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Assessing and reducing the vulnerability of mixed organic cattle-sheep farms

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Abstract

Mixed farming systems are gaining interest both as a risk management strategy and to apply agroecological principles. Diversity in organic farming systems is particularly important since those farms have limited access to external inputs and more frequently use direct marketing.

The main objectives of this study were to assess 1) how organic cattle-sheep farmers of the French Massif Central feel exposed to risks and how they manage them and 2) how alternative strategies can reduce their vulnerability to the main risks identified. This study focuses on farms combing beef cattle, sheep for meat and some annual crops. Among the European farms surveyed for the MixEnable project, four French mixed beef-sheep farms were interviewed during the winter 2020-2021 and alternative strategies were simulated for their farms with the Orfee bioeconomic farm model. Climate risk appeared to be the most serious risk for farmers, followed by market risks. They considered that bad yields tend to become normal. Short term adaptations such as grassland end-use, animal production or forage security stock varied between farmers but they all frequently purchased supplementary feeds. All of them had already reduced their stocking rate or plan to do so. All farmers planned to maintain or increase the mix of enterprise on their farm.

The states of nature of each hazard (grassland yield, cereal yield, intercrop yield, output and input price, policy) were crossed assuming independence between risks and their values were defined according to farmers' declarations. The Orfee bioeconomic farm was used to simulate the impacts of those hazards on the distribution of farm income. Two alternative scenarios were simulated and compared to the 2017 farm structure: 1) reduction of stocking rate either by a decrease in the size of the herd or by an increase of the surface in grasslands and 2) reduction of stocking rate associated with change in the animal enterprise mix with the addition of a pig enterprise or the replacement of beef enterprise by a dairy cow enterprise. The short-term adaptations such as feed purchase, feed stock, modification of grassland use, animal produced and sold and intercropping were optimized by the model for each combination of risks within the range of possibilities specified by farmers. We found that sensitivity was highest to changes in producer prices, particularly for pork and milk prices, followed by subsidies, spring pasture yield and then grain yield. They were not very sensitive to fuel prices of grassland fall yield. Farms that had more flexibility to adapt to hazards were somewhat less sensitive. Farms were also quite exposed to risks affecting grain yields, especially for a farm that sells all of its grain and shifts a high variability in yield. The reduction of stocking rate, reduced these sensitivities (except for cereal yield) by reducing farm exposure. The introduction of pigs or dairy also reduced the sensitivity by increasing average income. Three of the four farms were found to be vulnerable for the baseline situation since they had significant risk of very low incomes. Farms that had already low income because of low technical performance or high fixed costs in a normal year, or that had a higher probability of low grassland or crop yields had higher probability to fall below critical levels. The reduction of stocking rate reduced variability and standard deviation in all cases, nonetheless it was not sufficient to bring some farms out of vulnerability. The introduction of pig enterprise and the replacement of beef by dairy and cheese making did not reduce much the standard deviation due to significant risks associated to these enterprises but increased income; consequently, the farm vulnerability was reduced. Nonetheless, the ranges of profitability for pig or dairy are rather narrow. A poor technical mastery or a less good valorisation of the products on the market can call into question the profitability of these activities. Similarly, technical improvements could be made on these farms where farmers sometimes admit to neglecting certain workshops in order to concentrate on others.

Keywords

Mixed livestock, risk management, sensitivity, climate change, modelling, subjective probability

Introduction

Livestock farming systems based on grasslands have many advantages: grazing allows animals to express their natural behaviour, to maintain permanent grasslands that are an important biotope for biodiversity and carbon storage, and to produce food with land that could not be used directly for growing human food. However, these systems are directly impacted by climate change that affects the production of forages. This threat takes place in a difficult production context, particularly for cattle and sheep meat: the meat price context is structurally low, dependence on public aid is very high, while society's distrust of livestock farming systems is growing, particularly because of animal welfare and methane impacts on climate change. This accumulation of stresses can make livestock farms vulnerable. Vulnerability is the likelihood that at a given time in the future, an individual will have a level of welfare below some norm or benchmark (Hoddinott & Quisumbing 2010) which could lead to precarity or farm exit. The issue is to support farmers in their adaptation to these social and climatic transitions so that they can continue to provide services to society with a farming system that is sustainable and not vulnerable.

Mixed farming systems are gaining interest both as a risk management strategy and to apply agroecological principles. Diversity in organic farming systems is particularly important since those farms have limited access to external inputs and more frequently use direct marketing. According to Dumont *et al.* (2020), diversity of system components and interactions among these components can increase productivity, resource-use efficiency and farm resilience. The complementarity between two animal species appears as a promising leverage to more efficiently use plant resources and to stabilize farm performance and had been little studied until now (Martin *et al.* 2020; Mosnier *et al.* 2021). However, it may not be sufficient to make farmers able to cope with risks and additional strategies should be tested.

The objectives of this study are 1) to know how organic cattle-sheep farmers of the French Massif Central feel exposed to risks, manage them and plan to adapt, and, 2) to simulate current and alternative strategies in order to identify potential way to reduce vulnerability to risks for these farms.

Modelling offers a comprehensive way to understand complex farms in which exogenous and endogenous factors affect farm sustainability and to explore alternatives. Risk management is a sequential process (Antle 1983) mixing long term strategies and tactical adjustments that are made to improve expected income in response to seasonal conditions. Some simulation models parameterize farm strategies by fixing crop acreage and crop management, herd size and production per animal and tests impacts of economic and animal production variations (Benoit *et al.* 2020) or forage yield variations (Martin & Magne 2015) on farm production and economics. Bioeconomic models can endogenize strategies by optimising decisions considering the impacts of these decisions on expected outcomes, which enables to propose decisions consistent with the simulated situation. Various methods can be used to model sequential decision stages (Blanco *et al.* 2011; Robert *et al.* 2016). Among these methods are Stochastic Dynamic Programming (Kobayashi *et al.* 2007; Ritten *et al.* 2010; Behrendt *et al.* 2016) or discrete stochastic programming (Jacquet & Pluvinage 1997; Mosnier 2015). However, these models are limited either by the number of decision variables (SDP) or the number of states of nature (DSP) that can be included. In order to be able to simulate a large number of states of nature covering different sources of risks and a large number of decisions variables enabling to represent complex system, a hybrid framework is needed.

In this study, similar to (Mosnier 2009), the long term strategy was fixed and only tactical decisions such as feed purchases or sales, end-use of crop and animal production were optimized for a combination of hazards. A different optimization was made for each combination of hazards. A probability was associated to each optimisation results so that the distribution of all indicators could be analysed. The model used was the bioeconomic static farm model Orfee (Mosnier *et al.* 2017). Few other farm models were able to simulate organic systems (Olesen *et al.* 2006; Kerselaers *et al.* 2007), offered the possibility to simulate different livestock species (Kerselaers *et al.* 2007) with enough flexibility to explore a variety of management options in a mixed livestock farm.

This paper presents first the global methodology. Second, the results of four farmers interviews regarding their exposure to risks and their risk management are analyzed. The simulation scenarios, based on farmers' interviews and the simulation results are presented in the third section. These scenarios tested for subjective probabilities (Hardaker et al. 2004) regarding for grassland yield, crop and intercrop yield, meat prices tested strategies of adaptations including the reduction of stocking rate and the modification of the animal production mix. These strategies are discussed in the fourth section.

1 Method

1.1 Interview of 4 farmers in 2021

In 2017, a large number of organic farms with two commercial livestock production enterprises were surveyed as part of the project MixEnable in different European countries. In France, the production, structure, organisation and sometimes economic results of 17 organic farms were recorded for farms with beef cattle associated with meat sheep (n = 7), pigs (n = 6), or poultry (n = 4) (Steinmetz *et al.* 2021). This study remobilized the data of four mixed beef-sheep farms that had accepted to answer an additional telephone interview about their risk exposure and risk management. These farms were located in the Massif central (figure 1). Their sizes (from 75 to 196 ha and between 1 and 1.3 worker units) were comparable to the average size (88 ha and 1.5 WU) of mixed beef cattle- sheep for meat farms of the massif central (Granet 2016) (Table 1). Grasslands covered more than 80% of the agricultural area and the cereals produced were for three of them intra-consumed by their animals. The herd size varied between 73 Livestock Unit (LU) and 107 LU and the proportion of beef and sheep were rather balanced except for F74 who had only 19% of sheep. All the farms, except F63, had grazing pastures common to both species.

Figure 1: locations of the farms surveyed in France

Table 1: Main characteristics of the farms surveyed

	F63	F65	F67	F74
Labour (worker unit)	1	1.3	1.3	1
Agricultural area (ha)	75	116	196	107
grasslands (% total)	80%	92%	86%	81%
Consumption of own cereals	yes	yes	no	yes
Livestock Unit (administrative)	73	77	93	107
Cows (heads)	15	28	39	47
Ewes (heads)	220	185	200	100
% sheep LU	59%	50%	43%	19%
Mixed grazing	yes	yes	yes	no
Short channel	partly	no	no	partly
Stocking rate	1.2	0.7	0.6	1.2

The interviews were done in the context of the Covid pandemic in the winter 2020-2021 and were consequently made by phone (supplementary material). The objective was to identify the risks that have to be considered in the simulation in priority, to provide subjective intensity and probability for the main risk identified and to identify adaptations of interest. Farmers were first asked for different risks (personal health, product marketing, input prices, agricultural policy, damage to equipment, herd production, crop and forage production in relation to climate or pest, disease and weeds) if they perceived them as low, medium or high and why. For the grassland and crop production, animal production and meat prices, we asked them to define what were for them the production or price for a very bad, bad, medium, good and very good state of nature for each risk and how often it happened over the last 10 years. With a focus on forage production variability, farmers were asked if they adjust animal production, crop and grassland management, feed purchase and if they have security stocks. They were also asked how they plan to adapt in the future, with specific questions regarding the mix of animal enterprise, the mix between crop and livestock, the balance between cash crops and livestock, intercropping, insurance, irrigation or trees.

