OCL 2015, 22(6) D604

DOI: 10.1051/ocl/2015043

OCL
Oilseeds & fats Crops and Lipids
Available online at:
www.ocl-journal.org

RESEARCH ARTICLE – DOSSIER
OPEN ACCESS

FLAX AND HEMP
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Survey of 47 oilseed flax (*Linum usitatissimum* L.) growers to identify ways to expand its cultivation in France

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Received 27 February 2015 – Accepted 24 July 2015

Abstract – Over the past 20 years in France, oilseed flax (*Linum usitatissimum* L.) has usually been grown on less than 20 000 ha per year while needs of the French linseed sector are estimated at around 30 000 ha per year. In this article we identify ways to increase the cultivation of oilseed flax in France. Forty-seven linseed producers were surveyed in January 2013. The aim of this survey was to (i) describe farming systems that currently grow oilseed flax (*e.g.* size, nature of production, farmers' goals), (ii) identify farmers' perceptions of strengths and weaknesses of oilseed flax in their farming systems, and (iii) test farmers' reactions to scenarios created to facilitate expansion of oilseed flax cultivation. Surveys reveal a wide diversity of farming systems that produce linseed, from those specialised in crop production to those specialised in animal production. According to surveyed farmers, main advantages of oilseed flax are related to its compatibility with the farm work schedule. It is also useful agronomically, as it is a beneficial preceding crop and increases the duration of crop rotations. It is also a valuable alternative to crops that become difficult to grow. Its main drawback is that it provides insufficient profits. As for the expansion scenarios, cultivation of oilseed flax may increase if the linseed sector addresses genetic improvement (*i.e.* new oilseed flax cultivars), technical progress (especially in pest and disease management), and economic subsidies (*e.g.* a minimum price for linseed).

Keywords: Crop diversification / oilseed flax advantages / scenarios / expansion of oilseed flax cultivation

Résumé – En France le lin oléagineux (*Linum usitatissimum* L.) est régulièrement cultivé sur moins de 20 000 ha alors que les besoins de la filière française sont estimés à près de 30 000 ha. Cet article se propose donc de déterminer des leviers agronomiques, économiques et organisationnels à actionner pour développer la surface métropolitaine de cette culture. Quarante-sept agriculteurs produisant du lin oléagineux (ou en ayant produit récemment) ont été enquêtés en Janvier 2013. Cette enquête devait permettre (i) de caractériser les exploitations productrices de lin oléagineux (taille, nature des productions, objectifs de l'exploitant, *etc.*), (ii) d'identifier, aux dires des agriculteurs, les atouts et faiblesses du lin oléagineux dans leurs systèmes de production et (iii) de recueillir les réactions des enquêtés à l'énoncé de scénarios imaginés pour faciliter le développement de la culture de lin oléagineux. Les enquêtes révèlent une importante diversité de types de système produisant du lin oléagineux, depuis ceux spécialisés en grandes cultures jusqu'à ceux spécialisés en productions animales. Aux dires des agriculteurs, les atouts du lin oléagineux sont liés à sa facilité à s'insérer dans le calendrier de travail. Il est aussi apprécié pour sa capacité à allonger les rotations et à se substituer à des cultures pour lesquelles les agriculteurs sont dans une impasse technique. Son principal défaut est lié au fait qu'il procure une marge brute insuffisante. De l'analyse des scénarios, il ressort que l'expansion du lin dans l'avenir pourra se faire si la filière porte ses efforts sur les points suivants : l'amélioration des variétés, le progrès technique et une implication économique.

Mots clés : Diversification des cultures / atouts du lin oléagineux / scénarios / développement de la culture de lin oléagineux

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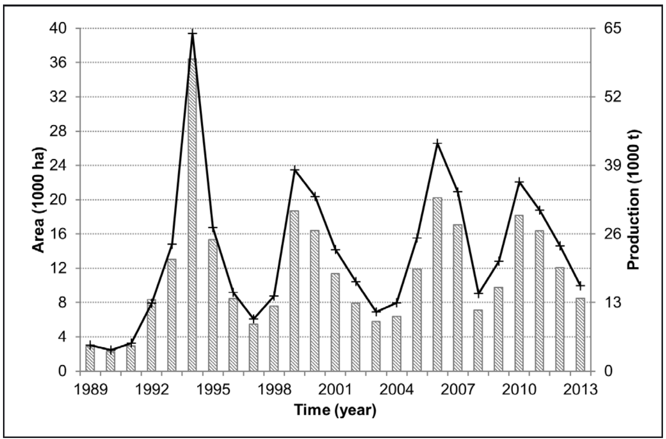

Fig. 1. Area of oilseed flax (*Linum usitatissimum* L.) (bars) and production of linseed (line) in metropolitan France from 1989–2013 (Agreste, 2015).

1 Introduction

Over the past 20 years in France, oilseed flax (*Linum usitatissimum* L.) has usually been grown on less than 20 000 ha per year, with mean annual production of 22 441 ± 13 842 t (Fig. 1). Consequently national demand is not satisfied as mean annual consumption of linseed was 45 848 t over the last five years (2009–2013), nearly twice the amount of French production (Agreste, 2015). Demand is high and comes from the agricultural industry (mainly to produce linseed oil, Merrien *et al.*, 2012; Zanetti *et al.*, 2013) and the cattle-feed industry. The latter incorporates linseed into animal feed to produce feed enriched with the high omega-3 fatty acid content which linseed offers (*e.g.* Corino *et al.*, 2014).

Cultivation of oilseed flax also has non-economic benefits, such as allowing farmers to diversify their crop rotations. Diverse crop rotations are known to reverse many of the negative socio-economic and environmental impacts of short rotations or rotations with few species, both of which are characteristics of modern crop-production systems (*e.g.* Davies *et al.*, 2012). Long and diverse rotations with an appropriate crop sequence may increase yields due to "rotation effects" such as improved disease control nitrogen nutrition and water supply. For example, wheat yield after a flax crop was higher than that after wheat or barley (Kirkegaard *et al.*, 2008). Less use of chemical inputs (particularly fungicides and mineral nitrogen fertilisers) than that for crops such as wheat is another benefit of growing oilseed flax; this reduction occurs for oilseed flax itself as well as for the following crop, especially wheat (Onidol, 2011).

However, despite "long-term breeding programs and in-depth agronomic studies" (Zanetti *et al.*, 2013), potential oilseed flax yields are difficult to achieve due to frequent unfavourable climatic conditions (*e.g.* frost, wind lodging), especially for spring-sown cultivars (Doré and Varoquaux, 2006). Moreover, certain steps of crop management are challenging such as harvest and straw management. For these reasons, farmers may consider its profits insufficient, especially compared to those of wheat (Merrien *et al.*, 2012).

This mix of advantages and disadvantages may explain why French oilseed flax cultivation remains low and inconsistent and depends on the economic context. Peaks in oilseed flax cultivation (Fig. 1) were due to subsidies of the Common Agricultural Policy of the European Union (1994, 1999) and development of new markets (*e.g.* cattle feed in 2006–2007) (Labalette *et al.*, 2011).

Currently, the French oilseed crop organisation (Onidol) and the French technical institute for oilseed crops (Cetiom) consider an area of 20 000–30 000 ha as an appropriate objective in France (Labalette *et al.*, 2011). To achieve this objective, the main issue is to discover ways to encourage more farmers to produce more linseed.

Based on one face-to-face survey conducted in 2013 with each of 47 French linseed producers in the main production areas, the present study aims to identify ways to develop oilseed flax cultivation on their farms and to introduce this crop to other farms.

2 Methods

2.1 The survey

We used the survey method of Merrien *et al.* (2013). From 21–28 January 2013, 47 farmers were interviewed for approximately 90 minutes each by students of AGROCAMPUS OUEST, a French university-level college, also known as a "*Grande École*". Farms were located in western France (Fig. 2) in three main production areas: Eure-et-Loir/Loiret ($n = 7$), Ille-et-Vilaine/Mayenne ($n = 10$) and Loire-Atlantique/Vendée ($n = 30$). The names of the farmers had been provided by two agricultural cooperatives (Cavac, Vegam), one agricultural company (Ets Dutertre), and one linseed producer's association (Graine de Lin 28). All farmers surveyed had grown oilseed flax (four for the first time in 2012–2013 and 15 who did not grow it in 2012–2013). Consequently, in 2012–2013, 32 farmers grew (or planned to grow – surveys occurred in January 2013 after farmers seeded winter-sown cultivars but before they seeded spring-sown cultivars) oilseed flax. This sample of oilseed flax growers is clearly not representative of French agriculture since only 0.3% of French farms grow oilseed flax: specifically 1.9% (155 farms) in Eure-et-Loir/Loiret, 0.9% (169 farms) in Ille-et-Vilaine/Mayenne, and 1.7% (213 farms) in Loire-Atlantique/Vendée (2010 agricultural census in Agreste, 2015).

