversification crops in cropping systems. Over and above comparison of market prices, these considerations are far from insignificant as obstacles to diversification.

### 2.3.3. Technological compatibility and specificity of diversification crops

For cooperatives or processing bodies, adopting a strategy to develop certain diversification crops sometimes assumes investment in specific agricultural equipment or the services of entrepreneurs who have purchased this equipment. In addition, the specific technical characteristics of diversification crops also demand advanced knowledge of their collection and storage operations and handling of the crops before they are marketed.

- **Specificity of machinery and/or knowledge required to effectively perform operations**

In some cases, cultivating diversification crops requires specific investments, whereas in others the adjustment of existing equipment is all that is required. But the specialisation of cropping systems has led to the standardisation of agricultural machinery fleets, suitable for a small number of crops. Modifying the setting of a seed drill, for example, can prove to be an obstacle - minor, but nonetheless mentioned - particularly when field operations are carried out by companies.

For hemp, while use of the grain appears to be advantageous to supplement income from the straw, whose price is limited due to strong competition with glass wool, it is difficult to harvest straw and grain simultaneously at any optimal stage, and separating the two operations involves extra cost. Two cooperatives are jointly investing in the design of equipment enabling grain and straw to be harvested simultaneously. For chick pea, it is recommended that specific sorting machines be used, while sorghum requires systematic drying before storage and thus investment in a dryer.

Some operations may require specific technical expertise. Lack of knowledge of high-quality drying (sorghum) or storage (linseed) conditions can then prove to be an obstacle, even though this is relatively easy to overcome through the provision of training. Storage of linseed (fragility and risk of liquefaction, low seed cohesion) has thus required the training of operators in cooperatives involved in the linseed for animal nutrition supply chain.

- **Diversification is not seen as a way of reducing inputs and improving the environmental performance of farms**

The diversification of cropping systems to reduce the use of inputs does not appear to be a priority solution in storage centre strategies. It is highlighted more as a strategy to find new outlets capable of bringing added value to farmers and storage
centres. To achieve this objective of improving the environmental performance of farms, many cooperatives appear to focus primarily on technological solutions. Numerous tools from “precision agriculture” have been developed, for example, to fine-tune practices relating to dominant crops, such as Farmstar, which uses satellite imaging to adjust nitrogen inputs, or Fongipro, a winter cereal management tool designed to limit systematic fungicidal use. The experts highlight the fact that varieties resistant or tolerant to certain pests or to water stress are also used to reduce inputs, but that these types of varieties are generally only available for dominant crops.

2.4. Role of processors and relationships with downstream stakeholders

The industrialisation of agriculture has led to crop choices being highly dependent on market demand trends. Hence farmers and cooperatives increasingly structure the products they offer on the basis of the downstream requirements of the supply chains. In addition, by creating competition between manufacturers, processors and cooperatives, the distribution sector encourages these stakeholders to minimise their raw material purchasing costs and standardise their processes. While some sectors attempt to compensate for this competition or stabilise their supplies by introducing detailed specifications for the use of certain raw materials, this strategy does not necessarily represent a lever for the use of diversification crops; in some sectors it even reinforces the obstacles to diversification. Finally, competition between suppliers can also lead to strategies that limit the development of these crops.

2.4.1. Competition between raw materials: quality and interest price

A number of characteristics for this competition between raw materials have been identified as potential obstacles to the use of diversification crops. These characteristics concern the quality of raw materials, their prices on the supply market and their accessibility (in time and space). A lack of knowledge of raw materials also affects the supply procurement choices made by manufacturers. While these issues are raised in every industrial sector, the manufacture of compound feeds for livestock is a particularly important sector, given its economic impact and the fact that it can use a large proportion of the diversification crops considered here.

- Quality of raw materials in the animal nutrition sector

The production of compound feeds is characterised by the high diversity of raw materials that can be used for a given nutritional objective (Box 5). The approach upon which formulation is based pits the various raw materials against one another in terms of their nutritional composition, and, in particular, their energy value and protein content (Figure 10).

For example, protein crops are subject to very intense competition from the soybean meal - wheat pairing, which is capable of effectively addressing the performance requirements of pig or poultry production operations, where pea, for instance, could nonetheless be used in large quantities. In some supply chains, with a quality label, since cereals play a dominant role, formulators are forced to use raw materials with a very high protein concentration to ensure that the feed covers animal requirements during the growth phase. Although lupin is potentially the crop that could best compete with soybean meal due to its high protein content (40%), its use is hampered by technological obstacles (digestibility by monogastric animals), and by the absence of any commitment to this crop on the part of the stakeholders involved. To this competition - already difficult for protein crops to withstand - is added pressure from by-products of the agrifuels industry, particularly rapeseed cake and distiller's wheat.
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Box 5. The development of compound feeds and formulation in the animal nutrition sector

Although forage accounts for around 70% of animal nutrition sources (all sectors combined), the use of concentrated industrial feeds has significantly increased in the past few decades. The tonnage of these feeds has increased 10-fold in 40 years and in some sectors, such as poultry, they can now account for up to 80% of the diet. This development has accompanied the process of livestock farm intensification, related to objectives of achieving more rapid growth of the animals, requiring the use of compound feeds in which the formulation has been optimised with respect to zootechnical performances. These concentrated industrial feeds are known as "compound" feeds since they are made using a variety of different raw materials, combined in accordance with nutritional objectives, but also on the basis of profitability targets. Since feed costs often represent more than two-thirds of the cost price of an animal (excluding structural costs), formulators thus seek to optimise the formula on the basis of raw material cost (Figure 9).

The general principle of compound feed formulation therefore consists in calculating - within a given price climate and for each type of feed aimed at a specific livestock sector - the percentage of each raw material to be incorporated so as to obtain the desired nutritional composition at the lowest possible cost. The quest for greater cost competitiveness has gradually transformed formulation practices into a genuine optimisation approach which, in turn, has had a profound impact on the organisation of the agricultural raw materials market. What this means is that feed manufacturers no longer reason on the basis of crops, but, instead, on the "nutrients" that can be extracted from the various raw materials, leading to the "anonymous nutrient" principle.

In increasingly globalised markets, the diversity of raw materials that can potentially be used to make livestock feeds is further reinforcing competition between them (cereals, soybean meal, rapeseed and sunflower cake, pea, etc.), traded primarily on the basis of a "spot" market principle, in which prices are set "day to day". This competition is heightened by the fact that other agro-industrial sectors seek to sell their by-products (waste or downgraded raw materials) on this animal feed market and there has been a considerable development in synthetic nutrient production technologies. However, despite this high level of substitutability of the raw materials used, the quest by animal feed manufacturers for economies of scale and transaction cost savings (minimising logistical costs, in particular), has led to formulation practices being refocused on a relatively small number of crops. While calculation methods make it possible to create complex recipes combining a large variety of different crop species, economic profitability objectives have tended to lead to a simplification of formulas. For the three main livestock categories - pigs, poultry and ruminants - formulas have significant refocused on two product families: cereals and oil-cake (mainly soybean). Since the end of the 2000s, a significant development of new supply sources has also been observed, associated with dregs, pulps and oil-cake from national agrifuel production processes. Against this background, with no major differentiating feature related to a specific comparative advantage and with no production volume of critical size, diversification crops struggle to find a place in this highly competitive market in which formulas are highly standardised today.

Conversely, some diversification crops present interesting characteristics, which can be highlighted in the sectors that use them. For example, the specific nutritional properties of linseed, in particular the "omega 3 / omega 6" ratio of its fats, have encouraged stakeholders to set up a supply chain promoting animal feeds containing linseed, the Bleu-Blanc-Cœur (BBC) label; in this case, linseed becomes a specific raw material with a specific market outlet (see Chapter 3). A considerable advantage of the linseed supply chain approach is that it does not affect the methods for distributing the feed to animals and does not require any specific investment on the part of the farmer, but simply a change in formulation parameters. Thermo-extruded linseed can be added in two ways: i) by mixing with the usual feed (maize silage, for example, for cattle), at a concentration of 5%, and ii) by substituting a proportion of the components in the feed, particularly for monogastric animals (pigs and poultry), in farms equipped with automatic distribution systems which can easily integrate this change.

Figure 9. Diagram of animal feed formulation practices
• Quality of raw materials in other industrial outlets

As in the animal nutrition sector, the absence of a specific demand for a particular quality places supply chains using diversification crops in competition with other supply chains. This is the case for flax and hemp, in particular, used in the manufacture of insulation panels for the building industry. These panels, for which production costs are relatively high, struggle to compete against glass wool panels, which are cheaper and very widely used. Product quality is assessed primarily on its insulating capacity only: the absence of any clear display of the positive environmental impacts of hemp panels compared to glass wool is detrimental to the development of hemp crops (see Chapter 3).

• Access to raw materials and supply of processing plants

In the absence of any quality differentiation recognised by the market and consumers, diversification crops will therefore be bought on the basis of their relative cost compared to the competing dominant crops. In livestock feed, a raw material is incorporated into a compound feed if its purchase price is less than or equal to the “interest price”, i.e. the maximum price to be paid to optimise the formulation. The interest price of a raw material depends on raw material market prices, as well as its accessibility, i.e. costs related to its transportation and regularity of supply. A supply that is limited in volume, geographically dispersed and/or distant from users (“Pigs are in Brittany, the pea is not”) penalises diversification crops. For manufacturers, it is often more attractive to procure on the global market raw materials that are always available in European silos, with constant compositions and at low costs (volume strategies), rather than to set up a local procurement process.

Uncertainty (real, feared or alleged) with respect to the supply of plants appears to have been an obstacle to the Terrena initiative to set up a supply chain for lupin used in sheep feeds, as well as the Céréales Vallée initiative to develop triticale aimed at feed for production operations benefiting from the “Volailles d’Auvergne” label.

Conversely, Valorex, which operates within a traced quality supply chain, is seeking to avoid untraced products available on the global market, and secure local linseed supplies by developing a strategy of contracts with upstream stakeholders to encourage farmers to grow linseed (see Chapter 3). In Burgundy, by working with cooperatives and taking advantage of the development of varieties used as catch crops, industrialists in the mustard sector have managed to create a local mustard seed supply source; this nonetheless remains marginal compared to imports, as the strategy implemented does not permit the development of production across France.

• Cost of processing the raw material

The trend in industrial processing is towards standardisation, whereas diversification crops may present specific technological characteristics requiring additional investments. Crushing plants, for example, have been adapted for oilseed rape processes (dehulling the cake which improves its use in animal feeds) and sunflower processes; soybean, for which crushing is more expensive and less profitable, is less used by this outlet, which is therefore very limited (except in organic agriculture). For dried alfalfa, the removal of drying subsidies has increased net costs, leading to the closure of some drying plants. It also led to the quest for alternative energies to fossil fuels, to harvesting methods that could reduce energy costs (flat pre-drying) and renew interest in livestock farms for alfalfa used directly as grazing and hay.