1.2 Simulations with the model Orfee

Orfee is a bioeconomic farm model (Figure 2) which simulates annual production of a livestock farm associated with grassland and/or annual crop production taking into account interactions between the different agricultural activities (Mosnier *et al.* 2017; Mosnier *et al.* 2021). Orfee runs on the General

Algebraic Modeling System (GAMS Development Corporation, Washington, DC, USA) and uses the Mixed Integer Programming solver CPLEX. Most of the input and output files are on Excel. The optimization model was used here to optimize (within the range of possibility of each farm) the age and liveweight of animals sold, animal diets, grassland end-use, feed purchase and sales, consumption of cereal produced on the farm by animals, intercropping. The levels of these variables were defined to maximize a function based on the target Motad framework with two criteria: expected operating results and the expected income below the minimum legal French wage per worker.

The model simulated herd composition, animal and crop production, labour, machine, and building uses, product sales, subsidies, variable and structural costs. Several indicators of sustainability were computed but the paper focused on farm income.

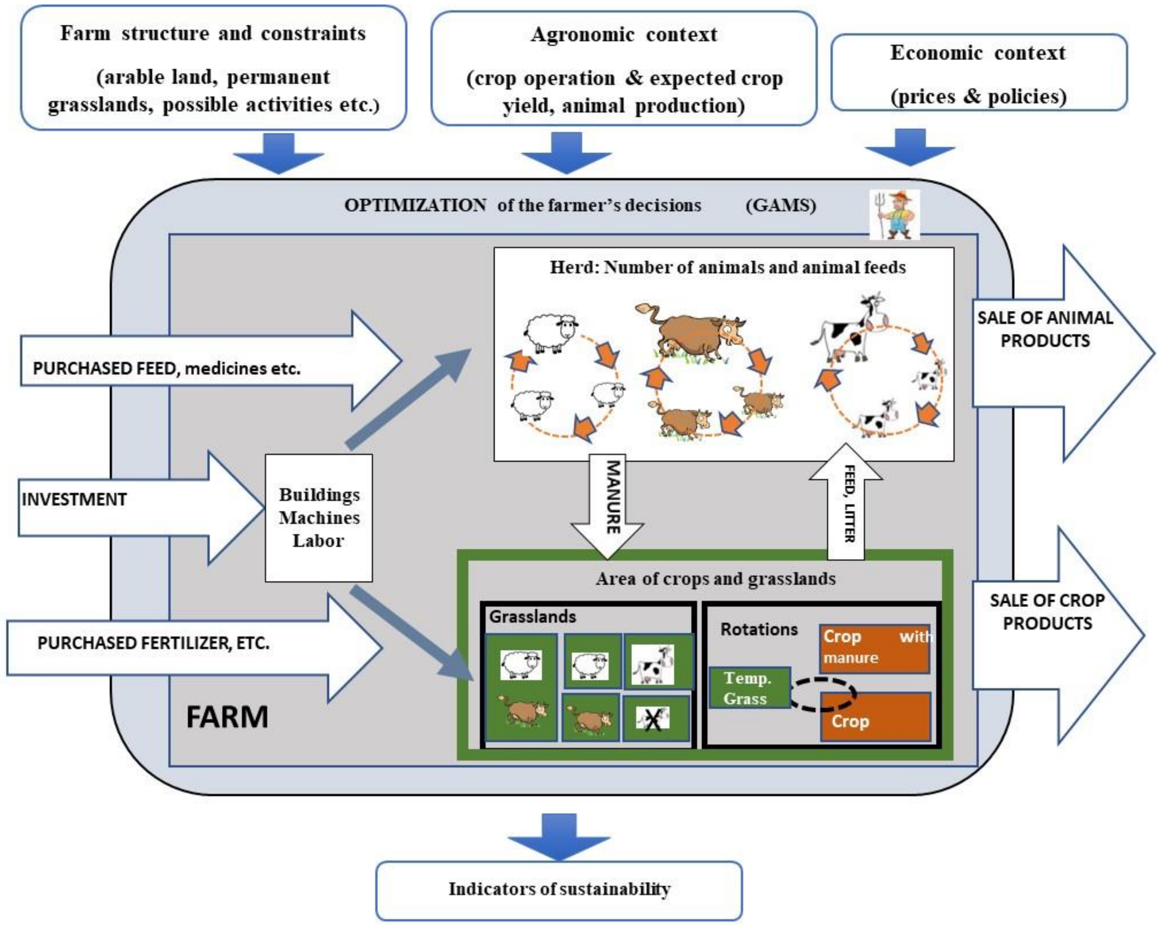


Figure 2: Representation of the Orfee Model (source: Mosnier et al., 2021)

In order to simulate the distribution of farm performance and income for a given long term strategy, only tactical decisions were optimized (Figure 3) for each combination of hazards (e.g. state of natures).

A probability is associated to each combination of risk so that the distribution of all indicators can be analysed.

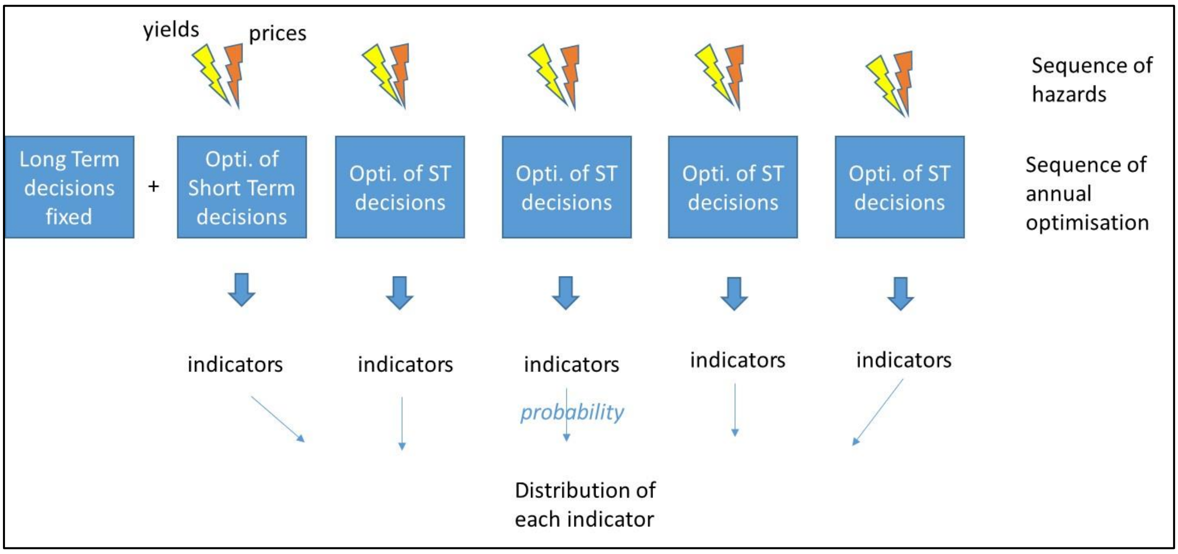


Figure 3: Sequence of optimization of short-term decisions in response to different combination of shocks, according to fixed long-term strategy.

1.3 Indicators to assess impacts of risks and farm vulnerability

This study focuses on the assessment of the impacts of risks on farming systems and particularly on farm vulnerability. Luers *et al.* (2003) proposed to measure vulnerability as the product of relative sensitivity to a perturbation and the probability of exposure to perturbation.

Sensitivity was first measured for each source of risk. Sensitivity is the degree to which the system is affected by a disturbance (Adger 2006). We measured it as the elasticity of income (Y) to a change of the value of a variable (X): $\varepsilon(x, y) = \frac{\Delta y}{\bar{y}} \frac{\bar{x}}{\Delta x}$. A sensitivity of 2 means that a 10% reduction of X will induce a 20% variation of income.

The distribution of income was then analysed, aggregating all combination of risks weighted by their probability. The distribution curves were built in order to visualize the probability to have different levels of income. For each class of 5k€ income (e.g. between 5 k€ to 10k€), a weighted average of income was calculated and associated to the probability of income recorded in this class. To characterize risks different indicators were computed. The probability to obtain income below 0k€ or 10k€ gives insight on the possibility of farm exit. The value at risk "VaR20" was also computed. It corresponds to the average of the 20% of the lowest income and indicates downside risk (Bell *et al.* 2021). The standard deviation of net income also provides a measure of the overall variability.

2 Results

2.1 Risk exposure and risk management according to farmer declarations

2.1.1 Farmers' perception of risks

Farmers were asked the importance of different types of risks for them (Table 2). Personal Health, plant disease and public policy represented low risks for most of the farmers interviewed. The low personal health risk was justified by the sustainable workload (F65), regular holidays (F63), but also by the fact that they were producing and consuming organic products which allowed them to remain in good health. Nonetheless some of them pointed that if they had health problems, they would certainly have problems to benefit from the replacement service due to the lack of available workers. All the farmers surveyed considered the presence of pests, diseases or weeds as rather low risks. They had damages due to the non-use of chemicals but they were used to rely on natural balance in organic production. Regarding public subsidies, the majority of the breeders said that they were well supported by the Common Agricultural Policy (CAP) until now, despite the existence of uncertainty on the new CAP as underlined by F65. F63 considered the risk of public support as medium, mainly because of the risk of non-compliance with rules during controls which could lead to a reduction of supports and because the exact amount of support was not well known in advance.

Machine breakdown, animal production and input prices were considered as medium by two out of four farmers. For those who renewed their machines regularly and maintained them as F65, the risk of breakdown was low. For two others, it was medium. F63 reported troublesome breakdowns the last two years. The risk related to herd production was perceived differently by the farmers surveyed. Some of them considered it to be low because of the presence of hardy breeds, which gave them a certain flexibility and regularity such as F65. F67 considered animal health as a big risk and feared large animal epidemics which could have dramatic impacts on the farm. F65 and F74 gauged animal production risk as medium. F63 mentioned the importance of avoiding mating seasons with risk of heat stress and also the negative impacts of a too low supply of forage on ewe reproduction. Regarding input prices, farmers made contrasting answers. F65 purchased little inputs and felt not exposed to this market risk. F63 had at the beginning the same position but changed it as medium when he considered the cost of feed purchase to offset years with low grassland production. F67 considered this risk as high as he had no control on input prices and thus felt powerless.

