International Journal of Plant Production 11 (1), January 2017
ISSN: 1735-6814 (Print), 1735-8043 (Online)
www.ijpp.info

GUASNR

Economic and environmental impacts of introducing grain legumes in farming systems of Midi-Pyrenees region (France): A simulation approach

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Received 8 April 2016; Accepted after revision 31 July 2016; Published online 17 January 2017

Abstract

The reconciliation of economy and environment is a key factor in achieving sustainability. The European Union wishes to achieve the sustainability of its agriculture in order to produce high quality food materials and to manage energy crisis and the risks related to climate and market fluctuations. These risks can be mitigated by reducing negative impacts of agricultural activities on the environment. Therefore, this study was designed to derive and promote the potential tools to increase the land area under grain legumes in Midi-Pyrenees region (France) where it currently stands at only 1 to 3%. For this purpose modeling chain APES-FSSIM-Indicator was used to assess different alternative scenarios of proposition of new grain legumes-based cereals rotations, provision of higher premium on grain legumes, increase in sale price and yield of grain legumes, reduction in price and yield variability of grain legumes and combination of all these scenarios. Results showed that alternative scenario of provision of more premiums on grain legumes was more efficient in increasing the grain legume area than other alternative scenarios, but this would require a level of subsidies much higher than the current crop-specific subsidies in EU. However, in case of combination of all these scenarios, the increase in grain legumes area was maximum for all three selected farms from the study area. In addition farm income was increased by 11 to 26% and energy consumption was decreased by 4 to 9% for the selected farms. It is concluded that grain legumes area in Midi-Pyrenees farming systems can be increased by following the above mentioned alternative strategies.

Keywords: Alternative scenarios; Cropping systems; Crop model; Bio-economic model; Sustainability indicators.

Introduction

Grain legumes belong to the *Leguminosae* family (subfamily *Fabaceae*) and are considered as the cheapest source of supplementary proteins (Magrini et al., 2016). Their grains are used either for human consumption (food legumes) or for animal feed (Nemecek et al., 2008; Singh et al., 2007; AEP, 2004). The unique characteristic of grain legumes as nitrogen-fixing plants makes them economical and environmentally-friendly compared to other arable crops (Reckling et al., 2016; Crews and Peoples, 2004; Graham and Vance, 2003). This characteristic is pivotal in sustainable agriculture of the future where there will be a need to limit mineral nitrogen and energy used in agriculture (Magrini et al., 2016; Nasim et al., 2016a). Previous studies showed that introducing grain legumes into European cropping systems offer many economic, agronomic and environmental benefits (Preissel et al., 2015; Nasim et al., 2011; Nasim et al., 2012; Nemecek et al., 2008; Ncube et al., 2008; Von Richthofen et al., 2006; Carrouee et al., 2002; Campbell et al., 2000; Rao et al., 1999). Despite, these advantages, the area under grain legumes in Europe is far less (1 to 7%) than for example in Asia where it is 10 to 44% of the total cultivated area (Wery and Ahlawat, 2007). Moreover, this negligible share of grain legumes is declining constantly (Preissel et al., 2015). In contrast, there is a substantial deficiency of vegetable proteins in France and in the whole of Europe and every year this deficiency is compensated by importing about 75% of the proteins used, mostly from America, for an equivalent of 35 million tons of soybean meal (Magrini et al., 2016). Moreover, farmers also show little interest in growing grain legumes on their farms, as a response to institutional, agronomic (Preissel et al., 2015), technical, climatic and economic constraints (Von Richthofen et al., 2006). The most frequent problems cited for legumes are: provision of less subsidies compared to other grain crops, higher susceptibility to pest and diseases (Gueguen et al., 2008; Wery and Ahlawat, 2007), need of greater technicality for their production (Carrouee et al., 2003) and low or fluctuating prices and crop yield (Jeuffroy, 2006), inducing an overall low competitiveness with cereal crops in farming systems. Due to these constraints, the EU grain legumes sector has strongly declined over the last decade. In France, their area has now reached its lowest level (165,000 ha) since the 80s with 63% decrease observed only between 2004 and 2008 (Magrini et al., 2016).

In this context, it is challenging to propose and evaluate strategies that would allow the promotion of grain legumes area by acting simultaneously on these constraints. This question must be addressed in the diversity of the contexts (institutional, socio-economic and environmental) and of the farming systems (Reckling et al., 2016). Extensive literature review shows that few studies propose quantitative approaches to assess the impact of policies aimed at promoting grain legumes area, more so at farm and small region levels. Usually, the behaviour of agricultural systems with regard to the cultivation of legumes-based cereals rotations are analyzed by using two types of approaches. The first type focuses on socio-economic factors, mainly with econometric models and aims to quantify the impact of economic incentive (price, premium) on farm income (Von Richthofen et al., 2006). In such type of approach, the integration of biophysical components is usually limited to a few quantitative agronomic variables (mainly yield) that are extracted from experiments or specific farm survey (Mahmood et al., 2016). The second type of approach is based mainly on experiments, in specific soil-climate conditions, for assessing the agronomic and environmental performances of legume crops under various crop practices (Nemecek et al., 2008). In both cases, the tendency is to unravel the integrated problem of promoting legume crops as an agronomic and socio-economic issue, in order to reach a compromise solution between different criteria (economic, social and environmental).

Therefore, the objective of this study is to assess the impacts of different alternative scenarios (technical and socio-economic) targeting the promotion of the grain legumes area in a French region. This study was conducted in Midi-Pyrenees region (MP) region which is a typical example of an EU region with a high agronomic potential for the cultivation of grain legumes. Alternative scenarios were defined as constraints/opportunities applied to farming systems simulated by the FSSIM bio-economic model (Louhichi et al., 2010) combined with a crop model, (Nasim et al., 2016b; Belhouchette et al., 2011). These scenarios were identified through consultation with local experts, stakeholders and extension services officers (Reckling et al., 2016) and were assessed through a relevant set of economic and environmental indicators.

Materials and Methods

Study area

Midi-Pyrenees (Location: 44.0859° North and 1.5209° East) is one of the largest regions of France with an area of 45350 square kilometers occupying 8.3% of the national territory. A wide range of agronomic conditions including crops, soils, crop management (mainly water and nitrogen) and weather (rainfall) can be observed. Almost all temperate grain crops are cultivated in this region including cereals (durum wheat, soft wheat, maize and barley), legumes (soybean, peas and fababeans) and oilseeds (sunflower and canola) (Mahmood et al., 2016). Soil types in the region can be split into loam and clay loam and further sub-divided into different types depending on soil depth and slope. Irrigated maize rotated with durum wheat, sunflower and peas are cultivated mainly on loam soil, while on clay loam soils, durum and soft wheat are generally rotated with sunflower (Nolot and Debaeke, 2003). Cereals represent 29% of the Utilized Agricultural Area (UAA) in the region and most of the farms grow cereal crops (Agreste, 2009). Grain legumes have a very small share of the UAA, varying between 1% and 3% depending on farm types and sub-regions (GL-Pro, 2007), while the potential is estimated to be between 15 and 25% (GL-Pro, 2007). Between 2001 and 2009, the regional grain legumes area and production decreased by 64% and 68% respectively, due to political (CAP reforms), agronomic, technical, climatic and economic constraints.

