ReMIX

Species mixtures for redesigning European cropping systems

ReMIX PROJECT

FROM THEORY TO PRACTICE OF SPECIES MIXTURES

Redesigning European cropping systems based on species MIXtures

Includes a study of the feasibility of harvesting and sorting + 52 technical sheets from farmers' experiences

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Summary

Intercropping or species mixtures, is an agriculturalpractice that consists of cultivating at least two species on the same plot of land during a significant period of their growth, and which has many advantages, such as: i) diversifying the crop rotation; ii) increasing the resilience of systems to hazards thanks to more stable yields and less pressure from biotic and abiotic factors; and iii) reducing the use of inputs and their impact on the environment.

The **ReMIX** project, financed for four years by the European Union within the framework of the Horizon 2020 program, has set itself the objective of proposing practical solutions adapted to farmers and to the various actors in the agricultural sector under various pedoclimatic and socio-technical conditions on a European scale.

Based on the observation that farmers lack technical references and support, in particular for the choice of species and varieties to be combined in a mixture, the **ReMIX** project has developed and implemented a multi-actor co-design approach in order to combine diverse and complementary knowledge to design species mixtures that meet the objectives, means, contexts and practices of each actor.

One of the main constraints to the development of species mixtures concerns the harvesting and sorting of grains when the mixture is not used as is, which is most often the case with the exception of certain mixtures for animal feed. Thus, the ReMIX project sought to know if it was possible to harvest and sort associated crops in such a way that the marketed products would respect food standards and ultimately offer a satisfactory economic value to farmers.

This document aims to promote the sharing of knowledge on species mixtures through: I) the presentation of the **ReMIX** project; II) nformation on the functioning and performance of the mixtures; III) the perception of stakeholders and the diversity of practices implemented; IV) technical sheets from farmers' experiences to facilitate the implementation of species mixtures, and finally V) insights on the issue of feasibility of harvesting and sorting.

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ReMIX and species mixtures

Figure 2

The ReMIX project

The European Union's agriculture must make the transition to more **agroecological systems that combine productivity and sustainability** (ecological, economic and social). The diversification of cropping systems, in particular through the use of species mixtures – the simultaneous cultivation of at least two species in the same field – can contribute to the production of **quality food, in sufficient quantity**, while reducing the environmental impact of current agricultural practices.

Started in May 2017, the European project **ReMIX** – Redesigning European cropping systems based on species MIXtures – has been awarded €5 million in funding for four years by the European Union, as part of the Horizon 2020 program (**Figure 1**).

This project, which brings together **23 partners** (research institutes, technical institutes, breeders, cooperatives and agricultural equipment manufacturers) from **13 countries** ranging from Greece to Sweden (**Figure 2**), had the objective of validating the services rendered by species mixtures in order to design agro-ecological cropping systems, both in conventional and organic agriculture, and for various soil and climatic conditions.

These new cropping systems were intended to be more **diversified**, more **resilient**, **less dependent** on inputs, more **environmentally friendly** and **acceptable** to farmers and stakeholders in the agri-food and agroindustrial sectors.

To achieve these objectives, the **ReMIX** project has developed and implemented a **multi-actor co-design approach** that consists of mobilising a diversity of actors (e.g. farmers, advisors, agricultural equipment manufacturers, cooperative technicians, technical institute engineers, collection and processing actors, **ReMIX** project researchers), in order to **combine diverse and complementary knowledge** to **design innovations** that meet the objectives, means and practices of each actor.

From the specification of end-user needs to the codesign of experiments and species mixtures implemented in farmers' fields in order to evaluate new varieties and diversified practices of species mixtures, this approach has made it possible to produce new knowledge, which is **both scientifically robust and socially useful**, and which ultimately contributes to the **development of agricultural systems** that are productive, resilient and less dependent on chemical inputs.

Figure 1 • **The ReMIX project in six points**

4 years starting May 2017

€ 5 million budget funded by Horizon 2020

11 multiactor platforms in 10 EU countries for on-farm demonstrations and co-design processes

5 crop models optimized for species mixtures

Improved harvesting and separation machinery for species mixtures

ReMIX toolbox ecosystem services tool and serious game

Definition of species mixtures

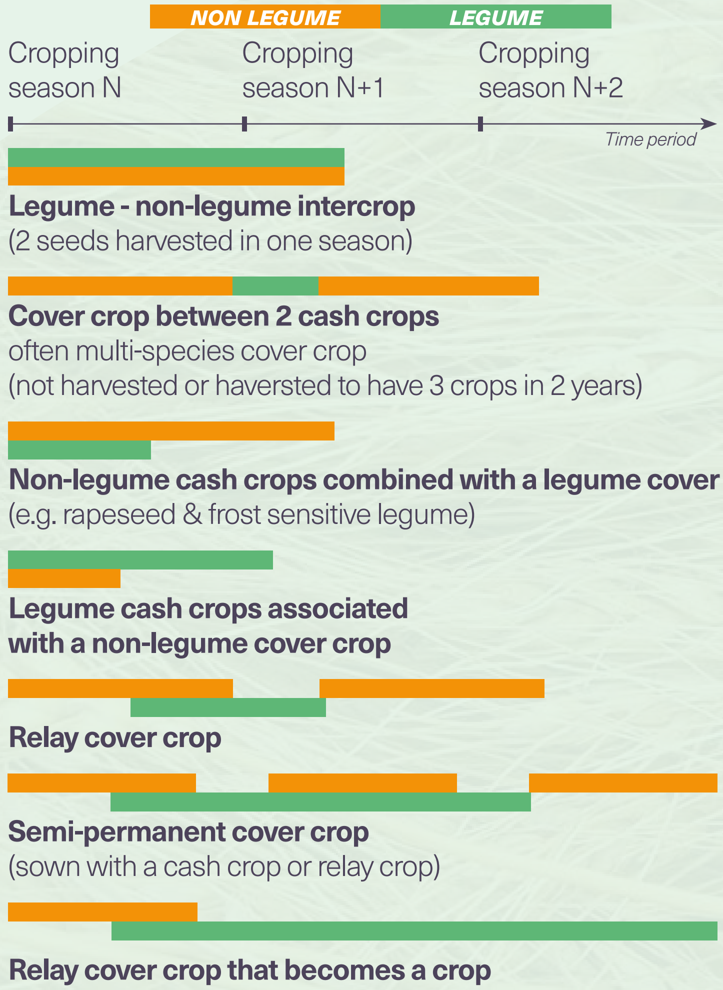
Species mixtures is an agricultural practice that exists in different forms (**Figure 3**):

• **Multispecies mixtures** where the species are harvested at the same time and produce grain, either for human consumption or for animal feed (e.g. lentil-wheat, soybean-sunflower, pea-wheat, lupin-triticale);

• Combinations of a **commodity crop and one or more unharvested service** plants that can replace chemical inputs (e.g. rapeseed with a mixture of clover, fenugreek and vetch);

• **Relay mixtures**, which consist of sowing different species in a time-staggered approach in order to optimise the use of space and resources while limiting competition, e.g. when fodder legumes are sown in a cereal cover.

Figure 3 • **The different forms of species mixtures**[2]



Performance of species mixtures

The association between one legume and one cereal is the most studied form in European systems. A synthesis of 58 experiments conducted in organic farming over 10 years in different European pedoclimates has made it possible to quantify the performance of this type of mixture in terms of yield, protein content of cereals and nitrogen use.

In this study, the yield of species mixtures is usually higher than the average for pure crops (+27% on average; **Figure 4)** and it is also more stable, due to compensation between species, but also due to facilitation of processes (less lodging for example) and not forgetting a reduction in weeds compared to those frequently associated with pure legumes.

In this study, the protein content of the cereal in mixture is generally higher than in pure stand (11.1% versus 9.8% on average; **Figure 4**). This is explained by the combination of two mechanisms: i) a lower yield of the cereal, linked to the competition of the legume and to a lower sowing density; and ii) an almost identical quantity of available mineral nitrogen to thepure cereal, due to the high fixation rate of the legume. Consequently, the quantity of available nitrogen perkilogram of cereal grain is about 50% higher for themixed cereal than for the cereal grown alone, whichcontributes to an increase in protein content. It shouldbe noted, however, that this improvement is only observed when the availability of mineral nitrogen in the soil is low.

Figure 3 • from the ANR Legitimes project brochure, 2018 • Jeuffroy M-H., Pelzer E., Bedoussac L., 2018. *LEGITIMES: LEGume Insertion in Territories to Induce Main Ecosystem Services – Construction et évaluation de scénarios territoriau x d'insertion de légumineuses.*

At harvest, the proportion of legume nitrogen from fixation is higher in a mixture than in a pure crop (73% versus 61% on average; Figure 5). This phenomenon is explained by the fact that the cereal rapidly depletes the mineral nitrogen available in the soil, due to a faster growth of its root system than that of the legume, forcing the latter to increase its symbiotic fixation to meet its nitrogen needs.

However, in a mixture, the yield of the legume is most often lower than that measured in a pure stand because of the presence of the cereal and a lower sowing density. As a result, the amount of nitrogen fixed per hectare is often reduced compared to that measured in a pure legume stand.

Ultimately, species mixtures have many advantages, but their introduction into cropping systems must be thought out and managed according to the pedoclimatic and socio-economic contexts, and combined with other practices, particularly the management of fallow periods.

In addition, research must also be carried out on the management of species mixtures (choice of species, varieties, sowing densities, weeding, fertilisation, etc.) in order to identify the best combinations adapted to different contexts.

Figure 5 • **Amount of nitrogen fixed or removed per hectare by a cereal or legume alone or in mixture**

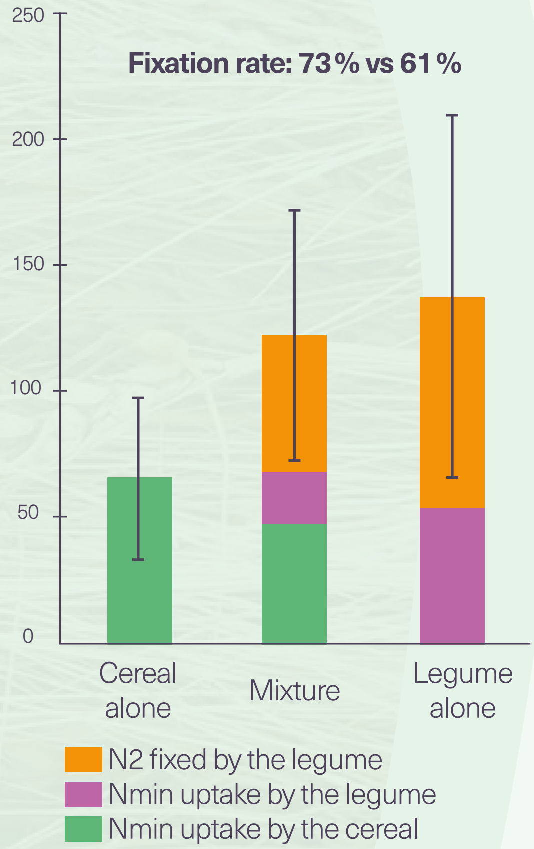


Figure 4 • **Yield of the mixture as a function of the average yield of the pure crops and organic protein content of the mixed cereal as a function of the pure cereal in organic farming**

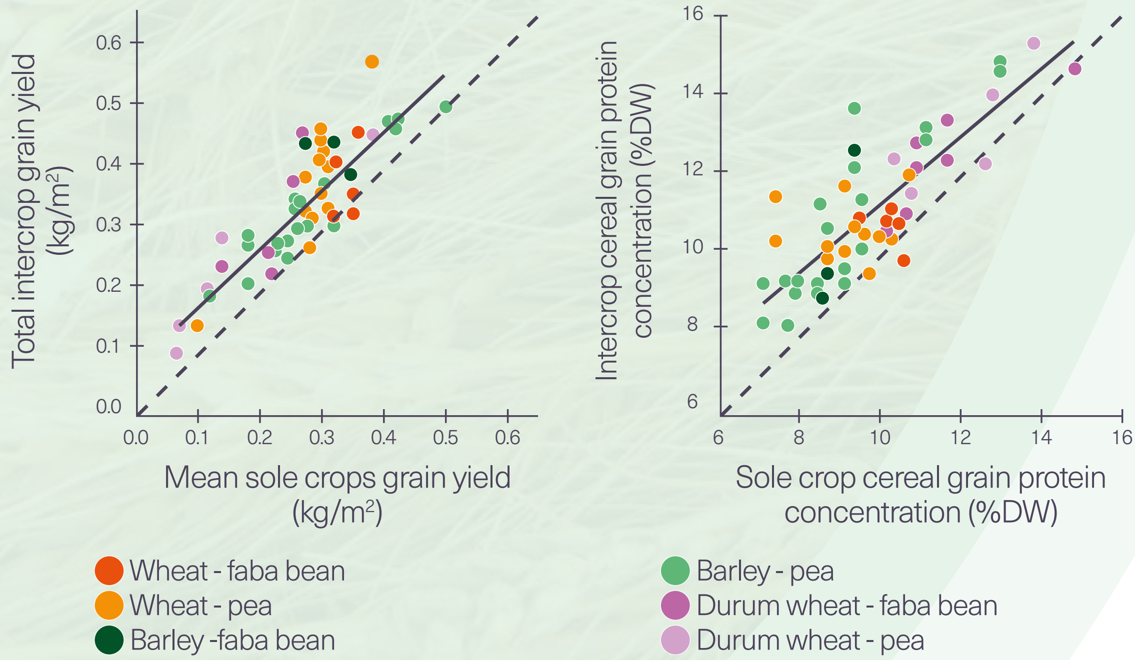


Figure 4 • Bedoussac et al. 2015 • Bedoussac L., Journet E.-P., Hauggaard-Nielsen H., Naudin C., Corre-Hellou G., Jensen E. S., Prieur L., Justes E. (2015). *Ecological principles underlying the increase of productivity achieved by cereal-grain legume intercrops in organic farming. A review. Agronomy for sustainable development 35(3):911-935* - Figure 5 • Bedoussac et al. 2015

Functioning of mixtures

Species mixtures makes it possible to use available resources more efficiently by exploiting the complementarity between species in order to increase the production and quality of harvested products, reduce the application of nitrogen fertilisers, but also control diseases, weeds and in some cases pests, while reducing the use of pesticides.

In species mixtures, there are different types of interactions, both direct interactions between species and indirect interactions where one species modifies the environment of its associated species (Figure 6).

When a species modifies the environment of its associated species in a positive way, it is called **facilitation**. For example, a species with a high risk of lodging in a pure crop, such as lentil or pea, can be supported by another more resistant species, often a cereal. On the other hand, when this environmental modification is found to be negative, it is called **competition**.

A large majority of species mixtures integrate cereals and legumes because they have different growth dynamics and aerial and root architectures, reducing their competition for the same resources, or at least spreading or deferring it in time and space. This is known as **complementarity** between species.s.

Mixtures of a legume with a non-legume are particularly interesting because of the capacity of the former to fix atmospheric nitrogen. This relationship translates into a process known as **niche complementarity**, which corresponds to the exploitation of different resources between the species (Figure 7). In this particular case, legumes can use atmospheric nitrogen, unlike cereals, which can only use mineral nitrogen in the soil.

This **niche complementarity** can also be linked to differentiated rooting when certain species exploit shallow horizons while others value deep horizons, or when the speed of soil exploration is different between species. The same applies to the use of light energy when, for example, a plant that covers the soil, such as a clover, is associated with a species that tends to grow more vertically, such as wheat. Finally, this interspecies **complementarity** is also expressed when the needs of the species are asynchronous, for example for rain or light between an early and a late species.

Ultimately, when the mixed species have differentsensitivities to environmental conditions, restricted growth observed for one of the two species can be compensated for by the other, less sensitive to these conditions. In this case, we speak of **compensation**.

Figure 6 • **The different types of interaction between species within a species mixture**

Compensation
The more difficult growth of one of the two species can be compensated for by the other, which is less sensitive to environmental conditions

Complementarity
Species do not compete for the same resources, or compte for them in a different way in time and space

Facilitation
The presence of a species on the plot positively modifies the environment of the other species

Competition
The presence of a species on the plot negatively modifies the environment of the other species

Figure 7 • from the ANR Legitimes project brochure, 2018

Figure 7 • **Operating principle of species mixtures**

Figure 8 • **Method used to track down innovations**

1. Define which innovative practices are tracked in contrast with dominant practices
   annual crop mixures, in which at least one crop is grown to produce grains or forage
2. Identify crop mixture growers
3. Describe the crop mixtures grown by farmers and their agronomic logics
4. Assess the crop mixtures regarding farmers' criteria
5. Specify the conditions of success of the mixtures
6. Propose a typology of mixtures and correspondence with farmers' objectives
7. Produce design support resouces form the cross analysis of agronomic logics of the various mixtures

Figure 8 • Verret et al., 2020

02

From tracking to co-design

Tracking down innovation

As part of the **ReMIX** project, an on-farm innovation tracking was carried out in France in 2017-2018 to identify and analyse farmers' innovative practices in terms of species mixtures4 using the method presented in **Figure 8**.

During this tracking, interviews were conducted with 47 farmers to identify the mixtures cultivated by them and their **logic of action**, i.e. the links of coherence between the targeted objectives, the practices implemented and the farmers' satisfaction criteria.

In total, **77 different** combinations involving **29 species** were identified. The vast majority of the mixtures practised by the farmers included legumes, in particular pea, faba bean and lentil. A typology of these combinations was carried out, leading to the definition of seven types according to sowing period, the harvest outlet or the temporal organisation of the mixture (**Figure 9**).

• **Type 1** : Mixture of two winter cash crops sown and harvested simultaneously

• **Type 2** : Mixture of more than two winter cash crops sown and harvested simultaneously

• **Type 3** : Mixture of two spring cash crops sown and harvested simultaneously

• **Type 4** : One cash crop sown simultaneously with one or more temporary companion plants

• **Type 5** : Mixture of two cash crops sown in relay for a double crop

• **Type 6** : One cash crop with one or more companion plants sown in relay

• **Type 7** : A cash crop sown in a previously established living cover

This tracking has shown that farmers' motivations for implementing these mixtures are very diverse (**Table 1**) although the introduction of nitrogen to the system and the limitation of weed development are predominant. Also, the farmers interviewed mentioned a certain number of limitations to the implementation of species mixtures, both technical (e.g. sowing, harvesting, sorting) and economic (e.g. regulations and outlets).

It is interesting to note that most of these elements have been acquired through research work on farm, confirming the production of knowledge from the practical application of species mixtures. This highlights that this type of knowledge, associated with scientific knowledge, is particularly **well valued** in the co-design of such innovations.

Figure 9 • **The different types of species mixtures encountered**

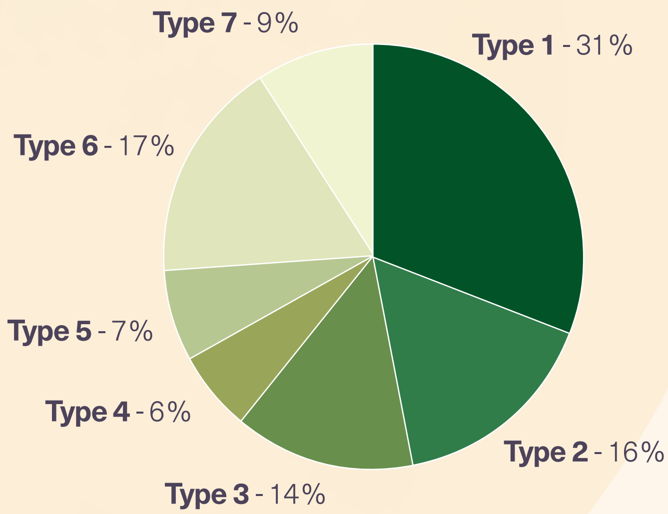


Figure 9 • Verret et al., 2020. Verret V., Pelzer E., Bedoussac L., Jeuffroy M.-H. (2020). *Tracking on-farm innovative practices to support crop mixture design: the case of annual mixtures including a legume crop. European Journal of Agronomy* 115:126018

Multi-actor platforms

The objective of the **ReMIX** project was to develop practical solutions that could be adapted by farmers and the various stakeholders in the agricultural sector under various soil, climate and socio-technical conditions on a European scale. In concrete terms, this has resulted in the setting up of 11 multi-actor platforms spread throughout Europe (**Figure 10**) including two in France (Centre West and South West).

The objective of these platforms was, among others, to: i) generate innovations that could be collectively evaluated in order to retain and ultimately implement the most relevant ones; ii) implement and manage this multi-stakeholder innovation dynamic, managing the design process and the diversity of experiments in the corresponding regions; iii) provide practical and accessible information on species mixtures for immediate use, as well as; iv) advise on overcoming regulatory and institutional barriers to the widespread adoption of species mixtures in the European Union.

These multi-actor platforms were used to support local experiments on station and on farm to test a variety of species mixtures and technical methods, as well as more analytical trials conducted by researchers, particularly on understanding the biological and ecological processes at work in these species mixtures in order to optimise their performance (agronomic and economic) and their management (choice of species, varieties and technical interventions). Thus, these multi-actor platforms acted as an excellent set of demonstration sites, open to both farmers and a variety of other actors during a series of dedicated open days.

Figure 10 • **Location and nature of the 11 multiactor platforms of the ReMIX project**

Co-design workshops

Based on the observation that farmers lacked technical references and support, particularly with regard to the choice of species and varieties to be combined, codesign workshops were organised in various multistakeholder platforms, including the one in southwestern France, to collectively imagine and discuss the species combinations to be tested under real conditions, taking into account the opinions, objectives and constraints of farmers.

A total of four workshops, each with between three and six farmers, were conducted in 2018 in south-western France (**Figure 11**) and each produced one or two technical association itineraries.

It should be noted that the majority of participants were in organic farming and were already practising intercropping (**Figure 12**), particularly with faba beans and peas, as well as alfalfa and lentils, confirming the results of the tracking of innovations mentioned above.

Most farmers volunteered to participate in this codesign process to improve their practices, underlining a strong expectation of the project in terms of exchange of experience with other farmers, but also combined with associated research.

The co-design workshops were organised in several stages, including one allowing farmers to express their point of view on species mixtures. It emerged from this consultation that the questions of outlet and marketing appeared to be central, in connection with harvesting and sorting.

Other elements were mentioned by the farmers, such as difficulties related to sowing and weeding. However, it is interesting to note that these elements are not perceived as difficulties by the farmers practising species mixtures, suggesting that the practical application allows the identification of solutions to solve these difficulties.

As far as the interests perceived by farmers are concerned, we logically find those mentioned in the context of the track for innovations, in particular the increase and stabilisation of yields, the reduction of weeds compared to pure legume stands, and improved quality of cereals, especially in terms of protein.

Prior to the co-design of crop management, workshop participants were asked to classify the priority themes, which revealed that their questions related firstly to technical aspects (e.g. choice of species and varieties to be combined, sowing, fertilisation and the place of associations in rotations) and secondly to the management of biotic factors and weeds (**Figure 13**).

By integrating the constraints and objectives of each participant, the co-design approach implemented made it possible to bring out different possible options for the same combination of species, allowing adaptation to be made depending on the different contexts.

In concrete terms, the transposition of the same objective resulted in different crop management in terms of species and technical choices (**Figure 14**), due to the adaptation to the particular context of each farmer (e.g. soil and climate, available equipment, presence of animals, size of the farm, ability to sort, etc.).

Figure 11 • **Photograph taken during a co-design workshop**

Figure 11 • L. Bedoussac

2. From tracking to co-design

Table 1 • **Strengths, opportunities, weaknesses and threats to the implementation of species mixtures**

STRENGTHS AND OPPORTUNITIES	WEAKNESSES AND THREATS
Nitrogen supply when legumes are present in the mixture, they fix atmospheric nitrogen, limiting the need for N fertilisation.	**Sowing** in terms of the choice of depths, varieties, dates and sowing densities of the two species.
Increasing and stabilising yields through a better use of abiotic resources and a balance between the two species limiting the sensitivity to biotic and climatic hazards.	**Harvesting** in terms of dates and settings to be adapted according to the maturity of the species and the differences in grain size.
Reduction of weeds due to less nitrogen and light availability for their development.	**Sorting** which requires time, skills and an initial investment whether it is done on the farm or at the cooperative.
Increasing the protein content of cereals when grown with legumes.	**Storage** which requires more storage options (one for the mixture and one for the grains of each species once separated).
Reduction of biotic pressure by dilution, barrier or other effects.	**Outlets** which constrain the choice of species to be combined according to what the collection agent will accept.
Better use of phosphorus resources due to root complementarity and facilitation processes in the presence of a legume.	**Protection** in connection with the few plant protection chemicals authorised for the two species and a more delicate mechanical weeding because it must be adapted to the two species.
Reduction in working time in connection with a reduction in fertilisation, weeding and crop protection operations.	**Regulation** because the mixtures are not necessarily recognised as protein crops (therefore specific premium may not be eligible) and the services rendered are not sufficiently recognised.
Increased biodiversity as several species grown together tend to favour the balance between pests and beneficials.	**Knowledge** related to a lack of experience, know-how, technical support and references.