The most important risks for farmers were output prices and climate conditions. The risks related to the marketing of products were considered low to high. F63 considered low market risks for outputs since for him prices and market opportunity are stable. However, he regretted that prices were always too low.

F65 was concerned about the maintenance of higher price for the organic products than for conventional products and the evolution of the demand of local communities such as scholar restaurants for local organic products. Similar to input prices, F67 and F74 considered that output price risks were high since they didn't control prices while these prices have high impacts on their income.

Regarding climate, all the farmers surveyed gauged that climatic conditions were a very important source of risks. They mentioned several types of climatic risks: irregular rainfall throughout the year, more frequent and severe heat waves and droughts (all farmers) and storms (3 farmers out of 4). They also feared frosts in spring for their cereals.

Table 2: Farmer perceptions of risks

	Human Health	Plant disease	Public policies	Machine breakdown	Animal production	Input prices	Output prices	Climate
F63	green	green	yellow	yellow	yellow	yellow	green	red
F65	green	green	green	green	green	green	yellow	red
F67	green	green	green	yellow	red	red	red	red
F74	green	green	green	green	yellow	yellow	red	red

Notes: Green: low, yellow: medium, red: high

2.1.2 Characteristics of climate and market risks

Climate risks were characterized through the variability of crop and grassland yields. Farmers were asked what they considered to be very bad, bad, normal, good and very good yields in terms of quantity produced and how often they had achieved this yield in the last 10 years.

Regarding spring grassland production, for all farmers the frequency of bad and very bad years was much higher than the frequency of good and very good years (maximum 1 year out of 10). The bad years eventually became "normal". For F63, F65 and F67, a very bad year for spring grassland production corresponded to a harvest of 1 tDM of grass per hectare and occurred between 2 and 3 years out of 10 over the last decade. F74 didn't report very bad years. For farmers, a bad spring grassland production corresponded to a hay harvest between, 2 and 3 tDM/ha and represented between 20% (F65) and 60% (F63) of years. Normal years ranged between 3 and 4 tDM/ha; good and very good years between 4 and 5 tDM/ha. Overall, F65 and F67 had a higher proportion of low yields (Figure 4), that is consistent with their lower stocking rates (Table 1). All farmers mentioned that very low (or null) grassland production in summer was becoming usual and that grassland production in fall was rather risky: F63 considered that 2/10 years there are 2/3 of grass less in fall. Farmer F63 also mentioned impacts on animal production in case of poor forage production with a reduction of 0.15 in productivity per ewe. F63 had also an agreement with his neighbour to buy him hay at a maximum of 130 €/tDM.

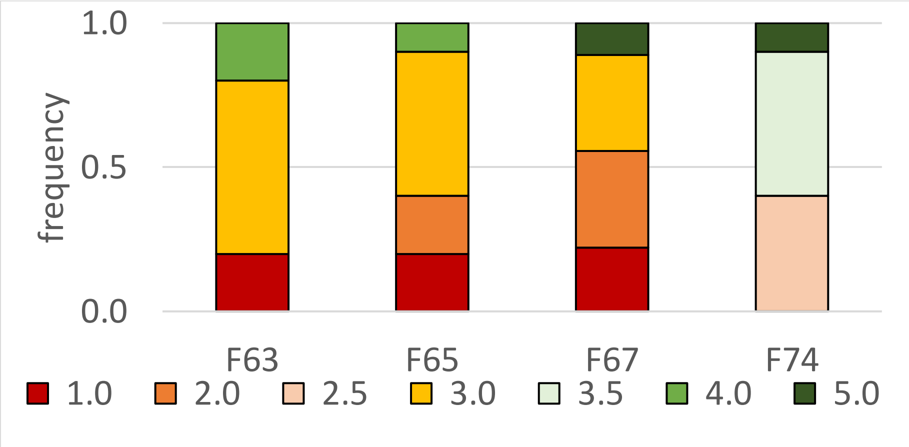


Figure 4: distribution of 1st cut grassland yield (tDM/ha)

Regarding straw cereals (Figure 5), F67 had the lowest yields: they mentioned 1 t/ha for a very bad year that happened 2 years out the last 10 years and 2 t/ha that occurred 6/10 years. F74 have the highest yields but also the most variability (between 2 and 5 t/ha). F63 told that staggering the sowing over 3 weeks contributed to reduce the crop yield variability.

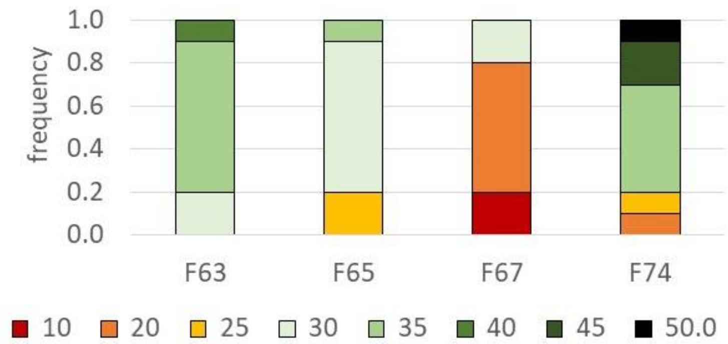


Figure 5: Distribution of cereal straw yield (tDM/ha)

Few farmers harvested mix cereal-legume crops for fodder. F67 who often did it estimated that production varied between 2 tDM/ha and 5 tDM/ha (Figure 6).

Table 6: Distribution of yields of the mix cereal-legumes crops harvested as fodder (tDM/ha)

	Very low	low	medium	good	Very good

Yield	2t	3t	4t	5t	6t
Frequency	30%	30%	30%	10%	0

Although price risks were considered as medium and sometimes high by farmers, they said that the variability of beef and cereal prices were rather low over the last years and that lamb price was stable. The following range of variation was cited:

- between 850 and 950€ for weanlings (F67)
- between 5.2-5.5 €/kgc for rosé veal and between 4.6 and 5.1 €/kgc for culled cows (F65)
- some problem of demand due to covid for F67

There is a high demand for organic cereals. Prices varied little: between 400€/t for a very bad year to 450€/t for a very good year.

Some farmers mentioned that they recently developed the production of rosé veal for short channel market and had problems to sell their products because of Covid and had to switch to the production of weanlings.

2.1.3 Current adaptations to climate risks

Farmers were challenged by climate variability and used different levers to face climate variability (table 7). Regarding grassland production, they experienced a shortening of the production period: grass started growing earlier in spring but growth stopped in June-July. Some farmers now only harvested their grasslands once instead of making two or three cuts. Adjustment of mowed areas varied from no change (F63, F65) to important variation (F67). F63 modified grazing management with shorter rotation and shorter grazing seasons for cows. F65 have the possibility to move his ewes to lake shores to provide 15 days of additional grazing. Some of them also benefited from wet meadows which can provide one more week grazing in dry periods. F63 also practiced rotational grazing to better use grasslands. Intercropping is not practiced on a regular basis except for F65. All of the farmers surveyed purchase fodder or concentrates, even in small quantities, almost every year in recent years to compensate for the lack of fodder produced on the farm. The majority of farmers attested to not having safety stocks. F74 declared that they did so three years ago by keeping 18% more than the production required during the winter.

Regarding animal production, most farmers preferred to keep producing the same kind of animals, except F63 that sold some animals younger and leaner, namely heifers because their cooperative was quite understanding. F63 also said that they had structurally reduced the number of cows. F74 told that in case of important drought they didn't hesitate to sell up to 20% of their cows (e.g. 10 cows).

Table 7: current management of grassland variability

	F63	F65	F67	F74
Grassland management	The same area of pastures are harvested. Faster rotations are done on grazed pasture. Cows are taken out of the pasture by the 15th of august in case of drought	often keeps the same management but prioritizes calves for grass consumption	Varies a lot	reduces mowed areas by an average of 20%.
Mountain pasture / low productive pasture		max 15 days for sheep	yes	
intercrop	Sometime 1 to 2 ha of mustard, forage cabbage, or oats	Meslin and early meadows planted with winter cereals and barley	Some rapeseed for grazing or for green fertilizer	Up to 16 ha of rapeseed but with low growth
Safety stock	no	no	no	Usually 18% but recently it was impossible
Purchase of feed	yes	In recent years: between 20t and 40t of hay	Frequently ≈ 30t of hay + soybean meal	Up to 110t of alfalfa
Adjustment of animal production	Yes: heifers are sold younger (24-25 months instead of 30 m.o.)	Little adaptations: want to finish animals (vealers) without keeping them longer (not possible for veal and not profitable for lamb)	no	Can sell 20% of cows in case of important drought but want to produce the same type of animal products

2.1.4 Potential long-term adaptations

Faced with climate change, farmers plan or have already started to change the structure of their farm to reduce their vulnerability (table 8). F63 and F67 have already reduced their herd size since the survey of 2017 to minimize costs related to the purchase of feed: F63 reduced the number of cows from 15 to 10 and F67 reduced their stocking levels and no longer think of using this type of adaptation. F65 and F74 plan to reduce their stocking rate. F74 wanted to increase the area of permanent grasslands.

All farmers planned to maintain several animal enterprises. F67 said that sheep are more versatile, consume less water, can graze pastures on the shores of lakes, and can even be moved seasonally to feed themselves (transhumance), but they are very sensitive to certain diseases. F74 confirmed that the sheep flock allowed them to compensate for losses related to the cattle flock, which mitigated the risk to their cash flow. It is for these reasons that they were in favor of the principle of diversification of products in the most difficult periods. Most of them wanted to maintain beef cattle and sheep for meat except F65. The son of F65 will take over the farm and want to replace beef cattle by dairy cattle and make cheese. Some farmers were thinking of adding a monogastric enterprise (F63 and F67).