The possibilities of using oil protein seeds is based largely on the development of technology making it possible to eliminate the antinutritional factors (ANF) of most of these seeds (through cooking), and to improve accessibility to the oil and starch (by extrusion, which destroys the cell walls), and protect certain proteins in the seeds. The relatively high cost of extrusion makes the use of seeds for conventional animal nutrition difficult (soybean, lupin); it is easier to use it in quality supply chains (Bleu-Blanc-Cœur in particular, see Chapter 3), thanks to the added value derived from sale of the products.

• Lack of knowledge of certain species

Some species have a negative image among manufacturers, sometimes unjustified but nevertheless formed following bad experiences and a lack of technical knowledge, and sometimes based on the nutritional qualities of the seeds. This is the case for the poor image of sorghum, for example (drying conditions and diseases), beans (ANF), and lupin (“blows up factories”, poorly understood nutritional quality).

2.4.2. Specifications: constraints or advantages?

Specifications can be restrictive to manufacturers to varying degrees, depending on their objectives. Some “simple” specifications only concern production characteristics, aimed at facilitating industrial processing. Others also include criteria aimed at differentiating the crop from “conventional” crops on the market. This is the case for the specifications of quality label supply chains, in particular, which recommend certain products, varieties or practices that may sometimes have a major impact on upstream production. Potentially, therefore, the use of a diversification crop covered by specifications can be a method of encouraging farmers and storage centres to commit to its production. For example, the specifications of the Bleu-
**Limitations in specifications**

In a highly competitive raw material market context, it appears that specifications may be either too restrictive (example of the *Rouge* (red) label limiting the incorporation of protein crops), or not restrictive enough (private specifications only prohibiting some raw materials, for example those derived from genetically-modified organisms), to serve as a lever for the use of raw materials.

For example, the *Rouge* label used for chicken production used to require a feed made up of 70% cereals, leaving little room for protein feed, and hence promoted raw materials with a high protein concentration, such as soybean meal. While the regulations for this label have recently evolved to require 5% proteins in the diet, manufacturers now appear to be finding it difficult to secure supplies of proteins to meet this requirement. Another example is the quality requirement of the *Jaune* (yellow) label concerning the colour of egg yolks: since a feed containing sorghum does not enable the required pigmentation to be obtained without using synthetic pigments, maize feeds are favoured by formulators in this supply chain.

The non-GM labelling of products has enabled numerous supply chains to present differentiated products on markets and to diversify their feed production plants. For a period, these differentiation strategies were seen as a method of using protein-rich raw materials of community origin. However, stakeholders ultimately focused on setting up traced supply chains from abroad and from Brazil in particular. The added value generated by selling "non-GM" products made it possible to fund the traceability of a non-GM soybean meal supply, rather than to go via the protein production supply chains in France.

**Excessively restrictive definition of specification standards and risks**

The categories of stakeholders participating in the definition of standards in specifications appear to vary depending on the supply chains. The level of participation of farmers in these negotiations appears to be highly variable and, in particular, extremely dependent on the method of operation of the cooperatives of which they are members. The specifications drawn up by Valorex for *inseed* (see Chapter 3) are a prime example. These had to be renegotiated several times due to the difficulties encountered by producers in meeting the requirements imposed (concerning omega 3 content in particular).

In human nutrition, the specifications often require additional treatment and an extra workload per hectare. The risk of downgrading the crop if it does not meet the standards can prove to be dissuasive to producers, preventing them from getting involved in these sectors. In particular, this is the case for beans destined for the Egyptian market and for soybeans used in "soyfood" (difference of €100/tonne between human nutrition and animal nutrition).

### 2.5. Conclusion: the obstacles and levers identified for twelve diversification crops

Understanding the obstacles and levers for crop diversification needs to be based on a systemic approach, considering all the links in the chain: seed companies and plant health product suppliers, farmers, collection and storage centres and advisory bodies, processors and distributors. Depending on the diversification crops considered, obstacles may appear at one or more links in the chain.

For all supply chains, the major obstacle concerns the size of the market for these diversification crops. On low-volume niche markets, seed and plant health product companies have no incentive to develop varieties and plant health products for the crops concerned, for which the development and approval costs may be too high compared to the expected return on investment. However, although public research is still largely focused on dominant crops, private initiatives, as well as public and private partnership networks are continuing or emerging, depending on the crops, corresponding to a market opening or an anticipation of future needs.

Some of the links in the various chains are more significantly affected by certain types of obstacles. For producers, for example, uncertainty about the future, associated with the highly variable regulatory context, weather conditions and cereal prices, encourages them to adopt short-term strategies, which do not promote the incorporation of diversification crops. It is for this reason that the agronomic and economic benefits of crop diversification need to be highlighted. These are expressed in the mid to long term and are assessed over a period of several years, based on agronomic and economic references concerning their performance at rotation level. In addition, the adoption and maintenance of certain diversification crops are impeded by the total or partial lack of information disseminated about plant ecophysiology and local references concerning their management. This leads to the fact that farmers find it difficult to understand why there are failures, and their response is to quickly abandon the crop. It appears to be crucial to support farmers while they are learning how to cultivate a new crop; trial and advisory networks need to be strengthened and innovative experiences pooled among farmer groups. To ensure that these crops are maintained in the farms and areas where they are introduced. To this obstacle can be added the...
technical and organisational constraints that can result from the addition of an extra crop, and which can tip the balance towards simplification of cropping plans and rotations.

As far as storage centres are concerned, greater diversification also poses organisational problems from a logistical point of view, although this constraint varies in intensity depending on the size of the farms and the extent of the economies of scale. Optimising industrial facilities, as well as economic activities (collection, storage, procurement of input supplies), and development activities (advice) by these centres requires volume strategies on a small number of dominant crops. The effect of this is to further reinforce farmers’ interest in favouring these crops, which are familiar and mastered. Finally, although the specialisation of industrial processing activities has supported the trend towards the specialisation of production areas, the development of technological innovations in processes may nonetheless help to develop the use of new crops. These technological innovations often accompany product innovations designed to conquer new market outlets. The quest for new sources of added value can also lead operators in supply chains to promote the production of diversification crops, but the quality of coordination between these stakeholders will be a determining factor to consolidate the production chain right from the start of the process, confronted by the various types of obstacles that have been highlighted. An analysis of the nature of this coordination will be central to the three in-depth case studies that follow.
3. In-depth study of three supply chains

The panorama of the various supply chains using the diversification crops considered in the study, along with the theoretical framework applied, led to the construction of several hypotheses concerning the impact of supply chain organisation on the choice to diversify crops. In fact, although the existence of commercial outlets is a necessary prerequisite for the development of crops, this condition is not in itself sufficient. The method of vertical coordination within supply chains, via the structuring of the various links in the chain, appears to be a key factor explaining the possible obstacles and levers for the development of these crops. This diagnosis guided the selection of three supply chains representative of the possible types of vertical coordination for the in-depth case studies.

- **Pea in animal nutrition**: this first case study describes a supply chain in which the degree of vertical coordination is low, since the dominant method of coordination is the “spot” market and the product of the crop is a “commodity” that competes with the other raw materials that can be used in feeds. This competition proves to be unfavourable to pea, significantly impeding the development of its cultivation.

- **Linseed in animal nutrition**: unlike the case with pea, this supply chain is highly coordinated. A single manufacturer/processor (Valorex) signs contracts with producers, setting specifications, to secure a high-quality seed supply. The construction of this niche sector is founded on a differentiation strategy in the market, based on the introduction of a label (BBC) claiming a specific nutritional quality of the products derived from animals fed with linseed.

- **Industrial hemp, aimed at the insulation market**: compared to the previous two polarised examples of coordination (weak or strong), the hemp supply chain demonstrates an “intermediate” degree of coordination. Although the upstream component of the supply chain is highly coordinated around cooperatives, the multiplicity of downstream outlets creates a competitive situation, obstructing the development of finished products (insulation panels) given the market alternatives (glass wool for example).

### 3.1. Pea in animal nutrition

#### 3.1.1. A reduction in surface areas due primarily to competition in animal nutrition outlets

- **Technical and economic factors driving the reduction in surface areas**

Pea surface areas rose from a few thousand hectares in 1973 to over 700,000 ha at the end of the 1980s. Up until 1988, the development of pea cultivation was supported by the payment of a minimum guaranteed price to the producer for his entire crop. From 1988 to 1992, the maximum amount was capped. The weakening of these support instruments following the implementation of the 1992 CAP meant that pea had to compete with the other raw materials used in animal nutrition. The result of this progressive competition was stagnation followed by a decrease in surface areas from 1994 onwards (Figure 11), exacerbated by weather scenarios unfavourable to the crop and the development, in some regions, of significant damage due to the *Aphanomyces euteiches* fungus. A second protein plan launched in 2010, granting aid to the crop for a period of two years, led to an increase in surface areas, with almost 250,000 ha in 2010. But this plan stopped in 2012, and surface areas fell back to 134,000 ha.

![Figure 11. Evolution in field pea surface areas (source: Agreste)](source)
• Pea in animal nutrition

The proportion of pea production used in animal nutrition was over 60% in 1994 (out of a total production of 3.5 million tonnes) whereas it was only 44% in 2012 (out of 300,000 tonnes produced). This evolution in production and its use is the result of difficulties in using pea in animal nutrition, an outlet that is not very profitable in comparison with other outlets, and, above all, with other crops competing with pea in the animal nutrition sector.

The animal nutrition market is characterised by a high level of diversity in the raw materials that can be used by livestock feed manufacturers to meet their objectives of minimising the cost of feeds. Thus pea, the main benefit of which is its high protein and energy content, has to compete against numerous other raw materials with the same nutritional benefits (cereals, soybean meal, rapeseed cake, other legumes). In a competitive context of this type, the benefits to farmers of growing pea would reside in the prior assessment of the yield expected and the sale price of the crop produced. However, since the early 2000s, significant falls in yield due to biotic and abiotic stress have masked genetic advances related to yield. Despite dynamic variety selection (development of new early winter varieties making it possible to avoid certain types of stress), and a relatively significant network of stakeholders, the weakness and instability of yields are a penalising factor in terms of the appeal of pea to farmers. In addition, in contrast with dominant crops such as wheat, which are traded on long-term markets, the sales price of pea for animal nutrition is generally fixed at the time of actual sale. This means that the farmer has less information about pea than about other competing crops in the cropping plan.

To understand the obstacles to the development of pea destined for the animal nutrition market, it is essential to understand the mechanisms structuring this competition at livestock feed manufacturer level. An analysis of formulation practices is particularly relevant to gain an understanding of these mechanisms.

3.1.2. Spot market and formulation

• Formulation: the nutritional benefit of pea compared to the market competition...