Figure 12 • **Examples of species mixtures practised by farmers in the multi-stakeholder platform in South-West France**

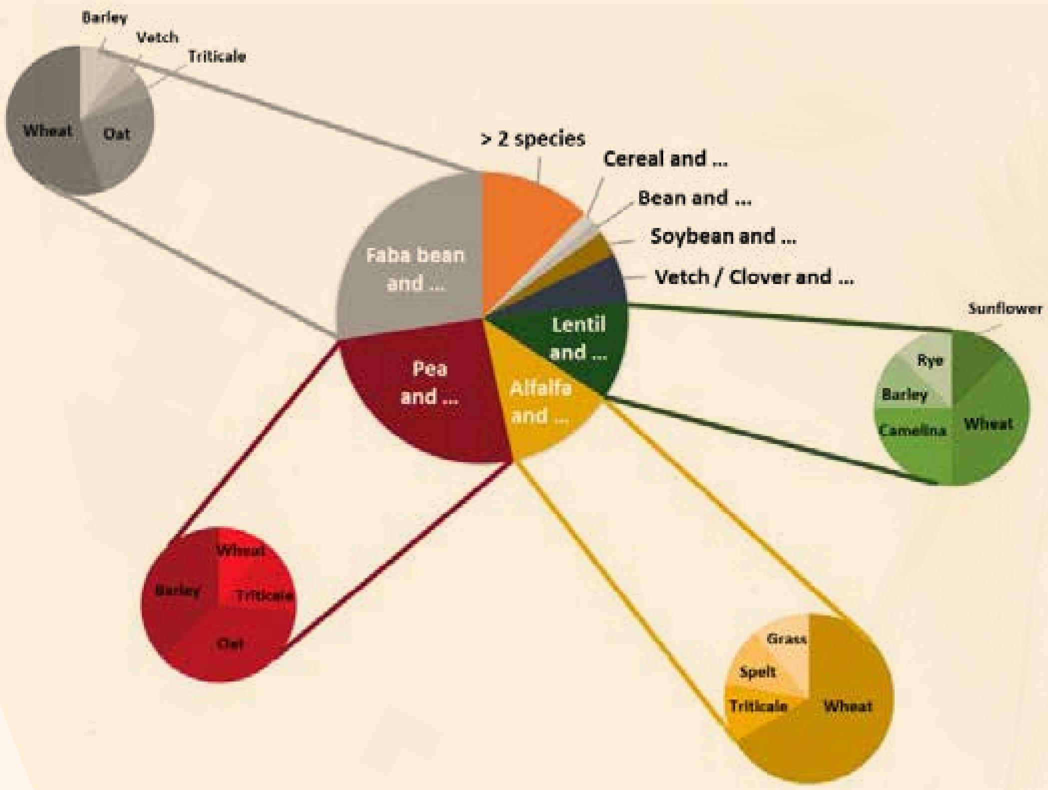


Figure 13 • **Result of the votes of the participants in the workshops of the South-West France platform, as to the themes of work on the mixtures to be prioritised.**

The size is proportional to the number of votes.

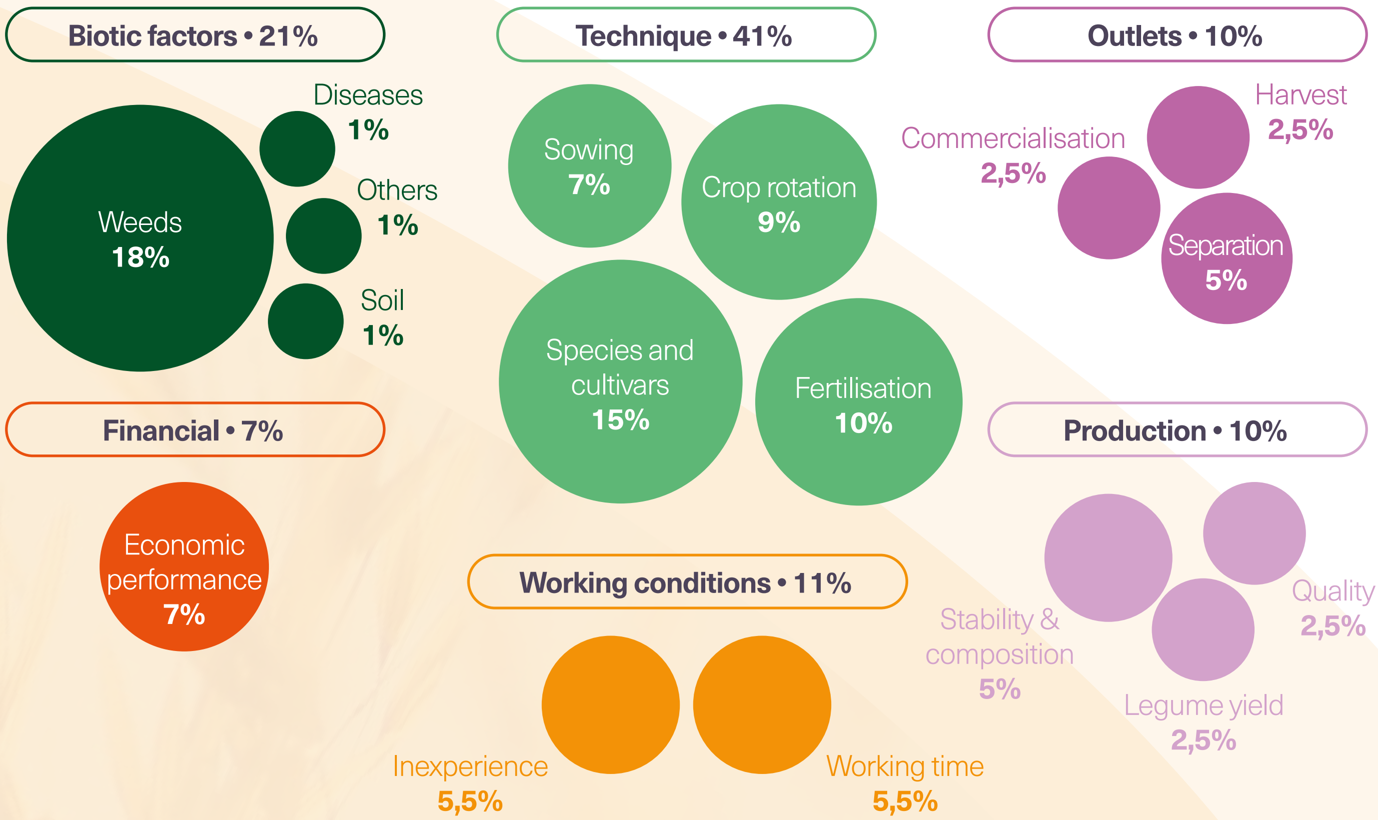


Figure 14 • **Example of crop managements co-designed during a workshop in the multi-stakeholder platform of South-West France to produce "quality" wheat**

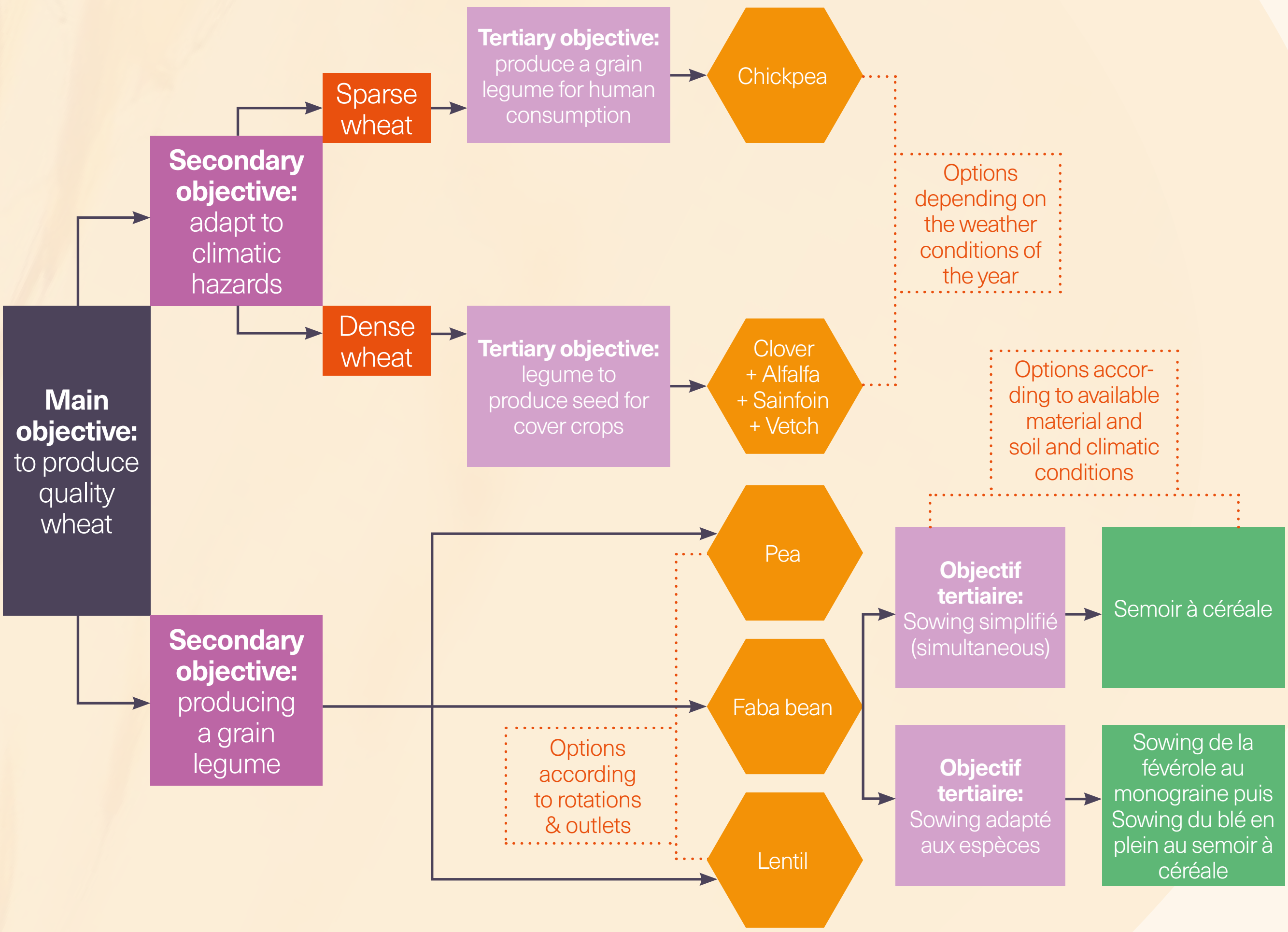


Figure 12, Figure 13, Figure 14 • C. Moreau, 2018

Table 2 • **Classification of data sheets from farmers' experiences according to species, knowledge status, objective and outlet**

N° sheet	Species	Main objective	Country
1	Wheat-Faba bean	Produce quality wheat	France
2	Wheat-Faba bean	Produce quality wheat	France
3	Wheat-Faba bean	Produce protein	Greece
4	Wheat-Faba bean	Produce a complete feed	Netherlands
5	Wheat-Pea	Produce quality wheat	Greece
6	Barley-Pea	Secure production and reduce working time	France
7	Barley-Pea	Secure production and control weeds	France
8	Barley-Pea	Produce a complete feed	France
9	Barley-Pea	Produce pea and control weeds	Switzerland
10	Barley-Lentil	Produce Lentil while limiting lodging	France
11	Barley-Lathyrus	Produce lathyrus and control weeds	France
12	Oat-Faba bean	Produce oat at lower cost and clean the field	France
13	Oat-Faba bean	Produce Faba bean and secure production	France
14	Oat-Faba bean	Produce Faba bean and control weeds	Switzerland
15	Oat-Pea	Control weeds and supply nitrogen	France
16	Oat-Lentil	Produce Lentil	Germany
17	Rye-Vesce	Producing vetch seed	Denmark
18	Triticale-Faba bean	Produce faba bean and control weeds	Switzerland
19	2 Cereals-2 Legumes	Produce a complete feed	France
20	3 Cereals-2 Legumes	Produce a protein-rich feed	France
21	2 Cereals-3 Legumes	Produce a protein-rich fodder	France
22	2 Cereals-2 Legumes	Produce a complete feed	Netherlands
23	Wheat-Faba bean	Produce a protein-rich feed and control weeds	Netherlands
24	Wheat-Faba bean	Produce a complete feed and control weeds	Denmark
25	Wheat-Pea	Increase production proteins in fodder	Poland
26	Wheat-Pea	Produce a complete feed	Scotland
27	Wheat-chick pea	Secure chickpea production and improve wheat quality	Spain
28	Wheat-Lentil	Produce Lentil while limiting lodging	France
29	Wheat-Lentil	Secure lentil production and improve wheat quality	France
30	Wheat-Lentil	Secure lentil production and improve wheat quality	Spain
31	Barley-Pea	Produce pea and control weeds	Switzerland
32	Barley-Pea	Produce a complete feed	Scotland
33	Oat-Faba bean	Produce faba bean and control weeds	Switzerland
34	Oat-Lupin	Produce lupin and control weeds	Switzerland
35	Oat-Lentil	Produce a protein-rich and easy-to-harvest fodder	Scotland
36	Maize-Bean	Increase and stabilise yields	Greece
37	Camelina-Lentil	Secure lentil production and harvest an additional crop	France
38	Camelina-Lentil-Lupin	Produce protein locally for human consumption	Switzerland
39	Soybean-Buckwheat	Secure soybean production and control weeds	France
40	Pea-Faba bean	Produce legumes for feed	Denmark
41	Maize-Barley	Control wireworms	France
42	Rapeseed-Legumes	Reduce chemical inputs	France
43	Rapeseed-Clover	Control weeds	France
44	Triticale-Meadow	Secure the establishment of the meadow	France
45	Meadow-Mixture Cereals/Legumes	Secure the establishment of the meadow	France
46	Soybean-Wheat	Produce two crops in relay	Denmark
47	Spelt-Clover	Protect and cover the soil after harvest	France
48	Wheat-Alfalfa	Protect and cover the soil after harvest	Denmark
49	Maize-Clover	Produce maize while limiting erosion and weeds	France
50	Mixture Cereals/Legumes-Alfalfa	Increase forage production and quality	France
51	Sunflower-Clover	Produce sunflower while limiting erosion and weeds	France
52	Barley-Pea-Clover	Produce a complete feed and protect the soil after harvest	Denmark

Typology	Status	Product	Organic	Separation	Outlet
1	Validated	Grains	Yes	Yes	Food and Feed
1	Validated	Grains	Yes	Yes	Food and Feed
1	Validated	Grains		Yes	Food
1	Validated	Grains			Feed
1	Validated	Grains		Yes	Food
1	Validated	Grains	Yes	Yes	Food and Feed
1	Validated	Grains	Yes	Yes	Food
1	Validated	Grains	Yes		Feed
1	Validated	Grains	Yes	Yes	Feed
1	To optimize	Grains	Yes	Yes	Food and Feed
1	To optimize	Grains	Yes	Yes	Food and Feed
1	Validated	Grains	Yes	Yes	Feed
1	Validated	Grains	Yes	Yes	Feed
1	Validated	Grains	Yes	Yes	Feed
1	To optimize	Grains	Yes	Yes	Feed
1	To optimize	Grains	Yes	Yes	Food ou Feed
1	To optimize	Grains		Yes	Food and Feed
1	Validated	Grains	Yes	Yes	Feed
2	Validated	Grains	Yes		Feed
2	Validated	Grains	Yes		Feed
2	Validated	Forage	Yes		Feed
2	To optimize	Grains or Forage	Yes		Feed
3	Validated	Grains	Yes		Feed
3	To optimize	Grains		Yes	Food and Feed
3	Validated	Forage			Feed
3	Validated	Grains	Yes		Feed
3	To optimize	Grains	Yes	Yes	Food
3	Validated	Grains	Yes	Yes	Food
3	Validated	Grains	Yes	Yes	Food
3	Validated	Grains	Yes	Yes	Food
3	Validated	Grains	Yes	Yes	Feed
3	Validated	Grains	Yes		Feed
3	Validated	Grains	Yes	Yes	Feed
3	Validated	Grains	Yes	Yes	Feed
3	Validated	Forage	Yes		Feed
3	To optimize	Grains		Yes	Food
3	To optimize	Grains	Yes	Yes	Food
3	To optimize	Grains	Yes	Yes	Food and Feed
3	To optimize	Grains	Yes	Yes	Food
3	To optimize	Grains			Feed
4	To optimize	Grains or Forage	Yes		Food ou Feed
4	Validated	Grains			Food
4	Validated	Grains	Yes		Food
5	To optimize	Grains and Forage	Yes		Feed
5	To optimize	Forage	Yes		Feed
5	To optimize	Grains			Food ou Feed
6	Validated	Grains and Forage	Yes		Food and Feed
7	To optimize	Grains and Forage			Feed
7	To optimize	Grains	Yes		Feed
7	Validated	Forage	Yes		Feed
7	To optimize	Grains	Yes		Food
7	To optimize	Grains			Feed

Table 2 • note that the typology is the one proposed by Verret et al (2020) and described in the 'Tracking down innovation' section of this document.

Table 3 • **Classification of data sheets from farmers' experiences according to species**

		LÉGUM					
		ALFAFA	BEAN	CHICK PEA	CLOVER	FABA BEAN	LATHYRUS
NON LÉGUMINEUSES	BARLEY						11
	BUCKWHEAT						
	CAMELINA						
	MAIZE		36		49		
	OAT						
	RAPESEED				43		
	RYE						
	SPELT				47		
	SUNFLOWER				51		
	TRITICALE					18	
	WHEAT	48		27		1 • 2 • 3 • 4 • 23 • 24	
	CEREAL MIXTURE						
OTHERS		50				40	

I N E U S E S

VETCH	LENTIL	LUPIN	PEA	SOYA BEAN	LEGUME MIXTURE	OTHERS
	10		6 • 7 • 8 • 9 • 31 • 32		52	
				39		
	37				38	
						41
	16 • 35	34	15			
					42	
17						
						44
	28 • 29 • 30			46		
					19 • 20 • 21 • 22	
						45

03

Farmers' technical data sheets

Beyond these aspects, as the practice of intercropping is still not widespread, it seemed important for us to enable farmers to share their experiences, whether or not they were novices in the practice of intercropping.

Thus, on the basis of the results of the innovation tracker and the trials carried out at farmers' sites in the various multi-actor platforms of the **ReMIX**, project, we have drawn up 52 technical sheets based on farmers' experiences with species mixtures in different contexts (each sheet compiles one to three experiences).

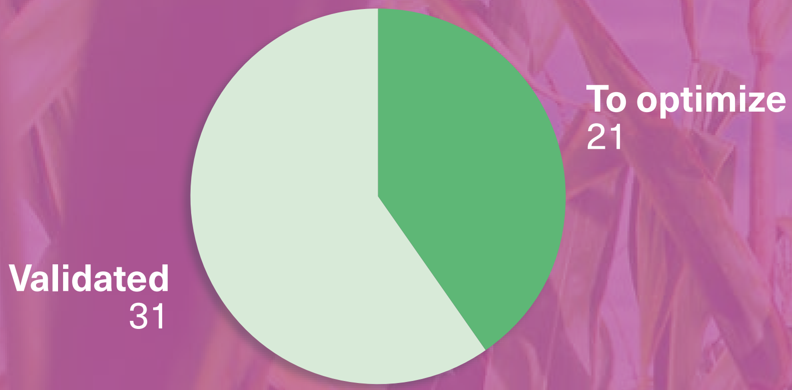
Given the diversity of farmers' expectations and farming situations, it seemed inappropriate to propose "standard" crop management for species mixtures to be followed to the letter. Indeed, as we observed, especially during the tracking, for the same combination of species, several crop management options can be implemented depending on the desired objectives and context of the farmers. This is why, in these situations, several sheets are presented (one per experiment). On the other hand, when the crop management proposed by the farmers were relatively similar, we reconstructed a typical approach that assumed efficient crop management in different contexts, based on their feedback.

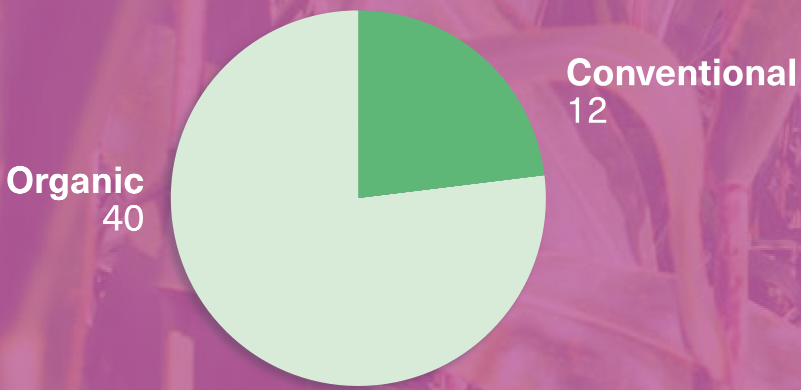
Finally, we have classified these data sheets from farmers' experiences into two categories according to the state of knowledge (**Table 2** and **Table 3**) :

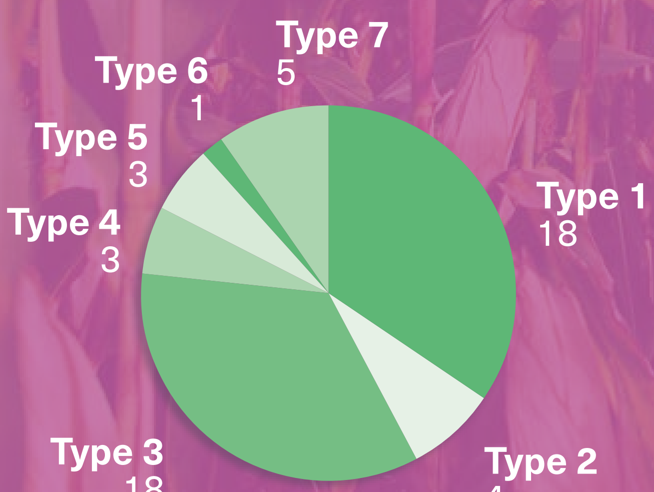
• **« VALIDATED »** when several farmers have given satisfactory feedback and the mixtures are known to work in different contexts;

• **« TO BE OPTIMIZED »** when the mixture has only been tested once and the feedback is positive but needs confirmation.

52
technical sheets from farmers' experiences







3
6
3
1
1
26
7
2
3

Specie A + Specie B

Latine names / Detail of composition if more than one species

Productions:
- ☐ grains for food
- ☐ grains for feed
- ☐ forage

INTERCROP STATUS

Organisation

Map with geographical location of the farm

Objectives: main objective

Other objectives

TECHNICAL MANAGEMENT

1. Soil preparation

Tools and tillage depth

2. Sowing

Tools, type of sowing (mixed on the same row, or on different rows), sowing depth, distance between rows, density in kg/ha (density in percentage compared to a sowing of the pure specie)

3. Crop management

Fertilization
Weeding
Irrigation

4. Harvest

Type of harvest (harvesting, mowing,...)
Special settings

5. Tri

Sorting location (farm, cooperative)
Type of sorter

Sowing: date
☐ simultaneous ☐ offset

Harvest: date
☐ simultaneous ☐ offset

CROPS USE

Destination of the harvest: sale or self-consumption

Production use: food, feed, or none (service plant)

EVALUATION BY THE FARMERS

Positive points: benefits of the culture / satisfaction with objectives, etc.

Neutral remarks: observations that are neither positive nor negative points

Negative points: difficulties / problems encountered / dissatisfaction with objectives, etc.

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING, AND IDEAS

After having identified the positive and negative points of this intercrop, the farmer has been able to venture advice or recommendations to improve crop management (sowing date, sowing density, variety, tillage, etc...)