The survey covered the following points:

- General information about the farmer: age, personal goals (*e.g.* have more free time, earn more money, preserve the environment), projects for the farm (*e.g.* farm expansion, field drainage, field irrigation, purchase of agricultural equipment).
- Description of the farming system: legal status of the farm, number of workers, areas of crops, yields of main crops, sizes and production of livestock populations, description of the main fields (*e.g.* surface area, advantages, disadvantages).
- Focus on the oilseed flax crop: reasons to grow oilseed flax, reasons to stop growing oilseed flax (if any), oilseed flax yields, description of rotations including oilseed flax, description of oilseed flax crop management.

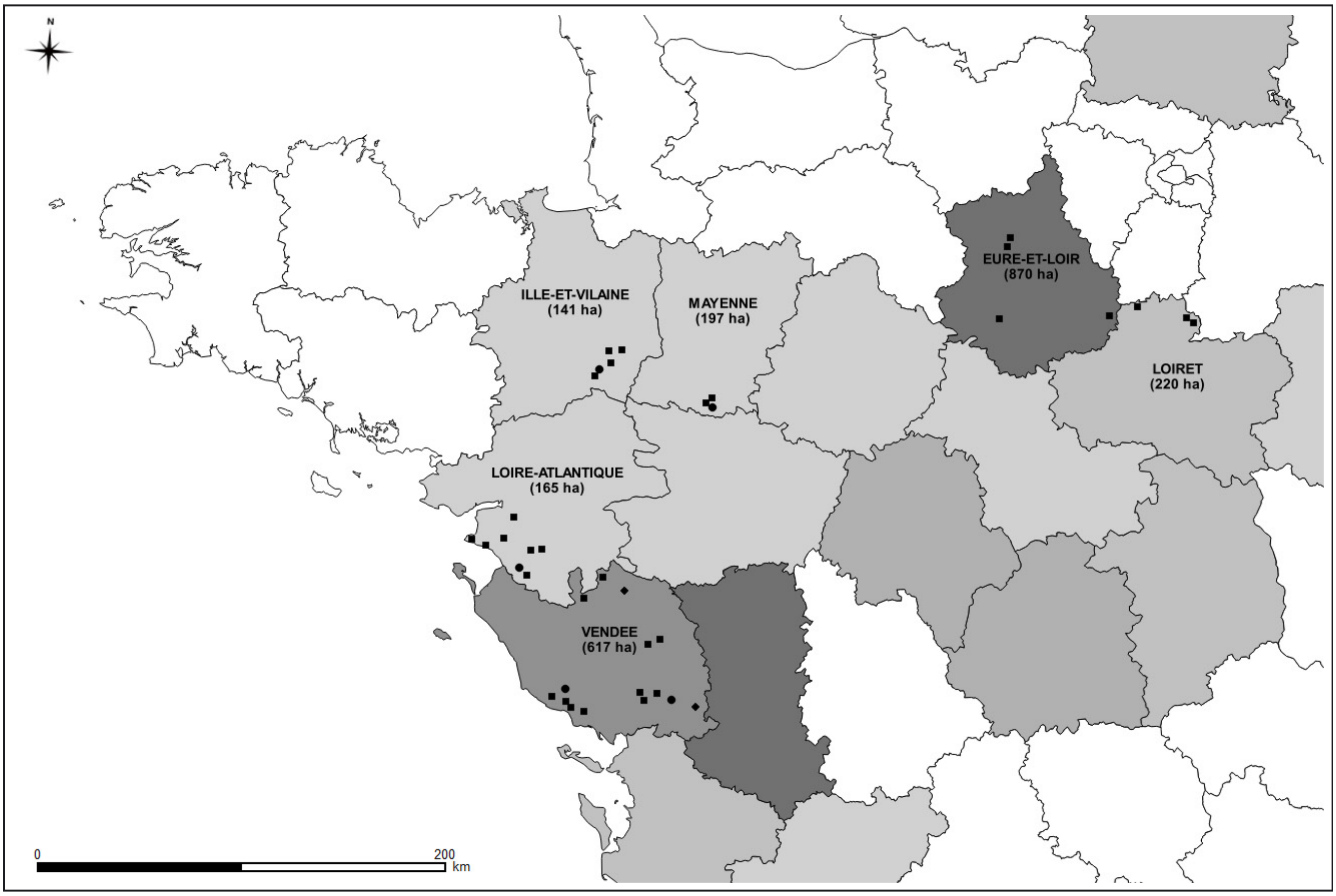

Fig. 2. Location of French communes where the 47 farms surveyed in January 2013 are located (square, one farm in the commune; circle, two farms in the commune; diamond, three farms in the commune). Names of French departments are followed by their oilseed flax surface areas in 2013 (Agreste, 2015). Darker shading of the departments indicates higher oilseed flax cultivation.

– Test of three scenarios for expanding oilseed flax cultivation on the farm.

Each "scenario" was a hypothetical situation described in detail to the surveyed farmers to test their reactions about expansion of oilseed flax crops on their farms. After each scenario was described, surveyed farmers were asked three questions: Would this scenario incite you to expand cultivation of oilseed flax on your farm? What are the advantages of this scenario? What improvements (of the scenario) do you suggest?

The first scenario ("economic") tested whether or not under certain conditions, payment of subsidies by authorities would be sufficient for farmers to increase oilseed flax cultivation. The compensation would be calculated as the difference between the gross margin of oilseed flax and those of main crops in the region. The conditions would require that at least four different crops be grown on the farm and that fewer pesticides and nitrogen fertilisers be applied to oilseed flax than to the main crops.

The second scenario ("agronomic") tested whether or not better information about agronomic advantages of oilseed flax and solutions to overcome its management problems would be sufficient for farmers to increase oilseed flax cultivation. Agronomic advantages include "rotation effects" and "break-crop benefits". Solutions to overcome flax-management problems include a wide range of oilseed flax cultivars adapted to multiple soil and climate combinations; new pesticides to control flax lodging, diseases and pests; new equipment for successful flax harvest; and the guarantee of useful technical advice.

The third scenario ("alternative") tested whether or not oilseed flax is a valuable alternative to other conventional crops if they become difficult to grow (*e.g.* pesticide bans, low prices, emergence of new pests).

The open-source, free software LimeSurvey® was used to create the online question-and-answer survey and to collect data (LimeSurvey, 2014).

2.2 Data analysis

The raw data file included 47 rows (individuals) and 377 columns (variables). Data editing and the descriptive analyses (percentage distributions, averages, standard deviations, 95% confidence intervals) were performed using Microsoft Excel®. A Multiple Factor Analysis (Pagès, 2014) was performed with R software (R Core Team, 2012) using continuous variables (age of farmers, farm arable land, proportion of farm arable area under oilseed flax in 2011–2012, importance of seven objectives in making decisions about farm management, ranking of the three scenarios for expanding oilseed flax cultivation

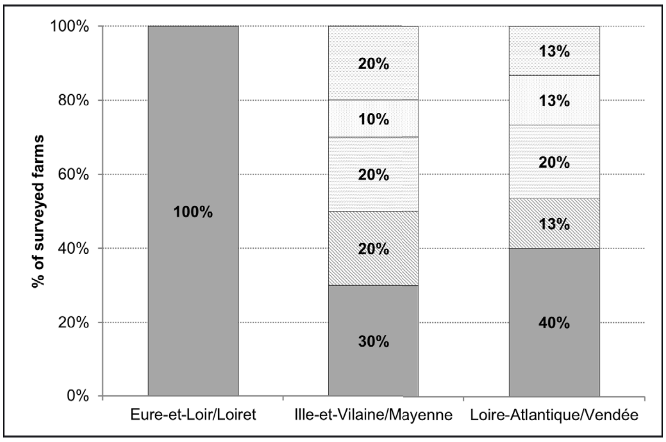

Fig. 3. Classification of 47 surveyed farms according to their farm type in each of three production areas. Farm types are as follows: plain grey bars, specialist field crops; thick grey hatched bars, specialist grazing livestock; thin grey hatched bars, specialist granivores; grey dotted bars, mixed livestock holdings; grey dashed bars, mixed crop-livestock.

on the farm) and categorical variables (farm type (see below), farmers' projects divided into seven categories). As one farmer did not rank scenarios, dataset is made of 46 rows and 21 columns.