The objective of formulation is to provide animals with all the ingredients they need to meet their daily requirements to ensure i) maintenance of the animals’ health, ii) their production function (milk, meat, eggs, etc.). Box 5 (Chapter 2) described the general principle of formulation, based on the “anonymous nutrient” concept, as a source of competition between the raw materials available, on the basis of their nutritional profile, for a given feed quality objective. The value of pea for livestock feed manufacturers lies primarily in its protein content and, to a lesser extent, its energy content; for these two aspects, pea has to compete against several different types of raw materials for animal feeds, depending on the type of livestock operation. To make pig feeds, for example, the biggest outlet for pea in the animal nutrition sector, the presence of maize (energy) on the market leads to increased simultaneous use of oil-cake, particularly soybean meal (proteins). Within the “protein complex”, soybean is pea’s main competitor. However, the majority of formulas are optimised on the basis of minimum essential amino acid requirements (lysine, tryptophan, methionine, etc.). The high lysine content of pea (15 g/kg on average) gives it a not insignificant competitive advantage within the “protein complex” of formulas.

Consequently, the price of pea fluctuates depending on the price of the dominant raw materials it replaces, such as wheat and soybean meal. The potential incorporation of pea to manufacture feeds aimed at various types of livestock operation was evaluated on the basis of the price ratio between pea and these two major competitors. It was revealed, over the course of marketing seasons at the end of the 2000s, that considerable efforts on the price of pea were still being made to increase its incorporation into formulas.

• ... but unfavourable optimisation of procurement?

The benefits to a livestock feed manufacturer of securing a supply of pea therefore depends on a complex ratio between the nutritional quality of pea and its competitors, and between their prices on the market. Even if this ratio is sometimes favourable for pea, the costs associated with looking for suppliers and transportation of batches are generally too high to encourage the processing plant’s buyer to secure supplies. On a national scale, the concentration of potential demand for pea (over 70% of pig feed is produced in Brittany) contrasts with the geographical dispersal of the crop production (Figure 12), with low volumes in the silos of each storage centre, and variable in terms of quality. Hence, securing pea supplies is still difficult for livestock feed manufacturers in comparison with soybean meal, which is more expensive but readily accessible in large quantities in Breton ports.
In addition, replacing one raw material with another in a feed production process assumes that it generates not insignificant savings for the manufacturer over the relatively long term. Against this economic background, securing pea supplies depends on specific sale conditions, such as the need for a supplier to release a storage unit, thereby encouraging him to sell batches of pea at a price that is more attractive to livestock feed manufacturers. Hence, in the compound feed market, pea has become an "opportunity raw material".

3.1.3. Re-organising supply chains around pea?

- Towards differentiation on the animal nutrition sector?

In a context in which the procurement strategies of livestock feed manufacturers and the cropping plan choices of farmers are determined by the spot market, only the competitiveness of pea can encourage, or otherwise, the processors to incorporate them into their feeds and the farmers to grow them. This "competitiveness" lever has been the subject of significant investment by public authorities and stakeholders in the supply chain. Research levels have remained relatively high, the aim being to stabilise/increase pea yields (listing of new varieties, integration of pea into agronomic trial groups) and the public authorities have long supported pea prices to increase the crop's appeal to farmers. But even though upstream investments have led to substantial improvements, particularly in terms of availability of varieties, farmers nonetheless do not always find sufficiently profitable economic outlets for their crops, apart from an emerging outlet in the human nutrition sector - mainly for export - to encourage them to grow pea more regularly. Pea growing is thus seen as an "adjustment variable", allowing farmers to benefit occasionally from its agronomic advantages, for example in terms of reducing nitrogen fertiliser requirements. Often, however, little consideration is given to economic benefits on a rotation scale resulting from more moderate use of chemical inputs - mainly fertiliser. So pea does not benefit from a specific development strategy on the part of storage centres, particularly in environmental terms.

An analysis of formulation parameters and the operation of the animal nutrition market clearly identify these levers "upstream" of the formulator, but it is difficult to engage these levers in the current context. "Downstream" levers, concerning the final outlet for the crop, represent a potentially useful avenue for the development of minority crops. The main way of triggering an evolution of demand in favour of pea would be to make it "less substitutable" with other raw materials; this could be achieved by the creation of a differentiated market in terms of animal nutrition and, ultimately, in terms of end products. The creation of a market of this type can be considered at several levels. The regulatory lever (via feed specifications, for example) is a possible route. The promotion of a particular nutritional quality in a specific supply chain is another (quality to be determined for pea). "Non-GM" supply chain development strategies may also open up new opportunities for pea. The issue of promoting pea on a specific market - as is the case for products with a quality label - therefore appears to be central in order to overcome the limitations of the animal nutrition spot market, in which pea cannot compete.

In addition, livestock feed manufacturers' interest in by-products from agro-industrial sectors (rapeseed cake, distiller's wheat, etc.), which are cheap and available in large quantities, suggest that competition will be increasingly difficult in years to come in "conventional" animal production sectors. The segmentation of downstream markets, both in the animal nutrition sector - which remains the traditional outlet for pea - and the human nutrition sector - which is a new market offering interesting opportunities - may contribute to the creation of better coordinated supply chains, seeking specific added value that can be disseminated throughout the pea production chain.

- Implementing contract-based production?

Farmers have little incentive to grow pea, since livestock feed manufacturers are unwilling to buy their crop at a sufficiently profitable price compared to other crops, such as wheat, oilseed rape or maize, and because the human nutrition outlet remains limited. Introducing contracts for pea, based on fixing a price in advance, could encourage farmers to include this crop into their cropping plan more often, and could lead cooperatives to better organise their offer with respect to the various possible outlets. The introduction of "smoothed" price contracts or "tunnel" contracts (see linseed case study), over a period of 1 to 3 years, is currently being discussed in the agricultural profession. However, implementing coordination tools such as contracts suggests a willingness on the part of contractors to specifically develop this crop. As long as pea is not specifically demanded by users, the crop remains at a significant disadvantage on the animal nutrition market.
3.1.4. At farm level: a crop with agronomic benefits recognised via a multi-year approach

Although French surface areas have decreased since the early 1990s, the traditional presence of pea has been maintained on some farms. Several arable farmers in the Eure-et-Loir region have made this choice, maintaining pea on their farms to the tune of between 9% and 16% of total surface area. This choice is made primarily for agronomic reasons, well known to farmers today thanks to the extensive research still dedicated to this crop and large-scale dissemination of results by R&D and advisory bodies. These agronomic benefits are related to “carry-over” effects that can be attributed to “starter crops” in general (such as the effect on yield) or which are specific to pea (such as simplification of planting for next wheat crop, particularly appreciated in minimum tillage cultivation), or to cumulative effects that can be attributed to the prolongation of rotations (such as weed control, attributed particularly to diversification of the control methods possible).

Box 6. Vertical organisation of the pea supply chain in animal nutrition: diagram of a supply chain with a low level of vertical coordination

The organisation of the pea supply chain on the animal nutrition market is characterised by the absence of specific links hinged around this raw material and the associated end products. The pea sold on the raw materials market is a “commodity” competing with numerous other raw materials. There are no strong regulatory mechanisms or mechanisms coordinating the stakeholders in this market, such as fixed-price contracts or particular specifications. There is no coordination between the different links in the chain to plan pea production aimed at a market making specific use of this raw material. In the absence of such links, farmers turn to more profitable crops in their cropping plans.

Pea yields also demonstrate a high level of variability between farms and individual years on the same farm, with the French average having been lower and more variable in the past ten or so years (Figure 14). Irrigation or the use of a winter variety can reduce uncertainty concerning yields compared to non-irrigated spring pea, with a lack of water being one of the factors restricting yields. Unlike most diversification crops, this crop has been the subject of numerous research studies and, in particular, various agronomic diagnoses. Greater use could be made of these and they could be consolidated at a local level in order to gain a more in-depth understanding of the factors determining yields, taking into account changing agricultural practices (use of winter varieties, irrigation, min-till cultivation, etc.).
Although pea growing does not require any specific equipment, the harvesting conditions and nature of the seed lead to more frequent renewal of harvesting equipment compared to cereals and do not encourage on-farm storage of the crop. Despite significant improvements to lodging resistance as a result of variety research, difficulties in harvesting still persist, making pea a restrictive crop in terms of organisation of labour at harvest time.

The case of spring pea highlights the additional constraint represented by the obligation for a number of farmers to plant a catch crop before spring crops. However, plant health problems appear to be limited in the farms studied thanks to the implementation of long rotations - thereby preventing the development of the *Aphanomyces* fungus related to returning pea too frequently in a rotation – and the availability of effective plant health products, although some pests remain difficult to control.

The economic benefits of pea on a rotation scale - taking into account its "carry-over" and cumulative effects on the other crops in the rotation - have been demonstrated by research and development and widely disseminated to farmers. The latter are convinced of the relevance of calculating profit margins on a rotation scale rather than an annual scale. Nonetheless, the farmers surveyed highlight the fact that multi-year calculations of this type are practically never performed, either by their advisers or by their accounting and administrative agencies, thereby not creating sufficiently strong incentive signals to encourage other farmers to include pea in their rotations. Without this multi-year assessment, only irrigated pea is seen as being competitive compared to other crops on the basis of annual gross profit margin comparisons.

### 3.1.5. Levers used or that can be used for the development of pea

On the basis of this analysis, the levers that can be used to promote the development of pea are of two types:

- Enhance the appeal of this crop for farmers: increase and harmonise productivity (technical and genetic levers); develop local references demonstrating the benefits of this crop on a rotation scale; develop regulatory incentives (premium or conditionality on legumes, related to recognition of their environmental benefits); this route, which has been favoured for a number of years, has demonstrated its limitations and only appears to be effective if it is combined with the approach outlined below;

- Avoid the spot market via (i) the development of varieties with a specific quality, differentiating pea on the animal nutrition market; (ii) the reorganisation of the links between plant and animal supply chains (for example: contract-based cultivation of pea to encourage farmers to grow the crop); (iii) the development of new outlets, such as human nutrition (direct consumption or as an ingredient for the food processing industry).

The human nutrition outlet was not explored in any great detail in the study. However, it is clear that its development would require significant R&D work, coupling genetic, agronomic, process and nutrition approaches. In particular, work on the properties of pea proteins and on fractionation/dehulling methods making it possible to limit flatulence appear to be priorities.
3.2. Linseed in animal nutrition

3.2.1. The emergence of a new market for linseed

- **A new outlet to support surface areas**

The development of various outlets for linseed (construction, industry, etc.) led to a very significant increase in linseed crop surface areas from the 1990s onwards (with almost 40,000 ha in 1994), although this was strongly influenced by changes made to the CAP, which were sometimes favourable and sometimes unfavourable for the crop (Figure 15). But while government support for production of the crop decreased during the 2000s, the development of a new market for animal nutrition led to a further increase in surface areas at the end of the 2000s, partially counteracting the strong competition from dominant crops. This resurgence was supported by a quality supply chain based on the use of thermo-extruded linseed in animal feeds and taking advantage of some of the seed’s specific nutritional properties (high omega-3 content). Surface areas, which had fallen to 6,000 ha at the start of the 2000s, rose again in fits and starts, reaching 15,000 ha in 2010. Western France has become a region of high production (Figure 16). The consolidation of these supply chains was supported by relatively dynamic public-sector variety research in the 1990s (despite the low surface areas), and by the creation of an economic interest group for transferring selection to the private sector.