Type 1 (n=18)

Binary mixtures
of winter cash crops sown
and harvested simultaneously

Wheat + Faba bean

Triticum aestivum + Vicia faba

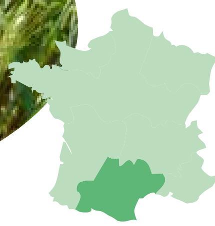
INRAE

Productions:

- [x] grains for food
- [x] grains for feed
- [ ] forage

INTERCROP VALIDATED

Photo: L. Bedoussac



Objectives: Produce quality wheat

Diversify the crop rotation and to break the diseases cycle by introducing faba beans

Cope with climatic hazards by ensuring production (harvest of at least one crop)

France

Degraded oceanic climate (700-800 mm/year)
Average annual T min 7,7°C / max 18,7 °C

Clay-limestone OR clay-silt soil

TECHNICAL MANAGEMENT

1. Soil preparation

Option 1: stubble cultivator + seedbed cultivator
Option 2: surface preparation + decompactor + surface preparation

2. Sowing

Sowing mixed on the row, with a cereal seed drill with rotary harrow or a vibroseeder, at 2-3 cm depth, and with a 12.5 cm row spacing. Wheat at 150-200 kg/ha (100 % pure crop) and faba bean at 50-60 kg/ha (30-60 % of the pure crop)

3. Crop management

Fertilization: 50 units of organic nitrogen manure
No weeding - No irrigation

4. Harvest

Axial harvester with threshing drum opening and an adjustment softer than wheat
Overripe wheat

5. Sorting

On the farm

Sowing: november
- [x] simultaneous
- [ ] offset

Harvest: early july
- [x] simultaneous
- [ ] offset

CROPS USE

Wheat and faba bean sold separately to a cooperative (wheat for food and faba bean for animal feed)

EVALUATION BY THE FARMERS

☺

Good wheat protein content (12 % in a bad year)

Relatively clean plot

Less rust on faba bean in intercrop than in pure culture

Taller strawed wheat is above the faba bean

3-3,5 t/ha total including 0,8-1 t/ha of faba bean

😐

Wheat and faba bean prices are about the same, so the proportion of the mixture is not really important

☹

Disadvantages: mixing at sowing and sorting at harvest

Very high faba bean which has get the upper hand over short straw wheat (about 30 cm below)

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

The optical sorter ensures a good sorting

Sow the faba bean a little deeper (4-5 cm) to improve its implementation

Increase the proportion of the high straw wheat variety to withstand competition from faba bean

Oat for an axial harvester to limit the faba bean seed breakage at harvest time

Choose wheat that is easy to pick and doesn't germinate on the stalk, in the event of a difference in maturity with the faba bean

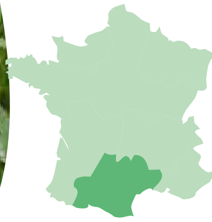
Wheat + Faba bean

Triticum aestivum + Vicia faba

INRAE

INTERCROP VALIDATED

Photo: L. Bedoussac



Productions:

- [x] grains for food
- [x] grains for feed
- [ ] forage

Objectives: Produce quality wheat

Diversify the crop rotation and to break disease cycles by introducing faba beans

Cope with climatic hazards by ensuring production (harvest of at least one crop)

France

Degraded oceanic climate (640-700 mm/year)
Average annual T min 8,5° / max 18,7°C

Clay-limestone OR sandy-clayey soil

TECHNICAL MANAGEMENT

1. Soil preparation

Option1: stubble cultivator + cultivator
Option 2: stubble plough + rotary harrow + seedbed cultivator

2. Sowing

Sowing in two passages on different rows, at a 14-15 cm row spacing
Wheat with a cereal seeder, at 2-3 cm depth, and at 130-200 kg/ha (65-100 % of the pure crop)
Faba Bean with a boom spreader or a single seed driller, at 4-5 cm depth, and at 80-90 kg/ha

3. Crop management

50-80 units of organic nitrogen
Weed control : rotary hoe or nothing
No irrigation

4. Harvest

Axial harvester with a faba bean setting

5. Sorting

To the cooperative

Sowing: november or january
- [x] simultaneous
- [ ] offset

Harvest: late june - early december
- [x] simultaneous
- [ ] offset

CROPS USE

Wheat and faba bean sold separately to a cooperative (wheat for food and faba bean for animal feed)

EVALUATION BY THE FARMERS

☺

Wheat yield doesn't seem lower than in pure culture

Correct operation of the bean spreader (also disc seed drill possible)

Wheat and faba bean prices are about the same, so the proportion of the mixture is not really important

Satisfactory overall yield (3 t/ha)

☹

Faba bean almost absent in the case of a late sowing due to drought, but partially compensated by wheat production

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Sowing the species in separate rows allows better control of the competition between the two species (in the case of a highly developed faba bean, the plants to compete with each other before competing with wheat)

Sowing in two passes is preferable because the different sized seeds tend to seperate in the seeder when they are mixed

Risk of frost on the faba bean if it's too cold, requiring a sufficiently deep sowing

Wheat + Faba bean

Triticum aestivum + Vicia faba

ARISTOTLE UNIVERSITY OF THESSALONIKI

INTERCROP VALIDATED

Productions:

- [x] grains for food
- [ ] grains for feed
- [ ] forage

Photo: C. Pankou

Objectives: Produce protein for human consumption

To increase grain protein content in wheat without any fertilizer and produce faba Bean which is important for Mediterranean countries

Secondary objectives:
Nitrogen fixation and lower input

Greece

Mediterranean climate (440 mm/year)
Average annual T min 9,2 °C/ max 20,8°C

Loam soil

TECHNICAL MANAGEMENT

1. Soil preparation

Conventional tillage in November

2. Sowing

Sowing in the first week of December, at a rate of 50% for both species

3. Crop management

No fertilizer
Herbicide application (pentimethalin) in December (lower than the cereal sole crop)
Insecticide application for bruchus April
Hand weeding in March and April

4. Harvest

Simultaneous harvest in ealry June to reduce lodging losses

5. Sorting

Separation after the harvest

Sowing: [x] simultaneous [ ] offset

Harvest: [x] simultaneous [ ] offset

CROPS USE

Wheat of high quality or bakery

Faba bean for human consumption but with the risk of gluten contamination

EVALUATION BY THE FARMERS

☺

Environmental benefits with lower fertilizer and herbicide usage

Possible to the added value product that was produced due to higher protein

Possible reduced use of N fertilizer for the following crop

Lodging of legumes is preventing with intercropping

Good establishment and similarmaturity of both species

😐

No difference in bruchus infestation between faba bean sole crops and intercrops

☹

One difficulty was the concern for the separation of the grains

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Successs: lower lodging due to faba bean

Risk : difficulty in separating the grains

Risk : extensive infestation from bruchus can be a problem for faba bean

Wheat + Faba bean

Triticum aestivum + Vicia faba

Productions:

☐ grains for food
☒ grains for feed
☐ forage

INTERCROP VALIDATED

Photo: B. Luske

Louis Bolk Instituut

Objectives:
Produce a complete feed

Provide protein and energy for dairy cows

Reduce risk for own feed production

Reduce costs

Produce high milk quality by managing feed productionand ration

Netherlands

Sea climate (760 mm/year)
Average annual T min 6,1°C / max 13,6°C

Heavy clayey and sandy soil (located exactly on the transition)

TECHNICAL MANAGEMENT

1. Sowing

Sowing at 6 cm depth.
Wheat at 50 kg/ha and faba bean at 150 kg/ha

2. Crop management

35 t/ha pig manure and 2-5 L Nova leaf fertilizer
Weedkillers Stomp Challenge and Basagran

3. Harvest

Simultaneous harvest Yield: 5,4-9 t/ha.
Bean : 15 -50 % of mixture, on average 24,4 % crude protein

4. Storage

Crushing and milling with hammer mill, storage in trench silos

5. Feeding

Feed ration is fine tuned and mixed with other feed resources

Sowing: ☒ simultaneous ☐ offset

Harvest: ☒ simultaneous ☐ offset

CROPS USE

Feed ration is fine tuned and mixed with other feed resources

EVALUATION BY THE FARMERS

☺

Strawberry growers in the region hire their land to the farmer to regenerate the soil with the crop mixture

The farmer knows exactly what the cows eat and the farm reaches high milk quality

The famer likes arable cropping and it reduces costs for feed purchase

☹

The farmer needs to have access to land (crop mixture is arable land use and dairy farmers can only use 20% of their land for arable crops (regulation of CAP)

It means extra work to grow your own food

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

It is a success in this particular case, as the farmer uses the mixed produce on his own farm. The sum of the benefits makes it a success.

The crop mixture is actually used to reduce risks, because the farm is situated at different soil types (heavy clay and sand).
A crop mixture always yields something, but the ratio differs per soil type and season.

Wheat + Pea

Triticum aestivum + Pisum sativum

ARISTOTLE UNIVERSITY OF THESSALONIKI

Productions:

- [x] grains for food
- [ ] grains for feed
- [ ] forage

INTERCROP VALIDATED

Photo: C. Pankou

Objectives: Produce protein for human consumption

Achieve higher and more stable yields in the Mediterranean countries

Fix nitrogen for the next crop

Increase protein rate of milling wheat

Greece

Mediterranean climate (440 mm/year)
Average annual T min

9,2 °C / max 20,8°C

TECHNICAL MANAGEMENT

1. Soil preparation

Conventional tillage in November

2. Sowing

Sowing in the first week of December, at a rate of 50% for both species

3. Crop management

No fertilizer
Herbicide application (pentimethalin) in December (lower than the cereal sole crop)
Insecticide application for bruchus April
Hand weeding in March and April

4. Harvest

Simultaneous harvest in ealry June to reduce lodging losses

5. Tri

Separation after the harvest

Sowing: early December
- [x] simultaneous
- [ ] offset

Harvest: early June
- [x] simultaneous
- [ ] offset

CROPS USE

Wheat of high quality or bakery

Pea for human consumption but with the risk of gluten contamination

EVALUATION BY THE FARMERS

☺

Environmental benefits with lower fertilizer and herbicide usage

Possible to the added value product that was produced due to higher protein

Possible reduced use of N fertilizer for the following crop

Lodging of legumes is preventing with intercropping

Good establishment and similar maturity of both species

😐

No difference in bruchus infestation between pea sole crops and intercrops

☹

One difficulty was the concern for the separation of the grains

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Risk: difficulty in separating the grains

Risk: extensive infestation from bruchus can be a problem for pea

Barley + Pea

Hordeum vulgare + Pisum sativum

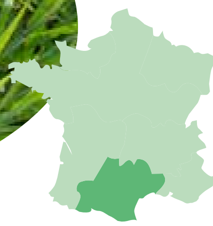
Productions:

- [x] grains for food
- [x] grains for feed
- [ ] forage

INRAE

INTERCROP VALIDATED

Photo: L.Bedoussac



Objectives: Secure production

Secure production by harvesting of at least one of the two species

Generate a margin without requiring too much work

France

Degraded oceanic climate (800 mm/year)
Average annual T min 7,4°C / max 18,5°C

Sandy, compacted soil

TECHNICAL MANAGEMENT

1. Soil preparation

Decompact soil in September and two shallow depth cultivations

2. Sowing

Sowing mixed on the row, at 2-3 cm depth, and with a 12.5 cm row spacing.
Barley at 120 kg/ha ((80 % of the pure crop) and faba bean at 80 kg/ha (80 % of the pure crop)

3. Crop management

No fertilization
No weeding
No irrigation

4. Harvest

Simultaneous harvest end of June - beginning of July

5. Tri

On the farm (rotary sorter)

Sowing: mid November
- [x] simultaneous
- [ ] offset

Harvest: late June - early July
- [x] simultaneous
- [ ] offset

CROPS USE

Barley and pea sold separately to a cooperative (barley for human consumption and pea for animal feed)

EVALUATION BY THE FARMERS

☺

The pea helps to maintain good nitrogen levels in the soil

Sorting is relatively simple

Proportion varies according to the zones : in nitrogen-rich zones there are few Pea and barley has taken over, and vice versa in nitrogen-poor zones

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Take into account the type of precedent to properlymanage fertilization and the proportion of species

Mix the two species well before sowing

Barley + Pea

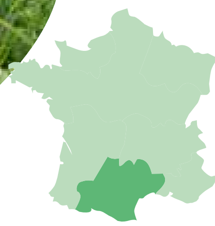
Hordeum vulgare + Pisum sativum

Productions:

- [x] grains for food
- [ ] grains for feed
- [ ] forage

INTERCROP VALIDATED

Photo: L.Bedoussac



Objectives: secure production

Weed control

Have a good preceding crop for the next crop

Avoid cover lodging

France

Degraded oceanic climate (730 mm/an)
Average annual T min 8,1°C / max 18,7°C

Clay-limestone soil

TECHNICAL MANAGEMENT

1. Soil preparation

Stubble ploughing, ploughing at 20 cm, then use of a tine tool

2. Sowing

Sowing mixed in the row, with a conventional seed drill, at 2-3 cm depth, and with a 17.5 cm row spacing.
Barley at 80 kg/ha and pea at 120 kg/ha

3. Crop management

No fertilization
No weeding
No irrigation

4. Harvest

Axial harvester with a flexible cutter, with a pea setting, so as not to damage seed

5. Sorting

On the farm
(JK-machinery sorter)

Sowing: mid-November
- [x] simultaneous
- [ ] offset

Harvest: late June
- [x] simultaneous
- [ ] offset

CROPS USE

Pea sold for human consumption (split Pea)

Malting barley sold for human consumption if it is not too rich in protein. Otherwise, sold as animal feed

EVALUATION BY THE FARMERS

☺

Intercropping seems to limit the lodging of both species

Few windows to pass the tine harrow, so no weeding, but clean plots, so no maintenance necessary

Heterogeneity in the plot which provides a good use of resources

Good yield

☹

Very ripe and brittle Pea make sorting difficult

The mixture of malting barley with pea increases its protein content

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Allocate the plots at harvest and after sorting, according to protein levels to increase the malting barley outlet

Barley + Pea

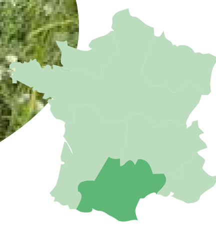
Hordeum vulgare + Pisum sativum

Productions:

- ☐ grains for food
- ☒ grains for feed
- ☐ forage

INTERCROP VALIDATED

Photo: L.Bedoussac



Objectives: Produce a complete feed

Produce a balanced mix of pea and barley to provide both energy and protein to the forage

France

Degraded oceanic climate (640-730 mm/year)
Average annual T min 8,4°C / max 18,7°C

Sandy-clayey OR silty-sandy soil

TECHNICAL MANAGEMENT

1. Soil preparation

Stubble ploughing at 10 cm and ploughing at 20 cm

2. Sowing

Option 1: sowing mixed on the row
Option 2: in two passages on the same day in different rows
Sowing with a cereal seed drill with rotary harrow, at 2-3 cm depth, and with a 12.5-14 cm row spacing.
Barley at 80-120 kg/ha (60-85 % of the pure crop) and pea at 40-100 kg/ha (20-50 % of the pure crop)

3. Crop management

Weed control : tine harrow OR none
No fertilization
No irrigation

4. Harvest

Harvester with reduced threshing speed and rear grate opening

5. Sorting

No sorting

Sowing: late Oct - late Nov
☒ simultaneous ☐ offset

Harvest: early July
☒ simultaneous ☐ offset

CROPS USE

Grains utilised on-farm or sold to a cooperative for animal feed

EVALUATION BY THE FARMERS

☺ The presence of barley limits pea lodging

Yield of about 5 t/ha

☹ For the farmer who cultivated alfalfa on this plot the year before, there is more alfalfa on the unploughed portion, but this doesn't affect yield

☹ The heat at the end of the season caused the pea pods to open

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Hail can damage the pea crop

The pea density must be sufficient to withstand competition from barley (about 70 kg/ha)

Seed mixing is long and tedious, so sowing in two passes is possible

A pre-cleaning with a separator could be interesting to limit impurities before the sale of the mixture

The presence of Pea attracts wild boars

Harrowing is possible before the tendrils appear, but few windows are available

Pea + Barley

Pisum sativum + Hordeum vulgare

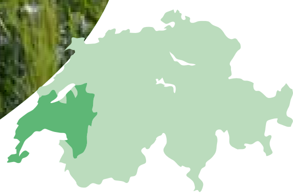
Productions:

☐ grains for food
☒ grains for feed
☐ forage

FiBL

INTERCROP VALIDATED

Photo: M. Klaiss



Objectives: Produce pea and control weeds

Control weeds

Prevent pea lodging

Switzerland

Continental climate (780 mm/year)
Average annual T min 1°C / max 22.4°C

Clay loam soil

TECHNICAL MANAGEMENT

1. Soil preparation

Plowing at 20 cm depth

2. Sowing

Combined seed drill with rotary harrow at 3 cm depth, species are mixed on the same row.
Pea : 80 pl/m2 (80%) and barley 150 pl/m2 (40%)

3. Crop management

No fertilisation,
One pass of coiled tine weeder,
No irrigation

4. Harvest

Combine harvester
Pea : 4,05 t/ha
Barley : 1,45 t/ha

5. Sorting

Sorting at the mill
Optical sorter

Sowing: mid October
☒ simultaneous ☐ offset

Harvest: early July
☒ simultaneous ☐ offset

CROPS USE

Destination of the harvest : sale

Production use : feed

EVALUATION BY THE FARMERS

☺

High proportion of pea at harvest

No lodging

Good weed control

☹

Variable proportion of pea at harvest

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

The sowing date should be after October 15 to prevent the pea from becoming too vigorous at the onset of winter and not overwintering properly

Sow deep enough, around 5 or 6 cm or pea will be damaged morere easily during the winter with the frosts and thaws.

Very wet or frosty conditions (>-12°C) are detrimental to Pea.

Nitrogen rich soils favour cereals to the detriment of Pea.

Lentil + Barley

Lens culinaris + Hordeum vulgare

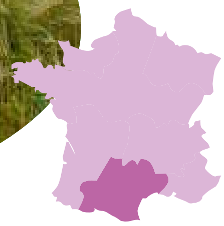
INTERCROP TO BE OPTIMIZED

INRAE

Productions:

- [x] grains for food
- [x] grains for feed
- [ ] forage

Photo: L.Bedoussac



Objectives: Produce lentil

Limit lentil lodging by means of an associated species that acts as a support and that can be valued

France

Degraded oceanic climate (800 mm/year)
Average annual T min 7,4°C / max 18,5°C

Clayey soil

TECHNICAL MANAGEMENT

1. Soil preparation

Decompaction in September and two shallow cultivations

2. Sowing

Sowing mixed on the row, at 2-3 cm depth, and with a 12 cm row spacing.
Lentil at 100 kg/ha (90 % of the pure crop) and barley at 50 kg/ha (60 % of pure crop)

3. Crop management

No fertilization
No weeding
No irrigation

4. Harvest

Simultaneous harvest end of June - beginning of July

5. Sorting

On the farm
(plate sorter and optical sorter)

Sowing: mid November
- [x] simultaneous
- [ ] offset

Harvest: late June - early July
- [x] simultaneous
- [ ] offset

CROPS USE

Lentil and barley sold separately to a cooperative (lentil for food and barley for feed

EVALUATION BY THE FARMERS

☺

The barley showed good ground coverage on the part of the plot that had been decompacted

The lentil is very high and did not lodge

Total yield is about 3 t/ha including 0,75 t/ha of lentil

On the compacted part, there is more lentil and less barley

😐

No effect on weevils compared to pure culture

☹

Barley is deficient in nitrogen

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Risk of damage to lentil by frost but will be used as a green manure for barley and will cover the soil to limit the development of weeds

The barley lodged a lot. It is possible to use instead a wheat that doesn't lodge

Lentil sowing in autumn works but wild vetch develops and it is then impossible to sort the lentil seeds ! It may be better to sow in the spring

Barley + Lathyrus

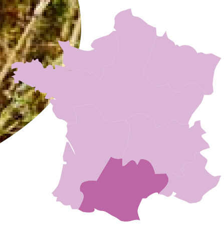
Hordeum vulgare + Lathyrus sativus

Productions:

- [x] grains for food
- [x] grains for feed
- [ ] forage

INTERCROP TO BE OPTIMIZED

Photo: L.Bedoussac



Objectives: Produce lathyrus

Limit the lodging of the lathyrus

Have a recoverable support plant to avoid lodging of the lathyrus

France

Degraded oceanic climate (700 mm/year)
Average annual T min 7,9°C / max 18,9°C

Clay-limestone soil

TECHNICAL MANAGEMENT

1. Soil preparation

2 passages of gascon stubble cultivator at 5-10 cm

2. Sowing

Sowing mixed on the row, with a wheat seeder with reciprocating harrow, at 3 cm depth.
Barley at 180 kg/ha (100 % of the pure crop) and lathyrus at 60 kg/ha (35 % of the pure crop)

3. Crop management

23 m^3/ha of slurry
No weeding
No irrigation

4. Harvest

Silmutaneous harvest at the end of July

5. Sorting

On the farm
(Denis plate sorter)

Sowing: mid October
- [x] simultaneous
- [ ] offset

Harvest: late July
- [x] simultaneous
- [ ] offset

CROPS USE

Barley sold to a cooperative for animal feed

Lathyrus sold to a retail store, for human food, or to livestock farmers as seed

EVALUATION BY THE FARMERS

☺

Good tillering of the lathyrus

4 q/ha of yield, including 0,4 t/ha of lathyrus

Lathyrus lodging less than in pure culture which allows a cleaner harvest

Barley is easy to combine at harvest

The plot is relatively clean

😐

Cover lodging due to too dense a seeding rate of the lathyrus

☹

The crop was affected by drought

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

The sowing densities must be well balanced to prevent the lathyrus from lodging

The barley/ lathyrus proportions vary greatly depending on the pedoclimatic conditions

Oat + Faba bean

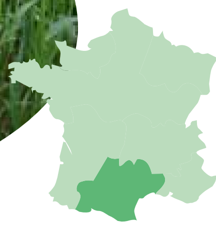
Avena sativa + Vicia faba

Productions:

- ☐ grains for food
- ☒ grains for feed
- ☐ forage

INTERCROP VALIDATED

Photo: R. Charles



Objectives:
Clean and produce at lower cost

Produce oat inexpensively

Clean the plot by covering the soil

France

Degraded oceanic climate (800 mm/year)
Average annual T min 7,4°C / max 18,5°C

Hydromorph, sticky black soil

TECHNICAL MANAGEMENT

1. Soil preparation

Two passages of tine stubble cultivator at 15 cm, then one passage of seedbed cultivator at 5-10 cm

2. Sowing

Sowing mixed on the row, at 2-3 cm depth, and with a 12.5 cm row spacing.
Oat at 100 kg/ha (100 % of the pure crop) and faba bean at 50 kg/ha (25 % of the pure crop)

3. Crop management

No fertilization
No weeding
No irrigation

4. Harvest

Simultaneous harvest at the beginning of July

5. Sorting

On the farm
(plate sorter and optical sorter)

Sowing: mid October
☒ simultaneous ☐ offset

Harvest: early July
☒ simultaneous ☐ offset

CROPS USE

Oat sold to a farmer for seed

Faba bean sold for animal feed or for seed

EVALUATION BY THE FARMERS

☺ The mixture provides diversity and the faba bean provides nitrogen

☹ The intercrop didn't limit wild oats

Faba bean is the same height as wild oats, so the wild Oat are impossible to cut away

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

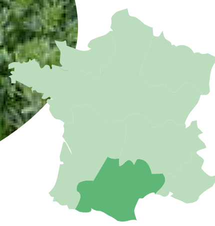
Sorting has to be done on several occasions despite the oat and faba bean having quite different seed sizes of

Oat + Faba bean

Avena sativa + Vicia faba

Productions:

- ☐ grains for food
- ☒ grains for feed
- ☐ forage



Objectives:
Produce faba bean

Ensure a good overall yield even if the yield of the faba bean is poor

Have a good previous crop for the following wheat

France

Degraded oceanic climate (700 mm/year)
Average annual T min 7,9°C / max 18,9°C

Clay-limestone soil

TECHNICAL MANAGEMENT

1. Soil preparation

One Gascon stubble cultivator passage at 5-10 cm, 7-8 t/ha of composted cattle manure input, then one stubble cultivator passage at 15 cm

2. Sowing

Sowing mixed on the row, with a cereal seed drill, and at 3-4 cm depth.
Oat at 80 kg/ha (50 % of the pure crop) and faba Bean at 100 kg/ha (75 % of the pure crop).
Then rotary harrow passage

3. Crop management

No fertilization
No weeding
No irrigation

4. Harvest

Harvester with a faba bean setting

5. Sorting

On the farm (plate sorter)

Sowing: mid October
☒ simultaneous ☐ offset

Harvest: late July
☒ simultaneous ☐ offset

CROPS USE

Oat and faba bean sold separately to a cooperative for animal feed

EVALUATION BY THE FARMERS

☺

Fewer diseases than in pure culture because of lower density

Overall yield (3 t/ha) balanced despite a fairly heterogeneous plot

No frost problem for Oat

☹

Faba bean attacked by rust and anthracnose

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Choose a disease tolerant variety of faba bean

Faba bean + Oat

Vicia faba + Avena sativa

Productions:

- [ ] grains for food
- [x] grains for feed
- [ ] forage

INTERCROP VALIDATED

Photo: M. Klaiss

Objectives: Produce Faba bean and control weeds

Control weeds

Prevent faba bean lodging

Switzerland

Continental climate (780 mm/year)
Average annual T min 1°C / max 22.4°C

Clay loam soil

TECHNICAL MANAGEMENT

1. Soil preparation

Plowing at 20 cm depth

2. Sowing

Combined seed drill with rotary harrow at 3 cm depth, species are mixed on the same row. Faba bean : 32 pl/m2 (80%) and oat 180 pl/m2 (40%)

3. Crop management

No fertilisation,
One pass of coiled tine weeder,
No irrigation

4. Harvest

Combine harvester
Faba bean : 2,5 t/ha
Oat : 0,75 t/ha

5. Sorting

Sorting at the mill
Optical sorter

Sowing : mid October
[x] simultaneous [ ] offset

Harvest : early August
[x] simultaneous [ ] offset

CROPS USE

Destination of the harvest : sale

Production use : feed

EVALUATION BY THE FARMERS

☺ High proportion of faba bean at harvest

No lodging

☹ 75% of oat disappeared during winter

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

In order to avoid frost damage on faba beans, sowing deep enough and not too early in October may be recommended.

Oat compete better with weeds than other cereals but have the disadvantage of being less winter hardy than triticale.

Nitrogen rich soils favour cereals to the detriment of faba beans.

Oat + Pea

Avena sativa + Pisum sativum

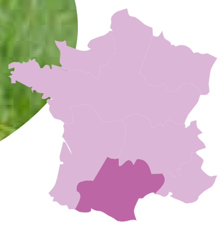
Productions:

- ☐ grains for food
- ☒ grains for feed
- ☐ forage

INTERCROP TO BE OPTIMIZED

INRAE

Photo: L.Bedoussac



Objectives:
Control weeds and supply nitrogen

Limit weeds by the allelopathic effect of oats

Enrich the soil with nitrogen from Pea

France

Degraded oceanic climate (712 mm/year)
Average annual T min 8,4°C / max 18,5°C

Clay and hydromorph soil

TECHNICAL MANAGEMENT

1. Soil preparation

Two disc passes after harvesting the previous crop, and one rotary harrow pass before sowing

2. Sowing

Sowing mixed on the row, at 4 cm depth, and with a 17 cm row spacing.
Oat at 100 kg/ha (70 % of the pure crop) and pea at 100 kg/ha (100 % of the pure crop)

3. Crop management

No fertilization
No weeding
No irrigation

4. Harvest

Adjustment of the thresher a bit slower and slacker than with oat, so as not to break the pea

5. Sorting

At the cooperative

Sowing: early Novembre
☒ simultaneous ☐ offset

Harvest: July
☒ simultaneous ☐ offset

CROPS USE

Oat and Pea sold as a mixture to a cooperative to be sorted and sold as animal feed

EVALUATION BY THE FARMERS

☺

Dense, high cover that limits weed development (except wild oats) and doesn't require mechanical weed control (limited opportunity to do this)

Crop requires relatively low amount of labour time

Easy to harvest : the oat is easily threshed, avoiding breaking of the pea

☹

The frost may have impacted the number of pea pods

Proportion of species unbalanced

Ripeness difference : oat is ripe when the last pods of pea are still green

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Is there an allelopathic effect of Oat especially on wild Oat ?