We used the typology for agricultural holdings of the European Commission's (EC) Farm Accounting Data Network (Commission regulation (EC) No. 1242/2008 of 8 December 2008) to classify surveyed farms according to their main production. This typology is defined by structural farm characteristics (*e.g.* crop areas, animal heads) and "standard output" of crop and animal products, which is a product's mean farm-gate price (€ ha^{-1} or € animal $head^{-1}$) over a 5-year period in a given region (Regulation (EC) No. 1242/2008). A farm's overall "economic size" (in €) is calculated as the sum of the quantities of products it produces (*e.g.* ha, head) multiplied by their respective standard outputs. A farm is considered a specialised farm type if the economic size of one or more types of production exceeds two thirds of its overall economic size. Farm types include the following: "specialist field crops", "specialist horticulture", "specialist permanent crops", "specialist grazing livestock", "specialist granivores", "mixed cropping", "mixed livestock holdings", "mixed crops-livestock", and "non-classified holdings" (Regulation (EC) No. 1242/2008). Farms specialised in animal production are one of those farm types: "specialist grazing livestock", "specialist granivores", "mixed livestock holdings".

3 Results and discussion

3.1 Farm types of the 47 surveyed farms

All seven farms in Eure-et-Loir/Loiret were considered specialist field-crop farms (Fig. 3). In Ille-et-Vilaine/Mayenne and Loire-Atlantique/Vendée, production systems were more diversified as the five farm types were observed ("specialist field crops", "specialist grazing livestock", "specialist granivores", "mixed livestock holdings", "mixed crops-livestock") and specialist field-crop farms did not exceed 40%. The distribution of farm types was similar between Ille-et-Vilaine/Mayenne and Loire-Atlantique/Vendée.

Among farms specialised in animal production, less than half were "specialist granivores" farms, whose main production is confined rabbits poultry and/or pigs. The other farms specialised in animal production were "specialist grazing livestock" and "mixed livestock holdings" farms (60% and 57% of farms specialised in animal production in Ille-et-Vilaine/Mayenne and Loire-Atlantique/Vendée, respectively), mainly dairy farms.

3.2 Descriptive statistics of the 47 surveyed farms

Mean arable land area (±1 standard deviation) of the 47 farms was 142 ± 62 ha, with larger farms in Eure-et-Loir/Loiret (194 ± 49 ha) and smaller farms in Ille-et-Vilaine/Mayenne (94 ± 38 ha) (Tab. 1). These differences are partly explained by the presence (or not) of livestock. Mean arable land area of farms specialised in crop production (148 ha) was higher than that of farms specialised in animal production (123 ha). As mentioned, all farms in Eure-et-Loir/Loiret specialise in crop production whereas farms specialised in animal production occur more frequently in the two other production areas.

Unlike arable land area the mean number of workers per farm (2.1 ± 1.1) varied somewhat among production areas as farms with animal production had more workers per ha (Tab. 1). The mean number of workers per ha equalled 0.023, 0.012 and 0.013 for specialised animal production, specialised crop production, and "mixed crops-livestock" farms, respectively.

Regardless of farm type and size, few farmers (13%) used only their own equipment for farm work; the others relied on service-supply agencies and/or cooperative associations for the use of agricultural equipment.

Contracting was common in the sample as 74% of surveyed farmers produced at least one crop under contractual arrangements in 2011–2012 (because surveys occurred in January 2013 we asked this question for the last complete cropping season; Fig. 4). Contractual arrangements were generally prepared and signed between farmers and an agricultural cooperative (here, Cavac and Terrena) or an agricultural company (here, Groupe Soufflet). In 2011–2012, all surveyed farmers in Eure-et-Loir/Loiret produced at least one crop under contractual arrangement, which contrasts with those in Ille-et-Vilaine/Mayenne where only 40% of farmers produced one or more crops under contractual arrangements. Among the 32 farmers who grew (or planned to grow) oilseed flax in 2012–2013 only ten (31%) had (or planned to have) contracts for this crop.

Regarding the economic dimension of farms, gross operating surplus helps analyse the economic profitability of an agricultural holding without considering its investment policy, financial management or exceptional charges. In our sample the 2011–2012 gross farm operating surplus varied greatly (121 897 ± 79 236 €; Tab. 1). It was similar in Eure-et-Loir/Loiret (129 353 ± 74 260 €) and Loire-Atlantique/Vendée

Table 1. Descriptive statistics of 47 farms growing oilseed flax in western France.

(a) Continuous variables			
Variable	Mean	Median	Range
Farm arable land (ha)	142	140	54–303
Farm workforce (number of workers[‖])	2.1	2.0	1.0–6.5
Farm gross operating surplus[†] (€)	121 897	100 000	28 109–400 000
Age of farmer	46.8	47.0	26.0–62.0

(b) Categorical variables		
Variable	*n*	Percentage of 47 farms
Farm with at least 1 livestock activity	31	66%
Ruminants only	12	26%
Granivores only	9	19%
Ruminants and granivores	10	21%
Farm type		
Specialist field crops	22	47%
Specialist grazing livestock	6	13%
Specialist granivores	8	17%
Mixed livestock holdings	5	11%
Mixed crops-livestock	6	13%
Farm work		
Self-sufficient in farm equipment	6	13%
Dependent on service-supply agency	11	23%
Dependent on machinery cooperative	9	19%
Dependent on the two previous groups	21	45%

[‖]A worker (farmer, farm worker) is a person who works full-time on a farm for one year. [†]Gross operating surplus is "the balance of the trading account for companies" and is equal to "value added minus payroll and other taxes on production and plus operating grants" (INSEE, 2014). Four farmers did not provide these data.

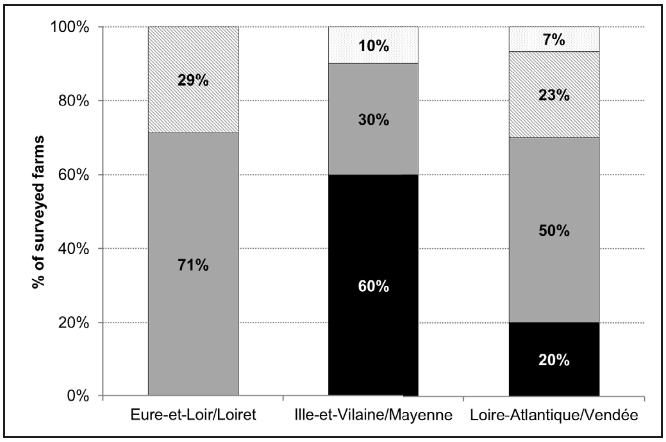

Fig. 4. Percentage of 47 surveyed farmers, grouped by production area, according to whether they produce crops under contractual arrangements in 2011–2012. Legend is as follows: plain dark bars, none; plain grey bars, for one or more crops except oilseed flax; thick grey hatched bars, for one or more crops and oilseed flax; grey dotted bars, for oilseed flax only.

(133 782 ± 94 927 €) but lower in Ille-et-Vilaine/Mayenne (85 333 ± 40 283 €). This is partly related to farm type as mean gross operating surplus of "specialist grazing livestock" – a farm type more common in Ille-et-Vilaine/Mayenne than in the two other production areas – was the lowest (87 111 €). For the four other farm types it varied from 96 411 € ("specialist field crops") to 230 850 € ("mixed livestock holdings").

3.3 Description of cropping systems of the 47 surveyed farmers

3.3.1 Crop areas in 2011–2012

In 2011–2012, cultivation of cereals (especially, winter wheat) was much higher than that of other crops: from a mean of 52% of arable area in Loire-Atlantique/Vendée to 62% of arable area in Ille-et-Vilaine/Mayenne (Tab. 2). Cultivation of oilseed rape was relatively high in Eure-et-Loir/Loiret (23% of arable area), lower in Ille-et-Vilaine/Mayenne (15% of arable area) and rare in Loire-Atlantique/Vendée (3% of arable area) while sunflower was present only in this last area. Unsurprisingly, fodder crops (*i.e.* grasslands, silage maize) were rarely grown in Eure-et-Loir/Loiret (0.3% of arable area) but represented 15–24% of arable area in the two other production areas. Except in grasslands no farmers adopted intercropping. Oilseed flax cultivation varied from 5% (Ille-et-Vilaine/Mayenne) to 9% (Eure-et-Loire/Loiret) of arable area.

