The role of risk aversion and labor constraints in the adoption of low input practices supported by the CAP green payments in cash crop farms

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***Abstract** – Since the late 1980s, many alternative practices have been proposed to European farmers to reduce pesticide and input use in general. These practices have been promoted by agro-environmental contracts signed between individual farmers and the European Union and by which farmers engage themselves in changing their practices. The adoption rate of these measures has remained very low in many European regions particularly in Southwestern France. This article aims at stressing the role played by risk attitude and labor constraint in farmers' adoption decision. After presenting a static theoretical model which assesses the impact of labor constraints and risk attitude on the level of adoption of low input practices supported by agro-environmental contracts, the article proposes a numerical application based on a mathematical programming risk-model implemented on two typical crop farms in South-western France. Three kinds of contracts (no tillage, long rotation, lower pest treatments) are tested, two of them (long rotation and lower pest treatments) aiming at directly reducing input use. The results show that, despite the overall positive impact of alternative practices under contract on environment and farmers' income, increased yield variability under positive risk aversion and larger labor requirements are actual barriers to adoption.*

***Keywords:** Low input practices, Risk, Adoption, Labor productivity, Agri environmental incentives*

Le rôle de l'aversion au risque et des contraintes de travail dans l'adoption des mesures volontaires agro-environnementales à bas niveau intrants

Résumé – Depuis la fin des années 1980, plusieurs pratiques alternatives ont été soutenues dans le cadre de programmes agro-environnementaux, par des contrats volontaires signés entre l'Union Européenne et les agriculteurs, par lesquels ceux-ci s'engagent à changer durablement leurs pratiques. Le taux d'adoption de ces contrats est resté très faible dans beaucoup de pays de l'UE et dans le sud-ouest de la France en particulier. Cet article vise à analyser le rôle du comportement par rapport au risque et des contraintes de travail sur la décision d'adoption de ces pratiques. Après avoir présenté un modèle théorique statique pour montrer l'impact du risque et du facteur travail dans l'adoption de pratiques à bas niveau d'intrants, nous proposons une application à l'aide d'un modèle de programmation mathématique représentant deux types d'exploitations céréalières spécialisées du sud-ouest de la France. Trois types de contrats agro-environnementaux sont testés (zéro labour, rotation longue, diminution des traitements phytosanitaires). Les résultats montrent que malgré l'effet globalement positif des pratiques alternatives sur les indicateurs environnementaux et sur le revenu des agriculteurs, la variabilité plus forte des rendements, en présence d'aversion au risque positive, ainsi que de plus forts besoins en travail sont des barrières importantes à l'adoption.

Mots-clés : pratiques de bas intrants, risque, adoption, productivité du travail, mesures agro-environnementales

JEL Classification: C61, C 67, Q12, Q18, Q57

Introduction

European agriculture has had to face a major challenge over environmental preservation. The intensive use of pesticides has led to serious water pollution in many agricultural areas. Member states of the European Union (EU) have set up clear directives about the permissible level of pesticides residues in drinking water and have launched different types of agro-environmental policy schemes to encourage farmers to reduce their use of pesticides and chemical inputs in general. Despite substantial subsidies and other significant policy incentives, the adoption of alternative farming practices remains limited. This issue is not specific to Europe and is observed in other industrialized nations with intensive agriculture (OECD, 2009; Quiggin, 2001).

Several studies have suggested that subsidies given through the different EU "green" payment schemes are not fully effective as they do not fully compensate farmers for the total costs (i.e. including "hidden" costs) associated with the adoption of alternative practices (Dobbs and Pretty, 2004; Horan *et al.*, 1999, Ridier *et al.*, 2011). The study of the determinants of adoption of new technologies by farmers, such as low input farming practices and biological pest management methods, continues to be of interest to agricultural economists (Fernandez-Cornejo *et al.*, 1998; Abadi Ghadim and Pannel, 1999). This adoption process can be considered as a long-term investment for which the cost effectiveness needs to be evaluated (Griliches, 1957). Production costs or the financial benefits/gains expected from adopting the technology can be added to the list of determinants of technology adoption in agriculture (Sunding and Zilberman, 2001; Jaffee *et al.*, 2003; Knowler and Bradshaw, 2007). A part of the production costs can be estimated according to the labor factor. Fuglie and Kascak (2001) demonstrated that farmers can reduce the cost of pesticide use by increasing labor on the farm, labor and pesticides being substitutable factors. The opportunity cost of labor indeed plays an important role. These authors showed that, under limited labor resources, arable farms with a livestock breeding activity tend not to adopt alternative pest management practices because they prefer to allocate their extra labor force to the execution of standard tasks rather than to the management of new technically demanding practices.