Need to have a cooperative that agrees to collect the mixture

Choose a protein-rich pea whose maturity is close to that of oats

Lentil + Oat

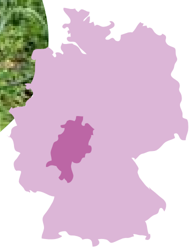
Lens culinaris + Avena sativa

Productions:

- ☒ grains for food
- ☒ grains for feed
- ☐ forage

INTERCROP TO BE OPTIMIZED

Photo: M. Clerc



Objectives: Produce lentil

Production of high-quality regional lentil (main cash crop)

Production of oat for fodder

Germany

Continental climate (785 mm/year)
Average annual T min 4,2°C / max 12,9°C

Calcareous soil

TECHNICAL MANAGEMENT

1. Soil preparation

Fine seed bed
Remove stones

2. Sowing

Sowing at 4 cm depth
Oat at 35 kg/ha and lentil at 55 kg/ha

3. Crop management

Hoeing five days after sowing (Lentil are vulnerable when emerging)

4. Harvest

Threshing as low as possible but avoiding stones

5. Sorting

Multiple steps required :
cyclone, rotary cleaner, gravity separator, eventually optical sorter

Sowing: October
☒ simultaneous ☐ offset

Harvest:
☒ simultaneous ☐ offset

CROPS USE

Lentil sold for food (local selling)

Oat sold outside the farm or consumed on farm

EVALUATION BY THE FARMERS

☺

Less lodging of Lentil allowing an easier harvest

Less weeds

☹

Separation technology required that is not usually available on farms

Lentil in general is a challenging crop

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Lentil yields can vary significantly

Low sowing density and short oat varieties are recommended to limit competition against lentil

Separation either on-farm or as a service needs to be organized

Use a narrow combine harvester to allow low cutting, because lentil seeds are low

Rye + Winter vetch

Secale cereale + Vicia villosa

Roskilde University

INTERCROP TO BE OPTIMIZED

Photo: A.K. Aare

Productions:

- [x] grains for food
- [x] grains for feed
- [ ] forage

Objectives: Producing vetch seed

To test whether vetch seeds can be produced for ownuse on sandy soil

To observe whether the vetch affects the health of the rye

Denmark

Continental climate (674 mm/year)
Average annual T min 3,8°C / max 11,5°C

Soil type coarse sand

TECHNICAL MANAGEMENT

1. Soil preparation

Glyphosate application
Soil tillage at 15 cm

2. Sowing

Sowing of rye at 100 kg/ha and vetch at 20 kg/ha

3. Crop management

Pesticide application (DFF)
Fertilizer application (125 kg N/ha)

4. Harvest

Rye is mowed, dried for 6-7 days, then harvested

Sowing: mid September
[x] simultaneous [ ] offset

Harvest: late July
[x] simultaneous [ ] offset

CROPS USE

As cover crop during winter

Rye sold for food and vetch used as seed

EVALUATION BY THE FARMERS

☹

Not very successful due to too high fertilizer application causing lodging

The interspecific competition was not working

Difficult harvest due to rain and lodging. Yield 18 qtx grains/ha

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Use a winter vetch (white flowers) that flower one month earlier and compete less with the rye

Faba bean + Triticale

Vicia faba + Triticosecale rimpoui

Productions:

- ☐ grains for food
- ☒ grains for feed
- ☐ forage

INTERCROP VALIDATED

Photo: M. Klaiss

Objectives: Produce faba bean and control weeds

Control weeds

Prevent faba bean lodging

Switzerland

Continental climate (850 mm/year)
Average annual T min 1°C / max 24.9°C

TECHNICAL MANAGEMENT

1. Soil preparation

Plowing at 20 cm depth

2. Sowing

Combined seed drill with rotary harrow at 5 cm depth, species are mixed on the same row.
Faba bean : 32 pl/m2 (80%) and oat 180 pl/m2 (40%)

3. Crop management

No fertilisation
No weeding
No irrigation

4. Harvest

Combine harvester
Faba bean : 2,5 t/ha
Triticale: 1,5 t/ha

5. Sorting

Sorting at the mill
Optical sorter

Sowing: mid October
☒ simultaneous ☐ offset

Harvest: early August
☒ simultaneous ☐ offset

CROPS USE

Destination of the harvest : sale

Production use : feed

EVALUATION BY THE FARMERS

☺

High proportion of faba bean at harvest

No lodging (faba bean is shorter than in pure stand)

Good control of weeds

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

In order to avoid frost damage on faba beans, sowing deep enough and not too early in October may be recommended.

Nitrogen rich soils favour cereals to the detriment of faba beans.

Type 2 (n=4)

More complex mixtures of winter cash crops sown and harvested simultaneously

Mixture of 2 cereals and 2 legumes

Triticosecale + Triticum aestivum + Pisum sativum + Vicia faba
Triticale + Wheat + Pea + Faba bean

Productions:

- ☐ grains for food
- ☒ grains for feed
- ☐ forage

INTERCROP VALIDATED

Photo: L.Bedoussac

Objectives: Produce a complete feed

Ensure feed self-sufficiency with a grain mixture

France

Degraded oceanic climate (730 mm/year)
Average annual T min 8,1°C / max 18,7°C

Clay soil

TECHNICAL MANAGEMENT

1. Soil preparation

Ploughing at 20 cm

2. Sowing

Sowing mixed on the row, with a combined seeder without rolling, at 2-3 cm depth, and with a 12.5 cm depth. Cereals at 140 kg/ha (50 % wheat and 50 % triticale), faba bean at 50 kg/ha and pea at 12 kg/ha

3. Crop management

No fertilization
No weeding
No irrigation

4. Harvest

Harvesting of the mixture for grains at the maturity of the later specie

5. Sorting

None

Sowing: late October
☒ simultaneous ☐ offset

Harvest: mid July
☒ simultaneous ☐ offset

CROPS USE

Grain mixture used for feeding cows (on-farm use)

Straw used for mulching

EVALUATION BY THE FARMERS

☺ Yield of about 4 t/ha

☹ Pea tended to lodge

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Slightly reduce the pea density to prevent it from lodging

Mixture of 3 cereals and 2 legumes

Triticosecale + Triticum spelta + Avena sativa + Vicia faba + Pisum sativum
Triticale + Spelt + Oat + Faba bean + Pea

Productions:

- ☐ grains for food
- ☒ grains for feed
- ☐ forage

Photo: L.Bedoussac

Objectives: Produce a protein-rich feed

Have a protein-richmixture for pig feeding

France

Degraded oceanic climate (730 mm/year)
Average annual T min 8,1°C / max 18,7°C

Acid, light, sandy, low in clay soil

TECHNICAL MANAGEMENT

1. Soil preparation

Stubble ploughing, liming,
10 t/ha of manure input, then ploughing at 20 cm

2. Sowing

Sowing mixed on the row, with a disc seed drill, at 2-3 cm depth, and with a 12.5 cm row spacing. Triticale at 80 kg/ha (45 % of the pure crop), spelt at 10 kg/ha, Oat at 5 kg/ha, faba Bean at 50 kg/ha and Pea at 5 kg/ha, then rotary harrow

3. Crop management

No fertilization
No weeding
No irrigation

4. Harvest

Harvesting of the mixture for grains at the maturity of the later specie, with a triticale setting

5. Sorting

None

Sowing: mid November
☒ simultaneous ☐ offset

Harvest: late July
☒ simultaneous ☐ offset

CROPS USE

Grains mixture used for feeding cows (self-consumption)

EVALUATION BY THE FARMERS

🙂

With the setting "triticale" used, the cereal is properly threshed

The cost of sowing is very low because the seed mixture is from a home-saved crop mixture

😐

There are some broken faba beans, but this is not a problem because it is ground into flour before being fed to the animals

Yield of about 4 t/ha

☹

The proportions are not very optimal (few oats, spelt and faba beans)

The cereal is not very successful because the soil lacks nitrogen, and the legume cover is not dense enough to compensate for it

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Sowing grains froma previous harvest is risky because the proportions are not balanced

Compensate for the lack of legumes with fertilizer to increase the amount of cereals

Mixture of 2 cereals and 3 legumes

Triticosecale + Avena sativa + Pisum sativum + Vicia sativa + Vicia faba
Triticale + Oat + Pea + vetch + faba bean

Productions:

- ☐ grains for food
- ☐ grains for feed
- ☒ forage

Photo: L.Bedoussac

Objectives: Produce a protein-rich fodder

Produce a fodder rich in nitrogenous matter

France

Degraded oceanic climate (730 mm/year)
Average annual T min 8,1°C / max 18,7°C

Acid, light, sandy, low in clay soil

TECHNICAL MANAGEMENT

1. Soil preparation

Stubble ploughing at 5 cm, 10 t/ha of cattle manure input, then ploughing at 20 cm

2. Sowing

Sowing mixed on the row, with double disc drill with rotary harrow, at 2-3 cm depth and with a 12.5 cm row spacing.
Triticale at 50 kg/ha, oat at 22 kg/ha, pea at 22 kg/ha, vetch at 8 kg/ha, faba bean at 50 kg/ha

3. Crop management

No fertilization
No weeding
No irrigation

4. Harvest

One part is ensiled, and the other part is harvested to save seed

5. Sorting

None

Sowing: late October
☒ simultaneous ☐ offset

Harvest: mid July
☒ simultaneous ☐ offset

CROPS USE

Fodder used for feeding cows (self-consumption)

EVALUATION BY THE FARMERS

☺

More than 8 t/ha of dry matter

Dense cover, very tall plants and satisfactory proportions

☹

A lot of broken seeds

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Sowing must be done early enough (here before October 20) so that the crop is well established before winter, to resist cold and rainfall

It is always necessary to re-mix before sowing to have the right proportions at sowing (minimum 50 kg/ha of faba bean) and avoid sowing weeds. For this, the mixture must be roughly sorted and completed with pure seeds

Mixture of 2 cereals and 2 legumes

Avena sativa + Hordeum vulgare + Pisum sativum + Lupinus alba
Oat + Barley + Pea + White Lupin

INTERCROP + TO BE OPTIMIZED

Louis Bolk Instituut

Productions:

- ☐ grains for food
- ☒ grains for feed
- ☒ forage

Photo: L.Bedoussac

Objectives: Produce a complete feed

Self-sustaining in cattle feed and manure

Closed system by producing plant protein

Netherlands

Moderate marine climate
NL avg. ann. precip. = 792mm; avg. Tmean 14,1°C Tmin=6,9°C Tmax= 14,1°C

Sandy soil, anthrosol

TECHNICAL MANAGEMENT

1. Soil preparation

Cultivation/drilling combination

2. Sowing

Barley + oats: 70kg/ha
Pea + lupin : 110-120 kg/ha
Drilled in one operation

3. Crop management

20t/ha cattle manure
3x harrowing (until mid May)

4. Harvest

Partially whole grains / green plant silage e.g. in case of too much weeds. 4t/ha (60% cereals, 40% pulses)

5. Sorting

No

Sowing: mid March
☒ simultaneous ☐ offset

Harvest: early August
☒ simultaneous ☐ offset

CROPS USE

Two possible outputs:

1) mix of crushed grains (own crusher) and stored in a silo

2) whole crop ensiled forage

EVALUATION BY THE FARMERS

☺

Weed pressure

Nitrogen fixation

Risk mitigation

☹

Drought risk!

No ‘true pricing’ yet

‘Energy’ production (for feed) easier than protein production

Not suitable to sell as feed due to purity and separation demands and large volumes

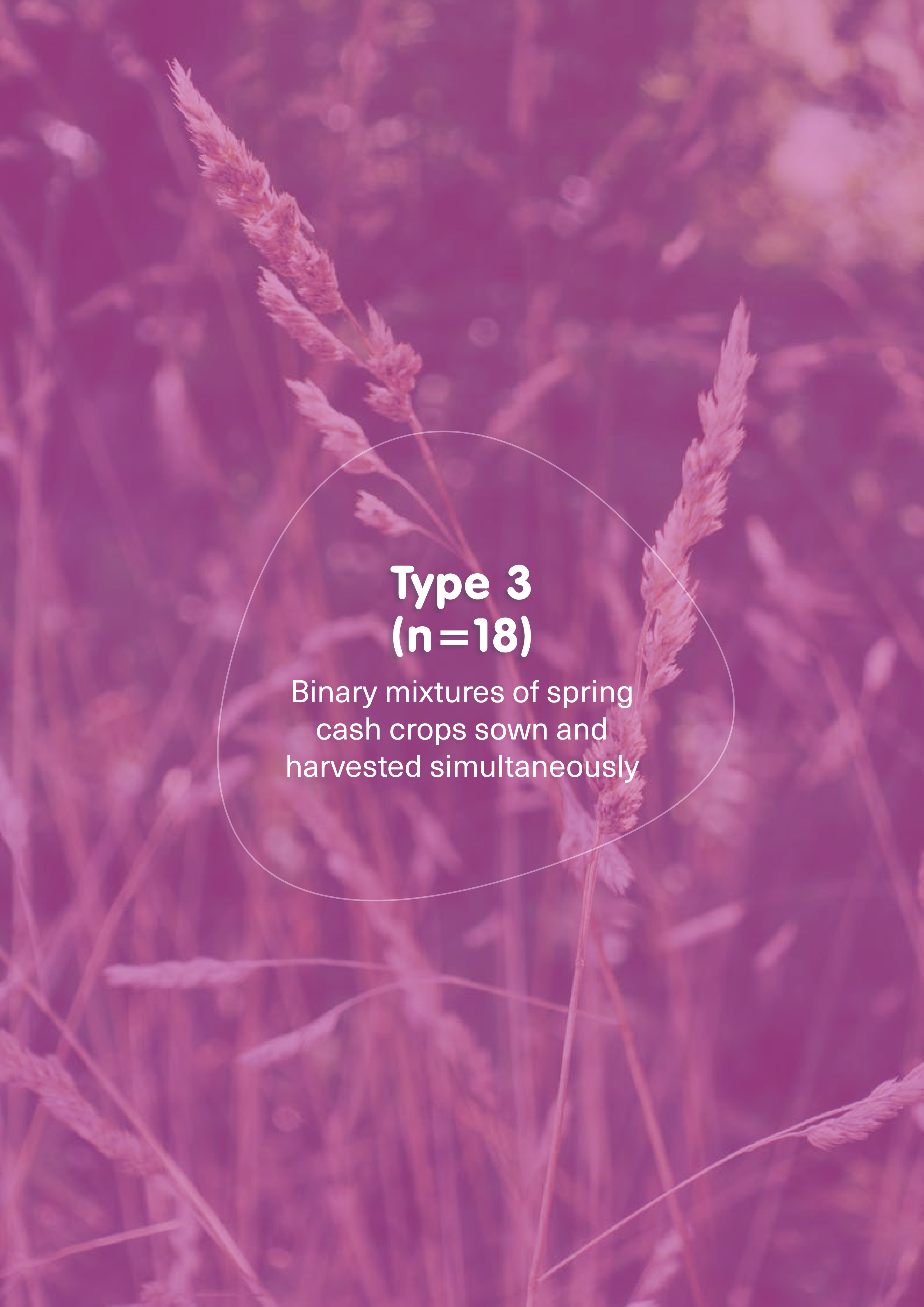
SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

This mixture is susceptible to drought on light soils

Lupin is adapted to acidic soils

Harvest issues: early ripening pulses lead to harvest losses, adjustment of combine is difficult

A winter crop would be preferable for weed suppression



Type 3 (n=18)

Binary mixtures of spring cash crops sown and harvested simultaneously

Wheat + Faba bean

Triticum aestivum + Vicia faba

Productions:

☐ grains for food
☒ grains for feed
☐ forage

INTERCROP VALIDATED

Louis Bolk Instituut

Photo: F. Van Malland

Objectives: Produce a protein-rich feed and control weeds

50% own feed production, protein feed for chickens

Weed suppression, beneficial insects, pollinators

Low nitrogen input needed, nitrogen rich residues for following crop

Netherlands

Sea climate (760 mm/year)
Average annual T min 6,1°C / max 13,6°C

Clayey soil

CROPS USE

The crop mixture is used at the farm as feed for poultry for organic egg production

According to biodynamic regulations 50% of the feed should be produced on the farm itself

Compared to other cased, the wheat fraction is rather high, the sowing ratio depends on your goal

TECHNICAL MANAGEMENT

1. Sowing

Sowing in rows, at 6 cm depth.
Wheat at 180 kg/ha and faba bean at 60 kg/ha

2. Crop management

Before and during emergence harrowing, after emergence hoewing

3. Harvest

With normal combine, finetuning of shell a little wider (compared to ony wheat)

4. Drying

Drying in special bags in cubic caskets in front of ventilation wall

5. Feeding

Mixture is crushed with a hammermill and mixed and fine tuned with other feed resources

Sowing: early April
☒ simultaneous ☐ offset

Harvest:
☒ simultaneous ☐ offset

EVALUATION BY THE FARMERS

☺

Healthy crop mixture, long flowering period of faba bean stimulates bumble bees and other beneficial insects in the crop

The chickens eat it well

Crop mixtures has several benefits that endorse the farmers mission (locally produced feed, good for soil and biodiversity)

☹

The wheat ripened two weeks earlier than the faba bean, the farmer needed to wait until the faba bean was ready for harvest

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

It is a success in this particular case, as the farmer uses the mixed produce on his own farm. The sum of the benefits makes it a success

There is a risk for unsynchonized ripening and it is more work (drying and hammering) compared to growing only wheat and buying soybean from abroad

Wheat + Faba bean

Triticum aestivum + Vicia faba

Productions:

- ☒ grains for food
- ☒ grains for feed
- ☐ forage

INTERCROP + TO BE OPTIMIZED

Photo: H. Hauggaard-Nielsen

Objectives: Produce a complete feed and control weeds

Increased total yield

Suppression of weeds

Lower infestation rate (pest, fungi)

Increased biodiversity in field

Decreased artificial fertilizer use

Danemark

No-till

Continental climate (614 mm/year)

Average annual T min 4,9°C / max 11,4°C

Loamy soil

TECHNICAL MANAGEMENT

1. Soil preparation

Use of glyphosate just Simultaneous harvest
Sorting at farm (max. 3t/hour)
before sowing (1200 g/ha)

2. Sowing

Simultaneous sowing. 70% of normal sowing density of both wheat and faba bean

3. Harvest

Simultaneous harvest

4. Sorting

Sorting at farm (max. 3t/hour)

Sowing: late March
☒ simultaneous ☐ offset

Harvest:
☒ simultaneous ☐ offset

CROPS USE

Sold to retailer seperated

7,5 ton/ha (50% wheat/50% bean)

EVALUATION BY THE FARMERS

☺

High yield

On-farm sorting was possible with a good quality result for sale as pure fractions to retailer

😐

Good year, so difficult to say whether the high yields are a result of the year or a successful mix

☹

Time consuming to sort using on-farm sorting equipment

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

The farmer wants to advance the setup of the sorting at his farm, so he should use less manpower on e.g. shovling the mixture or setting the sorting equipment.

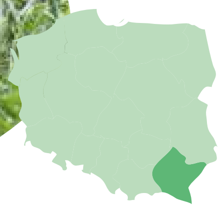
Wheat + Pea

Triticum aestivum + Pisum sativum

Productions:

- ☐ grains for food
- ☐ grains for feed
- ☒ forage

Photo: M. Krysztoforski



Objectives:
Increase production proteins in fodder

Diversify crop rotation and promote biodiversity

Nitrogen provision by pea

Poland

Continental climate (684 mm/year)
Average annual T min 4°C / max 12,2°C

Clayey soil

TECHNICAL MANAGEMENT

1. Soil preparation

Disking, cultivation with aggregate (harrow + roller) pre-winter plowing, fertilizing

2. Sowing

Sowing mixed on the row, with aggregate Roton. Wheat 50% and pea 50 %

3. Crop management

One harrowing at 3-4 leaf stage of cereal
Spraying Harmony at 15 g/ha or pendimetaline at 800 g/ha

4. Harvest

Simultaneous

5. Sorting

None

Sowing: mid April
☒ simultaneous ☐ offset

Harvest:
☒ simultaneous ☐ offset

CROPS USE

Forage used on-farm to feed livestock, mainly pigs, but also fish (carp), and freerange chicken

EVALUATION BY THE FARMERS

☺

In the variant 50% of wheat 50% pea crop was 1,46 t/ha wheat and 3,2 t pea = 4,66 t/ha mixture

In the variandt 75% wheat 25% pea crop was 3,62 t wheat and 1,4 t pea= 5,02 t

☹

Serious problems with bird (pidgeon) and lack of herbicides

In Poland, the decisive factor was administrative conditions - recognition of legumes only in pure sowing as crops meeting the requirements of "greening" and special payment for legumes in pure sowing

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Pea varieties should be selected properly, preferably semileafy, Pea should be coated by Rhizobia

The field should be free from weeds, due to lack of suitable herbicides

The mixture is best suited to organic farms

Wheat + Pea

Triticum aestivum + Pisum sativum

Productions:

- ☐ grains for food
- ☒ grains for feed
- ☐ forage

INTERCROP VALIDATED

Photo: R. Walker

SRUC

Objectives:
Produce a complete feed

Facilitate pea harvest with wheat scaffold

Enable harvest of high N wheat even if Pea fail

Increase protein yield for the total crop

Scotland

Oceanic climate (800 mm/year)
Averag annual T min 4,7°C / max 11,8°C

TECHNICAL MANAGEMENT

1. Soil preparation

Plough Jan/Feb

Power harrow
Roll after sowing

2. Sowing

Sowing at 225 kg/ha including

62 % of wheat and 38 % of pea

3. Crop management

Tine weeding before crops too big
(wheat no more than 3-4 leaves)

4. Harvest

Simultaneous harvest in September

5. Sorting

None
All fed to chickens after
propioninc acid treatment

Sowing: mid April
☒ simultaneous ☐ offset

Harvest:
☒ simultaneous ☐ offset

CROPS USE

Crop mixture used on the farm as a high protein and energy component of egg laying hens diets

EVALUATION BY THE FARMERS

☺

Wheat – pea intercrop peformed better than the sole wheat crop sown in the other half of the field

On average, over 4 years that this mixture has been grown on the farm, intercropping has improved the economic margin per hectare especially during unfavourable years for Pea

Noticeably improved soil « health » e.g. more worm activity

☹

Care needed to set up combine efficiently to limit damage to grain

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Choose disease resistant varieties

Choose early maturing spring wheat and late maturing spring pea varieties

Wheat + Chickpea

Triticum aestivum + Cicer arietinum

Productions:

- [x] grains for food
- [ ] grains for feed
- [ ] forage

INTERCROP + TO BE OPTIMIZED

Photo: C. Virto

INTIA

Objectives: Secure chickpea production and improve wheat quality

Improve margin by harvesting one more crop

Harvest one crop in case of failure of the other

Increase bread-making quality of wheat

Diminish weeds pressure

Spain

Mediteraneen climate (450- 550 mm/year)
Average annual T min 7,1°C / max 17,8°C

Alluvial terrain, terraces

TECHNICAL MANAGEMENT

1. Sowing

Chickpea sown at 50 plants/m²
(100 % of the pure crop)
Wheat sown at 150 and 250 plants/m²
(30 and 50 % of the pure crop)

2. Crop management

Mechanical weeding using a flexible spiketooth harrow or an inter-row cultivator depending of the sowing pattern

3. Harvest

Simultaneous harvest in July

4. Sorting

Sieve separation equipment

Sowing: mid January
- [x] simultaneous
- [ ] offset

Harvest: mid July
- [x] simultaneous
- [ ] offset

CROPS USE

Wheat with high baking quality sold for food

Chickpea sold for food, but with risk of gluten contamination

EVALUATION BY THE FARMERS

☺

30 % of weeds reduction in intercrops withoutmechanical weeding compare to sole crops

27 % (flexible spike-tooth harrow) and 63 % (inter-row cultivator) of weeds reduction after mechanical weeding

Yield: 2,2 t/ha of wheat and 1 t/ha of chickpea when wheat was sown at 50 % of the common dose

Yield: 1,9 t/ha of wheat and 1,2 t/ha of chickpea when wheat was sown at 30 % of the common dose

Intercropping treatments get better results than sole crops in terms of bakery quality

☹

LER slightly below 1 (2019) and above 1 (2020)

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Wheat seed rate should be reduced in order to increase chickpea yield

Lentil + Wheat

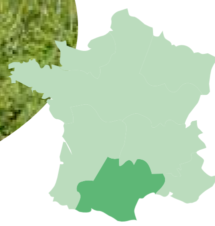
Lens culinaris + Triticum aestivum

Productions:

- [x] grains for food
- [ ] grains for feed
- [ ] forage

INTERCROP VALIDATED

Photo: L. Bedoussac



Objectives: Produce lentil while limiting lodging in organic farming

Limit lentil lodging by means of an associated species that acts as a support and that can be valued

France

Degraded oceanic climate (640–712 mm/year)
Average annual T min 8,5°C / max 18,6°C

Clay
OR clayey-limestone
OR sandy-clayey soil

TECHNICAL MANAGEMENT

1. Soil preparation

Option 1: ploughing + rotary harrow
Option 2: stubble plough + cultivator
Option 3: stubble plough + rotary harrow + heavy cultivator + seedbed cultivator

2. Sowing

Option 1: mixed on the row
Option 2: in two passes on the same day in different rows
Sowing with wheat seed drill with rotary harrow, at 2-3 cm depth, and with a 13.5-15 cm row spacing.
Wheat at 30-60 kg/ha (20-30 % of the pure crop) and lentil at 90-100 kg/ha (90 % pure crop)

3. Crop management

Weed control : tine harrow OR rotary hoe OR nothing
No fertilization
No irrigation

4. Harvest

Started with a wheat setting, then adapted after observation

5. Sorting

One part at the farm to keep seeds and the other part at the cooperative

Sowing: early March
[x] simultaneous [ ] offset

Harvest: late July
[x] simultaneous [ ] offset

CROPS USE

Lentil and wheat sold to a cooperative for human food

EVALUATION BY THE FARMERS

☺

No Lentil lodging : good wheat support effect

Wheat rich in protein (15 %)

Overall yield 1 t/ha

☹

The harvest is a bit "dirty", which would have required pre-sorting

Thistle problem for the farmer who has not weeded

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Pre-sorting can be considered (at the cooperative or farm) to reduce the sorting costs, but the volume must be large enough to make it worthwhile

Result highly variable according to weather conditions (risk of lentil failure)

Two species that mature at the same time should be chosen

Lentil + Wheat

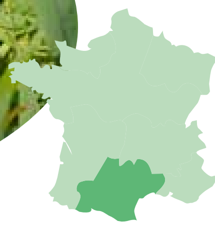
Lens culinaris + Triticum aestivum

Productions:

- [x] grains for food
- [ ] grains for feed
- [ ] forage

INTERCROP VALIDATED

Photo: L.Bedoussac



Objectives: Secure lentil production and improve wheat quality

Facilitate lentil harvest with wheat as nurse

Harvest one crop in case of lentil failure

Increase protein rate of milling wheat

France

Degraded oceanic climate (700 mm/year)
Average annual T min 7,9°C / max 18,9°C

Valleys and calcareous clay hillsides

TECHNICAL MANAGEMENT

1. Sowing

Sowing mixture, with a cereal seeder.
Lentil at 100 kg/ha and winter wheat at 50 kg/ha

2. Crop management

Weeding with tine harrow and rotary hoe.
Possibility to top if infestation with thistle or wild oats

3. Harvest

Simultaneous harvest at the beginning of August

4. Sorting

At the cooperative.
Difficult to perform on-farm with an alveolar sorter

Sowing: February
[x] simultaneous [ ] offset

Harvest: early August
[x] simultaneous [ ] offset

CROPS USE

Crop mixture delivered to a cooperative for separation, cleaning and sale for human consumption

Wheat of high baking quality

Lentil for human consumption, but with risk of gluten contamination

EVALUATION BY THE FARMERS

☺

Global yield gain : 0,8 t/ha of lentil + 0,8 t/ha of wheat with 15 % protein in intercropping, compared to 0,8 t/ha in sole lentil cropping

In average, intercropping improves economic margin per hectare (INRA trials) overall during unfavorable years for lentil (lodging, weevils)

☹

Cleaning cost is higher in intercropping and partially absorbs yield gain advantage

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Choose wheat varieties with high alternativity for sowing in late winter

Wheat density lower than 25 % of the full dose in sole cropping not to impact lentil yield

Lentil + Wheat

Lens culinaris + Triticum aestivum

INTIA

Photo: C. Virto

Productions:

- [x] grains for food
- [ ] grains for feed
- [ ] forage

Objectives: Secure lentil production and improve wheat quality

Wheat acts as a scaffold to facilitate lentil harvest

Harvest one crop in case of failure of the other

Increase bread-making quality of wheat

Diminish weeds pressure

Produce organic legumes to supply the growing local demand

Spain

Alluvial terrain, terraces

Cold winter, dry and hot summer with irregular and scarce rain. Annual rainfall: 450- 550 mm

TECHNICAL MANAGEMENT

1. Sowing

Lentil at 200 seeds/m2 (as sole crop), wheat between 15-30% of sole crop density (between 75-150seeds/m²), mixed in a cereal seeder.