3.3.2 Cropping sequences

Excluding grasslands, we identified 133 main cropping sequences on surveyed farms (Fig. 5). Despite this diversity, cropping sequences were dominated by wheat, which is consistent with its high coverage of arable areas. Oilseed flax was included 32% of the cropping sequences. Durations of cropping sequences varied from 1–7 years (mean = 3.3 years). In this sample, monocultures (mainly maize fields) were rare,

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Table 2. Mean (±1 standard deviation) distributions of 2011–2012 crop areas (% of arable area*) of farms of 47 surveyed farmers in three main linseed production areas.

Crop	Eure-et-Loir/Loiret	Ille-et-Vilaine/Mayenne	Loire-Atlantique/Vendée
Cereals	61.2 ± 11.3	61.6 ± 16.7	51.8 ± 17.9
Rape	22.5 ± 8.5	14.8 ± 7.8	3.1 ± 6.0
Grasslands	0.3 ± 0.7	8.1 ± 11.1	19.3 ± 20.3
Oilseed flax	8.5 ± 7.3	4.8 ± 4.7	5.5 ± 5.2
Silage maize	0.0 ± 0.0	7.0 ± 9.9	4.3 ± 7.3
Seed production	1.3 ± 2.9	0.0 ± 0.0	5.4 ± 9.7
Sunflower	0.0 ± 0.0	0.0 ± 0.0	4.3 ± 6.3
Other crops	6.2 ± 4.5	3.7 ± 3.6	6.3 ± 10.7

*In 2011–2012, arable area per farm is 194 ± 49 ha, 94 ± 38 ha, and 145 ± 61 ha in Eure-et-Loire/Loiret, Ille-et-Vilaine/Mayenne, and Loire-Atlantique/Vendée, respectively.

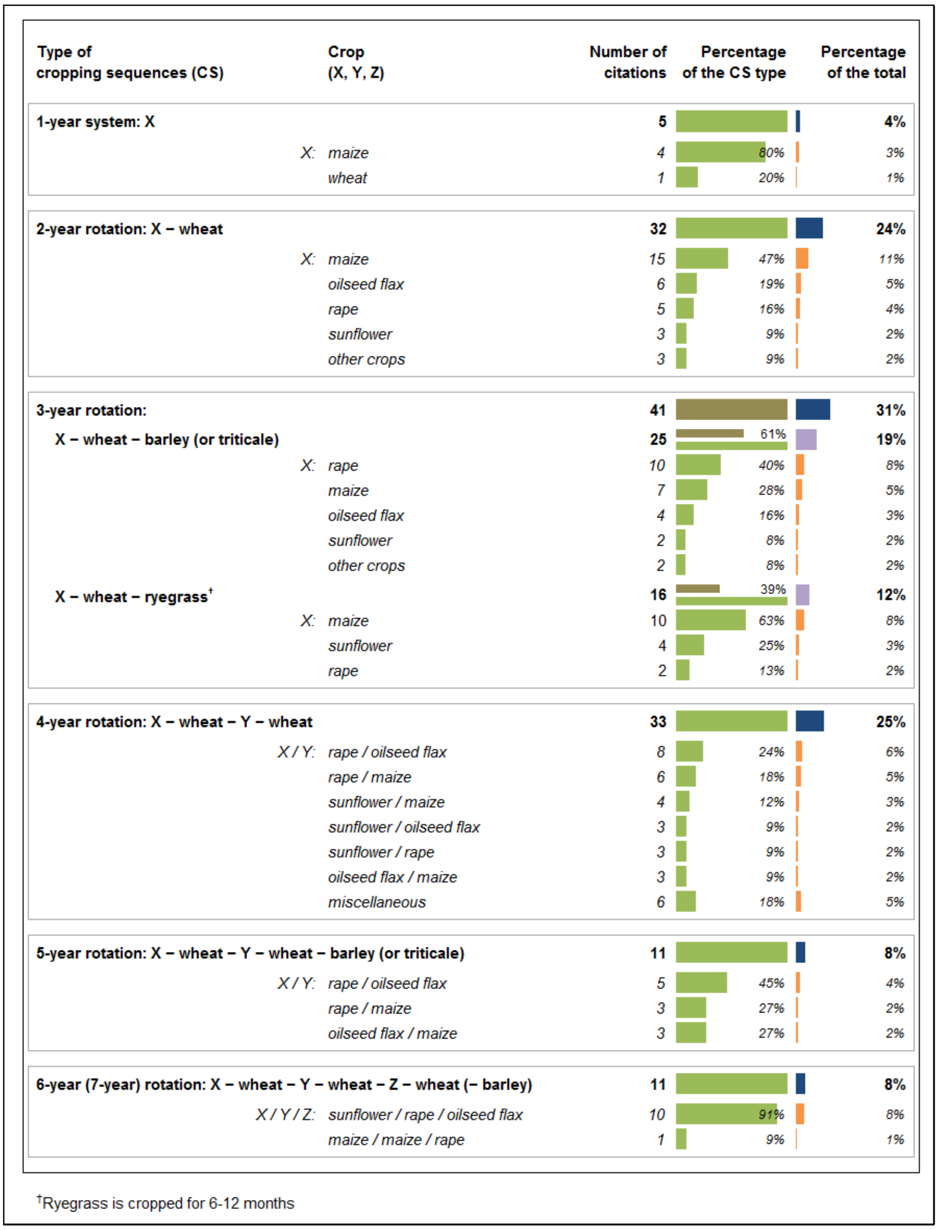

Fig. 5. Description of 133 cropping sequences mentioned by 47 surveyed farmers.

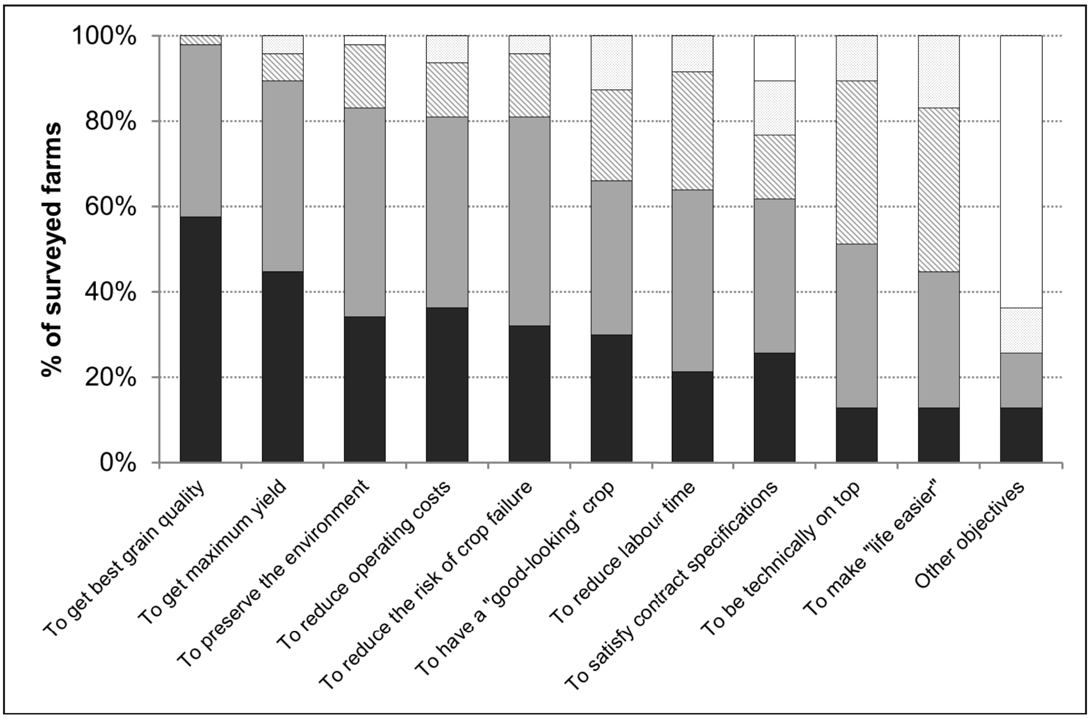

Fig. 6. Classification of the importance of ten objectives (plus one open-response: "other" objective) in making decisions about winterwheat management for 47 surveyed farmers. Legend is as follows: plain dark bars, crucial; plain grey bars, important; thick grey hatched bars, not important; grey dotted bars, not considered at all; white bars, no response.