- **A market sustained by health claims: creation of a quality label**

In the 1990s, demonstration of the link between the linolenic polyunsaturated fatty acid (ALA) content in animal feeds and the lipid profile of their products (milk, meat) triggered an upsurge of interest in crop types with a high ALA content, including linseed. Numerous scientific zootechnical studies highlight the benefits of linseed in the diets of various types of animals: dairy and beef cattle, pigs and poultry. The benefits of linseed have been demonstrated on the fatty acid profile of products, in particular, as well as on other zootechnical parameters (increased milk production, reduced risk of acidosis), contributing to the growing interest in the crop on the part of livestock farmers.

In parallel, the public authorities observed that the human diet was of poor quality in terms of lipid content. In particular, the PNNS (Programme National Nutrition Santé - French National Nutrition and Health programme) highlighted the poor nutritional balance of diets, pointing the finger at animal products because of their saturated fatty acid (SFA) content. The link between animal diets and human nutrition was demonstrated at the end of the 1990s and the start of the 2000s by various...
clinical studies. These results were to form the scientific basis for the construction of supply chains for animal products with a high omega 3 content (meat, milk, eggs). The Bleu-Blanc-Cœur (BBC) label was created for these supply chains in 2000. Marketing of these products is based on the construction of a specific demand on the part of consumers for products rich in omega 3. The retail price of these products, which is higher than that of a standard product, makes it possible to fund the operation of the supply chain and, in particular, compliance with the specifications.

- A differentiated market to promote the omega 3 in linseed

On the animal nutrition market for “standardised” products, linseed is not competitive compared to the other raw materials that can be used. The development of its use in BBC supply chains is based on two main innovations: one technological and the other organisational.

On a technological level, treating the seed by thermo-extrusion eliminates antinutritional factors, improves the digestibility of the oil (high omega 3 content) and starch of the seeds, and protects certain proteins. In 2006, Valorex registered the Tradilin brand, covered by a patent concerning the specific cooking treatment applied to oil and protein crop seeds. This brand benefits from a nutritional claim recognised by the public authorities. Thanks to its patents, Valorex presents itself as the only manufacturer capable of performing this processing operation.

On an organisation level, the construction of the supply chain on the basis of a quality label, with specifications defining obligations in terms of results for farmers and processors, led the latter to specifically seek to secure a supply of omega 3-rich foods. Valorex, the only stakeholder to control production on an industrial scale, is positioned as the main supplier. To meet the specifications, the challenge for Valorex is the need to secure traceable supplies and hence the development of a strategy to encourage linseed cultivation among producers.

3.2.2. An integrated supply chain: contracts and specifications

- Specifications: obligations in terms of results and methods

As regards animal nutrition, the obligations in terms of methods linked to the specifications do not impose on livestock farmers the choice of any particular raw materials used in feeds, with the exception of certain raw materials that are also banned in other specifications (ban on GMOs, meat and bone meal, certain growth factors, fatty acids from palm oil and cake, etc.). The use of linseed is not specified in the specifications, therefore. However, while the obligation in terms of methods specifies the minimum ALA content in the feed, the obligations in terms of results (balance between omega 3 and omega 6) prompt livestock farmers to turn towards the supplier whose feeds and formulations are capable of meeting these performance objectives, i.e. Valorex. The specific demand for animal products with a high omega 3 content has an impact on the raw materials market, with a specific demand for raw materials with a high omega 3 content. Linseed is therefore traded on a market that is differentiated from the conventional animal feed market. It is observed that, while the added value generated by sales of BBC products makes it possible to fund this system, linseed is also included in the formulations of livestock feeds belonging to “conventional” supply chains, as it has been recognised as a product that improves zootechnical performance.

At linseed production level, the specifications contain no obligations of result concerning seed quality. However, quality is rewarded, mainly relative to the omega 3 content. This reward system is specified in the production contract between the storage centre and Valorex, but is not always passed on to the farmers, as will be seen later on.

- Setting up contracts with producers: avoiding the spot market and competing with other crops

It is on the basis of this downstream differentiation of products that the supply chain has been constructed, gradually integrating upstream production, in order to guarantee traceability and secure a regular supply of seeds meeting the downstream requirements. To meet its raw material requirements Valorex was to develop a contract-based approach offering its suppliers guaranteed prices, accompanied by a quality-advice approach for farmers and storage centres. The production contract, variable from one supplier to another, is an essential coordination tool for all the stakeholders in the supply chain.

However, surveys conducted among producers and information provided by management centres indicate that linseed usually only generates small profit margins compared to dominant crops. To secure supplies that are as regular as possible, Valorex draws up production contracts with producer groups and cooperatives. Among the various contracts that exist, the “tunnel” contract appears to be a useful tool for taking this competition into consideration. This type of contract is based on setting a maximum purchase price for Valorex and a minimum sale price for the farmer, irrespective of trends in linseed market prices. The guaranteed price, which is within this range, is negotiated between Valorex and each supplier; it is generally index-linked to global linseed markets, but also to prices during the previous or same year for several reference crops, such as oilseed rape and wheat, which are often used by farmers to assess the economic benefits of a new crop. The price is therefore variable from one contract to another and from one year to the next.
Today, almost 80% of surface areas for the crop destined for Valorex are under contract. However, the "tunnel" contract model has one major drawback, inherent to the evolution in agricultural markets: in a context of a marked increase in cereal or oilseed rape prices, the maximum purchasing price practised by Valorex can be a significant potential limitation. Although the contract is generally considered to offer sufficient incentive, anticipation of a rise in prices for other crops leads to difficult negotiations with suppliers.

**Box 7. Organisation of the linseed supply chain in animal nutrition:** diagram of a supply chain with a high level of vertical coordination

The organisation of this supply chain is characterised by strong links between the stakeholders, in the form of contracts involving several links in the chain in negotiations, control of production via specifications imposing obligations in terms of methods and results, as well as active participation in support and coordination structures, such as associations. The latter are characterised by a high level of representation for each link. The BBC association, organised in the form of colleges (producers, processors, consumers, etc.), also includes supply chain support bodies, such as the scientific committee, which plays an essential role in the construction and modification of specifications. This type of supply chain is therefore characterised by a high level of vertical coordination, hinged around a specific market for omega-3 rich crops, principally represented by linseed.

### 3.2.3. An extensive coordination network

One of the main assets of the BBC supply chain is its network of stakeholders that has been built up over time. This network gives structure to the supply chain and coordinates the stakeholders involved at a variety of levels:

- In particular, information-sharing within this network feeds the debate concerning contracting, serving as a basis for negotiation between the stakeholders: the key role of the Brittany Regional Chamber of Agriculture can be noted, for example, in negotiations between the members of the BLin Tradition Ouest association, which brings together Valorex, cooperatives, producers and the Linéa economic interest group;
- The existence of local networks (merchants) linking together producers (farmers’ groups and cooperatives) from the various production areas and Valorex, makes it possible to organise the procurement of supplies, via highly dispersed collection across the country. These local networks also play a major role - although clearly inadequate according to the surveys conducted among producers - in agricultural advice activities;

- The organisation of the BBC association into colleges bringing together the various links in the chain (crop production, animal nutrition, animal production, consumers, distributors, etc.) appears to be an asset in terms of coordination and strengthening of relationships between stakeholders. This approach also makes it possible to construct a market shop window, via a shared logo visible to consumers;

- Checking compliance with specifications, via third parties, is also a crucial element in the coordination of the supply chain's stakeholders around well-defined production standards;

- The involvement of Cetiom (Technical inter-professional centre for oleaginous crops and hemp) in the network, via the integration of linseed in its trial networks, offers an opportunity for the coordination of selection research and agronomic research studies and the acquisition of references for a crop that is still poorly mastered by the majority of farmers;

- Finally, reinforcement of the supply chain within the inter-trade environment (ONIDOL) offers additional resources for the coordination and organisation of production.

Information flows (vertical and horizontal) and negotiation processes are facilitated by the existence of these networks of stakeholders, on a national and local scale. In particular, they consolidate the link between the production chains (seed companies, farmers, storage centres) and the processing and use chains (manufacturers, livestock farmers and consumers).

3.2.4. Variable agronomic and economic results at farm level

The competitiveness of linseed compared to other crops varies from one region to another due to price and yield differences between crops, but also due to the variability in quality (omega 3 content) of linseed. Hence, for example, linseed gives an average profit margin that is comparable to those of wheat and maize in Ile-et-Vilaine, but well below those of wheat, oilseed rape and flax in the Eure area.

Even within a given production area, the economic results for linseed vary substantially from one farmer to another, particularly due to marked differences in seed yields. Farmers struggle to understand the reason for these disappointing results and how to improve them; studies and experts attribute them partially to the crop’s sensitivity to climatic stresses and suggest that cultivation practice adjustments may mitigate them. Farmers highlight the lack of technical supervision, which is nonetheless essential to the success of a crop for which management methods need to be learned (concerning harvesting methods, in particular) and requiring constant adjustment to reflect changing regulations (plant health products authorised, ban on straw burning).

In addition, given that the factors determining seed quality - which is also highly variable between regions - are poorly understood and little studied, it would seem unlikely at the present time that farmers can rely on the improvement of this performance to improve the economic results for linseed.

Finally, the “carry-over” effect of this crop, judged overall to be comparable to those of other starter crops (oilseed rape, pea, flax), is not measured in the local references relative to the economic benefits of the crop. As with pea, neither local advisers nor accounting and administrative centres perform calculations on the overall performances of crop rotations.

The introduction of linseed on farms is faced with agronomic limitations since it is generally recommended that a return time of 6 or 7 years be allowed for linseed in the same field, which means that the crop is limited to a surface area of around 15%. However, it appears that this limit is rarely reached on farms (most of the producers surveyed in the Eure and Vendée areas only include 3 to 10% linseed in their cropping plans). Some farmers highlight the fact that they maintain linseed in their cropping plan primarily for its agronomic benefits as a starter crop enabling cropping rotations to be prolonged (and, in particular, reducing the increasing problems related to weed control in winter crops), as well as its benefits in terms of labour organisation (work carried out at a different period compared to other crops).

3.2.5. Levers used or that can be used for the development of linseed

The BBC supply chain has led to the development of linseed surface areas, in Brittany at least. A "break-out" from the socio-technical regime has been obtained thanks to:

- Differentiation of the product on the basis of a quality criterion recognised by the market;

- A technological innovation, treatment of the seeds by thermo-extrusion;
- A strong level of coordination between the various links in the chain, on a national and local scale. The definition and implementation of specifications linked to production contracts mean that all the stakeholders interact regularly.