Farm level risk models are now widespread in the literature (see Hardaker *et al.*, 2004; Moschini and Henessy, 2001 for a review and also Hardaker *et al.*, 1991; Lien and Hardaker, 2001), even with rather skeptical views (Pannel *et al.*, 2000). The specificity of our approach is the use of a classical risk Direct Expected Utility (DEU) model to study the adoption of different agro-environmental practices, perceived as risk increasing by farmers (Just and Pope, 1978; Feder, 1979; Lohr *et al.*, 1999; Acs *et al.*, 2009; Chavas *et al.*, 2009). The contribution of this paper to the literature on the adoption of alternative farming practices under policy incentives is an analysis of the impact of both labor benefits/costs and expected income revenue on the farmer's decision to adopt under yield risks.

After an analytical comparative static analysis of the adoption problem of new farming practices under limited labor resource and under risk aversion (Sandmo, 1971), a mathematical programming model of direct maximization of expected utility is proposed. These kinds of models have been extensively applied for farm-level or sector studies and are well suited to embracing mixed ecological-economic analysis (Lambert *et al.*, 1985; Falconer and Hodge, 2001; Lien and Hardaker, 2001; De Koeijer *et al.*, 1999; Havlik *et al.*, 2008; Mosnier *et al.*, 2009). The model is numerically developed on a case study of specialized crop farms in Southwestern France. In this region, environmental water quality concerns have been addressed to farmers. To overcome these problems, stewardship payments have been targeted to them. The paper focuses on the three most adopted alternative practices under contract: no tillage (decrease of mechanical operations, labor and cost saving technique but with more ambiguous impact on pest use), long rotation (more than two crops in the succession) and reduction of pesticides by 30%. The last two practices should contribute to directly reduce pesticide and input applications while the first one is a way of simplifying soil management in order to diminish machinery costs and to avoid soil erosion. The implementation of a numerical model enables us to account for the complexity of the farmer's decision, considering different crop rotation possibilities, risk aversion in the decision and labor cost as a factor limiting the adoption. The aim is to run adoption *scenarii* under different stewardship payment schemes and to evaluate the "efficient" levels of agro-environmental incentives under risk assumption. Agro-environmental incentives can play a role of adoption premium in so far as they compensate for both risk and increase in labor cost (when the technology is more labor consuming). Simulation results are presented in the third section. They not only show the level of adoption according to labor resource and level of risk, but also exhibit the impact of the different payment schemes on the environment and the farmers' expected income.

1. An analytical framework of the farmer's adoption decision

In this section, we propose an analysis of the adoption decision based on a model of specialized cash crop farm, which underscores the role of both income risk and labor constraint. We focus on a novel farming practice, qualified as "novel" as it diminishes pesticide applications while increasing labor input (since chemical treatments are replaced by mechanical operations and more time for observation and monitoring). Following Just and Pope (1978) and Feder (1979), pesticides are considered as yield risk reducing because they decrease sanitary risks (Carpentier *et al.*, 2005).

We first propose to focus on technology choice in a certainty framework, under limited labor input, by choosing a simplified discrete technology (represented by an optimization program with a set of activities)[1]. Then we analyze the same technology choice under risk aversion, using a mean-variance approach. In this case, the novel technology is considered as risk increasing (Feder, 1979).

1.1. Technology choice under certainty with labor as a limited input

We consider a farm facing a choice between a conventional (noted *c*) and a novel (noted *N*) cultivation technology, given the same crop.