Scenario simulation

A 7-steps framework derived from the regional component of the SEAMLESS platform (Belhouchette et al., 2011) was used in this study to assess farm behavior under innovative strategies and economic incentives for promoting grain legumes in the MP region (Reckling et al., 2016).

1. <u>Description of current activities:</u> the aim is to describe the main crop-based activities (defined as a crop species, in a rotation, on a soil, with a specific management) in the MP region for a wide range of farming systems, biophysical conditions and management practices and then to identify for each activity the yields and externalities in order to use them as input into the FSSIM model (Louhichi et al., 2010).
2. <u>Description of the farm types</u>: this step describes the most representative farming systems (farm types) in the MP region, which was considered in the scenario study. These farm types were identified from the SEAMLESS database and typology criteria for farming systems in EU (Andersen et al., 2007).
3. <u>Calibration of the FSSIM model</u>: this bio-economic model (Louhichi et al., 2010) that simulates farmer's decisions and farm performances indicators was calibrated for each farm type in order to reproduce the farmer's current choice on crops and activities.
4. <u>Definition and simulation of the scenarios</u>: this step targeted the definition of the scenarios, which were established in consultation with regional experts to address their questions of interest on grain legumes in a format compatible with the FSSIM model structure and input (Therond et al., 2009).
5. <u>Indicator selection and description</u>: the objective of this step was to select and define the calculation of a list of indicators which will be used to assess the impact each selected scenario for each selected farm type.

6. Sensitivity analysis: this step complemented the previous one to analyze how outputs of the scenarios (Indicators values) were sensitive to minor changes in selective scenario parameters (e.g. premium level).
7. Analysis of scenarios: in this step the scenarios were analyzed to see their impact on change in area per crop, intermediate variables and indicators values (Belhouchette et al., 2011).

Description of current activities (Step 1)

Data for current activities in the MP region (crop rotations and crop management: fertilization, irrigation) were collected through a survey of 10 local experts reported by Zander et al. (2009). Through this survey, 65 rotations with 11 different crops were identified (Belhouchette et al., 2011). The most frequent were the 2 year rotations with soft wheat–sunflower, durum wheat–sunflower and maize–maize. The 3 year (barley-sunflower-durum wheat) and 4 years (durum wheat–rape -durum wheat-sunflower) rotations were also identified. Only few grain legumes were found and in short rotations (2 years): winter barley-peas, winter soft wheat-peas and winter durum wheat-peas, maize-soybean, winter barley-soybean, winter soft wheat- soybean, winter durum wheat-soybean, for a total area of less than 3% of regional UAA. Combined with management types, soil types and production systems, these 65 rotations yielded a total of 103 current agricultural activities. For each crop and its current activities, a set of data were collected to run the FSSIM model. The set included the data on: i) management practices i.e. tillage events, amounts of irrigation water, fertilizers and pesticide applications; ii) soil characteristics i.e. clay loam and clay soils; iii) crop performances such as yield and externalities (e.g. nitrate leaching). The first two types of data were used, together with climatic data, to run the APES crop model, previously calibrated (Mahmood et al., 2016; Mahmood, 2011) in order to produce the third type of data as described by Belhouchette et al. (2011). In addition, local statistics for years 1999-2003, were used to derive a set of economic data, such as product sale price, variable costs of cropping and premiums. Variable costs were calculated with the input costs of fertilizers, seeds, irrigation, biocides and other crop management practices (Belhouchette et al., 2011). These data were used as input for the FSSIM model (Table 1).

Description of farm types (Step 2)

Since MP is one of the largest regions in France with 47451 farms (Agreste, 2009), modeling all individual farms was not feasible because of the large number and variability of fields and farms in terms of biophysical, economical and social characteristics. Therefore, we used the SEAMLESS farm typology (Andersen et al., 2007), based on Farm Accountancy Data Network (FADN) and Farm Structural Survey (FSS), to select the most representative arable farm types of the MP region. It allowed selecting three farm types (FT1, FT2 and FT3), representing respectively 2330, 990 and 1736 real farms of the MP region (Table 2). They are characterized as cereal (FT1), cereal/fallow (FT2) and mixed (FT3) farms. FT1 is based on cereals (37% of UAA) and oilseeds (21%). FT2 is based on oilseeds (30%) and fallow (22%) and FT3 on oilseeds (38%) and cereals (36%). The available irrigable area was 40, 28 and 15 % respectively for FT1, FT2 and FT3. As indicated in Table 2, grain legumes are only cultivated by FT1.

Table 1. Set of input-output coefficients used in the bio-economic FSSIM model (Source: SEAMLESS database).

Crops	Production techniques	Yield (T/ha)		Fertlizer (Kg N/ha)		Irrigation (mm/ha)		Labour (Hours)		Variable costs (Euro/ha)		Prices (Euros/T)	Premiums Agenda 2000 (Euro/ha)
		Soil loam	Soil Clay Loam	Soil loam	Soil Clay Loam	Soil loam	Soil Clay Loam	Soil loam	Soil Clay Loam	Soil loam	Soil Clay Loam		
Soft wheat	rainfed	4.35	-	150	-	-	-	3.10	-	467	-	116.23	309
	irrigated	-	-	-	-		-	-	-	-	-		
Durum wheat	rainfed		4.35	-	150	-	-	-	3.10	-	467	135.3	613
	irrigated	-	-	-	-		-	-	-	-	-		
Barley	rainfed	4.5	4	100	100	-	-	2.55	2.70	206	310	93.75	309
	irrigated	-	-		-	-	-	-	-	-	-		
Maize	rainfed	5	-	120		-		4.27	-	421	-	119.66	309
	irrigated	10.3	10.3	150	150	250	260	49.72	49.72	739	829		469
Sunflower	rainfed	-	1.90	-	-	-	-	-	3.93	-	263	213.27	363
	irrigated	-	-	-	-	-	-	-	-	-	-		
Soya	rainfed	2.59	2.8	0	0	-	-	3.93	3.93	263	297	196.30	363
	irrigated	3.03	2.9	0	0	110	110	40.29	40.29	512	380		523
Rapeseed	rainfed	3.20	3	140	140	-	-	2.67	2.67	211	416	203.78	363
	irrigated	-	-	-	-	-	-	-	-	-	-		
Peas	rainfed	2.39	2.36	0	0		-	2.47	2.47	365	365	132.68	364
	irrigated	4.34	4.32	0	0	40	40	11.56	11.56	423	383		549

Table 2. Main characteristics of the three arable farm types in the Midi-Pyrenees region.