However, surface areas of the crop remain low and fluctuating, due, particularly, to a lack of profitability at farm level. Several additional levers could be mobilised:

- The selection of winter linseed varieties, with higher yield potentials than spring varieties. The very early harvesting of winter linseed could make it possible to sow a second crop in the year. However, this change in varieties could lead to loss of one of the agronomic benefits of linseed, which currently helps to reduce weed pressure by introducing a spring crop in rotations dominated by winter crops (wheat, barley, oilseed rape).

- The development of outlets for components of the plant other than the seeds (straw for the construction industry and other industrial uses, for example). Competition or synergy could be established with the flax sector, which is also seeking outlets for the shorter fibres.

- Index-linking of linseed prices with dominant crop markets and the involvement of all stakeholders, in particular farmers, in the construction of the price, in order to guarantee transparency.

- Greater technical support for producers, backed up, in particular, by the acquisition of local agronomic references. These would be based on the performance of agronomic diagnoses aimed at gaining a clearer understanding of the factors determining yields and quality and their variability. This diagnosis could be linked to the production contract, offering farmers the opportunity to get involved in the observation of a few key indicators relative to the crop and the environment, in addition to knowledge of their management technique. This would enable collective interpretation of the variability of results and the emergence of potential avenues to help farmers adjust their technical choices instead of being left with inadequately explained failures. The economic benefits of the crop would be enhanced by increased yields and better quality, both assessed over a longer period of time in order to integrate the necessary learning phase.

- The sharing between production areas of references, as well as the experiences of the farmers who have achieved the best results at national level, and consolidation of references relative to “carry-over” effects (in the same way as has been done for pea).

### 3.3. Industrial hemp

#### 3.3.1. The emergence of "neo-industrial" stakeholders

Primarily destined for the paper-making industry, hemp surface areas in France remained stable at around 5,000 ha up until the mid-2000s, concentrated principally in the Aube region. The surface area increases observed in the 1990s can be explained by “premium-chasing” effects as a result of specific aids granted to encourage the use of set-aside land for non-food crops (Figure 18). Within the framework of the CAP, the inclusion of hemp crops gave farmers with a buying and selling contract with an approved processor the opportunity to have surface areas eligible for CAP aids, in the same way as aids for major crops.

![Figure 18. Evolution in hemp crop surface area (source Agreste)](image-url)
From the end of the 2000s, the development of R&D focusing on the use of plant fibres led to an upsurge in interest in a number of crops, including hemp, in particular. The completion of these studies led to the construction of new processing plants in France - as producers anticipated new markets - and the promotion of the crop (“greening” agriculture and at the same time making use of land where the cultivation of dominant crops is difficult). One of the potential markets to result from these new developments was the building insulation sector - particularly insulation panels - , which developed against a background of stabilising industrial processes. The emergence of new hemp-growing areas, driven by cooperatives investing in these markets (“neo-industrial” stakeholders), led to a significant increase in surface areas dedicated to the crop in 2008. However, as a result of the technical difficulties encountered by farmers, competition between production areas and a downstream market that was disappointing for processors, surface areas fell to 6000 ha in 2011. Currently, hemp growing in France concerns around 1000 producers, operating in five main production areas, organised and located around primary processing plants (Figure 19). To these five areas can be added surface areas grouped around small processing plants, generally owned by producer or tradesmen groups, for local use of the fibre and its by-products.

3.3.2. Structuring a production supply chain: upstream integration

- **Cooperatives are investing in the insulation market**

Although numerous outlets developed for the use of hemp straw during the course of the 2000s, the insulation market appears to be the most mature. The development of this supply chain has been characterised by a marked increase in the number of stakeholders involved (producers, processors, builders, tradesmen, distributors, etc.) in several French regions. The development of these production areas - highly independent of one another - has been notably marked by the investment of two major cooperatives - CAVAC in the Pays de la Loire area and Euralis in the Midi-Pyrénées area - in straw processing and insulation panel production plants. The supply chain in the Vendée region, in particular, is examined in depth in this study, especially the strategy implemented to encourage farmers in CAVAC’s collection area to include hemp in their cropping plans.

- **Encouraging farmers: upstream integration**

These new stakeholders have set up incentive mechanisms to encourage their members to include hemp in their cropping plans. These mechanisms are based on fixed-price contracts and a high level of production support. Since the objective is to secure straw supplies for plants, the strategy involves a strong commitment to producers on the part of the cooperative. The fixed price is generally above the market price for the straw (£130/t in 2012, compared to a market price of around £100/t), to which are added a variety of premiums related to storage and delivery of the crop to the plant, the aim being to optimise logistics. The producer’s commitment relates to the surface areas dedicated to the crop over a season and is based on a guarantee that it will deliver exclusively to the other contracting party. Farmers also undertake to adhere to the specifications concerning production methods, particularly the use of certified seed bought by the cooperative.

To encourage its members to adopt the crop, CAVAC has opted for a strategy aimed at ensuring maximum control of production parameters. The aim was first of all to overcome farmers’ potential aversion to a new crop, (in other words, to “facilitate” their support for the project), and also to control production methods in order to target a required straw quality for treatment in the pulping plant. From seed choice to quality monitoring in the field and sowing and harvesting operations, producers are supported by the cooperative’s technical services. In particular, harvesting is carried out by agricultural contractors, contracted by the cooperative, which schedules and organises the majority of operations (definition of sowing and harvesting dates, specifically).
This strategy of integrating activities at an upstream stage, reinforcing links through contracts and technical support, reflects a determination to share the risk between the various links in the supply chain and, by extension, to share the added value generated by the production chain. However, despite these incentives, farmers' choice of cropping plan is largely based on price trends for other dominant crops and it remains difficult for hemp to compete. Although the results have been disappointing overall during the first years of production, new production areas are now managing to stabilise a minimum supply, by consolidating producer "hard cores".

- **Downstream competition: an unfavourable "spot" market**

Downstream of manufacturers, the sale of hemp panels - the price of which is relatively high - has to compete with other insulation products offering an equivalent, or even sometimes superior, technical performance (thermal resistance, in particular). The diversity of insulation materials on offer is driving building professionals to compare the specific technical performance of each type of material. Although hemp panels demonstrate attractive thermal and environmental properties, they are not enough on their own to adequately differentiate the product on the market. Hence, this diversity raises the question of how to define construction standards and the potentially numerous comparison criteria: thermal resistance (main criterion), fire resistance, water resistance, mechanical resistance or environmental impact.

As things currently stand, the hemp panels produced by CAVAC Biomatiéaux find themselves in a similar position to that of pea in the animal nutrition sector, i.e. they can be substituted by less expensive products, of controlled quality and meeting the technological standards for the construction of a standardised product: building insulation.

**Box 8. Vertical organisation of the hemp supply chain in the Vendée region:**

*diagram of a "hybrid" organisation*

The organisation of this supply chain is characterised by strong upstream links, in the form of contracts, specifications governing production methods and technical support offered to producers by the cooperative, which has the industrial facilities required. This high level of integration means that raw material production can be adjusted to the plant's requirements. But the "spot" organisation of the downstream market, characterised by strong competition from other insulation products, is an obstacle to the development of this market for hemp. The inadequate demand does not "drive" production.
Since the main customers of manufacturers in this sector are super and hypermarkets, the “spot” market organisation is an obstacle to the development of a specific demand for hemp panels. Given the difficulties encountered in trying to compete with substitution products downstream, manufacturers struggle to win market share. Finally, demand is not “driving” supply and it would appear to be difficult to raise the guaranteed straw price for farmers without passing on this increase to the finished products, already relatively expensive compared to their competitors. Hence, despite a high level of production integration, theoretically allowing the upstream stakeholders to control the supply, the downstream spot market makes it impossible to adjust a sufficiently encouraging production strategy to ensure a return on industrial investments (Box 8).

### 3.3.3. Competition and the search for new outlets: the difficulties in coordinating a “fragmented” supply chain

- **Coordination to stabilise innovations**

In a market context of this type, the industry appears to have reached an impasse when it comes to using hemp fibre on the insulation market. The issue of changes to housing standards appears to be crucial if hemp-based products are to “find a space” on the building market. Although this is one of the options being explored by manufacturers and inter-trade bodies, other avenues are also being considered to encourage farmers to increase hemp crop surface areas. The objective is to harness markets with a higher level of added value by using other parts of the plant and, above all, to increase the supply of hemp panels and reduce their final cost, in order to be more competitive with other insulation products. These high added value markets are potentially numerous: the use of hempseed (oil mills, cosmetics, etc.) would generate per field profit margins very attractive to farmers; hemp chaff, previously considered to be a sub-product of straw pulping, could become a product in its own right used on a variety of markets (construction of hemp concrete for the construction industry, motor vehicle components, etc.); finally, the plastics industry is another potential market for the fibres and chaff.

But the development of these new markets comes up against a variety of technological obstacles at different points in the production process (harvesting of hempseed, construction of approved hemp concrete, definition of product standards, etc.). The supply chain is fragmented, consisting as it does of numerous different stakeholders organised on the basis of localised “production/processing/use” areas; competition with the super and hypermarket distribution sector leads to the exacerbation of certain tensions between various production areas. All these factors make it difficult to coordinate sufficiently to overcome these obstacles and organise the marketing of the product. However, the stakeholders in these production areas are continuing actively to seek to overcome these obstacles, setting up collaborative initiatives between companies (“coopetition” or cooperative competition), or partnerships with downstream firms and public and private-sector partnerships.

- **What solutions offered to farmers and manufacturers in terms of seed production?**

The fanning out of the supply chain on a national scale has not been accompanied in terms of selection and seed production. The selection (Fédération Nationale des Producteurs de Chanvre - National Federation of Hemp Producers) and propagation sector (Coopérative Centrale des Producteurs de Semences de Chanvre - Central Cooperative for Hemp Seed Producers) is characterised by a monopoly situation for selling seed to producers. This upstream concentration means that a single certified seed supplier needs to address a significant increase in demand. The costs associated with the control procedures that are compulsory for seed producers given the specific characteristics of hemp (psychotropic substance content) appear to contribute to the rise in seed prices and have an impact on producers’ gross profit margins.

In addition, the multitude of potential uses of the plant leads to highly variable downstream requirements in terms of selection. The priority selection criteria vary, therefore, depending on the target market. While selection previously focused on improving the behaviour of the straw in the paper-making industry, selection and propagation efforts must now be directed towards other industrial processes, such as the fibre or chaff content, or seed quality. And while certain markets and industrial processes have not been stabilised, competition between firms and the various outlets is limiting coordination to achieve a consensual definition of selection priorities on a supply chain scale. This coordination is made even more necessary by the fact that plant breeders (FNPC) have limited resources given the relatively small size of the sector.