Table 3. Mean and 1 standard deviation (SD) of typical yields (t ha^{-1}) of four main crops reported by 47 surveyed farmers.

Crop	Eure-et-Loir/Loiret			Ille-et-Vilaine/Mayenne			Loire-Atlantique/Vendée		
	n	Mean	SD	*n*	Mean	SD	*n*	Mean	SD
Grain maize	1	11.5	–	7	8.1	0.9	29	8.6	32
Silage maize	–	–	–	4	12.4	1.2	12	11.5	5.9
Rape	7	3.7	0.3	10	3.5	0.5	14	2.7	1.3
Winter wheat	7	7.6	0.7	10	7.9	0.6	29	7.4	1.0

comprising less than 5% of the 133 cropping sequences and 80% of cropping sequences lasted 2–4 years. Two-year cropping sequences alternated wheat with another crop such as maize (47%), oilseed flax (19%) and rape (16%). Three-year cropping sequences were also based on wheat: 61% alternated wheat and barley (or triticale) with rape (or another crop such as maize or oilseed flax) while 39% alternated wheat and rye-grass with maize (or another crop).

In order of importance, 4-year rotations alternated wheat with (i) rape and another crop (oilseed flax or maize), (ii) sunflower and another crop (maize, oilseed flax or rape), and (iii) other crops such as oilseed flax and maize.

3.3.3 Farmers' crop management strategies

To understand how farmers manage their crops, we asked them to classify ten objectives (plus one open-response: "other" objective) that drive winter-wheat management. Winter wheat was chosen because it was grown on all farms.

The most important objectives farmers expressed were related to wheat grain quality and maximum yield (Fig. 6). Preserving the environment, reducing operating costs, and reducing the risk of crop failure remained important objectives. Others, such as reducing labour time, remaining "on top" technically, and making life easier did not play a key role for wheat management strategies. Surveyed farmers' agricultural practices thus seemed intensive (seeking maximum yield) but oriented toward sustainability (*i.e.* preserving the environment, reducing operating costs, seeking the highest quality) and relatively traditional (*i.e.* no interest in the most recent cropping practices, aversion to risk-taking). This is consistent with the typical yields reported by farmers (Tab. 3) and their relatively low participation rate (26%) in European Union agri-environmental schemes.

3.4 Incentives and disincentives for linseed production on the 47 surveyed farms

3.4.1 Description of oilseed flax cropping systems

Thirty-two farmers grew oilseed flax in 2011–2012: 81% grew only winter-sown cultivars, 12% grew only spring-sown

Table 4. 95% confidence intervals of surface area (ha) and percentage of oilseed flax on farms of 47 surveyed farmers in 2011–2012 in three main production areas.

Cultivar	Variable	Eure-et-Loir/Loiret	Ille-et-Vilaine/Mayenne	Loire-Atlantique/Vendée
Winter	*n*	2	6	20
	Area (ha)	18.3 ± 16.3	9.4 ± 3.6	11.4 ± 3.2
	Percentage of farm arable area	8% ± 7%	8% ± 2%	8% ± 2%
Spring	*n*	5	–	1
	Area (ha)	17.3 ± 4.6	–	8.5
	Percentage of farm arable area	9% ± 2%	–	9%

Table 5. The 22 cropping sequences mentioned by the 28[‡] surveyed farmers who grew (or intended to grow) oilseed flax in 2012–2013.

Duration	Cropping sequence[*]	*n*
2 years	oilseed flax – *wheat*	4
	oilseed flax – *wheat*/maize	1
3 years	oilseed flax – *wheat* – barley	1
	oilseed flax – *wheat* – *wheat*/barley	1
	oilseed flax – *wheat*/barley – *wheat*	1
	oilseed flax – *wheat*/maize – *wheat*	1
4 years	oilseed flax – *wheat* – maize – *wheat*	3
	oilseed flax – *wheat* – rape – *wheat*	2
	oilseed flax – *wheat* – sunflower – *wheat*	1
	oilseed flax – *wheat* – ryegrass[†] – *wheat*	1
	oilseed flax – *wheat* – ryegrass[†]/sunflower/maize – *wheat*	1
	oilseed flax – *wheat*/barley – rape – *barley*	1
	oilseed flax – *wheat* – maize/rape/sunflower – *wheat*	1
	oilseed flax – rape – sunflower – *wheat*	1
	oilseed flax – *wheat* – (maize) – rape – *wheat*	1
	oilseed flax – *wheat* – rape – *wheat* – (rape)	1
	oilseed flax – *wheat* – sunflower – *wheat* – (*wheat*)	1
5+ years	oilseed flax – *wheat* – barley – rape – *wheat*/barley	1
	oilseed flax – *wheat* – rape – *wheat* – sunflower – *wheat*	1
	oilseed flax – *wheat* – sunflower – *wheat* – rape – *wheat*	1
	oilseed flax – *wheat* – barley – *wheat* – barley – rape – *wheat*	1
	oilseed flax – *wheat* – barley – sunflower – *wheat* – rape – *wheat*	1

[‡] Thirty-two surveyed farmers grew (or intended to grow) oilseed flax in 2012–2013 but when mentioning main cropping sequences including oilseed flax, four were inconsistent. [*]Wheat is in italics to show its high frequency of occurrence; slash (/) means "or"; crops within brackets are not necessarily grown. [†] For seed production.

cultivars, and 7% grew both (Tab. 4). In 2011–2012 winter-sown cultivars covered a mean of 8% of arable area and spring-sown cultivars covered a mean of 9%, both with low variability (95% confidence intervals = 2%). Some farms were atypical, however; for example, one grew a winter-sown cultivar on 24% of its arable area. At least 75% of farmers in each farm type grew oilseed flax, except for "specialist grazing livestock" (one of two farmers) and "mixed livestock holdings" (one of five farmers).

3.4.1.1 Cropping sequences including oilseed flax

Thirty-two farmers farmers grew (or intended to grow) oilseed flax in 2012–2013, 12% of them, all located in Loire-Atlantique/Vendée for the first time. Among farmers who did not grow oilseed flax in 2012–2013, 87% had decided definitively to stop growing the crop, of whom 60% had already stopped the previous year.

Farmers who grew (or intended to grow) oilseed flax in 2012–2013 cited 22 cropping sequences that included it (Tab. 5). Durations of cropping sequences varied from 2–7 years (mean = 3.9 years). Cropping sequences with oilseed flax included 2–7 crops (mean = 3). The simplest cropping sequences (oilseed flax – wheat/maize, oilseed flax – wheat/barley/maize – wheat/barley) were cited by 32% of farmers (mainly in Loire-Atlantique/Vendée), although a cropping sequence of at least three years between oilseed flax crops is recommended to control soil-borne or stubble-borne diseases (Rowland, 2002).

Oilseed flax could follow wheat in 93% of cropping sequences and may be followed by wheat in 96% of cropping sequences (Tab. 5). Surveyed farmers clearly considered this the best cropping practice. Fifty-seven percent of 28 farmers (those who grew (or intended to grow) oilseed flax in 2012–2013 and mentioned cropping sequences including oilseed flax) consider wheat the best preceding crop for oilseed