Specialisation land use	Farm type 1	Farm type 2	Farm type 3
	Cereal	Cereal/Fallow	Mixed
Farm represented (number)	2330	990	1736
Area by Farm (ha)	111	107	110
Irrigable area by Farm (%)	40	28	15
Soil Types (% of texture)	Loam (40%)	Loam (36%)	Loam (41%)
	Clay-loam (60%)	Clay-loam (64%)	Clay-loam (59%)
Available labour (hours)	2901.6	3260.3	3179
Observed Crop pattern (ha)			
Cereals (winter soft wheat, winter durum wheat, barley, oat)	37	21	36
Maize	14	21	15
Oilseeds (sunflower, rapeseed)	21	30	38
Grain legumes (peas, soyabean)	8	0	0
Fallow and other crops (Fruits…)	20	22	10

Calibration of the FSSIM model (Step 3)

FSSIM is a generic and modular bio-economic farming system model (Janssen et al., 2007), developed to assess, at farm level, the economic and ecological impact of agricultural and environmental policies on performance of farms through sustainability assessment indicators (Louhichi et al., 2010). It was designed for simulating a wide range of farming systems across Europe and elsewhere for addressing a variety of policies and technological innovation questions related to agricultural systems (Belhouchette et al., 2011). It is an optimization model that maximizes the farm's utility, when subjected to a set of biophysical, socio-economic and policy constraints (Louhichi et al., 2010). Being a mono-periodic model it can optimize an objective function only over one year, for which decisions are taken (Belhouchette et al., 2011). The main outputs generated from FSSIM are the forecasts on farm income, land use, labor use and environmental externalities (e.g., nitrate leaching, pesticide use, soil erosion, pesticide consumption, soil organic matter, water use etc).

The mathematical structure of FSSIM can be formulated as follows:

Maximize: $$U = Z - \phi\sigma \tag{1}$$

Subject to: $$Ax \leq B \; ; \; x \geq 0 \tag{2}$$

Where: U is the variable to be maximized (i.e. utility), Z is the expected income, x is a (n × 1) vector of agricultural activity levels, A is a (m × n) matrix of technical coefficients, B is a (m × 1) vector of levels of available resources, ϕ is a scalar for the risk aversion coefficient and σ is the standard deviation of income according to states of nature defined under two different sources of variation: yield (due to climatic conditions) and prices (Belhouchette et al., 2011). Overall, FSSIM considers farmer's behaviour toward two types of risk: i) yield variability due to climate (rainfall and temperature) and, ii) economic variability due to changes in market prices for inputs of agricultural activities and the implementation into the farming system of new activities. An already calibrated FSSIM for these farm types was used in this study (Belhouchette et al., 2011).

Definition and simulation of the scenarios (Step 4)

Reference scenario (RS)

The reference scenario interprets the projection in time of the current situation with possible future development in term of technological, structural and market changes. It represents the reference for interpretation and analysis of the alternative scenarios (Therond et al., 2011). In this study, the reference scenario refers to the implementation of the common agricultural policy (CAP) reform as decided in 2003 with national and regional adjustments and a time horizon up to 2013.

- Set-aside: minimum of 10% of UAA as fallow.
- Modulation: 3% reduction of premiums between 2003 and 2013
- Decoupling: decoupling of premiums from specific crops as currently implemented in the MP region.

In terms of technological and market change, three exogenous assumptions are adopted between 2003 and 2013:

- Inflation rate: 1.19 % per year.
- Yield trend: long term evolution of crop yield reflecting the projection of current genetic and technical progress based on the CAPRI database (Britz et al., 2006).
- Price trend: the evolution of agricultural products prices derived from the CAPRI database (Britz et al., 2006).

All other parameters are assumed to be unchanged up to 2013.

Alternative scenarios (AS)

Procedure for the identification of alternative scenarios

The identification of alternative scenarios was done through consultation with five local experts having expertise in farming and cropping systems of the region (Reckling et al., 2016) cropping behavior and growing conditions of grain legumes in the region (data not shown). The identification was accomplished in two 2 steps:

1- Briefing of experts on study area, objective and method: Details on study area and the objective of the study were sent to selected experts along with a summary of the method that can be followed to assess the impacts of the scenarios on the promotion of legume crops area in the MP region.

2- Identification of alternative scenarios: Intensive discussions were held with experts in the region to identify: (i) major biophysical, technical and socio-economic constraints for grain legumes production in the study area (data not shown) and (ii) a list of alternative scenarios to remove or reduce these constraints. For this purpose, the experts were asked to answer the following three main questions:

- What are the main biophysical, agro-environmental (soils, sensitivity to frost, pest and diseases, sensitivity to excess and deficit of water etc.) and technical problems (sowing, harvesting etc) faced by farmers during both sowing seasons (spring and winter) for the major grain legumes?
- In which types of cereal activities do farmers prefer to introduce grain legumes?
- What are the grain legume that can be irrigated and in which activities?

The following alternative scenarios were established from the information collected during these steps, while taking into account the FSSIM model capabilities and the available data.

Scenario based on technological innovation ($S_{tec.innov}$)

According to the experts the main grain legumes cultivated in the study area are peas and soybean, while fababean and lupin are also found in some places but crop data and farm model calibration are scarce for the later two legumes. Therefore, we focused on peas and soybean for this scenario. They are mainly cultivated in bi-annual rotations with cereals. The experts identified nine legumes-based activities suitable to the biophysical conditions of the region (Table 3) that were provided as technological innovation (called here alternative activities) at the gate of the simulated farm types (Table 4), to be further selected or not by the FSSIM model in the optimization process. Then for each activity, crop management practices, total cost and prices based on the SEAMLESS database (Andersen et al., 2007) were specified. Finally, the APES model, previously calibrated and evaluated for these crops in the region (Mahmood et al., 2016), was run for each activity to generate externalities such as nitrate leaching and soil erosion as proposed by Belhouchette et al. (2011).

Table 3. New grain legumes-based cereal rotations identified by the experts.

Climate condition	Rotations
Rainfed	S-DW-P-DW
	S-DW-P-DW-RS
	S-DW-P-DW-FB-DW
	S-DW-FB-DW
Irrigated	M-SJ-DW
	M-DW-P-DW
	M-DW-FB-DW
	M-DW-P-M
	M-SJ-M-P

S= Sunflower, DW= Durum wheat, P= Peas, RS= Rapeseed, FB= Fababean, SJ= Soybean, M= Maize.