In order to cope with climate change, some farmers surveyed were interested either in seeding more forages characterized by a rapid growth and being able to be harvested in spring (e.g., meslin), or in expanding perennial grasslands. Most of the farmers did not think to increase the area under cereal crops instead except F65 who might consider an increase of 5 or 6 ha. F63 was also thinking of adding legumes to make flour. F74 was upset by lacking of manure when reducing the stocking rate. Manure is essential to make the cereals more productive in the organic sector. He said that if they reduce the size of the herd, they will always resort to the purchase of biofertilizer and manure, which are expensive. In addition, most of the farmers surveyed reported that they will not use irrigation and irrigated crops although one started to make water retention with some success. According to the interviews conducted, almost all farmers did not plan to put in more trees or hedges to increase the amount of shade, as almost all of them were in communities with abundant forest. None of the farmers surveyed had taken out or planned to take grassland insurance which was considered too expensive.

Table 8: Potential long-term adaptations to climate change

	F63	F65	F67	F74
Reduction in the level of stocking	Already reduced the number of cows since 2017.		Already done since 2017.	Yes around 20% less
Forages? cash crops?	Reduce the proportion of spring cereals that are riskier than winter cereals. legumes to make flour for human?	5-6 ha of cereals	More forage crops for spring harvest or more permanent grasslands	30 ha of permanent grasslands
abandonment of beef or sheep workshop	no	His son will take over the farm → decide to replace beef cow by dairy cow to make cheese	Sheep are more flexible, more resistant to drought but more sensitive to disease→ keep both beef and sheep	No. Sheep are more profitable at the moment
Increase of trees for shade	no	no	No, already plenty of trees	No, already plenty of trees

New animal enterprise?	Poultry?	Dairy for cheese	Pigs? Poultry?	Not enough manure for cereals if they reduce herd size.
insurance	no	no	no	no

2.2 Simulations with the Orfee model

2.2.1 Simulation settings

2.2.1.1 Combination of hazards considered

Based on farm surveys, we considered seven types of risks: spring grassland yield, fall grassland yield, cereal yield, cereal price, beef price, input price and agricultural policy. Regarding the risk on spring grasslands production (Table 9), we assumed that all grassland management were impacted in the same proportion until may for grazing and for the first cut (silage or hay) and that this reduction of grassland yield was regional so that the local market of hay was impacted. The impact on forage price was lower for F63 that had an agreement with his neighbor to fix hay price not higher than 30% of the average price. We assumed that all farmers had a probability of 20% to have 70% of production less in fall, associated to a normal spring grassland production. For F63, ewe productivity was lower in accordance with F63 declaration.

Table 9: Variation in Grassland production

		spring							fall	
Var. grassland prod. (%)		**-70**	**-40**	**-30**	**0**	**20**	**30**	**40**	-70	0
Probability (%)	F63	20			60		20		20	80
	F65	20		20	50	10			20	80
	F67	20	20		50			10	20	80
	F74		40		50	10			20	80
Var. hay price (% de var.)	All	60	30	20	0	-20	-20	-30		
	F63	30	"	"	"	"	"	"		
Reduction of lamb/ewe	F63								0.15	

Regarding cereal yields (Table 10), we assumed that winter cereals and meslin for grain sown in winter will be affected in the same proportion by hazards. Variations considered were those reported by farmers assuming that their mean yield corresponded to the most frequent yield cited by them. The price of cereals depends on the world market and were not modified according to crop yield variations.

Table 10: Distribution of cereal production simulated

Cereal yield		**-50%**	**-30%**	**-15%**	**0%**	**15%**	**30%**	**50%**
Probability	F63			20%	70%	10%		
	F65			20%	70%	10%		
	F67	20%			60%			20%
	F74		20%		50%		30%	

Cereals price risks affected all cereals purchased (grains) or sold by farmers (Table 11). The range of variation considered corresponds to the variation mentioned by F67 (the only one who sold cereals). Soybean meal and complex industrial feed followed conventional price variations. Input prices and subsidies considered were those of the period 2010-2018. Input price variations between years were calculated as a reference price, multiplied by the index of price variation and deflated annually by the consumer price index. These indices were computed by the French national institute of statistics and economic studies.[1] The main national and European subsidies granted to bovine, ovine and crop productions were taken into account (Mosnier et al., 2017).

Table 11: Distribution of cereal prices simulated

Var. of price	-6%	0%	+6%
probability	20%	60%	20%

To reduce the number of risk combinations, beef price risks affect all beef categories at the same time (Table 12). No variation of sheep price had been introduced, according to farmers' answers.

Table 12: Distribution of beef prices simulated

Variations simulated	-2%	0%	+2%
frequency	40%	30%	30%

[1] Indexes are IPAMPA and 'indice annuel des prix à la consommation – ensemble des ménages': Insee https://www.insee.fr/fr/statistiques?debut=0&theme= 30&conjoncture=49

The variations of grassland yields, cereal yields and market prices were considered to be independent excepted for forage price that increased in case of local low forage yield.

2.2.1.2 Strategies tested

Two alternative scenarios were simulated and compared to the 2017 farm structure baseline: 1) reduction of stocking rate either by a decrease in the size of the herd or by an increase of the surface in grasslands and 2) reduction of stocking rate associated to a change in the animal enterprise mix either by the addition of a pig enterprise or the replacement of beef enterprise by a dairy cow enterprise (table 13). Farm setting for cattle, sheep and crop production used for each farm are presented in appendix A1. Parameters used to simulate the additional pig and dairy enterprises are given in appendix A2.

Table 13: Long term adaptation tested

	Base	**Reduction of stocking rate**	**Reduction of stocking rate + Animal mix (LU-mix)**
F63	« *F63* » : 15 SCow +220Ewes	« *F63_LU-* » : 10 SC + 200 E	« *F63_LU-_pig* » : 500 piglets +10 SC + 200 E
F65	« *F65*» 28 SC+185E	« *F65_LU-* » *and* « *F67_LU-* »*:* 80% of beef and sheep	« *F65_LU-_dairy* » 19 dairy cows; 185 E
F67	« *F67*» 39 SC+120E		« *F67_LU-_pig* » 500 piglets + 31 SC + 96 E
F74	« *F74*» [39-47] SC+ 100E	« *F74_PG+* » +30 ha of perm. grasslands	« *F74_PG+_pig* » 500 piglets + [39-47] SC+ 100E

The short-term adaptations such as feed purchase, feed stock, modification of grassland and forage end-use, intercropping and the type of animal produced and sold were optimized by the model for each combination of risk within the range of possibilities specified by farmer (table 14). For F63, cows were automatically kept indoors at the end of spring when fall production was very low. A bias in the model let the model optimize to some extent the number of lambing per ewe by decreasing the number of lambing up to 14% relative to farm potential.

Table 14: Short term adaptation allowed

	↓ age or liveweight of animals sold	↑Sell cows	↓ mowing	intercrops	↑Feed purchase	↓ lamb	End-use of meslin

F63	+			+	+	+	
F65				+	+	+	+
F67			+	+	+	+	
F74		+	+	+	+	+	

2.2.2 Simulation results

2.2.2.1 Short term adaptations simulated according to long term strategy

F63 and F74 had the possibility to modify beef production. F63 sold young bulls and heifers younger and lighter in case of very bad grassland production and heavier in the opposite situation which led to a variations of beef production between 442 and 521 kglw/cow for the baseline. When F63 reduced the herd size (F63_LU80), it enabled to increase meat production per cow for normal and good years. When the pig enterprise was introduced (F63_LU80_Pig), production per animal was slightly reduced due to family labor limitation. F74 culled more cows to reduce the stoking rate in case of bad grassland production cumulated with low cereal yield, this led to a variation of beef production between 457 and 592 kglw/cow. In addition, the number reproductive cows were modified (lower number of cows in bad years) which lead to a high variation of herd size. The long-term adaptations (additional permanent grasslands and introduction of pig enterprise) didn't modify much the range of variation of beef production for this farm. In all farms, the number of lambs was reduced in case of low grassland production or high cereal prices to reduce feed consumption.

Regarding the adjustments of the area mowed, only F67 and F74 had this possibility. When grasslands yields were down 1 tDM, the area of grassland harvested was drastically reduced: harvesting low grassland yield meadow is expensive and the priority was given to grazing. When grassland yields reached 5 tDM, it became profitable to harvest more and sell the surplus. These farms exhibited a higher variability of the quantity of hay harvested. Reducing the stocking rate modified the forage management. F63 and F65 didn't have the flexibility of modifying the area mowed and as a consequence, they harvested more forage per LU and bought less hay (F63) or sold more hay (F65). F67 and F74 reduced the area of grassland harvested in a "normal" year. All farmers largely offset variation of forage production by the purchase of straw, hay and concentrate feed. Most farms consumed less concentrate when stocking rate was reduced except F65 who produced mixed meslin grains that were assumed to be only consumed by the herd; consequently, for this farm, this is the surplus of forage that was sold and more meslin grain was distributed per LU. Adding a pig enterprise considerably increased the quantity of concentrate consumed and purchased which made the farm less self-sufficient. The dairy enterprise also consumed more conserved forages and concentrate feed.

The number of hours per worker unit was calibrated according to the number of workers declared by the farmer and the number of hours simulated by the model. We assumed that when the scenario reduced the number of working hours, farmers worked less. Conversely, when the scenarios induced a significant increase of the working hours, additional salaried workers were hired. Reducing herd size by around 20% reduced working hours by 17%. Labour was less reduced in F63_LU (11%) because the beef cattle were reduced in higher proportion than sheep which is more labour intensive. For F74, reducing the stocking rate by the addition of permanent grasslands increased labour by 3% which induced an increase of salaried workers. The addition of a pig enterprise cumulated to the reduced stocking rate situation increased labour by around 300 hours. These scenarios had a workload close to the baseline situation. However, the beef and sheep production were in most cases slightly reduced to avoid to hire workers. In the case of F65, for which beef cattle enterprise was substituted by the dairy cattle-cheese enterprise, 2.5 additional salaries workers were necessary to milk the dairy cows, produce and sell the cheese.