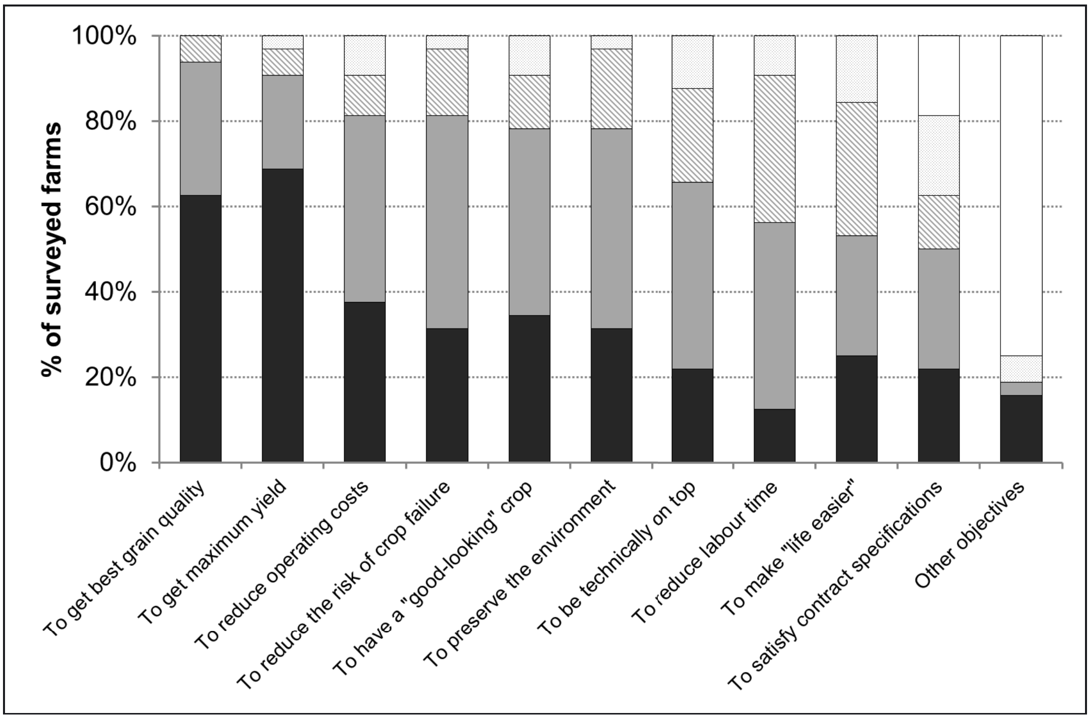

Fig. 7. Classification of the importance of ten objectives (plus one open-response: "other" objective) in making decisions about oilseed flax crop management for 32 surveyed farmers that grew (or intended to grew) it in 2012–2013. Legend is as follows: plain dark bars, crucial; plain grey bars, important; thick grey hatched bars, not important; grey dotted bars, not considered at all; white bars, no response.

flax (other preceding crops cited were maize, sunflower, and grasses), mainly due to the appropriate compatibility between the work schedules of oilseed flax and wheat. Sixty-eight percent of the farmers considered wheat the best crop to follow oilseed flax, mainly due to the impact of oilseed flax roots on soil structure. Crops often mentioned as not recommended before or after oilseed flax were oilseed crops (mainly rape and sunflower) and maize (data not shown).

3.4.1.2 Farmers' strategies for oilseed flax crop management

It is important to know that 66% of the 32 surveyed farmers who grew (or intended to grow) oilseed flax in 2012–2013 considered that they had mastered oilseed flax crop management, while 25% still considered themselves novices. As for wheat, we asked farmers to classify ten objectives (plus one open-response: "other" objective) that drive oilseed flax crop management.

For the 32 farmers that grew (or intended to grow) oilseed flax in 2012–2013, the most important objectives were related to grain quality and maximum yield (Fig. 7), as observed for wheat management Typical attainable oilseed flax yields reported by farmers were 2.0 ± 0.4 t ha^{-1} for winter-sown cultivars (25 mentions) and 2.1 ± 0.6 t ha^{-1} for spring-sown cultivars (2 mentions). Of these farmers, only 9% directly sowed oilseed flax; the rest decompacted soil and/or performed stubble cultivation and/or ploughed fields, then prepared the seedbed for oilseed flax (most used an integrated mechanical seed drill that combines a rotary harrow and a sowing machine) (Fig. 8). Soil decompaction was uncommon (16% of farmers). It was performed using a deep cultivator such as a subsoiler, a soil loosener, or a heavy cultivator. The aim of this operation is to restore damaged soil by eliminating the plough pan and to separate soil particles to increase pore space. Stubble cultivation was performed by 50% of the farmers, generally using disc harrows and tined cultivators in one or more passes (Fig. 8). The purpose of this operation is (i) to break and bury harvest residues, (ii) to manage weeds (it creates a false seedbed that promotes germination and emergence of weed seeds which are mechanically or chemically destroyed before sowing oilseed flax), and (iii) to remove compaction. Ploughing was less common (only 25% of farmers) (Fig. 8). Winter oilseed flax cultivars were sown from mid-September to mid-October.

Diseases, weeds, and pests were managed as follows:

- For disease control, 94% of farmers used pesticides, in 1–3 passes, mostly in autumn. The most frequently cited disease, stem break, is caused by the pathogenic fungus *Kabatiella lini* (Gruzdeviene *et al.*, 2008). Farmers often mentioned that treatments may not be successful due to difficulty accessing fields in autumn.
- For weed control, all farmers used herbicides, in 1–3 passes, mostly in autumn. Oilseed flax does not compete well with weeds (Ehrensing, 2008). Like for disease control, 22% of farmers mentioned that treatments may not be successful due to difficulty accessing fields in autumn.
- For pest control, less than 25% of farmers used pesticides. Pests are rarely an economic problem in linseed production (Ehrensing, 2008).