Scenario based on provision of more premiums to grain legumes ($S_{premium}$)

Ignoring the potential of grain legumes during the CAP reforms of 1992 and 2003 led to higher premiums for non N-fixing crops such as cereals and oilseed crops (Von Richthofen et al., 2006). As a consequence, the legumes area decreased drastically. According to the experts, the provision of higher premiums for grain legumes would be a primary incentive for the adoption of these crops by farmers. In agreement with this argument, the EU commission projected a total of 40 million Euros per year between 2010 and 2012 to rapidly achieve a legume area of at least 400 000 ha in EU. This gives a premium per ha of legumes of:

- 150 € / ha in 2010 to achieve an area of 267 000 ha
- 125 € / ha in 2011 to achieve an area of 320 000 ha
- 100 € / ha in 2012 to achieve an area of 400 000 ha

These amounts should be added to the European aid of 55.57 €/ha specific for legumes as specified in the CAP reform of 2003. But during our meeting with local experts, they claimed that these amounts of premiums would be insufficient for a significant increase in the grain legumes area in the MP region. With their experience they acknowledged that peas can be more profitable than wheat, only if it receives a premium higher than 900 €/ha. Therefore, in this study, instead of using the EU or experts' recommendations on premiums we conducted a sensitivity analysis for a wide range of premium (Table 4).

Scenario based on sale price (S_{price}) and crop yield (S_{yield})

Von Richthofen et al. (2006) reported that farmers in EU and France believe that lower sale price and grain yields are two of the major obstacles for legume production. This opinion was also expressed and acknowledged by experts during survey for scenario establishment. Moreover, according to Chamber of Agriculture Ariege (2009), in rainfed conditions, average yields of wheat and peas are respectively 5 and 2.5 t ha^{-1}.

On average, farmers sell the product (grains) at market price of 180 €/t for wheat and 140 €/t for peas. They spend almost the same amount of money to grow both crops: 460 and 480 €/ha respectively for wheat and peas. Obviously, this makes wheat more profitable than pea in these conditions, with a difference of gross margin of 516 €/ha (741-225). It is, therefore, assumed that an increase in sale price and/or crop yield would make grain legumes competitive compared to cereal. Therefore, a sensitivity analysis was conducted by combining product prices and yields of grain legumes (Table 4).

Scenario based on price ($S_{price.var}$) and yield ($S_{yied.var}$) variability

Von Richthofen et al. (2006) reported that in some cases the choices of crops are mainly determined by their yield and price stability across years. The experts confirmed this hypothesis and considered that, compared to other regional crops like rapeseed and wheat; grain legumes are riskier in economic terms because of yield and price instability. It was, therefore, assumed that a reduction of yield and price variability would make grain legumes more attractive to farmers. A sensitivity analysis was conducted with a reduction of respectively 20% and 50% of yield and price inter-annual variability (Table 4).

Scenarios combining the previous components (S_{comb})

The idea behind this scenario, which arose as a concluding hypothesis of the experts meeting, is that implementing one measure (e.g. premium) can only be partially effective and would never lead to significant increase in the grain legumes area. The hypothesis is that an increase in grain legumes area on MP farm can only be achieved by acting on several components of the farming system's economic environment (price, premium) as well as on the grain legume crop innovations (e.g. rotations, management, varieties) to improve yield. Therefore, this scenario was built as a combination of the previous ones, except $S_{price.var}$ and $S_{yied.var}$. As described in Table 4, the level of premium was fixed at 400 €/ha and the increase in price and yield were fixed at 50% compared to the current ones. These levels were defined using the results of the sensitivity analysis conducted for the corresponding scenarios (S_{price} and S_{yield}).

Table 4. Summary of alternative scenarios with their assumptions and measures.

Scenarios		Assumptions	Measures
Technological innovation	$S_{tec.innov}$	Biophysically suitable new rotations can increase the grain legumes area	Nine new rotations with 4 for rainfed and 5 for irrigated conditions
Economic	$S_{premium}$	More premium can make the grain legumes more profitable	Sensitivity analysis (0 to 5000 €/ha)
	S_{price} and S_{yield}	Increase in sale price and crop yield can make grain legumes more competitive with non-legumes	Sensitivity analysis (0 to 100% increase in price and yield than current one)
	$S_{price.var}$ and $S_{yield.var}$	Decrease in price and yield variability can attract the farmers attention to grow more grain legumes and hence their area	20% and 50% decrease in price and yield variability than current one
	S_{comb}	The combined scenario would be more effective and realistic	$S_{tec.innov}$ (nine new rotations) + $S_{premium}$ (400 €/ha) + S_{price} and S_{yield} (50% increase)

Indicators selection and calculation (Step 5)

The comparative impacts of reference and alternative scenarios on the performance of the three selected farm types were assessed through relevant socio-economic and environmental indicators. These indicators were identified on the basis of advantages and disadvantages of legumes-based cereals rotations (data not shown), taking into account the capability of the modeling chain with the available data (Reckling et al., 2016). All these indicators were expressed at farm level and, except for energy consumption; they were calculated directly by the bio-economic FSSIM model. The indicators and their calculation method in FSSIM model can be found in Louhichi et al. (2010).

The indicator of total energy use (E_t) was calculated outside the bio-economic FSSIM model. For this purpose, the INDIGO method for energy indicator, proposed by Bockstaller and Girardin (2003) and Pervanchon et al. (2002), was used (data not shown). Due to data limitations, only four out of the seven sources of energy consumption listed in INDIGO method, i.e., fertilization, machinery, irrigation and pesticides, were used. It was assumed that this did not impair the use of this indicator for relative changes analysis between scenarios, because the three remaining components (seeds, fuel and electricity) are only slightly modified by the rotation changes. The indicator of total energy use was calculated as the sum of the four components using the conversion factors given by Pervanchon et al. (2002).

Results

Overall scenario analysis

Table 5 presents the increase in pea area for each alternative scenario and farm type. It shows that the implementation of the alternative scenarios differently affected the behavior (in term of adoption of legume crops) of the three farm types. Thus, those alternative scenarios are divided into “non-significant” alternative scenarios (i.e. which did not change the pea area and indicator values) and “significant” alternative scenarios (i.e. which changed the pea area as well as indicator values).