Table 15: Main production characteristics for a 'normal year' and their range of variation across the different risk combinations

	Herbivorous			**Forage & straw**				**Cereals and concentrate**		**Labour**	
	Adm LU	Kg Lw/ cow	Kg carc /ewe	Area harv. (ha)	Hay and straw Harv (t).	Straw balance* (t)	Hay balance* (t)	consumed	Balance*	salaried worker (WU)	Hours (1000 hr)
F63_Base	65 *[61;67]*	462 *[442;521]*	18 *[16;18]*	27	91 *[29;117]*	-46 *[-70;-39]*	-6 *[-89;0]*	51 *[38;79]*	-9 *[-59;4]*	0	1.7 *[1.6;1.8]*
F63_LU^-	56 *[53;57]*	512 *[442;537]*	18 *[16;18]*	27	91 *[29;117]*	-33 *[-19;-36]*	-1 *[-50;20]*	37 *[32;66]*	4] *[-45;17*	0	1.5 *[1.4;1.6]*
F63_LU^- _Pig	55 *[52;57]*	474 *[434;530]*	18 *[16;18]*	27	91 *[29;117]*	-31 *[-18;-35]*	6 *[-50;20]*	197] *[191;221*	-155 *[-200;142]*	0	1.8 *[1.6;1.8]*
F65_Base	69 *[68;70]*	294	19 *[18;21]*	38	115 *[48;138]*	-45 *[-45; -47]*	0 *[-74; 38]*	29 *[24;53]*	-4 *[-43;-2]*	0	1.7 *[1.7;1.8]*
F65_LU^-	56 *[55;57]*	294	19 *[18;21]*	38	115 *[43;138]*	-36 *[-35; -40]*	26 *[-38; 70]*	26 *[22;36]*	0 *[-42;1]*	0	1.4 *[1.4;1.5]*
F65_LU^- Dairy	53	239	19 *[19;21]*	38	115 *[34;138]*	-86 *[-95;-86]*	-30 *[-95; -1]*	45 *[43;69]*	-18 *[-64;-14]*	2.6 *[2.6;3.2]*	7.3 *[7.3;7.5]*
F67_Base	95 *[91;95]*	322	26 *[23;26]*	47 *[13;47]*	169 *[30;239]*	-31 *[-49;-9]*	-3 *[-136;-3]*	37 *[32;48]*	25 *[-18;60]*	0	2.3 *[2.1;2.3]*
F67_LU^-	76 *[73;76]*	322	26 *[23;26]*	29 *[20;42]*	131 *[42;231]*	-19 *[-36;0]*	0 *[-75; 82]*	26 *[21;37]*	39 *[2;81]*	0	1.9 *[1.8;1.9]*
F67_LU^- _Pig	76 *[73;76]*	322	26 *[23;26]*	29 *[20;42]*	135 *[42;231]*	-19 *[-36;0]*	0 *[-75; 82]*	184 *[181;197]*	-111 *[-157;-79]*	0	2.2 *[2.1;2.2]*
F74_Base	101 *[83;101]*	457 *[457;592]*	26 *[22;26]*	*40* *[37;46]*	156 *[46;214]*	-42 *[-46;-29]*	15 *[-99;93]*	54 *[31;73]*	-14 *[-29;21]*	0.1 *[0;0.2]*	2.4 *[2.0;2.4]*
F74_PG^+	101 *[83;101]*	457 *[457;592]*	26 *[22;26]*	37 *[37;50]*	146 *[40;217]*	-42 *[-46;-29]*	0 *[-71;100]*	54 *[31;73]*	13 *[-11;20]*	0.1 *[0;0.2]*	2.4 *[2.0;2.4]*
F74_PG^+ _Pig	101 *[84;101]*	457 *[457;519]*	26 *[22;26]*	37 *[37;50]*	146 *[46;225]*	-42 *[-46;-29]*	0 *[-71;100]*	213 *[189;233]*	-173 *[-169;-138]*	0.5 *[0.1;0.8]*	2.5 *[2.3;2.7]*

*Notes: value for a "normal" year and Minimum and maximum values between brackets when variability is observed. *balance = sale + var. Stock– purchase*

2.2.3 Simulation results: Sensitivity

Sensitivity was highest to changes in producer prices, particularly for pork and milk prices, followed by subsidies, spring pasture yield and then grain yield. They were not very sensitive to fuel prices of grassland fall yield.

Farm incomes had a sensitivity around 1.5 to beef and sheep prices, with higher values for beef or sheep according to the importance of each enterprise and farm average income. This means that an increase in beef or sheep price of 10% increases income by 15%. This sensitivity was much higher for pig or milk (between 3.5 and 6.5) that are characterized by higher receipts but also higher production costs. Farms were very sensitive to variations of subsidies (around 4) since subsidies were higher than their income.

Sensitivity to grassland yield was between 1 and 2.2 but was not linear. The sensitivity of farms for the baseline situation to a 40% reduction was around 1 but was twice higher for a 70% reduction due to higher forage price and lower buffer possibilities. F74 was less sensitive (1.7) due to higher flexibility to adapt its system and F65 who had less flexibility was the most sensitive (2.2). The reduction of stocking rate, reduced this sensitivity. The sensitivity of F63 was less reduced because it harvested less forage per LU for a normal year: F63 had a larger proportion of sheep that consume less forage during winter and lower proportion of fall lambing which reduced even more the feed requirement during winter. The introduction of pigs or dairy also reduced the sensitivity by increasing average income. Dairy slightly increased the sensitivity to intermediate grassland loss because dairy needs more harvested forage than beef.

The sensitivity to cereal yield was between 0.5 and 1.5. It was more important for F67 and F63 due to a higher proportion of cereals crops than F65 and to a lower income than F74. The sensitivity to cereal yield was between -0.3 and 0.7. Sensitivity to cereal prices were the highest for F67 who sold cereals on the market. At the opposite, it was very low or even negative for other farmers that usually didn’t sell cereals and bought some grains. The sensitivity to price of concentrate feed (oil cake, industrial feed) was generally lower than 0.3 except for F67 (0.5) that bought all concentrate feed. However, it became very high with the introduction of a pig enterprise (between 2.7 and 5.8) which imported all concentrate feed.

When we crossed the maximum intensity of hazard mentioned by farmers with sensitivity, the risk associated with 70% reduction of grassland yield was by far the highest. The risk of cereal yield was also very high for F67 which was both sensitive and highly exposed. Note that the introduction of a pig enterprise induced also rather important market risks.