2. Weeding

Weeding not done or spike harrow

3. Harvest

Simultaneous harvest in July adapted to lentil

4. Grain separation

Using a sieves separation equipment to separate and clean wheat and lentil. Gravity separator to remove stones from lentil

Sowing: January-February

- [x] simultaneous
- [ ] offset

Harvest: July

- [x] simultaneous
- [ ] offset

CROPS USE

Weed reduction.

Production of wheat with high baking quality.

Production of lentil for human consumption, but with risk of gluten contamination.

EVALUATION BY THE FARMERS

☺

Variable global yield: Farmer 1 (207kg/ha of lentil + 1000kg/ha of wheat), farmer 2 (220 kg/ha of lentil + 2000 kg/ha of wheat), farmer 3 (800kg/ha of lentil + 200kg/ha of wheat) data of clean grain ready for sale.

Intercropping cleaning and separation compensate if the grain is sold in local market.

Higher plant height than in monoculture, lentil lodging reduction in the intercrop.

Less weeds in intercrop.

☹

Différentes variétés de lentilles avec différentes tailles de grain, liées à différents niveaux de difficulté de séparation du grain (plus le grain est similaire au blé, plus il est difficile à séparer)

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Choose wheat varieties with same sowing date as lentil (Jan.-Feb. instead of Oct.-Nov.) and baking quality.

Wheat density should be lower than 30% of the full dose in sole cropping not to impact lentil yield (high price).

Be cautious in the harvest adapting the harvester to both crops.

Adjust the cost of grain separation

Pea + Barley

Pisum sativum + Hordeum vulgare

Productions:

- ☐ grains for food
- ☒ grains for feed
- ☐ forage

Photo: M. Klaiss

Objectives:
Produce pea and control weeds

Control weeds

Prevent pea lodging

Switzerland

Continental climate (780 mm/year)
Average annual T min 1°C / max 22.4°C

Clay loam soil

TECHNICAL MANAGEMENT

1. Soil preparation

Cultivator to a depth of 7 cm

2. Sowing

Combined seed drill with rotary harrow at 3 cm depth, species are mixed on the same row.
Pea : 80 pl/m2 (80%) and barley 180 pl/m2 (40%)

3. Crop management

No fertilisation,
One pass of coiled tine weeder,
No irrigation

4. Harvest

Combine harvester
Pea : 4,95 t/ha
Barley : 1,13 t/ha

5. Sorting

Sorting at the mill
Optical sorter

Sowing : mid October
☒ simultaneous ☐ offset

Harvest : early July
☒ simultaneous ☐ offset

CROPS USE

Destination of the harvest : sale

Production use : feed

EVALUATION BY THE FARMERS

☺

High proportion of pea at harvest

Good weed control

☹

Lodging at the end of the growing period

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Drought can be very detrimental to Pea.

Nitrogen rich soils favour cereals to the detriment of Pea.

Barley + Pea

Hordeum vulgare + Pisum sativum

Productions:

- ☐ grains for food
- ☒ grains for feed
- ☐ forage

INTERCROP VALIDATED

Photo: R. Walker

SRUC

Objectives:
Produce a complete feed

Facilitate pea harvest with barley scaffold

Enable harvest of high N barley even if Pea fail

Increase protein yield for the total crop

Scotland

Oceanic climate (850 mm/year)
Average annual T min 4,7°C / max 11,8°C

TECHNICAL MANAGEMENT

1. Soil preparation

Plough Jan/Feb
Power harrow just before sowing
Roll after sowing

2. Sowing

Sowing at 132 kg/ha pea (60% full rate) and 80 kg/ha barley (40% full rate)

3. Crop management

Sow crop then no further inputs until harvest

4. Harvest

Simultaneous harvest in September

5. Sorting

None - fed to beef cattle

Sowing: mid April
☒ simultaneous ☐ offset

Harvest: mid September
☒ simultaneous ☐ offset

CROPS USE

Crop mixture used on the farm as a high protein and energy component to supplement beef cattle diets

EVALUATION BY THE FARMERS

☺

Barley – pea intercrop performed better than the sole barley or pea crops

On average, over 4 years that this mixture has been grown on the farm, intercropping has improved the economic margin per hectare especially during unfavourable years for Pea

Noticeably improved soil « health » e.g. more worm activity, improved soil structure and carry over effect on following crop yield (spring barley)

☹

Care needed to set up combine efficiently to reduce damage to grain

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Choose disease resistant varieties

Choose early maturing spring barley and late maturing spring pea varieties

Faba bean + Oat

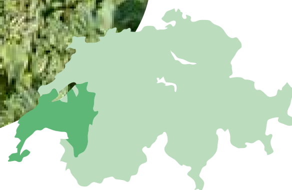
Vicia faba + Avena sativa

Productions:

- [ ] grains for food
- [x] grains for feed
- [ ] forage

INTERCROP VALIDATED

Photo: M. Klaiss



Objectives: Produce faba bean and control weeds

Control weeds

Prevent faba bean lodging

Switzerland

Continental climate (780 mm/year)
Average annual T min 1°C / max 22.4°C

Clay loam soil

TECHNICAL MANAGEMENT

1. Soil preparation

Cultivator to a depth of 7 cm

2. Sowing

Combined seed drill with rotary harrow at 3 cm depth, species are mixed on the same row.
Faba bean : 32 pl/m2 (80%) and oat 180 pl/m2 (40%)

3. Crop management

No fertilisation,
One pass of coiled tine weeder,
No irrigation

4. Harvest

Combine harvester
Faba bean : 2,5 t/ha
Oat : 1,1 t/ha

5. Sorting

Sorting at the mill
Optical sorter

Sowing : mid March
[x] simultaneous [ ] offset

Harvest : early August
[x] simultaneous [ ] offset

CROPS USE

Destination of the harvest : sale

Production use : feed

EVALUATION BY THE FARMERS

☺ High proportion of faba bean at harvest (can be variable)

☺ No lodging

😐 Some weeds but very small sized

☹ Oat can become very competitive over faba bean

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Oat compete well with weeds but can also be very competitive with faba beans

Nitrogen rich soils favour cereals to the detriment of faba beans.

Oat + Blue Lupin

Avena sativa + Lupinus angustifolius

Productions:

- ☐ grains for food
- ☒ grains for feed
- ☐ forage

Photo: M. Wendling

Objectives: Produce lupin and control weeds

Weed control

Prevention of lupin lodging

Fix nitrogen for the next crop

Switzerland

Continental climate (1050 mm/year)
Average annual T min 2.2°C / max 23.7°C

Clay loam soil

TECHNICAL MANAGEMENT

1. Soil preparation

Ploughing for efficient weed control

2. Sowing

Sowing in March, mixed on the same row, with a 15 cm row spacing.
Lupin at 130 plants/m^2 (100 % of pure crop) and oat at 40 plants/m^2 (10 % of pure crop)

3. Crop management

If necessary, hoeing possible until lupin plants reach 20 cm (but rarely required as oat is a cleaning crop)

4. Harvest

Simultaneous harvest, end of July

5. Sorting

Sorting realized by the miller

Sowing: mid March
☒ simultaneous ☐ offset

Harvest: early August
☒ simultaneous ☐ offset

CROPS USE

Lupin and oat are sold to a mill for feed

EVALUATION BY THE FARMERS

☺

Good control of weeds, no mechanical weeding needed

Good balanced proportion of each species

No lodging of lupin

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Lupin is very sensitive to lime : total lime content should be lower than 10%, otherwise there is a high risk of chlorosis and very low yield

Oat density should not be over 10% because it is highly competitive

Avoid cultivation of lupin in association after a legume crop or cover crop (oat will be too competitive over lupin)

Choose a late ripenning oat variety for good synchronisation with lupin and reduction of sprouting

Choose a high-yielding lupin cultivar (branched one)

Sowing in alternate rows allows to reduce the competition of oat over lupin

Lentil + Oat

Lens esculenta puyensis + Avena sativa

Productions:

- ☐ grains for food
- ☐ grains for feed
- ☒ forage

INTERCROP VALIDATED

Photo: R. Walker

SRUC

Objectives: Produce a protein-rich and easy-to-harvest fodder

Facilitate silage harvest with oat scaffold

Enable harvest of high N Oat even if Lentil fail

Increase protein yield for the total crop

Scotland

Oceanic climate (850 mm/year)
Average annual
T min 4,7°C / max 11,8°C

TECHNICAL MANAGEMENT

1. Soil preparation

Plough Jan/Feb
Power harrow just before sowing
Roll after sowing

2. Sowing

Sowing at 95kg/ha lentil (100% full rate) and 30 kg/ha Oat (15% full rate)

3. Crop management

Sow crop then no further inputs until harvest

4. Harvest

Simultaneous harvest in early August

5. Sorting

None - fed to beef cattle

Sowing: early-mid April
☒ simultaneous ☐ offset

Harvest: early August
☒ simultaneous ☐ offset

CROPS USE

Silage can be used on the farm as a high protein and energy component to supplement beef cattle diets

EVALUATION BY THE FARMERS

☺

Higher seed rate lentil crop performed better than low rate (63kg/ha lentil) crops with same oat seedrate

On average, over 4 years that this mixture has grown consistently well on the farm compared to other cerealgrainlegume intercrops (for silage)

Good carry over effect on following crop yield (spring barley)

☹

Not easy to take through to full grain harvest using a combine

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Choose disease resistant varieties, choose early maturing spring oats

Lentil seed difficult to get hold of as crop not well known in UK. ReMIX MAP experience found Anicia (green lentil) performed better than Gotland (yellow lentil)

Maize + Bean

Zea mays + Phaseolus vulgaris

Productions:

- [x] grains for food
- [ ] grains for feed
- [x] forage

INTERCROP TO BE OPTIMIZED

Photo: C. Dordas

ARISTOTLE UNIVERSITY OF THESSALONIKI

Objectives: Increase and stabilise yields

Achieve higher and more stable yields in the Mediterranean countries

Provide support for beans

Increase productivity of both species

Control weeds by covering the soil

Greece

Mediterranean climate (438 mm/year)
Average annual T min 9,9°C / max 20,3°C

Loam soil

TECHNICAL MANAGEMENT

1. Soil preparation

Conventional tillage in March

2. Sowing

Sowing at 40 000 plants/ha
for both species (50% of pure crop density)

3. Crop management

No fertilizer for intecrops (150 kg N/ha for pure maize). Herbicide pentimethalin in May. Insecticide against aphids and aleuroyds during July for beans

4. Harvest

Simultaneous harvest as the cultivars that were used had similar maturity time

5. Tri

Separation after the harvest

Sowing: early May
- [x] simultaneous
- [ ] offset

Harvest: September
- [x] simultaneous
- [ ] offset

CROPS USE

Produce grain for food

Can be used for forage - before plants reach maturity and especially for silage

EVALUATION BY THE FARMERS

☺

Environmental benefits with lower fertilizer and herbicide usage, and possible added value to product due to higher protein content

Lodging of legumes is prevented with intercropping

Good establishment of both species

☹

Une des difficultés concerne la séparation des grains

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Irrigation is needed because of the summer is very dry in Greece

Lentil + Camelina

Lens culinaris + Camelina sativa

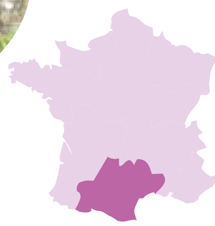
INRAE

Productions:

- [x] grains for food
- [ ] grains for feed
- [x] forage

INTERCROP TO BE OPTIMIZED

Photo: M. Clerc



Objectives: Secure lentil production and harvest an additional crop

Improve margin by harvesting one more crop

Control weeds by covering the soil

Reduce weevil attacks

Facilitate lentil's harvest with Camelina as a tutor

Tarn & Haute-Garonne, France

Degraded oceanic climate (640—700 mm/year)
Average annual T min 8°C / max 18,7°C

Calcareous clay hillsides

TECHNICAL MANAGEMENT

1. Sowing

Lentil sown with a combination seeder, at full seed rate.
Camelina seed broadcast, the same day, at 2-3 kg/ha.
Then harrowed.

2. Crop management

If weed infestation, possibility to top the Camelina, losing the harvest but keeping it as nurse

3. Harvest

With the combine set up at low-wind speed, then separation on farm or through external contract

4. Post Harvest

Stubbling sometimes triggers Camelina volunteers with an opportunity for a second harvest in the autumn

Sowing: [x] simultaneous [ ] offset

Harvest: [x] simultaneous [ ] offset

CROPS USE

Lentil sold to a cooperative, or marketed on-farm

Camelina sold to a cooperative for oil or cosmetics use, or pressed and marketed on-farm

EVALUATION BY THE FARMERS

☺

Lentil less sensitive to lodging which facilitates harvest

Camelina covers the soil well thus competing with weeds

No yield loss for lentil (0,5 – 1,5 t/ha) with some Camelina (up to 3 t/ha) that compensates during unfavorable years for lentil

☹

Camelina is not that clean after the first separation. Grain sorting needs more work

No effect observed on weevils

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Keep lentil density at 100 % (100 kg/ha) and do not exceed 3 kg/ha for Camelina. Seeds can be mixed with a bit of sunflower oil so that Camelina sticks to lentil, facilitating sowing

These crops are sensitive to extreme weather events after seedling (heavy rains and prolonged drought)

If cutting low, there is a risk to harvest soil dust that sticks to Camelina seeds making it unsuitable for on-farm use and marketing

Lentil + Camelina + Blue Lupin

Lens culinaris + Camelina sativa + Lupinus angustifolius

Productions:

- [x] grains for food
- [x] grains for feed
- [ ] forage

INTERCROP + TO BE OPTIMIZED

Photo: M. Wendling

Objectives: Produce protein locally for human consumption

Local production of protein for feed production

Reduce lentil lodging

Weed control

Fix nitrogen for the next crop

Switzerland

Continental climate (974 mm/year)
Average annual T min 5,5°C / max 14,1°C

Loam soil

TECHNICAL MANAGEMENT

1. Soil preparation

Ploughing and tillage

2. Sowing

Sowing of lupin and lentil in March
Lupin at 100 kg/ha (45 % of pure crop) and lentil at 55 kg/ha (65 % of pure crop)
Broadcast sowing of camelina, the same day, at 3 kg/ha (nearly 100 % of pure crop)

3. Crop management

Rolling to improve camelina emergence

4. Harvest

Simultaneous harvest, in August

Sowing: mid March
[x] simultaneous [ ] offset

Harvest: early August
[x] simultaneous [ ] offset

CROPS USE

Lentil (main targeted production) is sold for human consumption

Lupin is sold to a mill for feed (lupin aims at harvesting at least one crop if lentil fails)

Camelina is sold to a farmer for oil production

EVALUATION BY THE FARMERS

☺

Good control of weeds, no mechanical weeding needed

Good synchronisation of maturity between the three crop

High yield of lentil (800 kg/ha) and camelina (1000 kg/ha)

Lentil harvest is much more easier than in pure stand

Good complementarity between the three crops, always at least one successfull crop

☹

Lupin yield is too low (450 kg/ha)

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Lupin is very sensitive to lime : total lime content should be lower than 10 %, otherwise there is a high risk of chlorosis and very low yield

Lupin seeding density should be increased for higher yield if the first objective is lupin production

No weeds on the field at seeding to improve weed control by the crop

Buckwheat + Soybean

Fagopyrum esculentum + Glycine max.

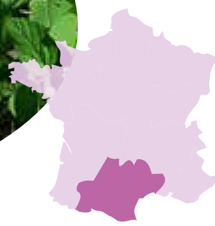
INRAE

Productions:

- [x] grains for food
- [ ] grains for feed
- [ ] forage

INTERCROP + TO BE OPTIMIZED

Photo: M. Klaiss



Objectives: Secure soybean production and control weeds

Control weeds by covering the soil

Increase productivity

Ease of soybean harvesting

France

Reduced tillage

Degraded oceanic climate (730 mm/an)
Average annual T min 8,1°C / max 18,7°C

Calcareous clay hillsides

TECHNICAL MANAGEMENT

1. Soil preparation

Diversified cover crops terminated at spring and soil preparationwith a seedbed cultivator

2. Sowing

Soybean sown at full density, with a 60 cm row spacing. Buckwheat row-sown or broadcast sown, at 5 kg/ha

3. Crop management

Hoeing between rows as needed, as in soybean sole cropping

4. Harvest

Simultaneous harvest

5. Sorting

Two times (1) to clean soybean and then (2) to eliminate soybean debris in buckwheat

Sowing: [x] simultaneous [ ] offset

Harvest: [x] simultaneous [ ] offset

CROPS USE

Soybean sold to a cooperative for human consumption

Buckwheat milled on farm and sold to local « crêpes » restaurants

EVALUATION BY THE FARMERS

☺ Buckwheat raises up the first pod of soybean, which makes it easier to harvest

2017 yield = 2,5 t/ha soybean (= sole cropping potential) + 0,25 t/ha buckwheat (as supplementary harvest)

☹ Buckwheat reaches maturity 3 weeks before soybean

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Reduction of buckwheat sowing density to limit competition. Soybean is the main crop

Irrigation is needed because water competition is enhanced when intercropping

Careful with Sclerotinia development in the dense canopy. Current lack of experience

Pea + Faba bean

Pisum sativum + Vicia faba

INTERCROP + TO BE OPTIMIZED

Productions:

☐ grains for food
☒ grains for feed
☐ forage

Objectives: Produce legumes for feed

Complementarity between Pea and faba bean

Danemark

No-till

Continental climate (614 mm/year)
Average annual T min 4,9°C / max 11,4°C

Fined clayey sand soil

TECHNICAL MANAGEMENT

1. Sowing

Direct seeding at 60-65 % of pure crops.
Pea at 32 kg/ha and faba bean at 140 kg/ha

2. Crop management

Pesticide application (Roundup) before crop seed emergence Herbicide application (Fighter 480 SC) three weeks after seeding
Placed fertiliser when seeding

3. Harvest

Simultaneous harvest

4. Sorting

None

Sowing: early April
☒ simultaneous ☐ offset

Harvest: late August
☒ simultaneous ☐ offset

CROPS USE

Pea and faba bean sold outside the farm as protein for pig feed

Alternatively, separation and selling for food (premium price, growing market)

EVALUATION BY THE FARMERS

☺

High yield : 3,2 t/ha of faba Bean and 1,4 t/ha of Pea

Easy to harvest

Clean product without seed damage from combining (might be possible to separate for food)

Time of ripening syncronises. Well functioning complementarity

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

It seems that it will be possible to use a higher sowing density of Pea in the mixture (eg. 80-100% pea and 60% beans) to increase yield (sp Pea)

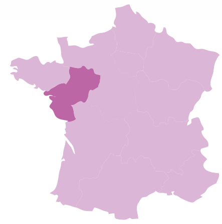
Type 4 (n=3)

Mixtures of one cash crop sown with temporary companion plants

Maize + Barley

Zea mays + Hordeum vulgare

INTERCROP + TO BE OPTIMIZED



Productions:

- [x] grains for food
- [x] grains for feed
- [x] forage

Objectives: Control wireworms

Reduction of wirewormattacks on maize seeds

France

Oceanic climate (820 mm/year)
Average annual T min 8,3°C / max 16,7°C

All types of soil

TECHNICAL MANAGEMENT

1. Sowing

Barley sowing between two maize rows at 75 kg/ha
Option 1: with a cereal seeder before the maize seeding
Option 2: simultaneously with maize, by using the fertilizer elements of a single-seed drill

2. Crop management

Typicalmaize crop management

3. Harvest

Barley destruction by hoeing at 3-4 maize leaf stage
Maize harvested in September-November

4. Sorting

None

Sowing: [x] simultaneous [x] offset

Harvest: September-November [x] simultaneous [ ] offset

CROPS USE

Maize used as grains for food and feed, or forage

Barley without outlet (a service plant)

EVALUATION BY THE FARMERS

☺ Barley seeds attract wireworms and therefore, protect maize seeds from wirewormdamages

☹ Barley seeding in the maize interrow can be quite challenging depending on the equipment available on the farm

Although the presence of barley seeds tends to reduce the wireworm attacks on maize, this alternative does not allow a complete suppression of insecticide at seeding

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Barley must be destroyed at 3-4 maize leaf stage or before tillering in order to avoid competition

To make a good decoy, barley should be placed at a 5-8cm depth and at about 20cm from the maize row

Rapeseed + Frost-sensitive legumes

INRAE

INTERCROP VALIDATED

Brassica napus + Lens nigricans + Lathyrus sativus + Vicia faba
Rapeseed + Lentil + Lathyrus + Faba bean

Photo: M. Clerc

Productions:

- [x] grains for food
- [ ] grains for feed
- [ ] forage

Objectives: Reduce chemical inputs

Save money with rapeseed establishment

No nematicide or insecticides in autumn

Nitrogen provision by companion plants

France

No tillage

Continental climate (830 mm/year)
Average annual T min 8,1°C / max 16,9°C

Calcareous clay soil

TECHNICAL MANAGEMENT

1. Sowing

Establishment of frost-sensitive legume cover crops + 1 full seed rate of rapeseed, by direct seeding, just after a cereal or pea crop harvest (end of July)

2.a Crop management in fall

No herbicide, insecticide and ematicide pellets
Continuation if good stand of rapeseed, otherwise terminate and grow winter or spring crop

2.b Crop management in spring

1 non-systemic insecticide
+ 1 fungicide

Sowing: late October
- [x] simultaneous
- [ ] offset

Harvest: mid July
- [x] simultaneous
- [ ] offset

CROPS USE

Rapeseed sold to a cooperative

Companion plants without outlet (service crop)

EVALUATION BY THE FARMERS

☺

Minimum investment for rapeseed establishment. No additional cost compared to systematicallysown winter cover crops

Vigorous rapeseed, low sensitivity to flea beetle attacks, which are confused

After frost, rapeseed is clean of weeds under companion plants

For three years, rapeseed has always been retained until it can be harvested. Yield 2,5 – 3,0 t/ha

☹

Lentil is not very competitive, and will be not be used anymore

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

No tillage sowing, as soon as possible after harvest (the same day, or the day after max.) to benefit from soilmoisture

For a homogenous seeding, verify the mixture in the seeder (possiblly require separation during the sowing operation because of vibrations)

Dense sowing to cover the soil well, and to suppress weeds (140 kg/ha, 80 € of seeds)

Rapeseed + Berseem clover

Brassica napus + Trifolium alexandrinum L.