Non significant alternative scenarios ($S_{tec.innov}$, $S_{price.var}$ and $S_{yield.var}$)

The implementation of these alternative scenarios ($S_{tec.innov}$, $S_{price.var}$ and $S_{yield.var}$) did not change the pea area (Table 5), as well as the values of the assessment indicators (data not shown), for none of the farm types (Mahmood, 2011). In $S_{tec.innov}$, the new grain legumes-based cereals activities, proposed to the FSSIM model were not sufficiently attractive from an economic point of view to be selected by the model. This is contrasting with Von Richthofen et al. (2006) findings, who reported that grain legume-based cereals rotation generally have slightly higher gross margin than intensive cereal-based rotations. They found that in Saxony-Anhalt (Germany), inclusion of peas in five-year cereals based-rotations increased the gross margin by 11%.

Even if grain legumes become less risky than other crops in scenarios $S_{price.var}$ and $S_{yield.var}$, this did not led to adoption of grain legumes by the farmer when simulated with FSSIM, even with a 50% reduction of price and yield variability, which is probably far above what can be expected in reality. This is again an invalidation of the common hypothesis that price and yield variability of grain legumes are two of the major limitations for grain legumes production (Von Richthofen et al., 2006).

In both cases, our study indicates that technological innovations leading to new rotations with legumes and reduction of prices and yield instability, when taken separately, would not be sufficient for the three types of farms in the region to increase the grain legume share in their cropping systems. It is well known that bio-economic models have some bias to simulate farmer's decisions not driven by income (Janssen et al., 2007), but this economic rationality is generally the argument given in the legume literature (e.g. Von Richthofen et al., 2006) and by our experts to promote such scenarios.

Significant alternative scenarios

$S_{premium}$ Scenario

The most significant impact in term of change in pea area and indicator values was observed in the $S_{premium}$ scenario. For example, for a supposed premium amount of 400 €/ha, pea area increased by 4, 18 and 21 ha (Table 5) and farm income by 4, 3 and 1% (data not shown) for FT1, FT2 and FT3, respectively. This is consistent with the finding of that provision of more premiums to legumes is one of the main driving forces for increasing their areas in EU and in France. Sensitivity analysis showed that the three farm types react differently to the premium level in their increase in pea area. FT1 requires a higher premium (4500 €/ha) than FT2 and FT3 to reach the maximum pea area of 45 ha per farm (Figure 1a).

This is mainly due to the difference in initial cropping pattern and the characteristics of each farm type, especially the initial area of cereals and the area of irrigated land.

The initial area of winter cereal crops was higher in FT1 (cereal farm type) than in FT2 (cereal/fallow farm type) and FT3 (mixed farm type). FT1 initially cultivated 37% of its UAA with cereals (winter durum wheat, winter soft wheat, winter barley and oats), 21% with oilseeds and 14% with maize. Grain legumes were already significant in this farm type, with 8% of the UAA, which is above the regional average. The results show that with gradual increase in premium level for grain legumes, the irrigated pea which was rotated with cereals, started first to replace irrigated maize grown as a monocrop, which became progressively less profitable than the winter cereal-pea rotation. In a second step, the cereal-pea rotation substituted progressively the maize-soybean rotation, which was more profitable than the irrigated monocrop maize. The maximum pea area was reached with premium level of 4500 €/ha, which is not realistic regarding the level of premium and it's not sustainable because pea was cultivated only in bi-annual rotations which would induce a high disease pressure on this crop.

The same explanation can be given for FT2 and FT3. However, for these farm types with gradual increase in premium level, the increase in pea area was quicker than in FT1 due to different cropping patterns. Pea mainly replaced successively fallow, maize monocrop rotation and then oilseeds. In both farm types and contrary to FT1, no maize was cultivated in rotation with soybean which was more profitable than maize monocrop rotation or oilseeds.

The share of irrigated area in the farm UAA seems to negatively affect the adoption of grain legumes. In fact, farmers prefer first the cultivation of more profitable irrigated maize and soybean and then irrigated pea. By increasing the premiums for legume crops, the irrigated pea first replaced the rainfed crops then the irrigated crops such as maize. This may also explain why FT1, which had the highest irrigated area (40 ha), reacted more slowly to the premium increase than the two others farm types.

S_{price} and S_{yield} Scenarios

Increasing pea price (S_{price}) or pea average yield (S_{yield}) led to increase pea area by 2, 10 and 8 ha (Table 5) and farm income by 2, 1 and 0% (data not shown) for FT1, FT2 and FT3, respectively. A more detailed analysis showed that the impact of these scenarios on farm behavior was similar to the $S_{premium}$ scenario. Overall, similar tendencies in term of change in pea area as well as for the indicators were observed for both of these scenarios (Table 5).

The sensitivity analysis showed that pea area in FT2 and FT3 can be increased more rapidly than in FT1 (Figure 1b and 1c). However, for both farm types (FT2 and FT3); even for very high levels of increase in price and yield (100%), the increase of pea area is very small and does not exceed 15 ha (Figure 1b and 1c). On the other hand, FT1 seems insensitive to these scenarios. This is despite a high level of pea yield increase (up to 100%) compared to the current one, for which the actual tendency is rather to a reduction during the past two decades.

S_{comb} Scenario

As shown by the previous scenarios, none of the individual drivers would be sufficient to increase pea area in the MP region, if we remain in a realistic range of technological changes (influencing yield) or economical changes (influencing prices or premiums). The originality of the modeling chain we used is that it allows combining several of these drivers in a single scenario to identify possible synergies between minor variations of these drivers. For example, the simulation of the S_{comb} scenario showed (Table 5) that combining a premium of 400 €/ha with a 50% increase of price and yield would induce a significant increase of the pea area (7, 34 and 32 ha for FT1, FT2 and FT3, respectively) and of the farm income (11, 26 and 20%, respectively). This price and yield increase are still very high but they are not unrealistic with a shifting to specific markets such as human consumption (for price) or to winter pea instead of spring pea (for yield). On the other hand for getting the same increase in pea area, it would require a premium of 750 €/ha for FT1, 850 €/ha for FT2 and 600 €/ha for FT3 (Figure 1a), or an unrealistic level of increase in price (Figure 1b), or yield (Figure 1c).