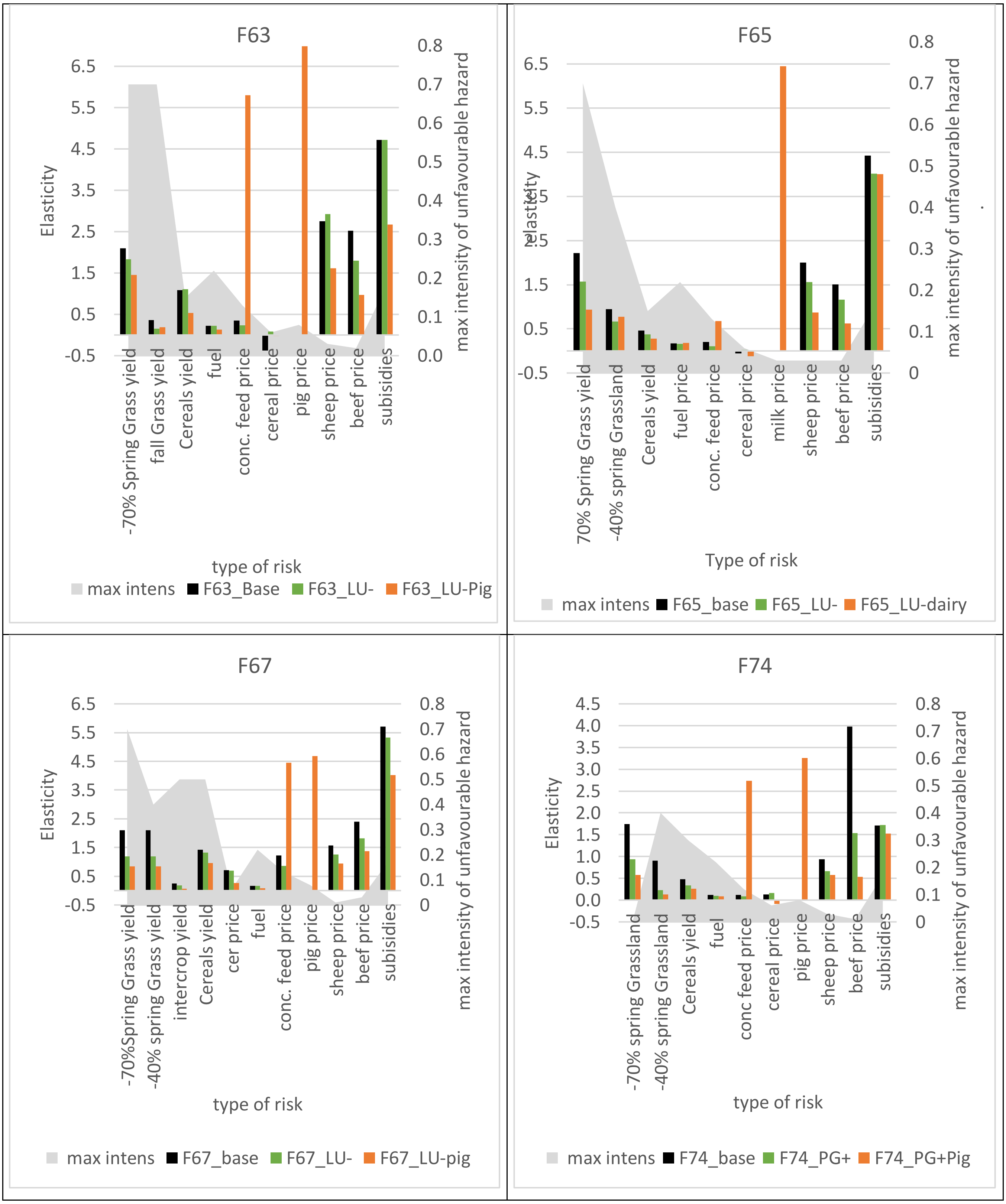


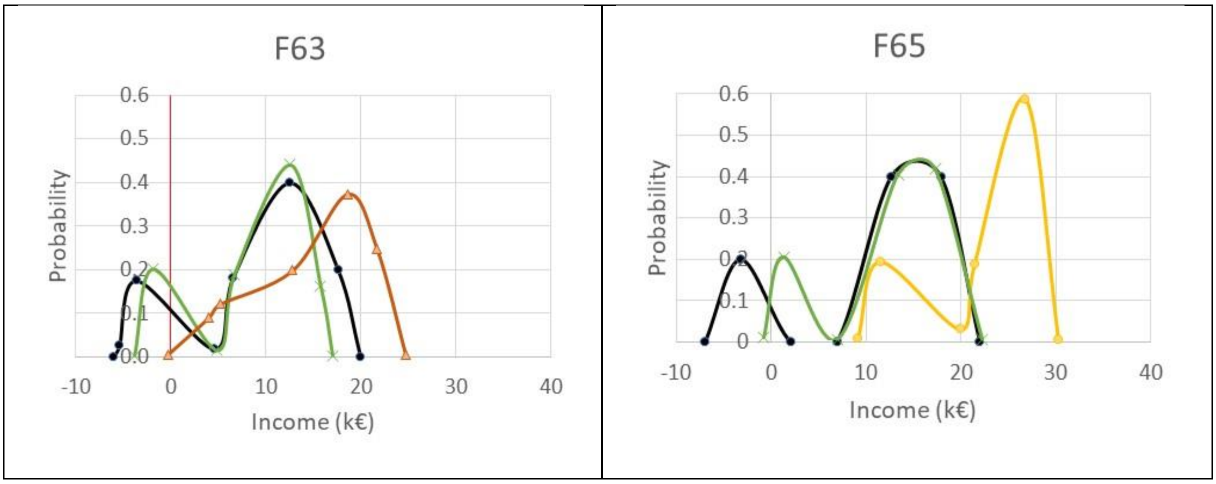
Figure 6: Sensitivity of farm income to the different source of risks and intensity of hazards simulated

2.2.4 Simulation results: Vulnerability

Three of the four farms were found to be vulnerable for the baseline situation since they had significant risk of very low incomes. F63 and F65 were the most vulnerable with probability to have negative income around 20% which corresponds to the very bad spring grassland yield probability for these farms (table 16). F63 had also a higher probability to have income below 10 k€ and negative VaR. Farms that had already low income because of low technical performance or high fixed cost in a normal year, had higher probability to fall below critical levels. F74 had both the less variable income and low risk of low income. F74 had lower exposure to grassland yield variation and was less sensitive thanks to a higher flexibility. We found that F67 had the most variable results, with the highest standard deviation and a distribution curve rather flat (figure 7). F67 was both very exposed to cereal yield risk and grassland production yield with a hay production per hectare varying from 1 to 5 tDM.

The reduction of stocking rate reduced variability and standard deviation in all cases, nonetheless it didn't remove the probability to have negative income (F63 and F67).

The introduction of a pig enterprise and the replacement of beef by dairy and cheese making did not reduce much the standard deviation due to significant risks associated to these enterprises but increased income. Consequently, the farm vulnerability was reduced.



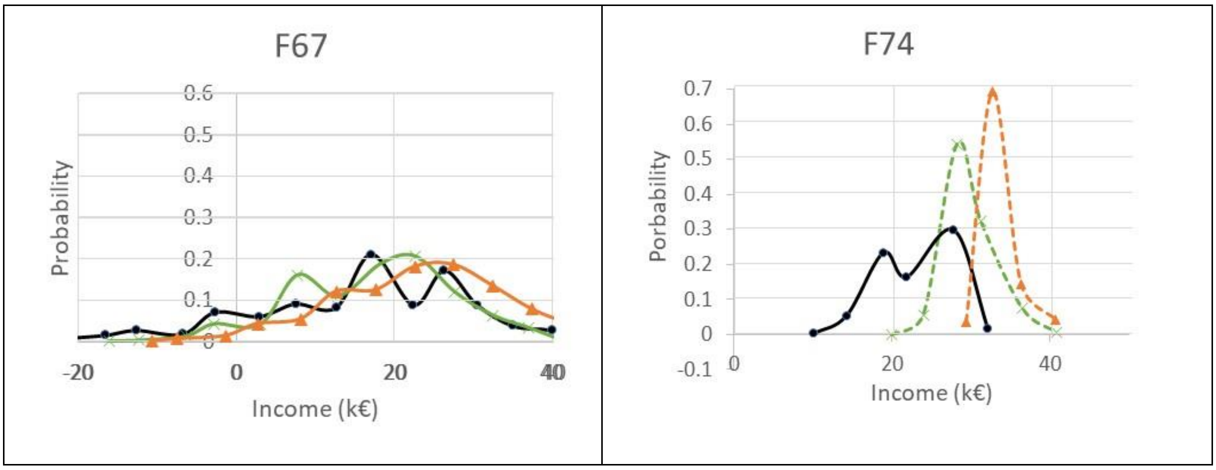


Figure 7: Distribution of income according to the different strategies tested

legend: black curves with circle: baseline; green curves with crosses: lower stocking based on herd reduction (continuous line) or more grasslands: (dotted lines); orange curves with triangles: lower stocking rate + pig enterprise, yellow curve with circle: lower stocking rate + dairy and cheese factory

Table 16: Indicators of income distribution

	INCOME				
	Mean	SD	% <0 k€	% <10 k€	VaR
F63_Base	9.2	7.0	20%	40%	-3.25
F63_LU80	8.9	6.3	20%	40%	-2
F63_ LU80_Pig	15.7	6.2	0%	20%	5
F65_Base	11.6	7.8	20%	20 %	-3.2
F65_LU80	12.5	5.9	0%	20 %	1.3
F65_LU80_Dairy	22.3	6.8	0%	7 %	11.7
F67_Base	16.7	14.8	14%	29%	-2.3
F67_LU80	17.3	11.1	7%	27%	4.2
F67_LU80_Pig	23.0	11.6	2%	12%	5.4
F74_Base	25.1	5.8	0%	0%	17.8
F74_LU80	29.6	2.9	0%	0%	27.5
F74_LU80_Pig	33.7	2.6	0%	0%	30.5

Notes: SD : standard deviation, VaR : Value at Risk which corresponds to the average value of the 20% of the lowest income

3 Discussion

3.1 A framework to test adaptation scenarios to reduce vulnerability

The intensity and probability of risks for output prices and production levels were defined based on farmers' memories of the last decade. Direct elicitation appeared as an easy way to obtain risk perception of farmers according to their own situation (Hardaker et al. 2004). However, it had also several limits.

Regarding grassland and crop yields, farmers declared very high intensities and probability of adverse events with a maximum of -70% of loss for the first cut of hay. It is much higher that the maximum variation of total grassland production at department level estimated by Agreste[2] which is around 30%. These differences could be explained by the fact that production in Agreste is summed up for one year and averaged at "département" scale. We may have overestimated these variations by not taking explicitly into account the variability between farm plots and by assuming that the same difference was observed for grazing availability. There is generally less grass wasted when the production is low (fewer refusals, trampling etc.) and lower senescence process so that the variation in grazing may be not as important as for haymaking. The same comments could be made for cereals. Some farmers explicitly considered variations of grain yield at farm level, but some others may have considered this variability at plot level.

Farmers said that the animal production and prices were rather stable. However, when they justified why they wanted to keep mixed livestock species, some of them mentioned that sheep were for instance more sensitive to diseases or that sheep allowed them to compensate for losses related to the cattle flock. In (Benoit *et al.* 2020), the variation in ewe productivity appeared as a major risk. The potential underestimation of these risks could be due to some bias in the course of interviews. Farmers had come through three years characterized by very low grassland production and the questionnaire was announced with an objective to study adaptations namely to climate change. Consequently, risks linked to animal production might have been minimized because they were not considered as a major problem at this moment and had consequently not the right figures in their mind. They could also be ashamed of not being able to maintain good technical performance and were not willing to mention it.

- Sensitivity

We simulated that the maximum quantity of hay purchased (Table 15) was much higher than the quantity of forage they mentioned to have bought the previous years (Table 7) for the farmers that have mentioned production loss of 70%. One reason could be that the variation of grassland production was

[2] https://agreste.agriculture.gouv.fr/agreste-web/disaron/SAANR_FOURRAGE_2/detail/

overestimated as explained in the previous section. Another explanation could be that some adaptations were not simulated. Farmers mentioned intercropping as a lever to face forage shortage while in the simulations, intercrops were either always or never chosen. The farms simulated had limited possibilities to have intercropping because they had mainly permanent grasslands and winter cereals or meslin. Farmers mentioned forage rapeseed which is not currently included in the model and which is probably more appropriate for their situation. Sheep moving on marginal lands (lake shore etc) were also not included. At the opposite, the adaptation of pasture mowing was largely used as also observed in previous studies on real farms (Mosnier *et al.* 2014). The animal production was also adjusted when possible, and sometimes in higher proportion than the range of variation initially planned: one farm not only culled more cows but also reduced the herd of reproductive cows and lambing was reduced in the case of low forage and cereal resources. The cost of replacing culled cows by pregnant heifers was considered but neither the highest difficulty to sell cows when forage shortage is widespread nor the risks to brings into the herd external pathogens were considered. An interannual analysis would have been interesting to analyse herd dynamics but also forage stocks over time to analyse how costs could spread over time (Mosnier *et al.* 2009) and to analyse how vulnerable farms are according to the successions of past events (Mosnier 2015).

- Vulnerability

In this paper, we assessed farm vulnerability by analysing income distribution under the main risks emphasized by farmers. Similar to Benoit *et al.* (2020), we did it by making several runs of a static model. In order to limit the number of simulations we didn't make random draws into different simulations but we chose to define a limited number of states of nature. This saved simulation time but required to weight each simulation by its probability. Another options would have been to use the scenario tree reduction technique (Kostrova *et al.* 2016). Other types of models can be used to analyse vulnerability such as stochastic viability framework that can be used to identify sustainable management strategies over time (*Joly et al, under revision*). However, these types of models had decisions rules that are exogenously defined and not always the best option regarding current farm stocks and production context. The optimisation framework proposed enable to simulate endogenous adaptation problems. However, the long-term strategies are still defined exogenously and prevent for instance to define what would be the optimal stocking rate or enterprise size.