- **The supply chain’s information subsystem: from a local scale to a national scale**

The construction of agronomic references put in the context of the various soil and climate conditions encountered is a major challenge for the supply chain. With knowledge mainly having been produced with reference to the Aube production area context, the need to geographically broaden the scope of research activities has significantly changed the way supply chain support is organised. When farmers began growing hemp in various regions, the lack of available and accessible technical and economic references proved to be a not insignificant factor in the failure of some crops shortly after they were introduced. Initially, work on the development of these references was not redeployed and did not therefore accompany the geographic scattering of production, therefore leading to certain tensions between stakeholders in the traditional production area and “neo-industrial” stakeholders.
The highly dynamic R&D projects under way reflect an active supply chain that is becoming increasingly structured and making progress. However, the fragmentation of its projects and the isolation of production areas in terms of access to information are challenges that require greater coordination. Public authorities can usefully assist in this coordination process. However, the gradual reorganisation of inter-trade bodies and changes being made to technical institutes on a national scale (integration of the Institut Technique du Chanvre into Cetiom) are a reflection of the determination to overcome these coordination difficulties by facilitating information flows between production areas and to raise the sector's profile on a national and international scale.

- **Short-circuited supply chains: overcoming coordination difficulties on a national scale**

In parallel with the emergence of industrial production areas, the supply chain is also characterised by the emergence of localised production in various regions of France, initiated by producer groups organised around a small processing plant. These producer groups represent a total of 1,000 to 3,000 ha of hemp surface areas, depending on the year, i.e. around a third of total surface areas planted with the crop. These producers considered hemp growing to be a very interesting option, independently of the development of industrial stakeholders. Since they carry out harvesting operations themselves, they avoid the significant costs incurred by having agricultural contractors carry out the work, as is the case in industrial production areas.

These groups are sometimes the source of innovations (modification of harvesting equipment, acquisition of approvals for various plant health products, etc.) and are positioned on niche markets, with small companies and local tradesmen as their main partners, thereby avoiding the costs of industrial-scale production. The result of this is the creation of a local network, within which interactions between the various stakeholders are relatively strong. On a national level, the C3 association (Chanvriers en Circuits Courts - Short Circuit Hemp Producers) brings together all the producers adopting a short-circuit approach and works on the standardisation and harmonisation of production standards. Given the difficulties faced by industrial approaches, local initiatives, initially driven on a small scale, appear to be a way of gradually integrating hemp into cropping systems. To this end, local authority support and the involvement of supply chain information system structures (Interchanvre, Cetiom, regional chambers of agriculture, INRA, etc.) appear to be key factors for introducing the crop into cropping plans, initially on a small scale.

### 3.3.4. A crop with significant agro-environmental benefits, potentially profitable for farmers

Hemp, a crop that has been tried and tested by farmers in the traditional Aube production area, has managed to win the support of numerous farmers in different regions, where a supply chain has been set up around this "new" crop, thanks to its agronomic and environmental benefits. Its low input requirements and low associated workload, as well as other agronomic properties reflected on a rotation scale, are confirmed by farmers. For instance they mention its "carry-over" effect on the yield of the next crop, although this has not been assessed precisely by farmers or development agencies, as well as its cleaning-up properties in terms of weeds and its effects on soil structure.

The rapid development of surface areas in the new Vendée production area, encouraged by a relatively non-restrictive contracting system, has been accompanied by the implementation of a relatively efficient organisation of agricultural work orchestrated by the cooperative, but has left farmers and technicians little time to master the management techniques for the crop. This has led to numerous farmers abandoning the crop, as a result of disappointing straw yields (and hence disappointing economic results) compared to the predicted performance levels, as well as harvesting difficulties. The marked increase in yields observed between 2009 and 2011 nonetheless reinforced a hard core of producers. However this masks a high level of variability between farms, something that is also observed in the traditional Aube production area. Research is now being carried out to determine the factors underlying this variability in straw yields, but very few studies are being conducted relative to seed yields (harvested in addition to the straw in certain production areas) and straw and seed quality.

A comparison of annual gross margins over the period 2007-2011 on the basis of surveys conducted among producers and information supplied by management centres, indicates that the average inter-year profitability of hemp is similar to that of wheat and oilseed rape in the Aube region despite high prices for these two crops in the most recent years. Hemp is less competitive in the Vendée region, where its margins are lower than those for the most dominant crops (wheat, oilseed rape, sunflowers, irrigated maize). However, these margins are improving significantly as a result of better yields; in addition, there is still room for improvement, particularly via the use of hempseed, something that should rapidly become possible thanks to the resources invested by the cooperative.

Hemp is included to the tune of 9% on average and up to 20% in the cropping plans of the farmers surveyed in the Aube and Vendée production areas. The relatively unrestricted growing areas for hemp mean that, even when its surface areas are significant, farmers have no difficulty adhering to the recommended return time of 4-5 years. The latter point is crucial in order to prevent the development of plant health risks in hemp crops, as happened in the Aube production area in the 2000s with the development of broomrape, currently the only hemp parasite. It is observed that although oilseed rape - a crop with
a significant presence in hemp production regions - is also a host of broomrape, diversification crops such as linseed/flax or pea reduce seed banks in the soil by promoting the germination of broomrape without permitting its propagation.

### 3.3.5. Levers used or that can be used for the development of industrial hemp

Study of the emergence of new production basins highlights the key role of cooperatives in the development of new crops in a region. The strategy of upstream-oriented integration and production support makes it possible to identify several levers to encourage farmers to include the crop in their systems: guaranteed-price contracts, support provided by cooperative technicians, reflecting a willingness to share the “cost of change”. However, on an agricultural production scale, a major obstacle resides in the acquisition of technical and economic references in the various production areas. These references should more accurately demonstrate the possible performances and risks in various environments (including “low-potential” environments) and make it possible to rationalise practices taking into account the conditions for expression of the positive “carry-over” effects of hemp. Finally, if hemp growing expands in a production area, it is important to be vigilant with respect to the risks of broomrape development, this being the reason that the crop is now being abandoned in one of the longest-standing production areas (the Aube region).

As with linseed, R&D priorities must be to improve knowledge with respect to (i) the impact of introducing this crop into rotations, (ii) the factors underlying yield variability, straw quality and hempseed quality. On a local level, the crop’s agronomic and economic performance for farmers would be improved by setting up mechanisms to increase understanding of the causes of production variations from one year to another and from one field to another, and by organising support and guidance for farmers in the design of appropriate cropping systems.

Downstream, competition with other insulation products adversely affects demand. Levers have been identified on two main levels:

- Recognition of the specific characteristics of hemp panels would make it possible to differentiate this product on the market. Government support for users, via recognition of the specific environmental and technological qualities of “ecological buildings” may lead to labels, or various support tools (tax credits). The question of the definition of construction standards and product approval procedures is also central to this issue.

- The use of other parts of the plant (hempseed, hemp chaff, grain) on new markets would make it possible to improve both the per-field gross margins and the profitability of the industrial equipment. The stabilisation of innovations on which to base the use of these parts of the plant raises the issue of the supply chain’s capacity to innovate and design production standards shared by the stakeholders.

These levers are related to the organisation of the supply chain as a whole, and the coordination of stakeholders within the inter-trade environment. The development and organisation of information flows are a major challenge in order to stabilise downstream outlets, define research and selection priorities and ensure upstream mastery of cultivation methods.

### 3.4. A cross-cutting overview of the three types of supply chain organisation

The literature concerning organisation economics reveals three main types of supply chain organisation, for which the characteristics are summed up in Table 3.

- **Spot-type organisation**

  The majority of animal feed supply chains in which diversification crops are used (except for linseed) are characterised by this type of organisation. Although pea is the example chosen for this study, other crops among the twelve types examined are also used in these types of supply chains. Hence the obstacles to the development of beans, lupin and sorghum originate from the type of market organisation, which pits them against dominant raw materials (soybean meal, wheat, maize, rapeseed cake, etc.). These supply chains are characterised by strong competition between the raw materials, which are easily substitutable in formulation processes aimed at ensuring standardisation of market outlets. Consequently, it is difficult to effectively encourage farmers to incorporate these crops in cropping plans and the same is true when it comes to encouraging downstream stakeholders to use them. The cost competitiveness of these crops is the only economic signal of interest to the stakeholders in these supply chains; however, it is unfavourable for diversification crops compared to dominant crops. The dispersion of collection areas compared to the geographic concentration of livestock feed manufacturers generates high transaction costs for the latter, dissuading them from seeking to secure a regular supply of a given diversification crop.

  These supply chains are therefore characterised by weak coordination links between the upstream and the downstream, either in terms of transaction methods (few contracts) or information exchange (knowledge, technical references, etc.).
Consequently, not only do farmers have difficulties finding outlets for these crops on a competitive market, but they also have to cope with a lack of specific technical support.

- **Vertical integration-type organisation**

These supply chains are characterised by strong vertical coordination, through the introduction of production contracts and specifications to guarantee traceable production, but also reflecting the need to ensure the specific quality of the raw material. To secure a regular supply, manufacturers sign contracts with collecting agencies, which in turn sign contracts with farmers. The latter are therefore encouraged to produce these crops by downstream stakeholders (firms and cooperatives), via production contracts with prices index-linked on the basis of the dominant crops in the cropping plan, as well as via a support and training mechanism. The risk is shared between the farmer and the other structures in the supply chain. The linseed supply chain for the animal nutrition sector is a good example of this type of supply chain, but the same method of organisation is also found for condiment mustard (contracts between manufacturers and producers) and several human nutrition sectors (beans for the Egyptian market, lupin, chick pea).

These sectors are also structured by networks of stakeholders bringing together the various links in the chain, on a national (BCC association, Linéa economic interest group) or local (Lin Tradition Ouest, Terre de Lin, Association Moutarde de Bourgogne, etc.) scale. These networks facilitate the exchange of information between the various operators, but also between operators and information system structures (ITA (agriculture and food technology institutes), research institutes, consumer associations, etc.).