Productions:
- [x] grains for food
- [ ] grains for feed
- [ ] forage

Photo: Bio Centre

Objectives: Control weeds

Save money for oilseed rape establishment

(control of flea beetle)

Nitrogen provision by companion plants

France

Oceanic climate (820 mm/year)
Average annual T min 8,3°C / max 16,7°C

All types of soil

TECHNICAL MANAGEMENT

1. Sowing

Sowing companion plants at 8 kg/ha and oilseed rape at full seed rate

2. Crop management

During winter, monitor companion plant growth and hoe them once if necessary

3. Harvest

At the end of Winter, destroy the companion plants by hoeing (if not already killed by frost)
In July, harvest the oilseed rape

4. Sorting

None

Sowing: mid-end of August
- [x] simultaneous
- [ ] offset

Harvest: July
unique

CROPS USE

Oilseed rape sold to the cooperative for food

Companion plants without outlet (service crop)

EVALUATION BY THE FARMERS

☺ After frost, oilseed rape is clean of weeds under companion plants

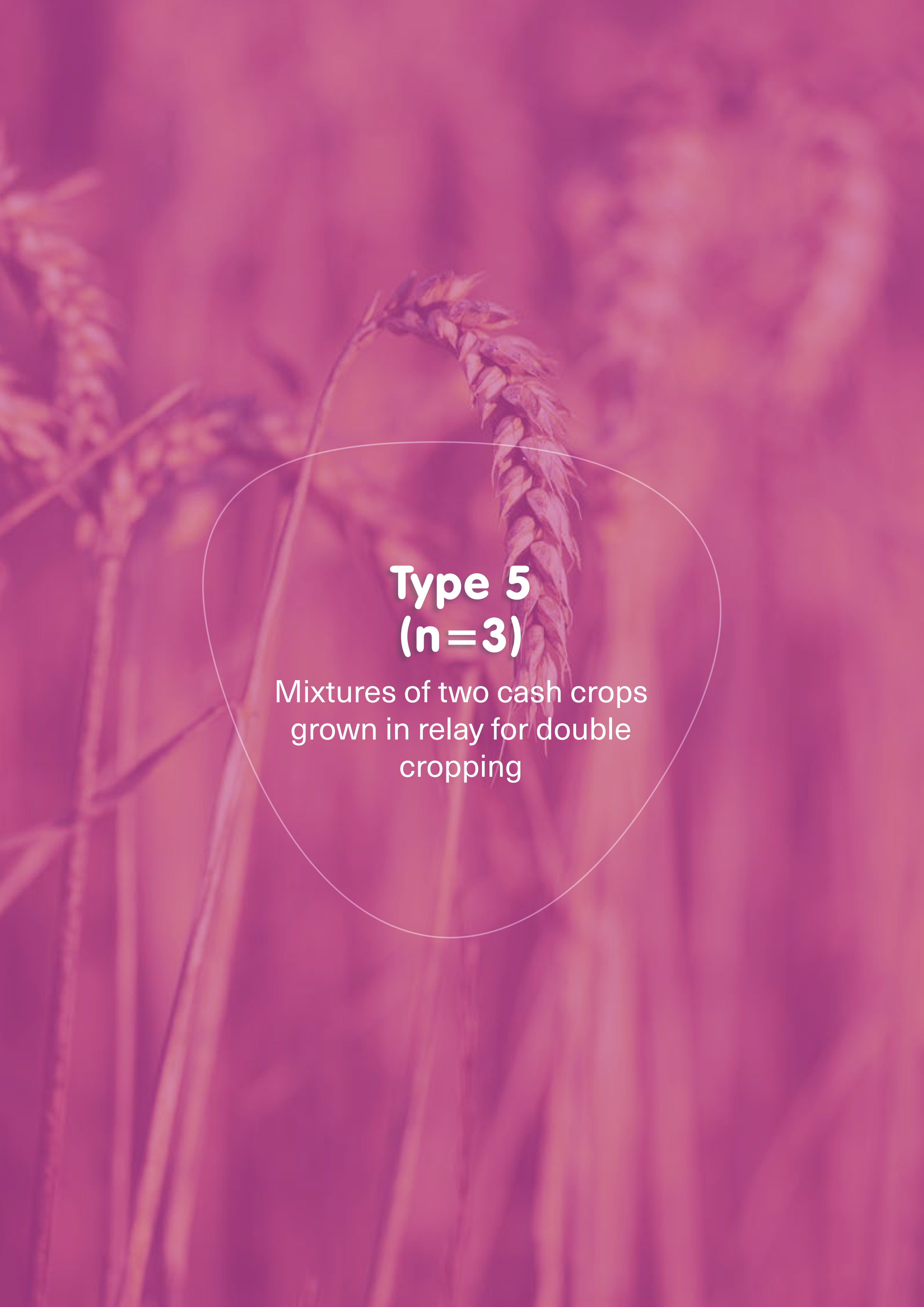
☹ In year 1, vetch (Vicia faba) was part of the covercrop which was tested in both, organic and conventional farming systems. Nevertheless, as vetch was not very sensitive to frost under oceanic climate, it was removed from the companion plant options in year 2

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

For a homogenous seeding, verify the mixture in the seeder (possiblly require separation during the sowing operation because of vibrations)

Dense sowing to cover the soil well, and to suppress weeds. Reduced density of legumes to limit their competitiveness

If necessary, companion plant destruction by hoeing at the end of Winter



Type 5 (n=3)

Mixtures of two cash crops grown in relay for double cropping

Triticale + Meadow

Triticosecale + Lolium perenne + Festuca arundinacea + Trifolium repens
Triticale + English ryegrass + Tall fescue + White clover

Productions:

- ☐ grains for food
- ☒ grains for feed
- ☒ forage

INTERCROP TO BE OPTIMIZED

Photo: L. Bedoussac

Objectives: Secure the establishment of the meadow

Secure the establishment of a meadow

Produce a sales culture in the event of poor meadow development

France

Mild oceanic climate (730 mm/year)
Average annual T min 8,1°C / max 18,7°C

Clay and hydromorph soil

TECHNICAL MANAGEMENT

1. Soil preparation

Manure input, then ploughing at 20 cm

2.a Tritical sowing (10/25)

Sowing with a combined seeder with a rotary harrow, at 2-3 cm depth, with a 12.5 cm row spacing, and at 80 % of the pure crop

2.b Meadow sowing (03/15)

I) Harrowing
II) Sowing with Delimbe, at 100 % of the density of a single meadow (150 kg/ha of triticale, 10 kg/ha of ryegrass, 10 kg/ha of fescue and 4 kg/ha of clover)
III) Harrowing and rolling

3. Crop management

No fertilization No weeding No irrigation

4. Harvest

Triticale harvested in July. Stubble ploughing and resowing of meadow

4. Sorting

None

Sowing: late October & mid March
☐ simultaneous ☒ offset

Harvest: mid July
☐ simultaneous ☒ offset

CROPS USE

Triticale used for feeding cows (on-farm use)

Meadow used for the cows

EVALUATION BY THE FARMERS

☺

Triticale production is partially satisfactory : 4 t/ha

☺ Harrowing in triticale when seeding the meadow has reinvigorated the cereal

☹

Sowing meadow in triticale is complicated when the triticale is tall

Meadow establishment is unsatisfactory, it has been out competed by triticale

Triticale production is insufficient to cover the cost of establishing the meadow

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Sowing the meadow in March ensures that the clover doesn't freeze

Reduce barley density to limit competition for light on the meadow

Cereals-Legumes mixture + Meadow

Triticosecale + Avena sativa + Vicia faba + Pisum sativum + Lolium perenne + Lolium multiflorum × Lolium perenne + Trifolium repens + Trifolium pratense
Triticale, Oat, Faba bean, Pea, English ryegrass, Hybrid ryegrass, White clover, Red clover

Photo: L. Bedoussac

Productions:

- ☐ grains for food
- ☐ grains for feed
- ☒ forage

Objectives: Secure the establishment of the meadow

Secure the establishment of a meadow

Have an economic guarantee by harvesting fodder from the first year if the meadow is not well established

France

Degraded oceanic climate (730 mm/year)
Average annual T min 8,1°C / max 18,7°C

Sandy, acid and fairly dry soil

TECHNICAL MANAGEMENT

1. Soil preparation

Stubble ploughing at 5 cm, liming, 10 t/ha of cattle manure input, then ploughing at 20 cm.

2. Sowing

I) Crop mixture sown with a double disc seeder, at 2-3 cm depth, at a 12.5 cm row spacing, and at 50 kg/ha including 75 % triticale, 20 % faba beans, 2-3 % Pea , 2-3 % Pea
II) Meadow sown with Delimbe, at 25 kg/ha ryegrass and 10 kg/ha clover
III) Rolling

3. Crop management

No fertilization No weeding No irrigation

4. Harvest

Crop mixture and meadow mowed simultaneously, and wrapped after three days of drying. The meadow will be kept for 3 years

5. Sorting

None

Sowing: late October
☒ simultaneous ☐ offset

Harvest: mid May
☒ simultaneous ☐ offset

CROPS USE

Fodder used for feeding cows (self-consumption)

Meadow preserved for three years

EVALUATION BY THE FARMERS

☺

Very well developed crop mixture (7 tons of dry matter/ha)

The meadow is well established and free of weeds (only some vetch and rumex)

The clover has developed very well and the proportions are good

The meadow is better than pure meadow

☹

The crop mixture had to be mowed with the meadow because the meadow was too high, and the ryegrass would have already earing

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Interesting to use a cold-resistant pea variety

Replace triticale, which has a fairly low dietary value, with more leafy and palatable oat (negative allelopathic effect of oat on the meadow ?)

The establishment of clover at the end of October is quite risky because this plant is sensitive to frost

Faba Bean and Oat are sown at low densities so that they are not too present, but it is possible to increase to 50 kg/ha for faba beans

Wheat + Soybean in relay

Triticum aestivum + Glycine max

Productions:

- [x] grains for food
- [x] grains for feed
- [ ] forage

INTERCROP + TO BE OPTIMIZED

Photo: F. V. Larsen

Objectives:
Produce two crops in relay

Evaluate the feasability of this species mixture (water / sunlight)

Evaluate the wheat yield in broad row distance and the damage from the spring sowing.

Denmark

No-till

Continental climate (614 mm/year)
Average annual T min 4,9°C / max 11,4°C

Loamy soil

TECHNICAL MANAGEMENT

1. Sowing 1st crop

Wheat sown (20th of september) in 37 cm row distance.
350 plants/m²

2. Crop management

In autumn: Roundup + boxer + DFF followed by Atlantis

3. Sowing 2nd crop

Soybean sown in beginning of April at about 25 plants/m²

4. Harvest

Harvest wheat the 10th of August.
Soybean was not harvested

Sowing: mid September
- [ ] simultaneous
- [x] offset

Harvest: mid August
- [ ] simultaneous
- [x] offset

CROPS USE

Destination of the harvest : sale

Production use : wheat for feed (8 t/ha)

Soybean was not harvested

EVALUATION BY THE FARMERS

☺ Wheat sown at double row spacing (37cm) continued to give an acceptably high yield of 8 tons / ha compared to 9,5 ("normal" yield)

☹ At double row spacing there was not enough light for the soybean crop. Thus, there was no soybean crop to harvest.

The wheat was harvested too late for soybean to develop sufficiently.

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

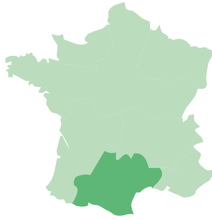
Light and ripeness are important for successful relay intercropping. Cereals should ripen as early as possible. Winter barley might be better suited since it is harvested 1 month earlier around 10th of July. The cereal should be sown with a larger row distance to allowmore light for the soy. For example, two rows of cereals then two rows of soybean and so forth.

Type 6 (n=1)

Mixtures of one cash crop with a companion species sown in relay

Spelt (or wheat) + Red clover + Berseem clover

Triticum spelta ou Triticum aestivum + Trifolium alexandrinum + Trifolium pratense



Productions:

- [x] grains for food
- [ ] grains for feed
- [ ] forage

INTERCROP VALIDATED

Objectives: Protect and cover the soil after harvest

Protect and cover the soil

Control weeds during fallow period

Fix nitrogen for the next crop

France

Degraded oceanic climate (700 mm/year)
Average annual T min 7,9°C / max 18,9°C

Valleys and calcareous clay hillsides

TECHNICAL MANAGEMENT

1.a Cereal sowing

Sowing in the autumn, as in sole cropping (same soil preparation, sowing and mechanical weeding)

1.b. Clover sowing

Sowing at tillering, in rows, with a cereal seeder with rotary hoe, and at 10 kg/ha

2. Harvesting

Cutting bar set up above clover, 20 cm below cereal spikes

3. Clover destruction

Ploughing in winter or following spring

Sowing: ☐ simultaneous ☒ offset

Harvest: ☐ simultaneous ☒ offset

CROPS USE

Spelt and wheat sold to a cooperative but local market is saturated for spelt, due to high number of organic conversions

Clover seeds for on-farm use or for sale

Clover biomass returned to the soil or harvested as hay for donkeys

EVALUATION BY THE FARMERS

☺

Good establishment of clover under the cereals

Quick soil coverage, lasting throughout the fallow period thanks to complementary life cycles/growth dynamics of the two clover species

Opportunity to harvest Berseem clover seeds in late summer or red clover hay in autumn, depending on the weather

Wheat protein rate up to 12.5-13 % withoutmanure/organic fertilizer

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Choose clover species with complementary life cycles to ensure an important soil coverage throughout the autumn

Choose long straw cereal species/ varieties, that can dominate clovers and limit competition for light

Use non-climbing clover species/ varieties, as this can cause combining problems due to green material

Type 7 (n=5)

Mixtures of one cash crop undersown in a permanent pre-established living mulch

Wheat + Alfalfa

Triticum aestivum + Medicago sativa

Productions:

- ☐ grains for food
- ☒ grains for feed
- ☒ forage

INTERCROP TO BE OPTIMIZED

Objectives: Protect and cover the soil after harvest

Normal yield for wheat

To have a strong alfalfamulch ready to function as a cover crop when wheat is harvested and before the next cash crop

Denmark

No-till

Continental climate (614 mm/year)
Average annual T min 4,9°C / max 11,4°C

Heavy clayey soil or silty soil

TECHNICAL MANAGEMENT

1. Soil preparation

Herbicide used to reduce weed infestation level in autum

2. Sowing

Wheat sown in September, in the alfalfa, at 250 kg/ha (360 plants/m^2)

3. Crop management

Herbicide application : 130 g/ha broadway in spring (to limit alfalfa growth and problems during harvest)
Fertilizer and fungicide application : similar to normal wheat treatment

4. Harvest

Wheat harvest.
Alfalfa is a permanent living mulch

4. Sorting

None

Sowing: late September
☐ simultaneous ☒ offset

Harvest:
☐ simultaneous ☒ offset

CROPS USE

Wheat sold for feed

Cut of alfalfa used for feed for local dairy cattle production

EVALUATION BY THE FARMERS

☺

Success both regarding competition and harvest

The alfalfa worked as a dense living mulch after harvesting the wheat

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Efficient weed control (spraying) prevented the alfalfa fromcompeting with the wheat

Next year: use of a 4 wheat cultivar mixture harvested at the same time to increase the diversity and resilience of the wheat

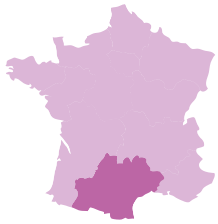
High sowing density of wheat to secure competitive ability towards alfalfa

Maize + Red clover

Zea mays + *Trifolium pratense*

Productions:

- ☐ grains for food
- ☒ grains for feed
- ☐ forage



Objectives:
Produce maize while limiting erosion and weeds

Limit soil erosion and the presence of weeds

Have a companion plant that releases nitrogen and organic matter

France

Reduced tillage

Degraded oceanic climate (700 mm/year)
Average annual T min 7,9°C / max 18,9°C

Clay-limestone soil, sloping

TECHNICAL MANAGEMENT

1. Soil preparation

None

2. Sowing

I) Clover sown the year before, in wheat at the end of tillering, at the surface, and at 10 kg/ha (70% of the pure crop)
II) Harrowing
III) Maize sown in April, in the clover, with a single seed driller, at 4-5 cm depth, at 6.5 plants/m^2, and with a 1.25 m or 60 cm row spacing

3. Crop management

10 t/ha of horse manure at the 5-6 leaves stage
Three grinder passages and one hoe passage
No irrigation

4. Harvest

Maize harvest only
Clover destroyed mechanically in June

5. Sorting

None

Sowing: April
☐ simultaneous ☒ offset

Harvest: mid October
☐ simultaneous ☒ offset

CROPS USE

Maize sold to a cooperative for feed

Clover without outlet (service crop)

EVALUATION BY THE FARMERS

☺

The presence of the cover on this type of soil, on a slope, makes it possible to limit erosion (seedling perpendicular to slope)

Wheat sown the following year is much greener in the area that had been associated with clover than in the area with pure Maize

Hoeing made it possible to reduce approximately 60 % of the seed stock (the wheat sown after the Maize harvest is much cleaner in the area which had been hoeed)

😐

Much better performance at a row spacing of 1.25 m than at 0.60 m

☹

The cover was abundant and consumed too much water, competing with the Maize which is poorly developed (50-60 cm tall)

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

The intercrop can be interesting to consider with irrigation, and to evaluate because of the risk of favouring the cover species

Consider sowing both species at the same time (clover in the inter-row). In this case the cover will only be at the seedling stage during the early stages of Maize development and its water consumptionwill be reduced, but the effect on reducing soil erosion will be less

Alfalfa + Crop mixture

Medicago sativa + Triticum aestivum + Avena sativa + Vicia faba + Vicia sativa + Pisum sativum
Wheat + Oat + Faba bean + Vetch and Pea

Productions:

- ☐ grains for food
- ☐ grains for feed
- ☒ forage

INTERCROP VALIDATED

Photo: Bio Centre

Objectives: Increase forage production and quality

Improve forage yield and quality

Limit weed infestation in alfalfa during winter

Grow rustic and low-input crops

Haute-Garonne, France

Direct seeding in living mulches

Degraded oceanic climate (640 mm/year)
Average annual T min 9,1°C / max 18,5°C

Calcareous loamy clay hillsides (up to 60% clay, 2.3% soil organic matter)

TECHNICAL MANAGEMENT

1.a Alfafa sowing

Sowing in spring, at 18-25 kg/ha

1.b Winter crop mixture sowing

Direct sowing after the 1st autumn alfalfa cut, at 1-2 cm depth and at 120 kg/ha, (320 g/m2, including 75% of legume species)

2. Harvest

In May, and then alfalfa cut every 70 days

3. Conservation de la luzerne

Alfalfa is kept 4-5 years winter crops are sown each year.
No fertilizer until the final year before winter wheat

Sowing: ☐ simultaneous ☒ offset

Harvest: ☒ simultaneous ☐ offset

CROPS USE

Forage are used on-farm to feed livestock

EVALUATION BY THE FARMERS

☺

Good weed control in alfalfa without any weeding. Winter crop mixture takes the space of alfalfa during winter. When alfalfa starts in spring, winter crops are vigourous enough to avoid competition

Good quality and yield for the first spring cut : 5 à 8 t/ha

☹

Winter crops seeds are expensive (100 €/ha)

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

Alfalfa establishment after soybean to get fine soil and limit slugs

Seed mixture is homogenous and stable in the seeder when more than three different species are mixed

No rye in the mixture because of its low palatability for livestock

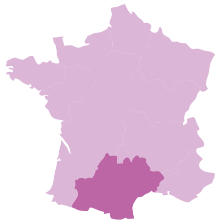
Tournesol + Trèfle violet

Helianthus annuus + Trifolium pratense

Productions:

- [x] grains for food
- [ ] grains for feed
- [ ] forage

INTERCROP TO BE OPTIMIZED



Objectives: Produce sunflower while limiting erosion and weeds

Limit soil erosion and the presence of weeds

Have a companion plant that releases nitrogen and organic matter

France

Reduced tillage

Degraded oceanic climate (700 mm/year)
Average annual T min 7,9°C / max 18,9°C

Clay-limestone soil, sloping

TECHNICAL MANAGEMENT

1. Soil preparation

None

2. Sowing

I) Clover sown the year before, in wheat at the end of tillering at the surface, and at 10 kg/ha (70% of the pure crop)
II) Harrowing
III) Sunflower sown in April, in the clover, with a single seed driller, at 4-5 cm depth, at 6.5 plants/m^2, and with a 1.25 m or 60 cm row spacing

3. Crop management

0,5 t/ha of poultry manure
Three grinder passes and one hoe pass
No irrigation

4. Harvest

Sunflower harvest only
Clover destroyed mechanically in June

5. Sorting

None

Sowing: April n-1 and mid April n
☐ simultaneous ☒ offset

Harvest: early September
☒ simultaneous ☐ offset

CROPS USE

Sunflower sold to a cooperative, for food

Clover without outlet (service crop)

EVALUATION BY THE FARMERS

☺

The presence of the clover on this type of soil, on a slope, makes it possible to limit erosion (seeding perpendicular to slope)

Wheat sown the following year is much greener in the area that had been associated with clover than in the area with pure sunflower

Hoeing made it possible to reduce approximately 60% of the seed stock ("the wheat sown after the sunflower harvest is much cleanerin the area which had been hoeed")

😐

Row spacing 1.25 m VS 0.60 m: no yield difference

☹

The clover was too abundant and consumed too much water. It competed with the sunflower which is therefore very poorly developed (50 % of the height compared to pure culture))

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

The intercrop can be interesting to consider with irrigation, but to evaluate because of the risk of favouring cover

Consider sowing both species at the same time (clover in the inter-row). In this case the cover will only be at the seedling stage during the early stages of sunflower development and its water consumption will be reduced, but the effect on reducing soil erosion will be less

Pea + Barley + Crimson clover

Pisum sativum + Hordeum vulgare + Trifolium incarnatum

Roskilde University

INTERCROP + TO BE OPTIMIZED

Productions:
- ☐ grains for food
- ☒ grains for feed
- ☐ forage

Photo: A. K. Aare

Objectives: Produce a complete feed and protect the soil after harvest

Nitrogen fixation through pea and clover (decreased need for N fertilization)

Denmark

No tillage

Continental climate (523 mm/year)
Average annual T min 5°C / max 11,4°C

Sandy loamsoil

TECHNICAL MANAGEMENT

1.a Clover sowing

Direct seeding of the clover crop at 10 kg/ha

1.b Pea and barley sowing

Direct seeding of mixture in plant cover.
Barley at 150 plants/m^2 and pea at 40 plants/m^2

2. Crop management

Herbicide application (Round up) 01-03 (n)
Herbicide application (Fighter) 18-04 (n)
Fungicide application (Comet Pro) 25-05 (n)

3. Harvest

Harvest of pea and barley seeds.
Clover stays as cover crop

Sowing: mid August and mid April
☒ simultaneous ☒ offset

Harvest: early August
☒ simultaneous ☐ offset

CROPS USE

Sold to neighbor with own fodder mixing equipment and used for pig feed

EVALUATION BY THE FARMERS

☺

Successful establishment and control of weeds

The three species seemed to complement each others in the growing season

The distribution of species corresponded to the initial distribution of seed rates for each crop indicating no major problems regarding competition between species

☹

Too late to use fungicides

Low yield (3 t/ha)

SUCCESS/FAILURE CONDITIONS, RISKS RELATED TO INTERCROPPING AND IDEAS

It might be an advantage to add some initial fertilizer to the mixture to increase the yield

It might be feasible to increase the amount of Pea

04 Harvesting and sorting

An evaluation in real conditions

Combining species seems to be an interesting solution for a more resilient and sustainable form of agriculture, in line with contemporary ecological concerns. Today, the main difficulty in implementing them on a larger scale lies in the ability to harvest and separate the grains with the machinery available. Indeed, most of the time, the mixtures cannot be marketed as they are, especially when targeted for human consumption.

However, the feasibility of this separation depends on the associated species and the desired quality of the harvest. It is therefore necessary to propose solutions to farmers in order to optimise the harvesting-sorting combination and increase the economic value of these mixtures.

From a theoretical point of view, it would be possible to develop specific machines (in particular "double" combiners adapted to species mixtures). However, the cost of developing such equipment and the existing market make this option unrealistic. Therefore, it seems more reasonable to optimise the use and settings of existing equipment by assessing the feasibility of their use to harvest and sort species mixtures.

The question we sought to answer was: **"Can species mixtures be harvested and sorted so that the marketed products meet food standards?"**, leading to several other questions:

• To what extent does the choice of harvester settings impact on the quality of the harvest of a species mixture and can losses and grain breakage during harvesting be limited?

• What are the characteristics of the products that allow for efficient and cost-effective sorting?

• What is the best harvest-sorting combination to optimise the economic performance of mixtures?

A partnership with two manufacturers

To answer these different questions, the **ReMIX** project included two industrial partners who, in addition to supplying the agricultural machinery, provided essential expertise in two distinct but interdependent tasks:

• The first, carried out by the **AGCO group**, concerns the harvesting of species mixtures and the choice of combine settings to minimise losses and the quantity of broken grain to facilitate sorting afterwards;

• The second concerns the separation of grains, carried out by the **Denis establishments**, consisting of testing the feasibility of sorting the batches harvested with different combine settings by minimising the rate of impurities in the products to be marketed as well as the losses during sorting.

Figure 15 • **Combine harvester Laverda M410 harvesting a wheat-lupin mixture**

Figure 16 • **New Holland TC5.90 combine harvester**

agriculture.newholland.com

Four mixtures tested

During the 2020 harvest, we were interested in different species mixtures, chosen in order to cover a wide range of characteristics that constitute constraints that need to be taken into account for both harvesting and sorting, and which concern in particular the size of the grains, their shape or the sensitivity of the species to threshing.

The trials were carried out on a farm in southwest France (FR) and on three farms in Denmark (DK). In total, four different mixtures were tested:

- Wheat–lentil (FR);
- Wheat–lupin (DK);
- Rapeseed–pea (DK);
- Barley–pea (DK).

Combine harvester and settings

The crops were harvested by AGCO using a Laverda M4105 combine (**Figure 15**) with the exception of the wheat-lentil combination which was harvested by the farmer using a New Holland TC5.90 combine (**Figure 16**)[6].

For each mixture, an initial series of settings were chosen by the AGCO group operators (Run 1: Test). Again according to expert opinion, the settings were adapted until a harvest judged satisfactory in terms of the rate of broken grains, grain losses at harvest, ears or unthreshed pods was obtained (Run 2: Reference).

From the reference Run 2 settings, we varied the combine parameters (**Figure 17**) one by one as follows (see details in **Table 1**):

- Drum speed (Run 3: +25%; Run 4: -25%);
- Fan speed (Run 5: +25%; Run 6: -25%);
- Drum and concave spacing (Run 7: +25%; Run 8: -25%), bearing in mind that in the case of the Laverda M410 this spacing can be adjusted differently at the inlet and outlet, unlike the New-Holland TC5.90, for which it is fixed;
- Opening of the upper and lower screens (Run 9: +25%; Run 10: -25%).