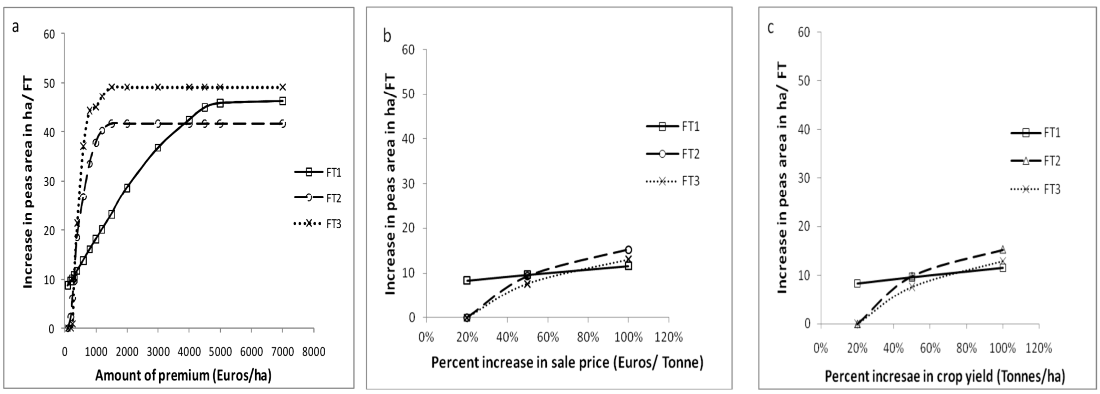

Figure 1 (a), (b) and (c). Sensitivity of pea area to the premium amounts (a), sale price (b) and pea yield (c) for the three farm types (FT1, FT2 and FT3).

Table 5. Difference in pea's area for reference and alternative scenarios for the three farm types.

Alternative scenarios		Measure	FT1			FT2			FT3		
			Reference scenario	Alternative scenario	Difference in reference and alternative scenario	Reference scenario	Alternative scenario	Difference in reference and alternative scenario	Reference scenario	Alternative scenario	Difference in reference and alternative scenario
			Area (ha)	Area (ha)	Area (ha)	Area (ha)	Area (ha)	Area (ha)	Area (ha)	Area (ha)	Area (ha)
Non-significant	$S_{tec.innov}$	Nine new rotation		7	-1		0	0		0	0
	$S_{price.var}$	50% decrease than current one		8	0		0	0		0	0
	$S_{yied.var}$	50% decrease than current one		8	0		0	0		0	0
Significant	$S_{premium}$	400 €/ha	8	12	4	0	18	18	0	21	21
	S_{price}	50% increase than current one		10	2		9	9		8	8
	S_{yield}	50% increase than current one		10	2		10	10		8	8
	S_{comb}	$S_{tec.innov} + S_{premium} + S_{price} + S_{yield}$		15	7		34	34		32	32

Analysis of intermediate variables

To understand the overall results of the S_{comb} scenario, a more detailed analysis of the intermediate variables (crop pattern and crop rotations) was conducted which also aimed to illustrate the potential of the modeling chain to combine the sustainability analysis based on the indicators with a depth agronomic analysis. This is important both for the understanding of the scenario and a participative analysis with farmers and local experts (Delmotte et al., 2016).

Farm cropping pattern

Figure 2 shows the difference in cropping pattern for the reference and S_{comb} scenario for the three farm types. The simulated results for FT1 show that in the S_{comb} scenario small modifications are observed in term of cropping pattern. The area of cereals increased by 2 ha and grain legumes by 7 ha at the expense of the maize area (-4 ha) and of other minor crops (Figure 2a). The same trend was observed for FT2 (Figure 2b) and FT3 (Figure 2c) with a more pronounced effect on maize (suppression) and on pea area (+ 34 ha and + 32 ha respectively for FT2 and FT3).

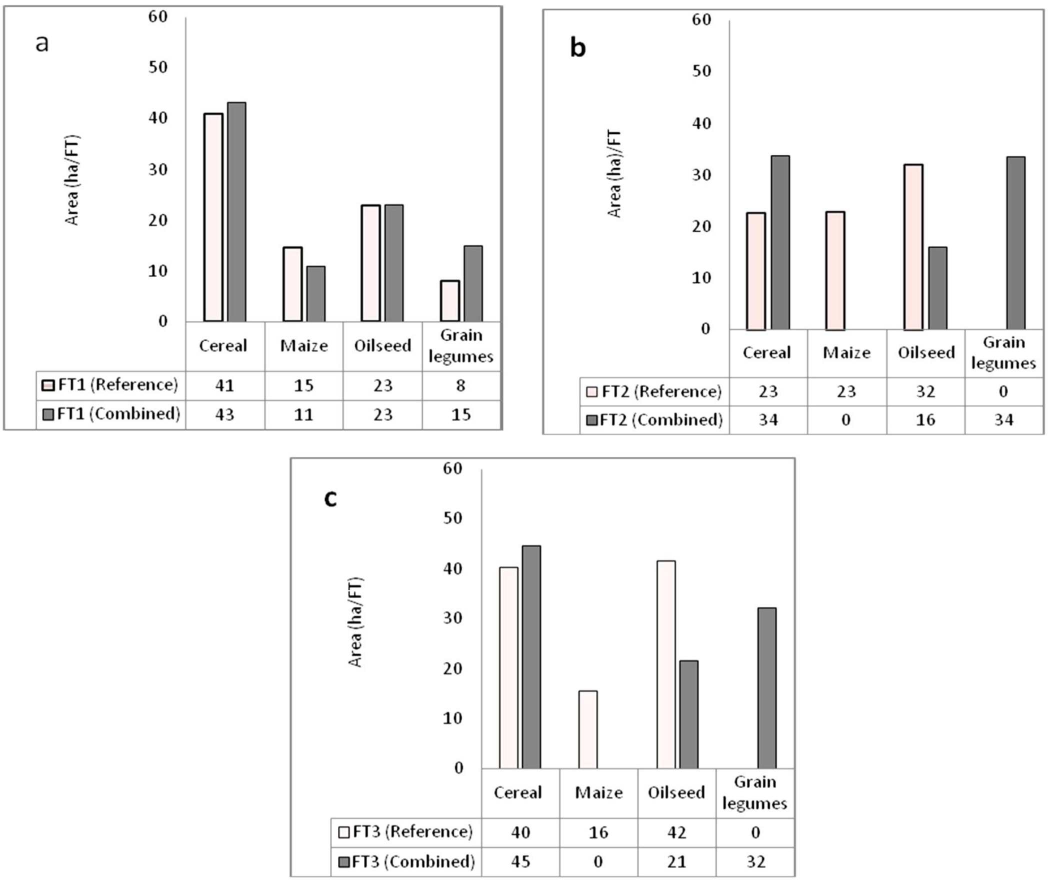

Figure 2. Cropping pattern for reference and S_{comb} scenarios for FT1 (a), FT2 (b) and FT3 (c).

Crop rotations

The S_{comb} scenario induced significant modifications of crop rotations in the three farm types (data not shown). For FT1, the area of the maize–soybean rotation (cultivated on loamy soil) was reduced by 12 ha to the benefit of the winter soft wheat–pea (+16 ha). The winter soft wheat–rapeseed rotation disappeared and new rotations appeared (oats–oats, winter barley–winter durum wheat and winter soft wheat–winter barley–winter durum wheat).