<table>
<thead>
<tr>
<th>Supply chain</th>
<th>Pea</th>
<th>Flax</th>
<th>Hemp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method of organisation of the supply chain</td>
<td>Spot</td>
<td>Integrated</td>
<td>Hybrid</td>
</tr>
<tr>
<td>Method of organisation of upstream relationships</td>
<td>Spot</td>
<td>Contract-based (+++)</td>
<td>Contract-based (+)</td>
</tr>
<tr>
<td>Incentive for upstream production</td>
<td>Incentives to adopt the crop</td>
<td>Low incentives (market price not very encouraging, occasional aids)</td>
<td>Incentives that vary in strength and credibility (index-linked guaranteed prices) depending on production areas</td>
</tr>
<tr>
<td>Transaction costs (related to logistics)</td>
<td>High (supply too dispersed)</td>
<td>Low (existence of intermediaries aggregating a dispersed offer)</td>
<td>Moderate (competition between production areas)</td>
</tr>
<tr>
<td>Technical support</td>
<td>Low at local level, loss of technical expertise for the crop</td>
<td>High: provided by storage centres, associations, etc. but variable depending on production areas</td>
<td>Existence of localised references, pooling of references difficult</td>
</tr>
<tr>
<td>Method of organisation of upstream-downstream relationships</td>
<td>Low coordination, “a-regionalised” supply chain</td>
<td>Strong: organisation into colleges of each link in the chain</td>
<td>Contract-based at industry level</td>
</tr>
<tr>
<td>Method of organisation of downstream relationships</td>
<td>Spot</td>
<td>Integrated</td>
<td>Spot (competition of outlets)</td>
</tr>
<tr>
<td>Organisation of the information system</td>
<td>Weak upstream-downstream information transmission</td>
<td>Strong upstream-downstream information transmission (numerous intermediaries)</td>
<td>Strong transmission, but only within production areas</td>
</tr>
<tr>
<td>Technical mastery of production</td>
<td>References relative to “carry-over” effects available; Irregular yields, causes known</td>
<td>References relative to “carry-over” to be reinforced; Irregular yields, causes often unknown</td>
<td>References relative to “carry-over” effects almost non-existent; Irregular yields, even in traditional production areas</td>
</tr>
</tbody>
</table>

Table 3. Comparison of the three diversification crop supply chains
• "Hybrid" organisation

Characterised by a variable degree of integration between the various links in the production chain, upstream, these supply chains are generally highly vertically integrated (production contracts between storage centres and farmers), but the downstream products are subject to marked competition on a less differentiated market from other products with similar properties (for example, hemp panels compete against glass wool, linen clothing against cotton clothing, alfalfa pellets against soybean meal, etc.). Manufacturers, who are often structurally linked to cooperatives seeking to diversify their markets, specifically want to secure supplies of a raw material and hence want to encourage farmers to incorporate these crops into their cropping plans. But the competitive difficulties encountered by the downstream market do not allow them to obtain sufficient added value to be able to fund these incentives and thereby extend their supply pool. This competitive difficulty may be due to a perception of inadequate product differentiation by consumers.

These supply chains are relatively firmly anchored in the region since plants are mainly supplied by local producers. However, this type of production area approach generates rivalries in the case of hemp and makes it more difficult to coordinate a supply chain with multiple outlets for information sharing or the construction of technical references accessible to farmers. In the case of dried alfalfa, the implementation of a single marketing structure overcomes this hurdle.

Analysis of these three types of organisation therefore raises broader questions concerning the evolution of the French agricultural production system. It reflects the diversity of stakeholders and the complexity of the relationships between companies and between the information subsystem and the operational subsystem of a supply chain. To increase the surface areas for a given diversification crop, a detailed analysis of this complexity is required and a diversity of levers need to be employed simultaneously, adopting a systemic approach.
4. General conclusion and recommendations

The hypothesis adopted at the start of the study is that crop diversification assumes break-out from the socio-technical regime that dominates current agriculture. The case studies - and the three in-depth cases, in particular, - confirmed this hypothesis and introduced greater precision: all the stakeholders (from farmers to manufacturers, research institutes to advisory structures, seed companies to storage centres) have built their strategies on the basis of "major crops", for either organisational or logistic reasons, in order to address the supply or demand of their economic partners, to achieve economies of scale or to reduce transaction costs. Numerous self-reinforcement mechanisms, characteristic of technological lock-in, were described in this study, with the interconnections between these being particularly highlighted by the in-depth studies in the pea and hemp supply chains. The socio-technical system organised on the basis of dominant crops and the simplification of cropping plans is therefore an obstacle to the development of diversification crops as a result of various closely interlinked processes:

- Difficulty coordinating the evolution in demand and production volumes in these supply chains; when demand increases (linseed), the production volumes do not always follow and the difference is made up by imports; when production increases, driven by government support (pea), the potential users, who have found a different solution (livestock feed manufacturers located near ports), are not necessarily interested.
- A lack of technical references relative to most minor crops concerning management of the crops in various soil and climate conditions, their "carry-over" effects and the causes of poor yields (that need to be known to be corrected). These shortcomings affect the competitiveness of production. In addition, when a new crop gathers momentum, competition between growing areas can also delay the development of these references.
- Genetic progress that is less rapid than for "major crops", due to lower investment in selection, but also the difficulties that plant breeders have in anticipating the requirements of supply chains that are not yet stabilised. Plant breeding companies require a minimum level of visibility concerning future demand before they will decide to invest in a minor crop, or select on the basis of precise quality criteria related to an industrial process liable to give impetus to a sector.

The network of stakeholders, innovations and reference and key skill acquisitions that have accompanied the construction of major crop supply chains mean that they are better equipped to strengthen their competitive position on markets. If we wish to encourage diversification, it is essential, as demonstrated by the three in-depth case studies, that these crops can offer sufficiently compelling competitive advantages. To achieve this, it would appear to be essential to act simultaneously and in a coordinated manner on three complementary levers: market outlets, coordination of supply chain stakeholders and improvement of production techniques and genetics.

Promoting crop diversification requires the prior promotion of new market outlets

Against a background of agricultural policy deregulation, governments are demonstrating a desire to rely on more regulation by markets. Although it needs to be supported by the public authorities to be triggered, diversification will only be sustained in the long term if the actions of public authorities are supported by market mechanisms. Hence the choice, in this study, to begin with market outlets and to examine agricultural production approaches on the basis of market principles.

To create new outlets, a constant factor revealed in the case studies is the importance of basing the differentiation of products derived from diversification crops on qualities that are recognised by the market: nutritional quality (promoted by the Bleu-Blanc-Cœur label in the case of linseed); technological quality, often associated with a new patented process (thermo-extrusion of oil and protein seeds by the industrial firm Valorex, production of lupin protein powder by the cooperative Terrena, extraction of pea starch by the firm Roquette, etc.); environmental quality in the use of the product (hemp in the eco-construction sector); quality related to the source (official labels already present or to be created). Promotion of these qualities by the market brings extra added value liable to encourage and support the production of these diversification crops. However, this differentiation can lead to transaction costs (collection, storage, traceability, etc.) that might reduce the economic value, particularly in the presence of a fragmented diversification crop offer across the territory. The coordination of stakeholders in the supply chain is essential to reduce these transaction costs.

Stakeholder coordination and structuring of supply chains play a major role

Given that only a strategy based on differentiation via quality could generate enough added value to promote the development of diversification crops, the supply chains related to these crops must manage the various transaction costs that could affect them at various stages: upstream production (choice of management techniques, choice of varieties, etc.), processing (choice of technological processes, choice of additives and ingredients, etc.), marketing (choice of distribution channel, etc.). For a farmer, adopting a new crop requires specific investments (in terms of equipment, as well as training...
and new knowledge in order to master management techniques). Opting to diversify is a risky strategy and these investments can therefore be considerable. To encourage farmers to make these choices, it is essential to guarantee an adequate and stable return on their investments. To achieve this, it is important that the supply chain providing access to the diversification crop market be coordinated on the basis of contracts, guaranteeing farmers technical support and an outlet for their product, and securing supplies for processors in the long term. Generally speaking, contracts signed for a period of several years help to encourage the long-term commitment of the various links in the supply chain to the specific production process set up. This approach thus provides greater transparency in terms of production choices, from the upstream to the downstream; it can reinforce cohesion between agricultural and food supply chains, as well as between plant and animal supply chains, ensuring that added value and knowledge are more effectively shared between the various stakeholders. However, the efficiency of a contract-based approach of this type requires the contracting parties to be sufficiently balanced to ensure that the contract cannot be weighted too far in favour of one or the other. To this end, public policy regulating these long-term contracts may be useful.

This coordination between the stakeholders involved is crucial. The case of flax perfectly illustrates the risk of a market outlet opening up and then being filled by imports, due to a lack of adequate coordination between production and processing stakeholders. This coordination requires specifications guaranteeing the quality of the agricultural product and its traceability. It must also include the development and dissemination of references, as is demonstrated by the case of pea: it has been shown that it is possible to encourage farmers to produce a crop with a low annual profit margin by making them aware of the benefits of evaluating their cropping system over a period of several years. Inadequate structuring of supply chains and poor coordination between the various upstream and downstream stakeholders appear to represent a major cause of failure for the building of certain diversification supply chains.

In most of the cases analysed, the impetus for diversification was initiated on a local level, with the production area appearing to represent an ideal scale for the emergence of a new supply chain and the coordination of the stakeholders involved in it. Sometimes the supply chain remains limited to this scale (chick pea, mustard) and sometimes it is extended to other regions (flax, hemp). Cooperatives play a major role in the construction of these local supply chains, by mobilising farmers and negotiating agreements with downstream stakeholders, opening up market outlets. But the in-depth analysis of the three cases demonstrates the importance of simultaneously mobilising other stakeholders: agricultural R&D, plant breeders, management centres. It is necessary to promote the emergence and consolidation of local drives of this type in order to develop innovation niches. What can be done to ensure that the various stakeholders involved in the supply chains (cooperatives, processors, distributors) and in agricultural R&D (research bodies, technical institutes, chambers of agriculture, cooperatives, Civam (French centres that promote agriculture and the rural environment), etc.) and the farmers coordinate their strategies with respect to a diversification crop? Would it be possible to create original partnerships inspired by the industrial clusters developed in other fields (such as aviation or computing, for instance)? The latter, which are supported by long-term public policies (10 years, with assessment midway through the period, for example), could promote the application of technological, agronomic and organisational innovations and capitalisation on the experience (technical and economic) required for the construction and long-term future of new agro-industrial supply chains. To this end, European Innovation Partnerships (EIPs) in the area of “agriculture”, as envisaged by the European Commission, could offer the ideal framework. These EIPs aim to develop “local innovation groups”, uniting the various stakeholders in an area around local issues, while encouraging capitalisation on knowledge and experience.

**Getting R&D, advisory and plant breeding stakeholders involved on a national and regional level**

Although the impetus for coordination between the various stakeholders often originates at local level, an investment on the part of national research and development bodies, working in a coordinated manner with their European counterparts, is essential, both to create knowledge relative to diversification crops (genetics, ecophysiology, agro-ecology, processing technology, economics of supply chains, etc.) and to provide methodological support to the stakeholders involved in the emerging supply chains (selection methods, support for the construction of crop management techniques and cropping systems or industrial processes, for example). Investment in some diversification crops is already significant, as demonstrated by the bibliometric analysis conducted in this study. However, several crops do not appear to be the subject of any real Research & Development (R&D) investment at present, for French conditions: lupin, condiment mustard, chick pea, as well as lentils, buckwheat, etc.; others are relatively well known on an agronomic level, but very few basic genetic studies have been conducted: hemp, flax, oats, etc. Setting a national objective of curbing the specialisation process implies questioning the balance of R&D investments between major crops (wheat, maize, oilseed rape, etc.) and minor ones. Reinvestment that focuses on these minor crops needs to be carefully thought out and coordinated at regional, national and European level.