For each run, between 291 kg and 609 kg were harvested and an estimate of the amount of grain lost during harvesting was made using a tray placed on the ground as the harvester passed.

Figure 17 • **Operating diagram of a combine harvester (A. Morrison)**

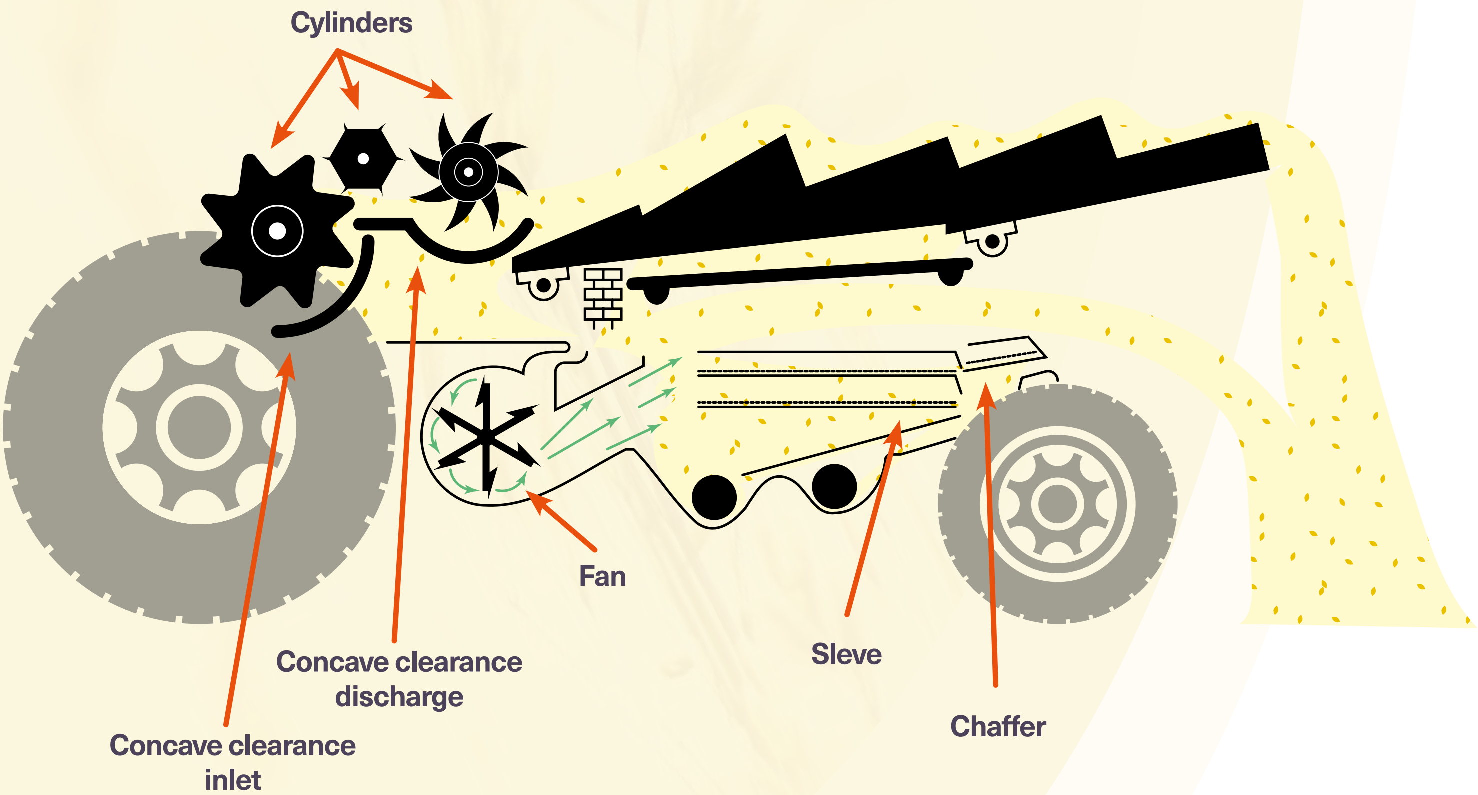


Table 1 • **Summary of combine and sorter settings tested for each species mixture tested**

Run	Dry weight (kg)	Harvest							Separation with SVD 100			
		Speed	Drum	Fan	Concave clearance (mm)		Screens (mm)					
					Inlet	Outlet	Chaffer	Sieve	First separation		Second separation	
Wheat-Lentil (FR)		New Holland TC5.90							**Clean Wheat-Lentil (main exit)**		**Wheat fraction (large exit) Lentil fraction (main exit)**	
1: Test	552	3,25	740	780	9	9	5	4				
2: Ref.	321	3,25	680	790	11	11	6	5	Top grids (mm)		Top grids (mm)	
3	325	3,25	850	790	11	11	6	5	Entrance	Exit	Entrance	Exit
4	338	3,25	510	790	11	11	6	5	6.0 rond	5.5 rond	2.50x20	2.50x20
5	305	3,25	680	970	11	11	6	5	Bottom grid (mm)		Top grids (mm)	
6	360	3,25	680	610	11	11	6	5	Entrance	Exit	Entrance	Exit
7	291	3,25	680	790	14	14	6	5	3.0 rond	1.75x20	Pleine	Pleine
8	298	3,25	680	790	8	8	6	5	Fan (from 1 to 5)		Fan (from 1 to 5)	
9	372	3,25	680	790	11	11	8	7	Entrance	Exit	Entrance	Exit
10	387	3,25	680	790	11	11	4	3	3	4	1	2
Rapeseed-Pea (DK)		Laverda M410							**Clean Pea (main exit) Durty Rapeseed (small exit)**		**Clean Rapeseed (main exit)**	
1: Test	509	1,50	600	450	15	25	12	8				
2: Ref.	525	3,00	600	800	10	15	12	8	Top grids (mm)		Top grids (mm)	
3	609	3,00	750	800	10	15	12	8	Entrance	Exit	Entrance	Exit
4	332	3,00	450	800	10	15	12	8	11 rond	10 rond	3 rond	2.75 rond
5	323	3,00	600	1000	10	15	12	8	Bottom grid (mm)		Bottom grid (mm)	
6	369	3,00	600	600	10	15	12	8	Entrance	Exit	Entrance	Exit
7	331	3,00	600	800	13	19	12	8	4.50x20	4.00x20	Pleine	1.60 rond
8	346	3,00	600	800	7	11	12	8	Fan (from 1 to 5)		Fan (from 1 to 5)	
9	358	3,00	600	800	10	15	15	10	Entrance	Exit	Entrance	Exit
10	339	3,00	600	800	10	15	9	6	3	3	3	1
Barley-Pea (DK)		Laverda M410							**Clean Barley (main exit) Durty Pea (large exit)**		**Clean Pea (main exit)**	
1: Test	360	3,00	800	800	10	15	14	10				
2: Ref.	438	4,00	600	950	15	25	14	10	Top grids (mm)		Top grids (mm)	
3	416	4,00	750	950	15	25	14	10	Entrance	Exit	Entrance	Exit
4	427	4,00	450	950	15	25	14	10	6.0 rond	6.0 rond	11 rond	10 rond
5	383	4,00	600	1050	15	25	14	10	Bottom grid (mm)		Bottom grid (mm)	
6	501	4,00	600	700	15	25	14	10	Entrance	Exit	Entrance	Exit
7	486	4,00	600	950	19	31	14	10	2.10x20	3.0 rond	4.00x20	4.50x20
8	440	4,00	600	950	11	19	14	10	Fan (from 1 to 5)		Fan (from 1 to 5)	
9	368	4,00	600	950	15	25	18	13	Entrance	Exit	Entrance	Exit
10	368	4,00	600	950	15	25	10	7	3	2	4	3
Wheat-Lupin (DK)		Laverda M410							**Clean wheat (main exit) Clean lupin (large exit)**			
1: Test	343	3,50	800	850	3	12	11	8				
2: Ref.	350	3,50	790	850	7	12	11	8	Top grids (mm)			
3	345	3,50	990	850	7	12	11	8	Entrance	Exit		
4	345	3,50	590	850	7	12	11	8	5.0 round	5.0 round		
5	318	3,50	790	1050	7	12	11	8	Bottom grids (mm)			
6	352	3,50	790	640	7	12	11	8	Entrance	Exit		
7	358	3,50	790	850	9	15	11	8	2.10x20	3.0 round		
8	347	3,50	790	850	5	9	11	8	Fan (from 1 to 5)			
9	337	3,50	790	850	7	12	14	10	Entrance	Exit		
10	335	3,50	790	850	7	12	8	6	4	2		

Sorting with the SVD 100 vibrating separator

The sorting of the harvested batches was then carried out with the SVD 100 vibrating separator from Denis (**Figure 18**), which is a flat sorting machine equipped with two blowers (one at the inlet and one at the outlet) and comprising two superimposed floors of two grids, i.e. a total of four grids that can be chosen independently.

Figure 18 • **Vibratory separator SVD 100**

The SVD 100 separates the batches into five fractions by vibration(**Figure 19**) :

• Very light impurities are removed through the "Dust" outlet by the two inlet and outlet blowers;

• Light impurities are removed through the "Winds" outlet by the two inlet and outlet blowers;

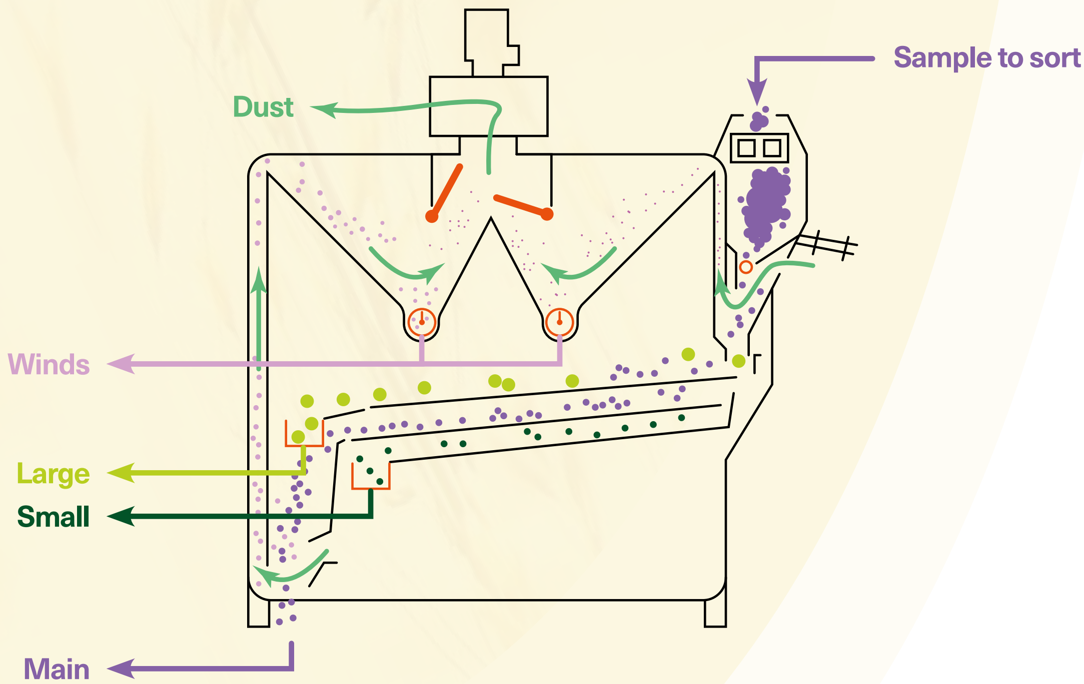
• Small particles are collected in the "Small" outlet and correspond to the fraction passing through the upper stage grids and then through the lower stage grids;

• Large particles are collected in the "Large" outlet and correspond to the fraction not passing through the upper stage grids;

• Intermediate size particles are collected in the "Main" outlet and correspond to the fraction passing through the upper stage grids, but not through the lower stage grids.

For each mixture, the choice of grids (shape and size of holes) was made by the operators of Etablissements Denis on the basis of manual tests on small samples (see details in **Table 4**).

Figure 19 • **Diagram of the SVD 100 separator**



Assessment of batch quality

For each batch harvested, the material introduced into the sorter was weighed, as was the mass obtained at each outlet after sorting in order to quantify losses during sorting. A representative sub-sample of 100-200 g was taken from each outlet and then manually sorted into seven fractions:

- **Whole grains** of the species in the mixture;
- **Broken grains** of the species in the mixture;
- **Unthreshed grains** of the species in the mixture;
- **Shrivelled grains** of the species in the mixture;
- **Other plant material** (leaves, straw, ...);
- **Inorganic material** (soil and stones);
- **Animal material** (insects).

Each fraction was then oven dried at 80°C for 48 hours and weighed to estimate the dry matter composition of the harvested sample.

On the basis of the *Codex alimentarius*[7], we chose to apply the following maximum levels for all species:

- **5.0%** broken, shrivelled or unthreshed grain;
- **1.5%** other vegetable matter (leaves, straw, grains of other species...);
- **0.5%** inorganic material (soil and stones);
- **0.1%** animal matter.

Composition from harvest to sorting

Batch composition at harvest

We analysed the composition of each of the batches harvested by distinguishing: I) "potentially marketable" grains from mixed species, which correspond to whole, broken and unthreshed grains; and II) impurities of all kinds (shrivelled grains, inorganic impurities, animal impurities and other vegetable impurities). It should be noted that shrivelled grain is effectively unmarketable regardless of combine settings and has therefore been included in impurities.

On average, the proportion of the two species varied greatly according to the mixtures (Figure 20), with a good balance between the two species for the barley– pea mixture (47% vs. 43%), whereas the legume was in the majority in the wheat–lentil (32% vs. 50%) and wheat–lupin (31% vs. 65%) mixtures and very much in the majority in the case of rapeseed–pea (7% vs. 86%). **The variability of the proportion of the two species between mixtures can be explained by the crop management implemented by the farmers (choice of species and sowing densities in particular) and their interaction with the soil and climatic conditions**.

For a given mixture, the proportion of the two species also varied, which is mainly explained by the heterogeneity of the plots (Figure 20), which is particularly marked for the wheat–lentil and barley–pea associations, with a proportion of legumes that varies from 42% to 61% and from 37% to 51% respectively.

Our results show that the levels of impurities varied according to the mixtures, with low values for the wheat–lupin (4%), intermediate values for the rape– pea (7%) and barley–pea (10%) mixtures, and high values for the wheat–lentil mixture (18%). **The variability of impurity rates between mixtures can be explained by a combination of factors (species, plot weediness and combine settings)**.

For a given mixture, the percentage of impurities varies between batches, directly related to the combine settings. This hypothesis is supported by the fact that the percentage of impurities does not depend on the proportion of the two species, even if we cannot totally exclude an effect linked to the heterogeneity of the plot, especially in terms of weeds. It should be noted that this variability is particularly marked for the wheat–lentil mixture with impurity rates varying from 9% to 29%, and, to a lesser extent, for the barley–pea mixture with values ranging from 7% to 13%.

Non-compliant harvested batches

The economic value of the batches depended on the quantity of each type of impurity, the maximum values of which were defined earlier: I) unmarketable grains (broken, unthreshed and shrivelled) with a maximum threshold of 5%; II) inorganic impurities (earth and stones) with a maximum threshold of 0.5%; III) other vegetable impurities with a maximum threshold of 1.5%; and IV) animal impurities with a maximum threshold of 0.1%. **It should be noted that all the batches harvested had less than 0.1% animal impurities, so they were not be taken into consideration in the following.**

From a methodological point of view, since the batches harvested correspond to mixtures of species, we considered that broken, unthreshed and shrivelled grains of the two species fell into the category of nonmarketable grains, whereas grains of other species were considered as other impurities.

A detailed analysis of the impurities of the batches with regard to the maximum authorised thresholds (Figure 21) **shows that, at the end of the harvest, none of the batches of wheat–lentil complied with the standards, in particular because of rates of other impurities** of between 7.7% and 26.2% and rates of inorganic matter of between 0.9% and 4.9%. The latter can be explained by harvesting as low to the ground as possible in order to collect the maximum amount of lentil grains, but with the consequence that a lot of soil particles were also included.

Similarly, none of the rape–pea and barley–pea batches met the standards, with respectively 1.4%, 6.0%, 6.1% and 11.5% of other impurities.

On the other hand, 40% of the wheat–lupin batches met the standards (batches 3, 5, 7 and 8) and batches 2 and 4 were very close to it with 1.7% and 1.6% of other impurities respectively.

Harvest losses

Based on the measurements made at harvest, we considered **the amount of grain not collected by the combine to be negligible and, above all, comparable between the different settings**, so that these losses were considered to be zero in the following.

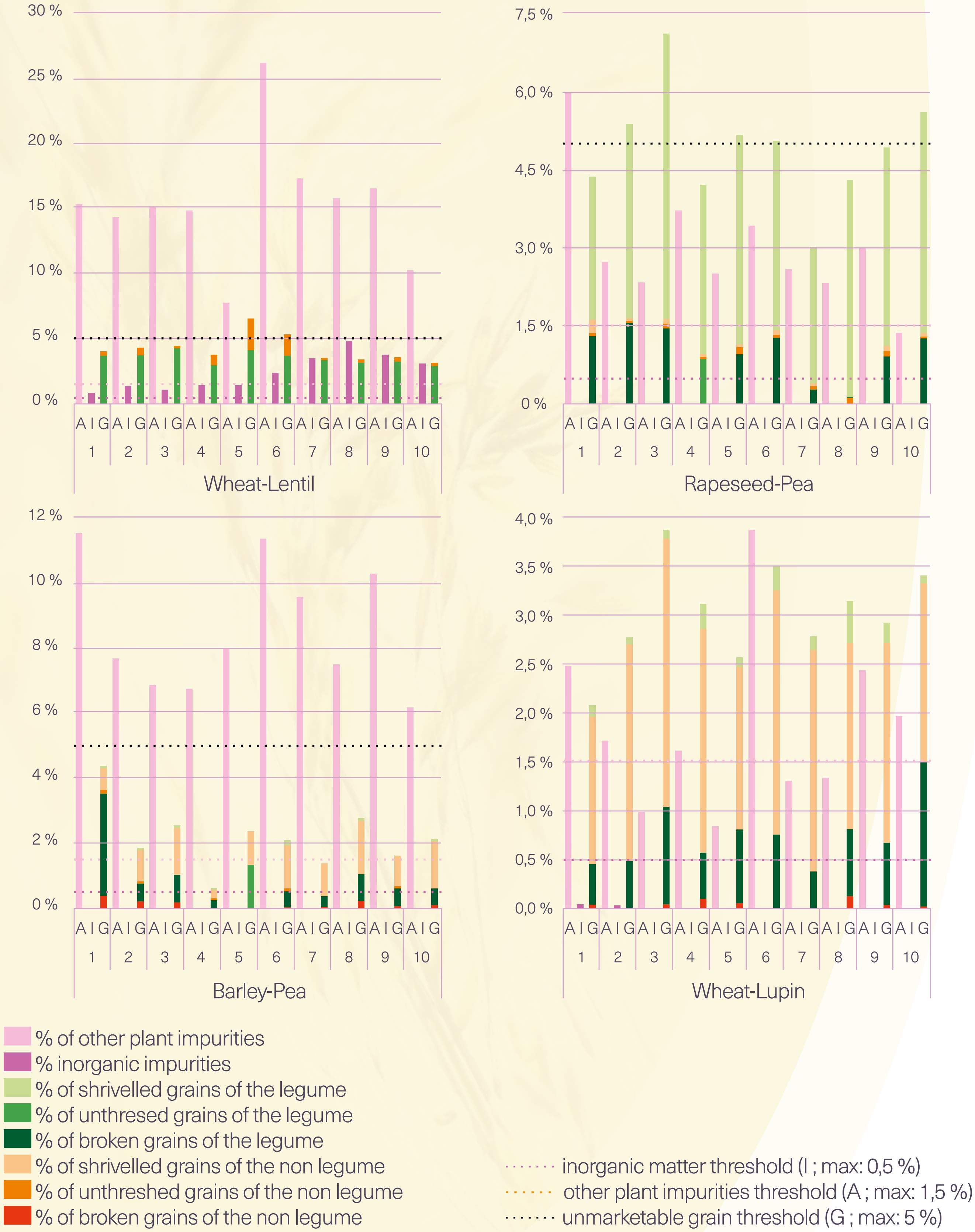
As we have just seen, the batches harvested had a significant proportion of unmarketable grain (broken, unthreshed and shrivelled grain). We therefore **compared the effect of combine settings on the rate of unmarketable grains, without taking into account shrivelled grains**. Indeed, their proportion was independent of the chosen settings and they were not considered as harvest losses.

Figure 20 • **Composition of the batches at harvest as a percentage of dry matter harvested, distinguishing, for each species, the "potentially marketable" part, corresponding to whole, broken and unthreshed grains, and the remainder comprising various impurities (shrivelled grains, inorganic impurities, impurities of animal origin and other vegetable impurities)**

The numbers above the species correspond to the batch identifier.

Figure 21 • **Percentage of impurities in batches at harvest as a percentage of dry matter harvested in terms of other plant impurities (A), inorganic matter (I; soil and stones) and unmarketable grain (G; broken, unthreshed and shrivelled).**

The dotted lines indicate the maximum permitted standards.
The numbers above the species correspond to the batch identifier.



In order to compare the different batches, and through them the different settings, **we chose to express the rate of broken and unthreshed grains as a function of the potentially marketable mass**. Indeed, this corresponds to the case of a perfect harvest allowing all the grains to be threshed without generating broken grains. This situation is of course theoretical, but it represents an objective to which we should aim.

Our results show that **losses at harvest were relatively limited, with an average of only 1.9% of potentially marketable grains broken or not threshed at harvest for the 40 batches** (**Figure 22**).

These losses were systematically lower for the nonlegume than for the legume (2.3% vs. 7.1% for wheat–lentil, 0.8% vs. 1.2% for rapeseed–pea, 0.4% vs. 2.0% for barley–pea and 0.2% vs. 1.1% for wheat–lupin). Since the percentage of broken and unthreshed grains does not depend on the proportion of the two species (result not shown), we can consider these differences to be explained by a higher sensitivity to threshing of legumes in connection with the settings chosen to thresh the mixtures correctly to limit losses in the field.

Similarly, our results show that, **for a given species in a given mixture, the percentage of broken and unthreshed grains varied from batch to batch, again due to combine settings**. This variability was particularly marked in the case of wheat combined with lentils, with values ranging from 0.2% to 8.1%, as well 19 as in the case of lentils (5.5% to 9.0%) or peas combined with barley (0.6% to 8.0%). Conversely, the different settings had a limited effect on losses in rapeseed (0.1% to 1.5%), pea combined with rapeseed (0.0% to 1.8%), barley (0.0% to 1.0%), wheat combined with lupin (0.0% to 0.4%) and lupin (0.6% to 2.3%). These results reflected the effect of the range of settings tested in relation to the sensitivity of the species to threshing and the pedoclimatic context.

However, **it is not relevant to compare the percentage of broken and unthreshed grains of wheat between the wheat–lentil and wheat–lupin mixtures, just as it is not relevant to compare the percentage of broken and unthreshed grains of pea between the rapeseed–pea and barley–pea mixtures**. Indeed, these were not the same varieties, not the same combine settings (nor the same model for wheat) and these combinations were not grown in the same soil and climate conditions, which exhibited a consequent variability in terms of grain moisture at harvest.

Note the **particular case of lentils, for which losses were much higher than for the other species, which can certainly be explained by grains that had been weakened by infestation by bruchids**. Our protocol did not allow us to fully validate this hypothesis, and these grains (in the same way as shrivelled grains) should not been considered as losses linked to the harvest, as they were independent of the settings chosen.

Sorting to reduce impurities

The batches harvested corresponded to mixtures of species whose impurity levels were almost always systematically higher than the standards, so that their economic value was greatly reduced. Sorting was therefore necessary to eliminate a maximum of impurities and to separate the two species.

In the vast majority of cases, it was not possible to clean the mixture and separate the two species in one pass through the sorter. In the present case and as indicated in **Table 1**, the **purpose of the sorting depends on the mixtures of species**, namely: I) cleaning the wheat–lentil mixture; II) separating the rapeseed from the pea by cleaning the pea; III) separating the barley from the pea by cleaning the barley; and IV) separating the wheat from the lupin by cleaning the wheat.

As with the harvesting operation itself, a portion of the marketable grain was eliminated with the impurities because it was carried away by the material flow without having time to pass through the sieves. Our results showed that **losses of marketable grain during sorting were negligible** with: I) 0.1% of wheat and lentil (not shown); II) 0.02% of pea and rapeseed (not shown); III) 2.7% of barley and 0.2% of pea (**Figure 23**); and IV) 2.1% of wheat and 0.3% of lupin (**Figure 23**).

We analysed the composition of the different batches with respect to the impurities thresholds after sorting (**Figure 24** and **Figure 25**). **Our results showed that after a single sorting, none of the wheat–lentil batches complied with the defined standards**, mainly because of the rate of other impurities (3.1% on average ranging from 0.4% to 7.7%), but also because of the rate of

Figure 22 • **Percentage of broken and unthreshed grain at harvest for legume and non-legume expressed as a function of the "potentially marketable" mass of each species corresponding to whole, broken and unthreshed grain**

The numbers above the species correspond to the batch identifier.

Figure 23 • **Percentage of whole grains lost during sorting, expressed as a percentage of total whole grains before sorting the non-legume and the legume**

The numbers above the species correspond to the batch identifier.