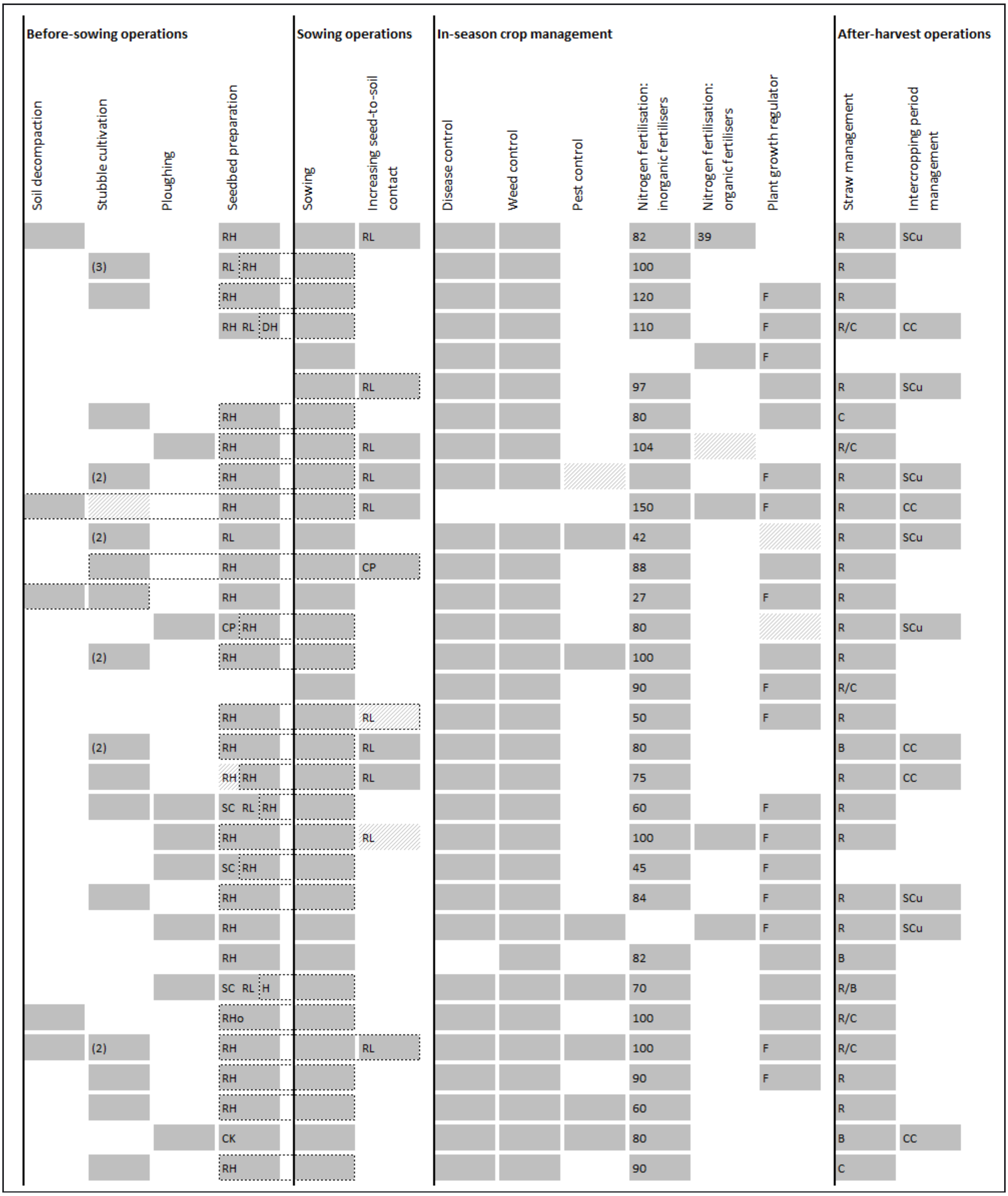

Fig. 8. Description of 32 oilseed flax management strategies reported by surveyed farmers who grew (or intended to grow) it in 2012–2013. Each row represents main agricultural practices of oilseed flax crop management. Contrary to the others, the penultimate line describes crop management for a spring-sown cultivar. Solid grey boxes indicate that farmers manage these operations, while thick grey hatched boxes indicate that farmers sometimes manage these operations. Boxes surrounded by a dotted line represent operations performed together. For stubble cultivation, the number in parentheses is the number of tractor passages (if >1). For nitrogen fertilisation, the number is the nitrogen application rate in kg N ha^{-1} (if mentioned). For plant growth regulator, F means that the farmer indicates the plant growth regulator is a fungicide. B, buried straw; C, chopped straw; CC, cover crop; CK, crosskill roller; CP, cultipacker; DH, disk harrow; H, harrow; R, straw removal; RH, rotary harrow; Rho, rotary hoe; RL, roller; SC, S-tine cultivator; SCu, stubble cultivation.

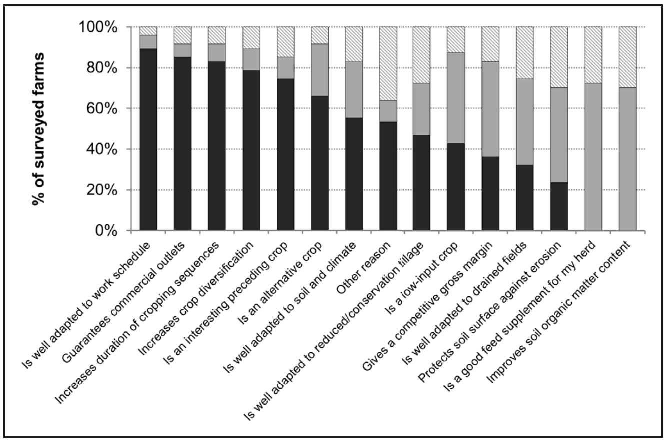

Fig. 9. Reasons why 47 surveyed farmers decided to grow oilseed flax. Legend is as follows: plain dark bars, agree; plain grey bars, disagree; thick grey hatched bars, no opinion.

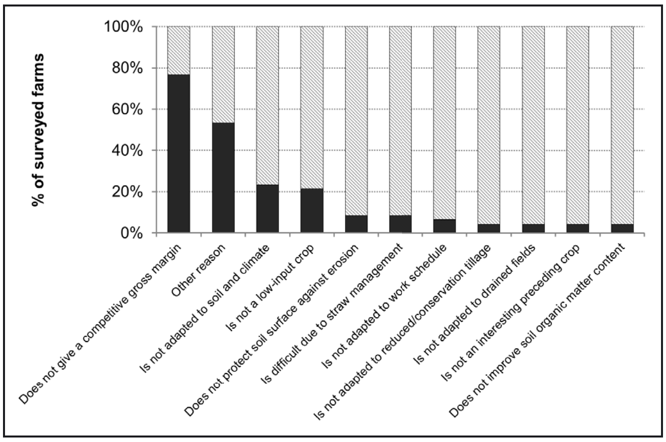

Fig. 10. Reasons why 47 surveyed farmers decided to stop (or would decide to stop) growing oilseed flax. Legend is as follows: plain dark bars, agree; thick grey hatched bars, no opinion.

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For nitrogen fertilisation 84% of farmers used only mineral fertilisers. The amounts of nitrogen applied in mineral fertilisers ranged from 27–150 kg N ha^{-1} (mean = 84 kg N ha^{-1}), which are higher than those reported by Easson and Long (1992), Reyneri and Caballero (1997), and Kirkegaard *et al.* (1997), as cited by Giménez *et al.* (2007).

Lodging was a significant concern for farmers: 69% always used a plant growth regulator. These farmers often mentioned that plant growth regulation is a known effect of a fungicide they use for it.

After harvest and field retting, 78% of farmers removed straw from fields and usually sold it as a co-product. Even though straw management period is a crucial one (retting is a long process that delays future agricultural practices such as stubble cultivation), farmers appreciated this additional income.

3.4.2 Why surveyed farmers grow or stop growing oilseed flax

Among suggested reasons for growing oilseed flax, two were not chosen by farmers: improvement of soil organic matter content by oilseed flax straw and use of linseeds as a feed supplement for animals (Fig. 9). Several organisational and agronomic reasons were chosen by most farmers; for instance:

- Oilseed flax crop management is well adapted to the farm work schedule and allows farmers to spread their workloads, especially sowing and harvesting which occur in different seasons than those of wheat.
- Introducing oilseed flax into rotations diversifies and increases durations of cropping sequences.

Some reasons were seen as constraints that hinder oilseed flax expansion to other farms. Oilseed flax was not perceived as a crop that (i) requires few inputs; (ii) provides a competitive gross margin; (iii) is well adapted to drained fields, or (iv) protects soil against erosion.

As for reasons to stop growing oilseed flax, many farmers had no opinion, knowing better why they grow it than why they stop (or would stop) (Fig. 10). Nonetheless, 77% of farmers identified the lower profitability of linseed is its main weakness. Among "other" reasons, farmers also cited problems during harvesting, inconsistent yields and crop sensitivity to climate (*e.g.* freezing).

3.5 Scenarios: how to expand oilseed flax cultivation

Of surveyed farmers, 43% considered the agronomic scenario the most favourable for expanding oilseed flax cultivation on their farms or additional farms, followed by the economic scenario (37%) and the alternative scenario (20%) (Tab. 6). Differences appeared among production areas. In Eure-et-Loir/Loiret more than 70% of farmers ranked the economic scenario last. In Ille-et-Vilaine/Mayenne, 56% ranked the agronomic scenario first, while 44% ranked it last.

3.5.1 Opinions of the three scenarios

Sixty-six percent of the 44 farmers with an opinion considered the economic scenario a favourable solution for promoting linseed production: gross margin compensation would encourage farmers to increase cultivation of this crop (Tab. 7). This is in agreement with Meynard *et al.* (2014) who suggested that actors of oilseed fax sector adjust price of oilseed flax to price of dominant crops. However, in Eure-et-Loir/Loiret, more than 66% of farmers rejected this scenario, in contrast with those from the two other areas. Main weaknesses of this scenario were the agri-environmental restrictions as farmers would like to receive financial aid without any governmental control over their agricultural practices. Farmers also considered over-dependency on public aid as dangerous. Some considered the economic scenario unrealistic since its success depends on technical and genetic improvements that do not yet exist.

Since the agronomic scenario assumes that the main problems of oilseed flax cultivation are resolved, 66% of the

Table 6. Ranking of three scenarios for expanding/introducing oilseed flax cultivation on a farm from the most (rank 1) to the least favourable (rank 3). One farmer did not rank scenarios.

Scenario	Short description	Rank 1	Rank 2	Rank 3
Economic	• Payment of gross margin compensation by authorities • Conditions for payment: – at least four different crops on the farm – lower use of pesticides and nitrogen fertilisers on oilseed flax	37%	30%	33%
Agronomic	• Better information about agronomic advantages of oilseed flax ("rotation effects", "breakcrop benefits") • Highlighting solutions to overcome crop management difficulties (*e.g.* wide range of cultivars, new pesticides, new harvest equipment, relevant technical advice)	43%	28%	28%
Alternative	• Oilseed flax as a valuable alternative to conventional crops if they become difficult to grow	20%	41%	39%

Table 7. Strengths and weaknesses mentioned by at least three surveyed farmers of three scenarios for expanding oilseed flax cultivation on their farms (or to introduce oilseed flax to additional farms). Scenarios are as follows: under agri-environmental conditions, payment of compensation for the income foregone and additional costs incurred (economic scenario); better information on agronomic advantages of oilseed flax and highlighting solutions to overcome crop management difficulties (agronomic scenario); oilseed flax cultivation as a valuable alternative to other conventional crops if they become difficult to grow (alternative scenario).