On a regional level, it would appear to be essential to consolidate and adapt the references relative to productivity, profit margins and the “carry-over” effects of diversification crops. Although, nationally, the scientific literature often highlights the beneficial effects of diversification crops on subsequent crops (and sometimes quantifies these benefits), the...
references rarely have a regional focus. The accounting and management bodies that calculate for their customers average profit margins per crop in their region do not have the data required to qualify these margins on the basis of the previous crop or, better still, to perform calculations over a period of several years. While price fluctuations encourage the adoption of a short-term approach to cropping plans, farmers tend to lose sight of the benefits of a rotation-based approach. A sustained effort (on the part of R&D, advisory and accounting/management bodies) to disseminate quantified information concerning the comparative profit margins of rotations diversified to varying degrees is essential to counter-balance this trend. Still on a regional level, it appears to be crucial to organise support for farmers while they learn how to cultivate a new crop, by reinforcing trial and advisory networks, and to encourage innovative experience-sharing within farmer groups. The production contracts offered to farmers could schedule the incorporation of simple mechanisms to collect indicators suitable for explaining performance variability (between fields, between years) and guiding practices. Thus, as stakeholders in the collective innovation process related to the development of the diversification process, farmers would be more inclined to invest in the new supply chain for the long term.

However, tensions were revealed between competing regional trajectories, which could be detrimental to the setting of consensual selection objectives and the sharing of references. While the development of diversification crops remains the domain of local stakeholders, uncoordinated on a regional level, it will rapidly reach a ceiling. From the moment that several production areas are formed with different stakeholders, it would appear to be essential to construct a solid structure linking these stakeholders in order, firstly, to initiate dialogue with plant breeders regarding the selection objectives to be favoured and, secondly, to organise exchange and the adaptation of references between areas.

For a plant breeder, investing in an emerging supply chain is a major risk, particularly if the quality criteria sought have still not been clearly defined. The public authorities undoubtedly have a role to play by helping plant breeders (as was done for pea or lupin in the 1970s and 80s) to invest in a few strategic crops. Coordination of minor crop selection strategies on a European scale is essential. There is a strong demand on the part of the stakeholders in the supply chain for reinvestment in public research in the field of "minor" crop genetics and selection.

Paradoxically, pest control in diversification crops appears to be an obstacle to their development, even though it is one of the reasons for seeking to diversify cropping plans and rotations from an agronomic and environmental point of view. The approval of plant health products suitable for diversification crops is impeded by the low economic value represented by the reasons for seeking to diversify cropping plans and rotations from an agronomic and environmental point of view. The Paradoxically, pest control in diversification crops appears to be an obstacle to their development, even though it is one of the reasons for seeking to diversify cropping plans and rotations from an agronomic and environmental point of view. The approval of plant health products suitable for diversification crops is impeded by the low economic value represented by the reasons for seeking to diversify cropping plans and rotations from an agronomic and environmental point of view.

What levers for public action?

One of the major conclusions to emerge from the study, supported both by the scientific literature (lock-in and transition theories) and the results of the field survey, is that any process towards diversification is necessarily dependent on the simultaneous and organised mobilisation of numerous stakeholders. To drive or facilitate this mobilisation, public action must adopt a systematic approach and combine a variety of complementary measures designed to link together and coordinate the strategies of the different stakeholders involved. In the complex situation described in the study and given the numerous interdependences and sources of lock-in that it highlights, there is no longer any place for superficially attractive over-simplifications, such as "one problem, one solution" or "one public policy objective, one instrument".

The theory of transitions leads us to propose the simultaneous and coordinated mobilisation of two major categories of levers: (i) develop innovation niches, places for the implementation of learning processes and the construction of new economic networks; the purpose of these niches will be to play host to the construction and consolidation of diversification supply chains; (ii) encourage the standard socio-technical system to evolve, to open up new windows of opportunity, through which certain diversification supply chains will be able to grow and expand beyond the niche status, or even to form a hybrid with the standard system, thereby contributing to its evolution, i.e. its transition.

1. Support the development of innovation niches, for the construction and consolidation of diversification supply chains. The supply chains to be supported could be chosen on the basis of their potential market outlets and the dynamism of the stakeholders concerned, as well as their impact on the environmental performances of cropping systems. The possible actions will have the following objectives:

- To promote and support the implementation of relatively long-term (for example 10-year) partnership mechanisms between supply chain, R&D, advisory and public research bodies, plant breeders and local authorities, aimed at constructing diversification supply chains on a local or regional level. In particular, these mechanisms should help build and secure the long-term future of networks of stakeholders and contribute to the

Crop diversification: obstacles and levers
incubation and validation of the technological, agronomic and organisational innovations required to ensure the competitiveness of the supply chain... They would aim to rally the support of all the stakeholders in the supply chain and the area around projects favourable both to regional development and the environment. It is possible that mechanisms of this type could be supported as part of the second pillar of the CAP and, in particular, within the European innovation partnerships currently being constructed.

- **To reinforce the label system (primarily official quality labels)** making it easier to signal characteristics of the products derived from diversification crops to consumers by highlighting a specific quality, such as an environmental and/or nutritional quality. To this end, HVE (Haute Valeur Environnementale - High Environmental Value) certification could contribute to the development of diversification crops. The introduction of an “agriculture-health” quality label for products with a high nutritional quality (such as animal products with high omega 3 content, dried vegetables) could also promote some diversification crops.

- **To sustain technological and genetic innovation relative to diversification supply chains.** Generally, this point is related to the programming of public research choices, the funding of clusters in the agrifood sector and, doubtless, the priorities of the future investment bank. As regards varietal innovation more specifically, several routes (non-exclusive) can be taken: encourage public research reinvestment in orphan species, organise public and private partnerships for the selection of minor crops, support private plant breeders investing in diversification crops, in a coordinated manner with production and processing stakeholders. Innovation support should also concern the provision of plant health solutions for minor uses, in particular “diversification crop / pest” pairings for which there are no efficient alternative solutions.

- **To promote investment on the part of the entire French agricultural R&D system** in the field of ecophysiology and the management of diversification crops (to understand and reduce yield instability), diversified cropping systems and the ecological role of crop diversification at landscape level. A priority would be to develop, for all diversification crops: (i) regionally adapted references concerning their performance, from a quantitative, qualitative and environmental point of view; (ii) references concerning their “carry-over” effects and the profit margins over a period of several years; (iii) diagnostic tools to help farmers analyse and resolve failures while they are learning to grow new crops. The creation of references concerning diversification crops and diversified rotations could be a compulsory theme in the objectives contracts of bodies financed by Ministry of Agriculture funds dedicated to agricultural and rural development (CASDAR). Farm management bodies could be encouraged to offer their clients analyses over a period of several years including “carry-over” effects or rotational margins. Finally, although the study did not examine this point in detail, it would be a good idea to step up research in the area of mixed arable and livestock farming systems, the historic decline of which has contributed to the simplification of cropping plans (see Box 1).

- **To promote an observatory to monitor minor crops in regions and their role in cropping plans and rotations,** in order to track the diversification process at work and be able to assess the agronomic, ecological and economic implications. To do this, it would be necessary to differentiate between the various minor crops in statistics, since at present they are often grouped together into a single category, making monitoring difficult.

2- **Encourage the standard socio-technical system to evolve, in order to more effectively integrate diversification crops.** The following proposals aim to modify the “landscape” of the standard socio-technical system in order to encourage stakeholders to change their behaviour with respect to diversification crops and markets. These levers are not derived from the three in-depth cases but were mentioned by the experts questioned for the first part of this study:

- **Encourage crop diversification via CAP regulations:** the diversification measure in the CAP 2013 greening component represents a first signal, even though studies conducted under the auspices of the General Commission for Sustainable Development⁴, for example, suggest that it will have only limited effects as it currently stands. The long-term maintenance and stepping up of specific support for leguminous crops could have a beneficial effect, as long as the supply chains related to these crops are consolidated.

- **Promote diversification supply chains via public contracts** (mass catering for public institutions, insulation using local agricultural resources in public buildings, etc.), which almost certainly requires changes to contract awarding criteria.

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• **Encourage the reduction of inputs:** given the historic link - highlighted in the introduction - between the simplification of cropping plans and rotations and the increase in input consumptions (water, pesticides, fertilisers), any public action aimed at reducing the use of inputs will be liable to facilitate a trend towards crop diversification.

Since they are aimed at processes with a high level of inertia, all these proposals can only be effective if the corresponding measures are implemented over the long term (10 years rather than 5 years) and highlighted, from the time they are implemented, as measures that need to be sustained. This condition is essential to encourage - both for selection and for the processing supply chains - the specific and long-term investments required to trigger innovation and to consolidate credible, long-term actions by all the stakeholders involved.
Selection of bibliographic references

N.B.: All bibliographic references used in this study are indicated at the end of each chapter of the French report, which can be consulted online.

Introduction


Box 1 « simplification »


Technological lock-in


**Diversification**


**1.2.1. Panorama of the obstacles and levers mentioned with respect to twelve diversification crops**


Crop diversification: obstacles and levers


Case study of pea supply chain


Céréopa. Un éclairage original sur la consommation des matières premières en alimentation animale. CEREOPA : Présentation du modèle Prospectif Aliment. 2000 (Site Internet).


Valorex, 2011. Valorex s’investit dans la filière végétale avec des prix garantis (Dossier de presse), 17 p.

Case study of linseed supply chain


Valorex, 2011. Valorex s’investit dans la filière végétale avec des prix garantis (Dossier de presse), 17 p.

Case study of industrial hemp supply chain


CETIOM, Tableau récapitulatif des variétés de chanvre inscrites au catalogue


**Case study of pea production at farm level**


**Case study of linseed production at farm level**


**Case study of industrial hemp production at farm level**


Main accessed internet websites

AFIP : http://afip.asso.fr
Agreste : http://agreste.agriculture.gouv.fr
Céréopa : http://www.cereopa.com/fr
CETIOM : http://www.cetiom.fr
Chanvre Mellois : http://www.chanvre-mellois.com
Coop de France : http://www.coopdefrance.coop/fr
Coop de France Déshydratation : http://www.luzernes.org ; http://culture-luzerne.org
DRIAAF Ile de France : http://driaaf.ile-de-france.agriculture.gouv.fr
Commission Européenne : http://ec.europa.eu/agriculture
Feedbase : http://www.feedbase.com
GNIS : http://www.gnis.fr
INRA : www.inra.fr
INSEE : http://www.insee.fr
Interchanvre : http://www.interchanvre.com
ITL : http://lin-itl.com
La Chanvrière de l'Aube (LCDA) : http://www.chanvre.oxatis.com
OCDE : http://www.oecd.org/fr
UNIP : http://www.unip.fr
VALOREX : http://www.valorex.com