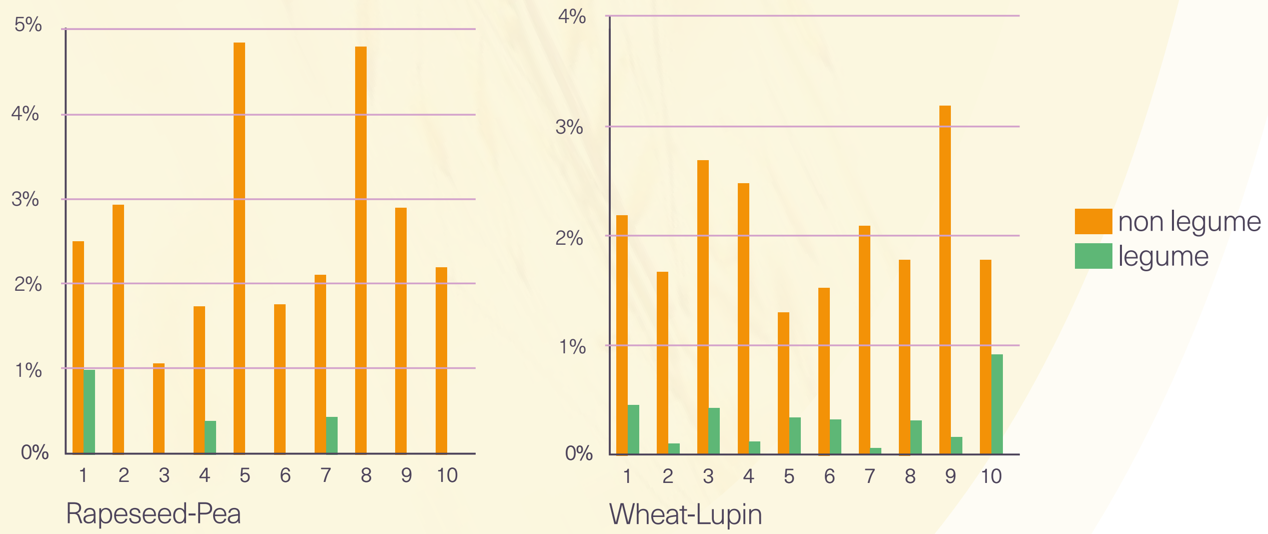
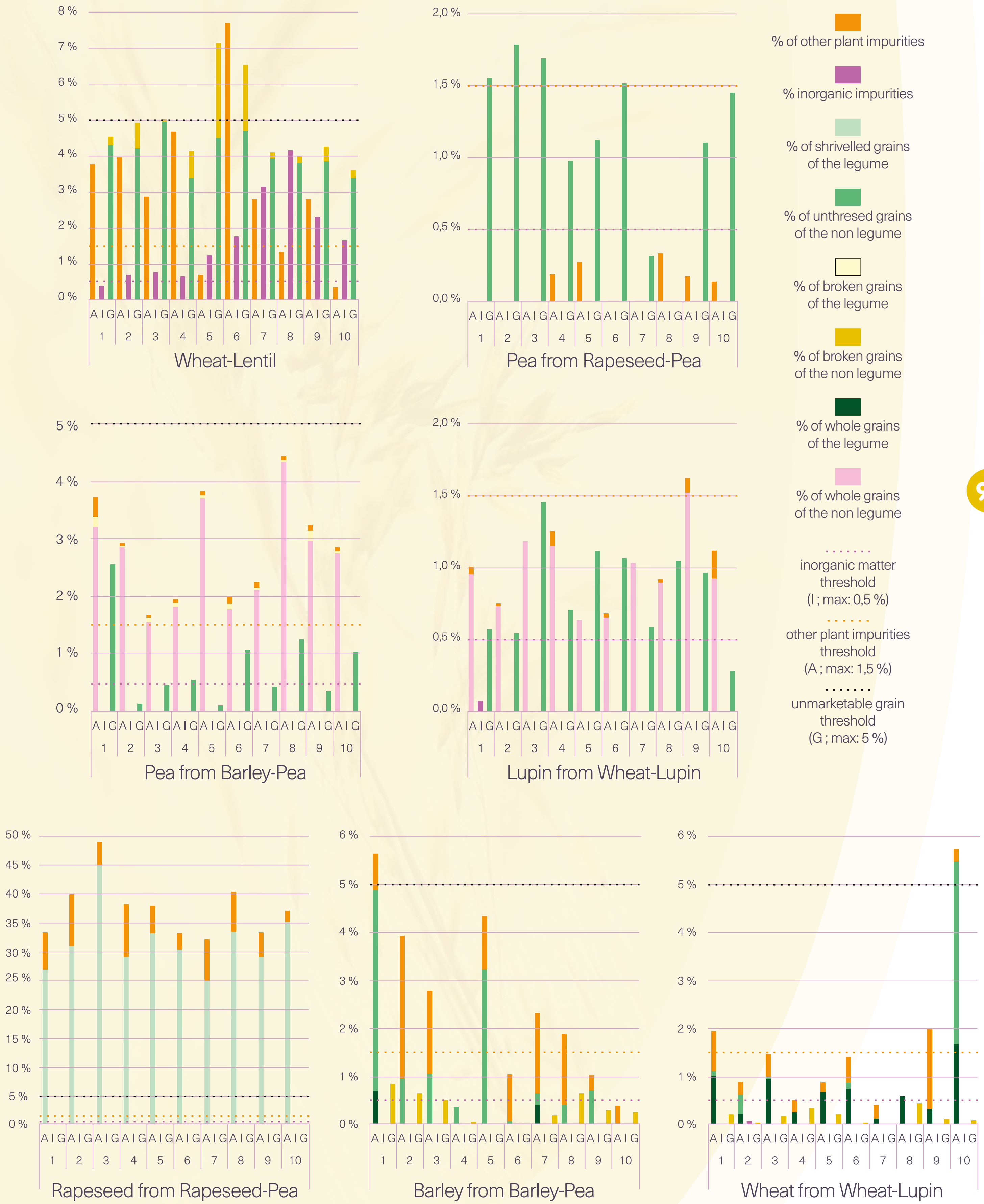


Figure 24 • **Composition of the batches, after an initial sorting, as a percentage of dry matter, distinguishing, for each species, the marketable part corresponding to whole grains and the remainder comprising miscellaneous impurities (broken, unthreshed, shrivelled grains, inorganic impurities, animal impurities and other vegetable impurities)**

The numbers above the species correspond to the batch identifier.

Figure 25 • **Percentage of impurities in sorted batches as a percentage of dry matter sorted in terms of other plant impurities (A), inorganic matter (I; earth and stones) and unmarketable grain (G; broken, unthreshed and shrivelled)**

The dotted lines indicate the maximum permit ted standards.
The numbers above the species correspond to the batch identifier.



inorganic matter (1.7% on average ranging from 0.4% to 4.2%) and, in some cases, because of the rate of non-marketable grains (4.8% ranging from 3.6% to 7.2%).

In the case of the separation of the rapeseed-pea mixture, **none of the batches of rapeseed complied with the standards**, due to the levels of other impurities (37.4% on average, ranging from 32.1% to 48.9%), consisting mainly of shrivelled peas. On the other hand, **all the peas from the sorting of the rapeseed–pea mixture were in compliance**, in line with the objective of cleaning the peas.

Conversely, **none of the peas from the barley–pea mixture complied**, due to other impurities (2.9% on average, varying from 1.7% to 4.4%), bearing in mind that the objective was to clean the barley. This objective was **only partially achieved, as only 40% of the barley batches were compliant** (batches 4, 6, 8 and 9), while the others had other impurities at levels that were too high (2.4% on average ranging from 0.3 to 5.7%), with many broken peas.

Finally, in the case of the wheat–lupin mixture, **all the lupins met the standards**, except for batch 9, as well as 70% of the wheat batches, with the exception of batches 1, 9 and 10, due to the presence of too many broken or shrivelled lupin grains.

At the end of the first sorting, it appeared that a certain number of batches did not meet the expected quality standards, with these requiring a second sorting pass. This was the case for all rapeseed, all peas from the barley–pea mixture and all wheat–pea mixes.

A second sort not always relevant

The second sorting aimed at: I) separating the wheat–lentil mixture into two fractions (one predominantly wheat and one predominantly lentil); II) cleaning the rapeseed; and III) cleaning the pea from the barley–pea mixture. **It should be noted that no whole grains were lost during this second sorting.**

At the end of this second pass through the sorter, we analysed the composition of the different batches with regard to the impurity thresholds (**Figure 26** and **Figure 27**). In the case of the sorting of the wheat–lentil batches, the wheat-dominant fraction contained on average 86% wheat and 7% lentil and, as such, must be considered as a mixture of grains. The same applied to the lentil-dominant fraction, which was 75% lentil and 15% wheat. In both cases, **none of the sorted batches of the wheat–lentil mixture complied with the defined standards**. Indeed, the lentil-dominant fraction contained on average 6.1% of non-marketable grains (between 4.8% and 10.4%) and 2.9% of other impurities (between 0.0% and 6.2%). In the case of the predominantly wheat fraction, it was mainly inorganic impurities that lead to the downgrading of batches (4.3% on average with values between 0.9% and 11.9%).

The cleaning of the rapeseed brought 40% of the batches up to standard (batches 1, 6, 7 and 10), while four other batches were relatively close to the maximum threshold of 1.5% of other impurities (batches 3, 5, 8 and 9 with 1.5%, 2.1%, 2.2% and 2.1% of other impurities respectively).

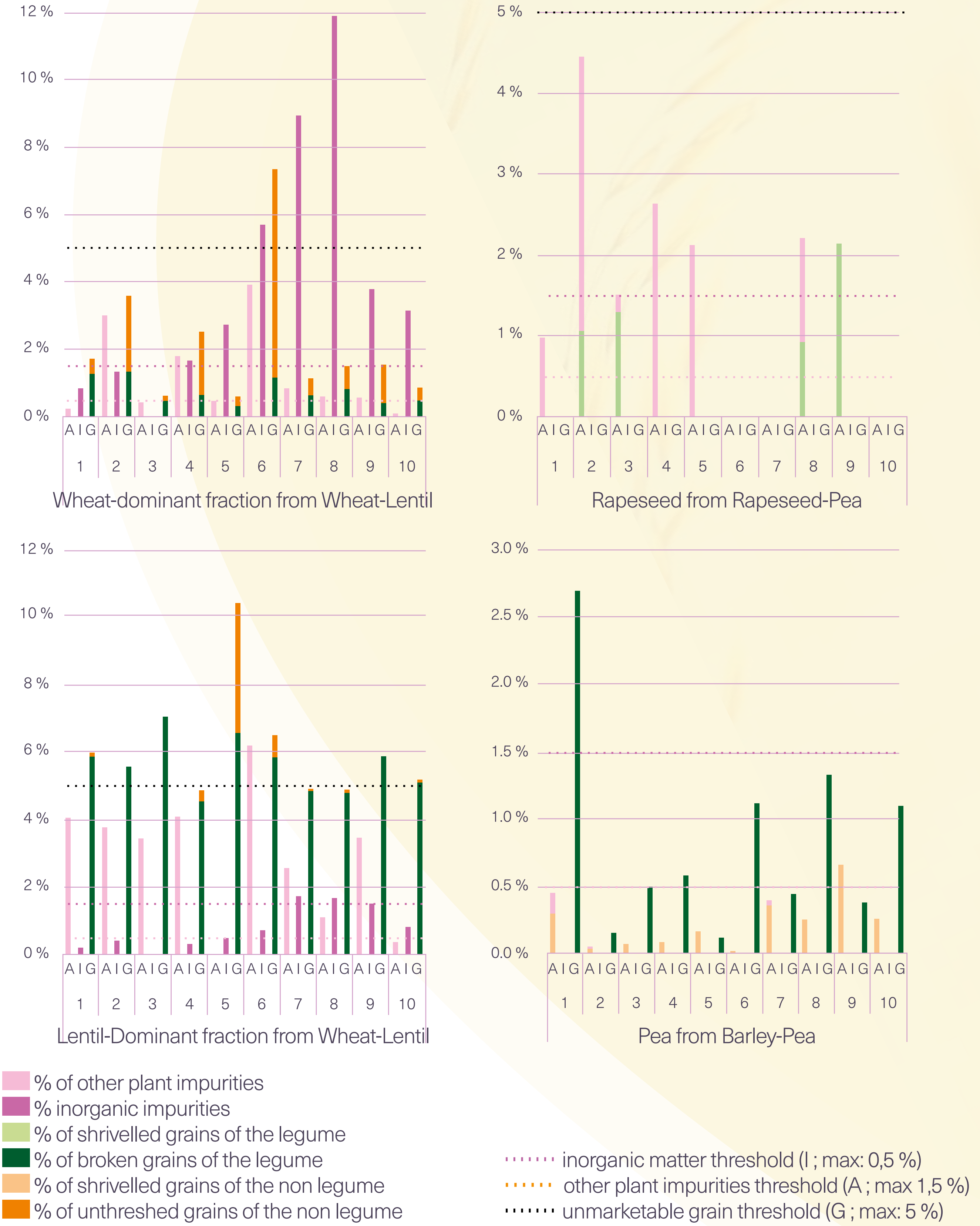
Finally, after cleaning the pea from the barley–pea mixture, all batches were within the standards with an average of only 0.8% of unmarketable grains and 0.2% of other impurities.

Figure 26 • **Composition of the batches after a second sorting, as a percentage of dry matter, distinguishing, for each species, the marketable part corresponding to the whole grains and the rest grouping together the various impurities (broken grains, unthreshed and shrivelled grains, inorganic impurities, animal impurities and other vegetable impurities)**

The numbers above the species correspond to the batch identifier.

Figure 27 • **Percentage of impurities in batches after second sorting as a percentage of dry matter after second sorting in terms of other plant impurities (A), inorganic matter (I; earth and stones) and unmarketable grain (G; broken, unthreshed and shrivelled)**

The dotted lines indicate the maximum permitted standards.
The numbers above the species correspond to the batch identifier.



Value from harvest to sorting

The previous results showed that some sets of combine adjustments, coupled with one or two passes with a vibrating separator such as the SVD 100 from Etablissements Denis, were quite capable of limiting the quantity of impurities and broken grains in the finished products from a rapeseed–pea, barley–pea or wheat–lupine combination, and thus allow their use in human food. On the other hand, in the case of the wheat–lentil mixture, this type of separator remained insufficient on its own, but must be seen as a prerequisite before the use, in a second phase, of more specific technology such as a densimetric table or an optical sorter. However, these elements raise the question of the economic viability of such an approach, which could be formulated as follows:

• What is the economic loss at harvest?

• Is there any added value in sorting and resorting?

• How much of the value produced in the field can be recovered?

• Do the different harvest settings lead to differences in final value?

Calculation of the economic value

For the price of the crops, considering the total absence of impurities and products with 14% moisture, we used the following values:

- Wheat: 400€/t (465€/t at 0% moisture);
- Barley: 260€/t (302€/t at 0% moisture);
- Rapeseed: 750€/t (872€/t at 0% moisture);
- Peas: 350€/t (407€/t at 0% moisture);
- Lentils: 1400€/t (1628€/t at 0% moisture);
- Lupin: 600€/t (698€/t at 0% moisture).

In the case of the sale of a mixture of two species, we considered that the price was reduced by 20% compared to the price of pure crops.

On the basis of the maximum permitted impurity levels we chose to include a penalty according to the impurity levels, considering a 5% price reduction when at least one of the impurity levels (broken, shrivelled and unthreshed grains; other plant matter; inorganic matter and animal matter) was between one and two times the maximum permitted standard, 10% between two and three times the maximum standard, and so on.

Economic reference value

To analyse the economic value of the batches, we chose as a reference the theoretical value in the field, calculated from the weight of all the grains present in a tonne of product harvested at 0% moisture, excluding shrivelled grains.

This calculation amounts to the consideration of reference a situation where one would be able to harvest and separate all marketable grains without breaking any. It should be noted that the use of such a standardised reference makes it possible to avoid intraplot variability in terms of the proportion of species in the mixture or weeds, which has an impact on the value of the different batches independently of the quality of the harvest.

Thus the reference values of the mixtures calculated from the average of the 10 batches were:

- 969€ (858 to 1076€) for wheat–lentils;
- 414€ (402 to 420€) for rapeseed–pea;
- 319€ (306 to 329€) for barley–pea;
- 597€ (586 to 605€) for wheat–peas.

2% value lost at harvest

As mentioned above, a first loss of value was linked to harvesting which generates a fraction of broken and unthreshed grains.

Harvest losses were relatively limited, so that the value of the harvested product represents 99% of the reference value for the rapeseed–pea, barley–pea and wheat–lupin (Figure 28). Conversely, for the wheat–lentil mixture, the harvest losses represented 6% of the reference value (between 5% and 8%). However, this loss was largely related to broken lentil grains that are probably infested by bruchids, so the actual loss is likely to be lower.

These results showed that overall, **for a given mixture, combine settings had no effect on the proportion of broken and unthreshed grain**. Conversely, the proportion of broken and unthreshed grains depended on the associated species.

At standards, 38% of value lost at harvest

The harvested products correspond to grain mixtures, which, according to the assumptions made above, led to a reduction in value of 20% compared to pure crops. Above all, due to the settings of the combine and the mixtures harvested, the batches had considerably different levels of impurities. However, as mentioned earlier, we considered a price reduction of 5% when at least one of the impurities levels was between one and two times the maximum allowed standard, 10% between two and three times the maximum standard, and so on.

In the end, the value of the harvested product represented, on average for the four associations, only 62% of the reference value (38% for wheat– lentil, 74% for rapeseed–pea, 58% for barley–pea and 77% for wheat–lupine; Figure 28).

In contrast to harvest losses, combine settings had a strong impact on impurity levels and thus on the real value of the harvested product. This result was particularly noticeable in the case of the wheat–lentil mixture, with values between 11% and 55% of the reference value, and in the case of the barley–pea mixture, with values between 50 and 64% of the reference value. Conversely, in the case of the other two mixtures, the effect was smaller with differences of 9% between the minimum and maximum values.

A first sorting to find 80% of value

The first pass through the cleaner-separator made it possible to significantly reduce the levels of impurities but also to separate the two species (with the exception of the wheat–lentil mixture, for which it was only a cleaning operation), making it possible to recover a large part of the value of the test batches.

These results showed that, **in the case of the wheat–lentil mixture, a second sorting was necessary to separate the two species, as well as a cleaning of the rapeseed and pea initially associated with the barley**.

Conversely, **in the case of the wheat–lupin mixture, a simple sorting allowed the majority of the wheat and lupin batches to be brought up to standard**.

Thus, on average for the four associations, **the sorted product represented 80% of the reference value** (60% for wheat–pea, 80% for rapeseed–pea, 87% for barley–pea and 95% for wheat–lupin; Figure 28), knowing that, for all the batches, these values included €15 towards the cost of sorting one tonne of harvested product.

These results also showed that **this first sorting allowed, in the case of rapeseed-pea and wheatlupin mixtures, to reduce the heterogeneity of the 25 batches, linked to the combine settings**, as shown by the small difference between the minimum and maximum values (77% vs. 81% and 91% vs. 96% respectively).

On the other hand, **in the case of wheat–lentil and barley–pea mixtures, the variability of the batches linked to the combine settings remained important** in view of the differences between the minimum and maximum values (44% vs. 69% and 77% vs. 91% respectively).

Varying interest in the second sort

The sorting of the wheat–lentil mixture by a second pass through the cleaner-separator only allowed the recovery of 1% additional value added (60% vs. 61% respectively before and after the second sorting), knowing that the cost of this separation represents on average 12.8€ per batch, i.e. 1.3% of the reference value. This result confirmed that **this type of sorter does not allow the efficient separation of wheat and lentil, so that in the end the two fractions must be considered as either a mixture of species or as pure products with very high levels of other impurities, with a reduced commercial value.** These two steps (cleaning of the mixture and then separation into two fractions) should however be seen as a prerequisite to the use of more specific sorting tools, such as a densimetric table or an optical sorter, in order to increase the efficiency and throughput of the latter and to reduce their operating costs. Indeed, **this second pass further reduced the heterogeneity of the batches**, as shown by the smaller difference between the minimum and maximum values (11% vs. 25% respectively after and before the second sorting).

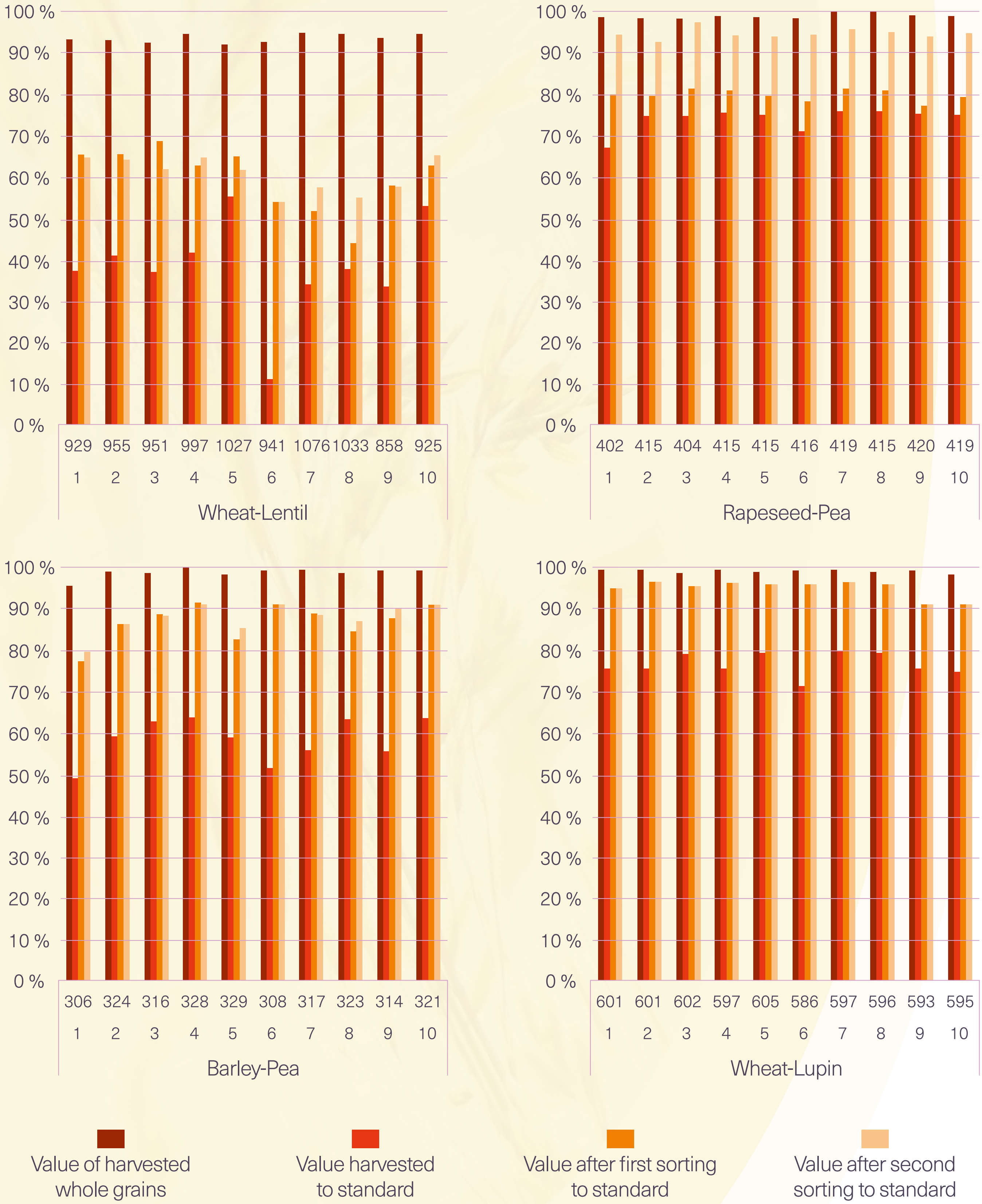
For the **barley–pea mixture, the cleaning of the pea only recovered a further 2% of the reference value of the mixture** (87% vs 89% respectively before and after the second sorting), knowing that the cost of this separation is on average 6.3€ per batch, representing 2.0% of the reference value. It should be noted that cleaning the barley would certainly have allowed some added value to be regained, but only marginally due to the ratio between the cost of sorting and the price of the barley.

Conversely, **cleaning the rapeseed allowed the recovery of 15% of the reference value of the rapeseed–pea mixture** (80% vs. 95% respectively before and after the second sorting), bearing in mind that the cost of this cleaning is low (1.1€ on average per batch, i.e. 0.3% of the reference value) due to the fact that the mass of the rapeseed represented only 7% of the mass of the mixture harvested.

Finally, even though our calculation does not take into account the time spent sorting or the cost of labour, **our results show that a second sorting is not always economically relevant and the cost of sorting must be factored in to this decision, relative to that of the price of the crops, while taking into account the level of impurities and the penalties applied**. Thus, the second sorting of a fraction does not appear relevant in cases where: I) the impurity levels and therefore the associated penalties are low, II) the market value is low relative to that of the sorting cost because of the price of the crop (e.g. barley) or the share of the more valuable crop in the mixture is low (e.g. wheat vs. lupin), and III) it is unable to provide an efficient separation.

Figure 28 • **Economic value of the batches, expressed as a percentage of the theoretical value, and which correspond to the value in the case where one would be able to harvest and separate all the grains: I) after harvest by taking into account only the whole grains, II) after harvest by considering a valuation of the mixture at 80% of its value and by integrating a penalty according to the rates of impurities, III) after a first sorting by integrating a penalty according to the rates of impurities; and iv) after a second sorting by integrating a penalty according to the rates of impurities.**

The numbers above the species correspond to the batch identifier and the theoretical value.



Harvesting and sorting: *yes we can!*

We have shown that **species mixtures can be properly validated economically by optimising the combine settings and by performing an adapted sorting**. To do this, it is necessary, on the one hand, to know one's combine well in order to optimise its operation, but this optimum must be defined in relation to the capacity to sort the grain further. Therefore, the operator must be able to analyse the quality of the crop according to the availability and effectiveness of the sorting tools at his disposal, which requires another form of expertise. Finally, the cost/benefit ratio of sorting must be systematically taken into account, knowing that it depends on many factors and in particular on the penalties applied by the buyers according to the impurity levels and the equipment used.