Several studies underlined the importance of external social factors such as social structures, institution or agricultural policy (Reid *et al.* 2007; Chuku & Okoye 2009; Cardona *et al.* 2012). In this study, the focus was on the farms themselves. The current subsidies were accounted for but the support of the government in case of very low forage production, technical supports offered by local extension services or farmers education were not considered.

3.2 Reduction of stocking rate: a solution to reduce vulnerability?

The reduction of stocking rate was cited by farmers as an important element of adaptation of farmers to climate change. The reduction of stocking rate already occurred since the first survey 2017 or farmers planned to do it. The simulations showed that in the four cases the reduction of stocking rate enabled to reduce income variability and, in most cases, increased slightly expected farm income.

The fact that the reduction of stocking rate reduces income variability is in line with previous studies. Mosnier *et al.* (2012) found that in suckler cow systems of the north Massif Central in France, both results from a modelling study and farm database analysis showed that standard deviation of income per worker unit was lower in farms with lower stocking rate. Ritten *et al.* (2010) simulated with a stochastic dynamic programming model that an optimal adaptation to increased precipitation variability was a reduction of stocking rates. Beukes *et al.* (2019) also simulated that systems with lower stocking rates were less exposed to climate and economic risks. Regarding the impacts on average income, more heterogeneity exists. Ritten *et al.* (2010) and Mosnier *et al.* (2012) found that systems with lower stocking rate have similar or higher income, but Beukes *et al.* (2019) found the opposite. The impacts of the variations of grassland production are asymmetric (Mosnier *et al.* 2014): a lack of forage induces higher production costs due to the purchase of supplementary feeding at high price or lower receipts linked to lower animal productions while an excess of forage is sometime difficult to exploit and to sell because of low demand for forage in good years or low storage capacity. In this study we assumed that forage price was higher when forage production and lower when forage production was high, with limited possibilities to adjust animal production. Consequently, it was profitable to keep herd size below average grassland capacity. However, the impacts of under-grazing on the botanical composition of grasslands (Behrendt *et al.* 2016) and encroachment (REF) which could reduce the grassland production of meadows was not taken into account and would limit the advantages or reduce the stocking rate.

We simulated that the reduction of stocking rate smoothed income but was not sufficient to avoid very low income induced by very low level of grassland production. It would be very costly for farmers to design their farming systems to be able to buffer 70% loss of forage. The cost of self-insurance (reduction of stocking rate and security hay stock for instance) increases for important and rare losses and in this case insurance could be more efficient (Mosnier 2015). The farmers interviewed were opposite to this option because of its cost, probably also because public compensation is still currently proposed in case of very low grassland production occurring at regional level. They were also more interested in diversifying their forage production.

3.3 Adding monogastric to mixed sheep and cattle farms: a solution to reduce vulnerability?

This study had not compared specialized systems *vs* mixed livestock systems as reviewed in Martin *et al.* (2020) or tested in Mosnier *et al.* (2021), or analysed the optimal proportion of each species as did Joly *et al.* (2021) or Diakité *et al.* (2019). The farmers interviewed were already convinced by diversified systems and wanted to keep both sheep and cattle. However, these mixed systems often generated rather low income as confirmed by farm surveys made in 2017 (appendix A3) and the risk of very low income remained high. Three out of four farmers were thinking of diversifying with a monogastric enterprise. Another farmer wanted to reduce its stocking rate but was upset regarding his self-sufficiency in fertilizers and consequently a monogastric enterprise was tested to help him to be self sufficient in manure. Although farmers were initially thinking about a poultry enterprise, a pig fattening unit was tested because the local demand for this production is important. Results from this study showed that the introduction of a pig fattening enterprise increased average income by around 5 k€ for selling price of 3.6 €/kgc. However, many organic farmers interviewed in the project MixEnable sold their pig on short channels and obtained heterogenous prices. The lowest price was 3.2 €/kgc which would induce 14 k€ of income loss (it concerns farms with less than 40 pigs); the maximum price was 5.7 €/kgc which would increase receipt by 79 k€ but this farm used twice the quantity of feed consumed per pig which cancelled out the surplus. We also showed in this study that the farming system was really sensitive to a change in feed costs and pig sales, consequently farmers had to fine tune their production system to make it profitable. The results also showed that the standard deviation was not significantly lower when adding a pig enterprise although one could think that a higher level of diversification would reduce variability. Pig enterprise was indeed associated with a rather high market risk. This result is in line with a previous study made on conventional mixed pig-cattle enterprise in the Aporthe project (Boukhriss *et al.* 2021). Note that we assumed that between year variability of organic prices was similar to conventional pig systems, which could have led to an overestimation of market risks since in general organic prices are more stable. Notwithstanding, we have assumed that the addition of a pig enterprise wouldn't deteriorate the performance of the other enterprises. Increasing the level of diversification may reduce the performance of farmers due to the increasing complexity of systems (de Roest *et al.* 2018). Most mixed livestock farmers interviewed in MixEnable were satisfied with their working condition. Nonetheless, some of the four farmers interviewed justified the low performance of their sheep flock by saying that the sheep herd was not their priority. In this case, we could wonder if it would be not more profitable to focus on improving the performance of each enterprise prior to multiplying them.

4 Conclusion

The objectives of this study were to assess how organic cattle-sheep farmers of the French Massif Central feel exposed to risks and how they manage them and to simulate the impacts of different strategies to reduce their vulnerability. A framework was developed to simulate ex-ante and ex-post adaptations to risks based on the orfee static optimisation model: main structural variables and margin of manoeuvre were fixed exogenously while herd management, forage end-use, intercropping, feed purchased or sold are optimized for different combination of hazards, that are aggregated afterward and weighted by their probabilities. Based on farm surveys, seven types of risks were aggregated: spring grassland yield, fall grassland yield, cereal yield, cereal price, beef price, input price and agricultural policy. The distribution of yields and output prices were based on subjective farmer probabilities. Two alternative scenarios were simulated and compared to the 2017 farm structure baseline: 1) reduction of stocking rate either by a decrease in the size of the herd or by an increase of the surface in permanent grasslands and 2) reduction of stocking rate associated to a change in the animal enterprise mix either by the addition of a pig enterprise or the replacement of beef enterprise by a dairy cow enterprise. We assessed farm sensitivity to risks by estimating elasticity of income to the different source of risks and farm vulnerability by analysing income distribution. Grassland production risk appeared to be the most serious risk, followed by market risks. Three of the four farms had significant risks of very low income for the baseline situation. The reduction of stocking rate reduced variability of income in all cases, nonetheless it didn’t remove the probability to have very low income. However, the variations of grassland production may have been overestimated since we had assumed similar reduction of production for hay and grazed grass, without accounting for grassland plot heterogeneity regarding their sensitivity to climate risks. Current governmental supports in case of very low grassland yield, could also limit income losses. The introduction of pig enterprise and the replacement of beef by dairy did not reduce much the variability but increased all incomes and consequently reduced the farm vulnerability. However, these new enterprises being particularly sensitive to feed costs and sales, farmers have to maintain a good control of their production, which could be more difficult in a diversified system managed by a very small work group.

Appendix

Appendix A1: Farm setting

To account for farm heterogeneity, we adjusted the model parameters to each farm characteristics. Animal liveweight and age at selling, prices, culling rate, mortality rate, and grazing period were fixed based on 2017 farm survey (Appendix A1.1 and A1.2). Sometimes, we couldn't directly use the parameters recorded during the survey. Between year variations can be important, above all for farms with small numbers of animals. For instance, advancing or postponing the sale by a few months can have important impacts on annual technical parameters such as the culling rate. The Orfee model represents a herd functioning at equilibrium, some assumptions were thus needed to obtain renewal rates equal to culling rate. Mortality was also adjusted in some cases to avoid 0% kid mortality which is not achievable on the long run or very high mortality which was not representative of the normal farm running. Regarding cereal and grassland productions, average yields were fixed upon the 2021 phone survey (Appendix A1.3).

Appendix A1.1: Farm setting for cattle production based on the survey made in 2017

	F63	F65	F67	F74
Cattle sold	-Cow 640 kg: 2.3€/kg -Heifer 640 kg: 5.1€/kgc -Steer 860 kg:2.5 €/kgc -Young bull 530 kg:6.0€/kgc -Weanling 300 kg: 4.1 €/kgc	-Cow 720 kg: 3.3€/kgc -Veal 65 kg: 4.9€/kg -Weanling 340 kg: 2.4 €/kg	-Cow 670 kg: 2.2€/kg -Cow 395kgc: 3.8 €/kgc -Weanling 8m 284 kg: 3.3€/kg	-Weanling 300 kg: 1.7€/kg Veaux 220 kg: 9.7€/kgc -Heifer (for renewal) 500 kg: 2.6 €/kg b-steer 670 kg:8.2€/kgc
Herd renewal	Survey 2017: culling 20%; Renewal: 13% → hyp: R=C=14%	survey 2017: culling 60% Renewal 17% →Hyp: R=C=17%	Survey 2017: 8% culling ; 15 % renouv (with 4 heifers purchased) → hyp: R=C=15%	Survey 2017: 0% culling. 15% renouv; hyp: R=C= 15%
Calf mortality	3%	5%	Survey 2017: 0% hyp: 4%	Survey 2017: 17% Hyp checked with farmer: 4%
Grazing period	Weeks 15 to 43	Weeks 14 to 3	Weeks 13 to 49	Weeks 9 to 48

Appendix A1.2: Farm setting for sheep production based on the survey made in 2017