Scenario	Strengths and Weaknesses	*n*
Economic	*Strengths*	
	It provides financial support	27
	It is technically feasible	9
	It reduces workload	3
	Weaknesses	
	It requires environmental considerations / authority controls	9
	It depends on public aid	7
	It requires technical improvement (which does not exist yet)	5
	It requires genetic improvement (which does not exist yet)	4
	Selling price of linseed is still the same / is not guaranteed	4
Agronomic	*Strengths*	
	It offers technical solutions to current problems (weed management, harvest)	23
	It offers new crop varieties (that produce more, that are more resistant)	23
	It highlights technical supervision	14
	It is based on up-to-date knowledge	5
Alternative	*Strengths*	
	It is realistic (it is the reason why surveyed farmers grow oilseed flax)	10
	It increases crop diversification / durations of cropping sequence	10
	It is a solution to current problems (weed and disease management)	9
	Weaknesses	
	Oilseed flax cannot be the only solution (others must be offered)	9
	It does not mention economic aspects	8
	Oilseed flax is not a credible solution	4

46 farmers with an opinion considered it a favourable solution for promoting oilseed flax (Tab. 7). However, in Ille-et-Vilaine/Mayenne, only 50% of farmers approved of this scenario in contrast with those from the two other areas. Strengths of this scenario included technical solutions (especially for weed and harvest management), genetic advances (*e.g.* more oilseed flax cultivars, selected for yield potential and resistance against biotic and abiotic stresses), and technical supervisions (Tab. 7). Meynard *et al.* (2014) also highlighted a need for selecting new winter-sown cultivars and improving technical supervision.

Seventy-two percent of the 46 farmers with an opinion considered the alternative scenario a favourable solution for promoting oilseed flax, even though 80% of farmers ranked this scenario last. This was because several farmers already grew oilseed flax as an alternative crop (mainly to replace rape and pea); for them, it is not a scenario but the reality. Even though many farmers considered that introduction of oilseed flax into crop rotations is an effective solution to prevent emergent problems, they also believed that it cannot be the only solution (Tab. 7). Some disliked that this scenario did not mention gross-margin compensation for growing oilseed flax or a minimum price guaranteed by the linseed sector.

3.5.2 Do farm characteristics influence the choice of scenarios?

The structure of the dataset detailed in Section 2.2 was explored by means of Multiple Factor Analysis and a two-dimensional model was obtained, explaining 27.5% of the whole data variance (Fig. 11). Age of farmers, farm arable area, proportion of farm arable area under oilseed flax in 2011–2012 as well as the economic and agronomic scenarios are well represented on the first plane issued from Multiple Factor Analysis (Fig. 11a). Objectives for making decisions about farm management and the alternative scenario are less well represented. Farmers who grew oilseed flax in 2011–2012 preferred the agronomic scenario whereas farmers who did not grow it (or farmers who grew it on a low proportion of farm arable area) preferred the economic scenario. According to the representation of categorical variables (Fig. 11b), we specify that farms specialised in crop production (FT_1) preferred the agronomic scenario whereas farms specialised in animal production (FT_4, FT_5) preferred the agronomic scenario. The alternative scenario is considered as a favourable solution for promoting oilseed flax by farmers who owned large-sized farms and gave priority to two objectives for making decisions in farm management: "to improve social recognition of farmer profession" (O4) and "to increase farm income stability" (O6).

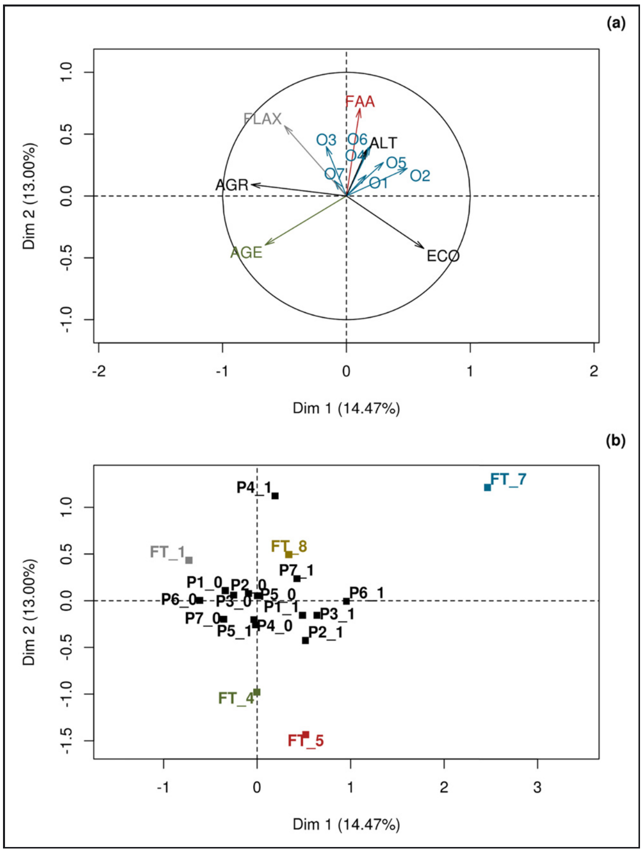

Fig. 11. Representation of continuous variables (a) and categorical variables (b) on the first plane issued from Multiple Factor Analysis. Individuals are not plotted to enhance graphical display. Objectives for making decisions about farm management are as follows: O1, to get more free time; O2, to improve quality of life; O3, to preserve the environment; O4, to improve social recognition of farmer profession; O5, to increase farm income; O6, to increase farm income stability; O7, to facilitate farm succession. Importance of these objectives in making decisions about farm management varies from 1 (not considered at all) to 4 (crucial). Other continuous variables are as follows: AGE, age of farmers; FAA, farm arable area; FLAX, proportion of farm arable area under oilseed flax in 2011-2012; AGR, ranking of the agronomic scenario; ALT, ranking of the alternative scenario; ECO, ranking of the economic scenario. Ranking of the three scenarios varies from 1 (the least favourable) to 3 (the most favourable). Farm types are as follows: FT_1, specialist field crops; FT_4, specialist grazing livestock; FT_5, specialist granivores; FT_7, mixed livestock holdings; FT_8, mixed crop-livestock. Farmers' projects (0, no; 1; yes) are as follows: P1, change in farm size; P2, change in type and intensity of animal production; P3, change in type and intensity of crop production; P4, change in crop management; P5, change in farm territory; P6, change in farm equipment; P7, change in work organisation.

4 Conclusion

Forty-seven French linseed producers were surveyed to identify ways to increase oilseed flax cultivation on their farms and to introduce it to other farms. This was achieved by characterising farming systems that currently crop oilseed flax. Farm types were diverse, from farms specialised in field-crop production to farms specialised in animal production. The mean area of arable land on surveyed farms was 142 ha, and oilseed flax covered < 10% of that, on average (compared to > 50% for cereals). Oilseed flax was mainly included in short cropping sequences (< 4 years long). Farmers' crop-management practices seemed intensive but oriented toward sustainability and relatively conventional.

According to surveyed farmers, oilseed flax was interesting mainly because it was compatible with the farm work schedule (*i.e.* farmers can spread their workloads) and diversified crop production. It was agronomically useful because it was a beneficial preceding crop and increased the durations of crop rotations. It was also a valuable alternative to conventional crops if they become difficult to grow. Finally it guaranteed commercial outlets. One drawback was that it was not a low-input crop. Because oilseed flax yields are usually low and highly variable, profitability was the main reason why farmers stopped (or would stop) growing flax. To conclude, expansion of oilseed flax cultivation would occur if the linseed sector focuses on the following:

– Genetic improvement by developing new oilseed flax cultivars that are more productive and more resistant against biotic and abiotic stresses.
– Technical progress that offers new solutions for pests diseases and problems during harvest.
– Subsidies to ensure a minimum price (or a minimum gross margin) to linseed producers.

Acknowledgements. We thank the students of AGROCAMPUS OUEST who conducted farmer surveys (M. Boury, A. Calvez, A. Gobillot, E. Guillossou, M. Havard, Y. Hily, M. Hirschy, T. Kerdraon, M. Lagathu, D. Loussouarn, E. Penguilly, R. Pesset, E. Pipon, T. Queuniet, and M. Soulié). We also thank the French technical institute for oilseed crops (Cetiom) for financial support during this study.

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Cite this article as: Matthieu Carof, Jean Raimbault, André Merrien, Philippe Leterme. Survey of 47 oilseed flax (*Linum usitatissimum* L.) growers to identify ways to expand its cultivation in France. OCL 2015, 22(6) D604.