These modifications in crop rotations were also observed in FT2 and FT3 but with higher amplitude. For example, in FT3, strong reductions of some rotations (-15 ha for maize–maize, -33 ha for winter barley–rapeseed and -10 ha for winter durum wheat–sunflower) were compensated by an increase in area of others rotations (+11 ha for winter soft wheat – rapeseed, +27 ha for winter barley–pea, + 27 ha for winter durum wheat–pea and +10 ha for winter soft wheat–pea).

Analysis of the assessment indicators

The modeling chain allows assessing the impact of the scenario on a set of indicators reflecting the farming systems sustainability, which is analyzed below for the S_{comb} scenario. They cover the socio-economic domain for the farmer (farm income, total costs and labor use), the policy domain (share of premium in farm income) and the environmental domain (water use, nitrogen fertilizer use, nitrate leaching, soil erosion, energy use).

Farm income

Farm income increased in the S_{comb} scenario for all farm types (Table 6) with the increased legume crop area (i.e., 11, 26 and 20% for FT1, FT2 and FT3, respectively). This is consistent with the results of Reckling et al. (2016); Von Richthofen et al. (2006) and Rao et al. (1999) who reported that inclusion of more grain legumes into cereals-based cropping system can increase farm income.

For FT1, this was obtained (data not shown) by replacing rotations having lower gross margin (i.e. on average 677 €/ha/year for maize–soybean) with rotations having higher gross margin (i.e. winter soft wheat-pea with an average of 751 €/ha/year). The same type of results was also observed in FT2 and FT3. For example, the 20% increase in farm income for FT3 in S_{comb} (Table 6) can be explained by the replacement of the barley–rapeseed rotation (on average 665 €/ha/year) with winter soft wheat–rapeseed (on average 759 €/ha/year), winter barley–pea (averagely 836 €/ha), winter durum wheat–pea (on average 1021 €/ha/year) and winter soft wheat–pea (on average 830 €/ha) rotations.

Total costs

S_{comb} scenario increased total costs of farming for FT1 (+18%) and reduced them for FT2 (-26%) and FT3 (-18%) (Table 6). The increase in FT1 is a result of the replacement of some maize area (-4 ha) by pea (+7 ha), although the former is costlier (624 €/ha of variable costs compared to 373 €/ha for peas), but the 4 ha decrease in maize area (representing 2496 € of total cost) and the 7 ha increase in peas area (equivalent to 2611 €) slightly increases the total cost (+ 3%) in FT1. The reduction of total cost in FT2 and FT3 is also the result of the replacement of the costlier maize by the same area of peas (data not shown).

Labor use

Labor used in S_{comb} scenario increased slightly in FT1 (+3%) and strongly decreased for FT2 (-67%) and FT3 (-65%) (Table 6). Rao et al. (1999) reported the requirement of the same labor hours for cereals monocrop rotation and legumes based-cereal rotation, while Wery and Ahlawat (2007) concluded on the reverse trend, supported by the findings of (Nemecek et al., 2008; GL-Pro partners, 2006). In our case the reduction of labor requirements is clearly linked to the reduction of maize area, a crop requiring more labor, especially for irrigation (50 hours/ha for irrigated and 4.3 hours/ha for rainfed) than grain legumes (12 hours/ha for irrigated and 2.5 hours/ha for rainfed) but also than winter cereals (3 hours/ha for rainfed) which are rotated with pea.

Share of premium in farm income

Table 6 shows that S_{comb} has increased the share of premium in income by 6, 13 and 11% respectively for FT1, FT2 and FT3. This can be explained by the reduction in area of rotations with lower subsidies (e.g. in FT1 the maize–soybean rotation with a premium of 423 €/ha) at the benefit of rotations with a higher premium (e.g. 640 €/ha for winter soft wheat–pea in FT1). Similar explanation also applies for FT2 and FT3.

Water use

S_{comb} significantly reduced water consumption (between 54 and 93%) for all farm types (Table 6). Again the major driver is the reduction of maize area which is mostly cultivated under irrigated conditions across the three farm types. Even when a crop substituted to maize was irrigated, at least on some soil types, the amount of water required by this new crop was lower. For example, pea crop receives on average 40 mm in the region compared to 250 mm for maize (Table 1).

Nitrogen fertilizer use

As expected, when grain legumes (without any N fertilization) replaced cereals (systematically fertilized), the amount of fertilizer used by the farm was significantly reduced (Nasim et al., 2016a; Nasim et al., 2016b; Plaza-Bonilla et al., 2017; Preissel et al., 2015) (38 and 28% respectively for FT2 and FT3) (Table 6). For FT1, the reduction was not significant (1%) because the development of pea-based rotation (+17 ha for winter soft wheat–pea, fertilized with 120 kgN/ha on wheat crop) was done at the expense of only 12 ha only of the maize–soybean rotation, fertilized with 150 kg N/ha on the maize crop.

Nitrate leaching

Impact of the S_{comb} scenario on the average amount of nitrate leached at farm level also differed between farm types. In comparison with the reference scenario, it increased by

6% for FT1 and decreased by 7% on FT2 and 17% on FT3 (Table 6). Nemecek et al. (2008) and Von Richthofen et al. (2006) and Plaza-Bonilla et al. (2015) reported a higher risk of N leaching by including more legumes in cereal based rotations, while Drinkwater et al. (1998) and Reckling et al. (2016) reported the opposite results, with a 7% reduction of N leaching with legumes based systems, compared to cereal monocrops. The analysis of our results require a more in depth analysis of changes in crop rotations, their allocation to soil types and nitrate leaching of each crop depending on the preceding crop and on crop management (Belhouchette et al., 2011). For example, the increase in N leaching for FT1 can be explained by the replacement of the maize–soybean rotation area (-12 ha for a yearly average N leaching of 30.4 kg N ha^{-1}) by crop rotations inducing more N leaching: winter soft wheat–pea (+17 ha with 79.5 kg N ha^{-1} leached per year) and a four-year rotation of winter soft wheat–rapeseed–winter durum wheat–sunflower (+9 ha with 52.1 kg N ha^{-1} leached per year).

Similarly, the 17% decrease of N leaching for FT3 can be explained by the replacement of high N leaching rotations (winter barley–rapeseed with 70.2 kg N ha^{-1} leached per year) with lower N leaching rotations (winter barley–pea and winter durum wheat–pea with 41.2 and 35.8 kg N ha^{-1} respectively). Similar explanation can be found for FT2 (data not shown).

Soil erosion

Soil erosion increased with S_{comb} for FT1 (+6%) and FT2 (+13%) and was reduced for FT3 (-18%) (Table 6). Again this complex behavior emerged from the evolution of crop rotations selected by the farmer simulated with FSSIM and their biophysical functioning simulated by the APES model. For example, in FT1, 12 ha of the maize–soybean rotation (1 t ha^{-1} of average soil erosion per year) were replaced by 16 ha of winter soft wheat–pea rotation (2 t ha^{-1} of average soil erosion per year).