	F63	F65	F67	F74

Lamb sold/ewe	0.8	1.17	1.20	1.25
Type of sheep sold	-ewe 56 kg : 2.5 €/kgc -lamb 35 kg : 8€/kgc	-ewe 63 kg: 3.0€/kgc -she-lamb 32 kg: 4,6€/kg -lamb 15 kg: 1.1€/kg -lamb 28 kg: 7.6€/kg	- ewe 50 kg:0.24€/kg -lamb 20 kgc: 6.7 €/kgc -ewe+lamb: 2.6€/kg	-ewe 60kg: 1.2€/kg -lamb 37 kg: 4.1€/kg
% lambing in fall	20%	40%	30%	45%
Mortality rate of lamb	25%	21%	15%	23%
Grazing period	Weeks 13 to 36	Weeks 20 to 32	Weeks 13 to 46	Weeks 9 to 46

Appendix A1.3: Farm setting for crop and grassland production

	F63	F65	F67	F74
Cereals	6.5 ha : 35 qtx/ha	1 ha: 30 qtx/ha	25ha wheat and spelt: 25qtx/ha 5 ha buckwheat 20 qtx/ha	5 ha: 30-35 qtx/ha
Meslin- grain	8.5 ha: 23 qtx grain/ha	7.6 ha: 30 qtx grain/ha		15 ha:33 qtx grain/ha
Grasslands: 100% grazing	33 ha	69 ha	116 ha	36 ha
Grasslands: 1 cut hay of bale silage + grazing	22 ha: 3t DM/ha hay	38 ha: 3.1 tDM/ha hay	42 ha:3.1 tDM/ha hay	51 ha: 4tDM/ha hay
Grasslands: 2 cut hay+pasture	5 ha			
Notes	no grazing of cereal residues, wet grasslands not differentiated		Spelt replaced by wheat; no grazing of cereal residues	

Appendix A2: Parameters considered for pig and dairy production

Table A2.1: Parameters considered for pig production

	Paramètres	Source
Piglet purchased	500 / year at 91€/piglet	Organic mixed farm in Allier surveyed in 2017 for the Aporthe project
Pig sold	465 pig sold (mortality of piglet: 7%) at 124 (kg of liveweight (0.65 carcass yield) ; 3,6 €/carcass → 290€/pig	
Feeding	344 kg feed purchased/pig → ≈ 175€/ pig	
Housing	Building with 220 places. 4 boxes of 55 pigs + one piglet box to make buffer	
Labour	0.52 h/piglet (1 h/ day + 2 days of cleaning + various)	
Manure	3.7 kg dejection /day (N:9,1; P 7,2; K: 12,9 → mineralisation of N during the year ≈0,3)	Institut Technique du Porc, (2005)
Housing	300€/ place, depreciated over 20 years → 15€/place/year	Ifip, Revue technique (2019)
Charges diverses	0,034€/kgc pig for veterinary cost 0,05€/kgc pig for miscellaneous costs	Aporthe project

Appendix A2.2: parameters considered for dairy production

	hypothese	Source
Milk production	4400 L/dairy cow/year	F65
Cheese price	18€/kg	F65
Depreciation cost for the cheese factory	65 m² and 90 000 l/year: 75k€ HT depreciated over 15 years	Fiche technique transformation de produit Ohier suamme 2013 - Languedoc Roussillon
Depreciation of milking parlour	-herringbone parlour: 2175€/ dairy cow, depreciated over 20 years	
Depreciation of housing	-strawbedded stall: 3400€/cows depreciated over 25 ans	
Labour associated to cheese production and marketing	For 20 kg of cheese: 5h fabrication + cleaning, 2h affinage, 1h selling → +170h/dairy cow	www.Diversiferm.be (M carlier, vendre ses produits au juste prix)

Variable costs for cheese production	Ferment, rennet, packaging, small equipment, water: 23,3€/ 20 kg	www.Diversiferm.be (M carlier, vendre ses produits au juste prix)
Milk price excluding variable costs related to cheese production	For 10 L milk used per kg of cheese → 1.7 €/L	
Slurry and manure spreader shared with other farmers		

Appendix A3: Comparison of the simulation results with real farm results for the baseline

Simulated results when fixing herd composition and land allocation were compared to data recorded on the farm in 2017 (Appendices A3.1 and A3.2). Differences between the herd size in livestock unit and the quantity of animal sold were lower than 7%. These small differences could arise from some model simplifications that didn't consider for instance the heterogeneity between farms for the age of ewe at first lambing, or because some categories of animals have not been distinguished. We compared the simulation results with 2017 farm records. Appendix A3.1 shows that animal production and forage production simulated are very closed to recorded farm results (difference <7%). Grain production simulated for F74 is 16% lower because in 2017 because average crop yield provided by farmers were lower than 2017 yields. The difference of concentrate consumed by animals is generally below 16% except for F67 that recorded a high quantity of concentrate feed consumed by animals (700 kg / LU). The farmer told us that they tried to get into an organic rosé calf production in 2017. They had both rosé calves and weanlings that were all supplemented in the same way. Usually, they consumed around 450 kg/head which is closer to the value simulated. We simulated higher crop sales and no seeding while farmers did it because this reseeding option was not available in Orfee. We simulated that F67 purchased some hay in 2017 whereas this farm was self-sufficient in 2017. We certainly parameterized a production too low for a part of grasslands which could lead to an overestimation of the sensitivity to grassland yield variations in the result section. Regarding economic results (Appendix A3.2), we found that most of the differences are fair which lead to comparable operating results. Differences were higher for F67: we simulated an operating result of 21 k€ while the accountancy of this farm reveals -18 k€. Note that the farmer declared an income of 34 k€ which give some doubts about what is considered exactly on the farm.

Appendix A3.1: comparisons of simulations and data recorded on the farm for the year 2017

	Sim63	Real_63	sim65	Real_65	Sim67	Real _67	sim74	Real_74
Suckler cows	15	15	28	28	43	43	47	47
Ewes	220	220	185	185	200	200	100	100
Administrative LU	68	73	72	77	93	93	102	107
Live Meat beef produced (t)	8,2	8,5	9.1	9	14	15	15	14
Live meat sheep produced (t)	7,5	7,2	8.0	7.5	10	10	4.5	4.6
Harvested forage (t DM)	77	79	113	115	118	119	171	171

Grain produced (t)	43	44	27	21.3	72	80.9	68	80.5
Grain sold (t)	5.5	0	1.6	0	72	77	18	10
Grain for reseeding	0	2.3	0	1.3	0	3.9	0	3
Concentrate consumed (t)	53	52	35	30	47	66	62	66
Forage stored or purchased (t DM)	36	37	0	0	15	0	-	-

Notes: Spring grassland production was reduced by 8% for F74 and increased by 5% for F67 to account for the difference between the average yield declared by farmers and the yield recorded for 2017.

Appendix A3.2: comparisons of simulations and data recorded on the farm for the year 2017

	Sim63	Real_63	sim65	Real_65	Sim67	Real _67	sim74	Real_74
Revenue beef sales (k€)	22	26	16	19	39	33	50	na
Revenue sheep sales (k€)	27	26	25	22	26	25	18	na
Sales of crops (k€)	1	0	1	1	29	22	16	na
Subsidies (k€)	45	46	54	65*	98	104	45	na
Var. Costs for animals (ke)	12	16	19	16	31	44	24	na
Var. Costs for crops (ke)	6	5	13	2 **	20	19	14	na
Structure, financial and depreciation costs (k€)	61	62	54	60	120	139	67	na
Operating results (k€)	14	12	18	19	21	- 18 k€ accountancy *vs.* +34 k€ farmer declaration	24	na

**10 k€ of insurance indemnity included*

*** the model simulates some purchase of manure and do not offer the possibility to reseed own cereals*

Supplementary material

S1: Survey form

Form

Farm resilience to risks & adaptation

Name : …………………………………… Date :

5 Crop Production

How do you perceive the weather conditions risks on forage and crop production?

- Low □ medium □ High □

Which type of climate risks are the most important for you?

How do you perceive the risks on crop production related to pest, disease and weed?

- Low □ medium □ High □

For each production, could you tell us what is for you :

	Very bad	bad	normal	good	Very good
Average yield					
Frequency of this yield over the last 10 years					
What you have done in reaction					

If they have not been mentioned earlier :

Are you self sufficient in feed in general? Until how much of a decrease in harvested forage yields? Which kind and how much forages do you purchase?

Do you have forage security stock? if yes how much?

Do you sell forages? if yes how much?

Do the areas harvested / grazed varied to adapt to variations in crop production

Do you produce other forages such as between crops forages?

6 Animal production

How do you perceive the risks on beef production?

- Low □ medium □ High □

How do you perceive the risks on sheep production?

- Low □ medium □ High □

If these results are variable, could you give us the values and probabilities of performance other the 10 pas years?

		Very bad	bad	normal	good	Very good
reproduction	Value					
	frequency					
mortality						
Kg produced / LU						

Do you reduce herd size or the type of animal sold to face variations of forage production? For Beef? Sheep? why

Do you think that you could improve the performance of your beef or sheep herd? (If you have some reference regarding animal productivity, concentrate consumption etc., maybe you can point out some aspects that seems not very performing)

7 Market

How do you perceive the market risks?

- Low □ medium □ High □

Which type of market risks are the most important for you?

……………………………………………………………………………………………………

		Very bad	bad	normal	good	Very good
Beef price	Average price					
	Frequency of over the last 10 years					
	What you have done in reaction					
Sheep price	Value					
	Freq					
	Ajustment ?					
Cereal price	Value					
	Freq					
	Ajustment ?					

8 Other risks

How do you perceive the risks on Public subsidies ?

- Low □ medium □ High □

Why?

How do you perceive the risks on input prices ?

- Low □ medium □ High □
- Why?

How do you perceive the risks on machines breakdown ?

- Low □ medium □ High □
- Why?

How do you perceive the risks on your health and ability to keep the farm running?

- Low □ medium □ High □

Why?

Potential medium and long term adaptations

1. Do you plan to modify herd size ?
2. What do you think of stopping or reducing one animal enterprise? Or replacing it by dairy or pig production?
3. Have you planned to increase the share of cash crop production?
4. Is irrigation an option?
5. Do you plan to put in more trees or hedges to increase on shaded areas?

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