Energy use

As expected with an increase of legume area (Wery and Alhawat, 2007), the S_{comb} scenario led to a reduction of energy use: by 4, 9 and 8% respectively for FT1, FT2 and FT3 (Table 6). This energy reduction was mainly due to the reduction of maize, which needs more N fertilizer (on average 150 Kg N/ha) with a high energy consumption for N fertilization (on average 278 MJ/ha) to the benefit of peas receiving no N fertilization. Moreover, maize uses more water (on average 250 mm/ha) with high energy consumption (1485 MJ/ha) than peas, which needs less irrigation water (40 mm/ha) implying a lower energy consumption (220 MJ/ha) (data not shown). These results are similar to those of Carrouee et al. (2007) who reported in a five years experiments (1994-1998) conducted in the Bassin Parisien (France) that, when compared to wheat monocrop, the legumes based-cereal rotation of peas-wheat can reduce N fertilizer use by 22%, which ultimately can save 24% of the energy. A 14% reduction of energy used through fertilizers was also obtained by Nemecek et al. (2008) for peas-wheat rotation compared to wheat monocrop. But in our case this effect through N fertilizer reduction is analyzed in the context of a farm with an amplification through the reduction of energy consumption for irrigation of maize and a counter-effect of reduction of another legume area (soybean) suppressed when the plant it is rotated with (maize) has been suppressed in the simulated scenario.

Table 6. Simulated results of economic and environmental indicators at farm scale using the APES-FSSIM modelling chain for three farm types.

Selected indicators	Farm type 1 (FT1)			Farm type 2 (FT2)			Farm type 3 (FT3)		
	Reference	Alternative	Difference (%)	Reference	Alternative	Difference (%)	Reference	Alternative	Difference (%)
Economic									
Farm income (Euros)	109488	121765	11	73785	92828	26	78539	94075	20
Share of premium in income (%)	36	38	6	45	50	13	51	56	11
Total cost (Euros)	31657	37343	18	75025	55338	-26	76741	62935	-18
Labour use (Hours)	466	482	3	1075	350	-67	942	328	-65
Environmental									
Nitrate leaching (kg N-NO_3 ha^{-1})	45	48	6	54	50	-7	64	53	-17
Soil erosion (t ha^{-1} per year)	1.6	1.7	6	1.6	1.8	13	1.7	1.4	-18
Water use (m^3 ha^{-1})	26	12	-54	60	5	-91	39	3	-93
Nitrogen fertilizer use (kg N ha^{-1})	109	108	-1	113	71	-38	130	94	-28
Total Energy use (MJ)	283485	273556	-4	269405	246229	-9	304539	281576	-8

Discussion

The scenario simulated in this study for the MP region provided quantitative evidence of the major role of economic constraints, frequently raised in the literature to explain the poor development of grain legumes (Von Richthofen et al., 2006). Premium paid specifically to legumes ($S_{premium}$ scenario) or specific increase of market price for these crops (S_{price} scenario) are required to “force” the farmer simulated with FSSIM to adopt grain legumes. Nevertheless, the amounts required appear much too high to be applied in the real world. Technological innovations leading to higher yields (S_{yield} scenario) could also be a significant driver of legume development of grain legumes (Reckling et al., 2016), provided it reaches a doubling of the current level of pea yield in the region, which is also out of expectations with the current technologies. The reduction of inter-annual variability in pea prices ($S_{price.var}$ scenario) or yield ($S_{yield.var}$ scenario) did not change the simulated farmer’s behaviour, even for a 50% reduction of this variability which would require very efficient market regulations (for price) or crop management (for yield).

It’s only when several of these measures were combined (S_{comb} scenario) that the simulated farmer replaced some of its cereal crops (mainly maize) by a grain legume (pea), sometimes at the expense of another grain legume (soybean) tightly linked to maize through the rotation process. In that case, the economic performances of the farm (assessed with the farm income indicator) were increased for all farm types, in comparison with business as usual scenario. But at the same time the share of premium in total farm income increased, making the farming systems more dependent on the public policies and finances. The potential environmental impacts of the farms were reduced for all farms through water use, N fertilizer use and total energy use.

But the impact also depended on farm types for the other sustainability indicators: total cost, labor use and N leaching increased in the S_{comb} scenario for FT1, while they decreased for FT2 and FT3. Detailed analysis of the intermediate variables of the simulations showed the importance of the initial situation of the farm and of the rotations selected in each farm type.

The modeling chain APES-FSSIM-Indicators used in this study appears as a powerful tool to analyze the current constraints and propose some levers to the development of grain legumes in the main farm types of a region. By combining simulation of the biophysical behaviors of crops in a rotation (with the APES model) and of the farmer’s decisions of crop allocation and management (with the FSSIM model) it allows to analyze the farming system’s response to complex scenarios combining economic and technological changes, assessed with economic and environmental indicators. These models cannot reproduce all aspects of the complex agricultural systems under study (e.g. disease impact on nitrogen uptake in rotations with high frequency of legumes and nitrate leaching or farmer’s decision driven by other aspects than resource management (Belhouchette et al., 2011). But when used, as in our study, in interaction with experts for the elaboration of crop databases (e.g. with yield depending on soil and previous crop) and for strategic thinking with farmers and stakeholders (Delmotte et al., 2016), the modeling chain is likely to bring significant improvement in impact assessment and policy analysis as well as to improve the extension services devoted to legume development.

Conclusion

This study opens up many opportunities to extend and enrich the analysis for the promotion of grain legumes in the MP region in particular and in other EU regions for arable farms (Magrini et al., 2016; Reckling et al., 2016). In fact, the particular novelty of this modeling chain approach is that: i) it goes beyond earlier impact assessment models focusing on specific issues and scales, by combining disciplines and scales in a flexible and generic way depending on the policy issue to be addressed (Therond et al., 2009; Ewert et al., 2009) and ii) it sets up assessments of grain legumes in context of a wide range of biophysical conditions (soil, weather), type of land use system (grassland, cereal, legumes, perennial crops) and type of socio-economic contexts (CAP reform, nitrate directive).

Acknowledgement

The authors are grateful to experts in different departments of the studied region for providing the expert knowledge data. We are also grateful to Dr. Kamel Louhichi, who provided consistent support for solving our problems during the running of FSSIM model and Dr. Martin K. Van Ittersum and Marie-Hélène Jeuffroy for their valuable comments during different developmental stages of this publication. Furthermore, the reviewers are highly acknowledged for their valuable comments and suggestions for improvement of manuscript.

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