We note:

l_c l_N: units of labor *per hectare* allocated respectively to conventional and novel technologies. Considering that the *N* technology is more labor demanding:

s_c s_N: units of area allocated respectively to conventional and novel technologies

π_c, π_N: profits per hectare of crop under conventional and novel technologies. The adoption of the novel technology is supported by an Agro-Environmental Incentive (AEI) payment scheme, so that $\pi_c < \pi_N$

$\bar{L}$: family labor (limited input)

$\bar{S}$: limited land resource on farm so that $l_c\bar{S} \leq \bar{L}$

The maximization problem can be written as follows:

$$Max\left\{\pi_c s_c + \pi_N s_N \, subject\, to\, s_c + s_N \leq \bar{S}\right\} \tag{1}$$

Case 1: if the labor supply is unbounded, then the solution is: $s_N = \bar{S}$

Case 2: if the labor supply is bounded to family labor, then the solution is: $l_c s_c + l_N s_N \leq \bar{L}$

If $s_N l_N \leq \bar{L}$ the solution is: $s_N = \bar{S}$

If $s_N l_N > \bar{L}$ we assume that the entire area is cultivated, so that $s_c = \bar{S} - s_N$, the problem becomes ;

$$Max\left\{s_N \, subject\, to\, s_c l_c + s_N l_N \leq \bar{L}\right\} \tag{2}$$

[1] In the empirical section, we represent both technologies with a mathematical optimization program, in a more complex way.

When the labor constraint is upper bounded the problem is reduced to $\left(\bar{S} - s_N\right) l_c + s_N l_N = \bar{L}$:

$$s_{N^*} = \frac{\left(\bar{L} - \bar{S} l_c\right)}{l_N - l_c} \geq 0 \tag{3}$$

The optimal area under the novel technology increases when the differential between labor demand under novel versus conventional management decreases, and when the total labor demand for the entire cropping area under conventional technology ($\bar{S} l_c$) is lower than the total labor supply on the farm ($\bar{L}$) (eq. 3).

1.2. Technology choice under uncertainty with labor as a limited input

We now consider the same technology choice but income is risky due to production and market uncertainties; crop *i* is perceived as riskier than crop *c.*

$\tilde{\pi}_c = \bar{\pi}_c + \varepsilon_c$ and $\tilde{\pi}_N = \bar{\pi}_N + \varepsilon_c + \mu$,

We assume that:

$$\bar{\pi}_N > \bar{\pi}_c \tag{3a}$$

$$\sigma_c^2 = V\left(\varepsilon_c\right) \text{ and } \sigma_N^2 = \sigma_c^2 + \sigma_\mu^2 \text{ and } cov\left(\varepsilon_c, \varepsilon_N\right) = \sigma_c^2$$

We propose to solve the maximization problem by considering α the coefficient of Arrow-Pratt of absolute risk aversion and by using a Mean-Variance approach.

Case 1: The labor supply is unbounded

We consider the maximization problem as follows:

$$\begin{aligned} Max_{s_N} \Big\{ & \pi_c \left(\bar{S} - s_N\right) + \pi_N s_N - \frac{1}{2}\alpha (V\left(\tilde{\pi}_N s_N\right) + V\left(\tilde{\pi}_c s_c\right) \\ & + 2Cov\left(\tilde{\pi}_N s_N, \tilde{\pi}_c s_c\right))\Big\} \end{aligned} \tag{4}$$

$$\begin{aligned} Max_{s_N} \Big\{ & \pi_c \left(\bar{S} - s_N\right) + \pi_N s_N - \frac{1}{2}\alpha \left(s_N^2 \left(\sigma_c^2 + \sigma_\mu^2\right) \right. \\ & \left. + \left(\bar{S} - s_N\right)^2 \sigma_c^2 + 2 s_N \left(\bar{S} - s_N\right) \sigma_c^2\right)\Big\} \end{aligned}$$

$$Max_{s_N}\left\{\pi_c\left(\bar{S}-s_N\right)+\pi_N s_N-\frac{1}{2}\alpha\left(\bar{S}^2\sigma_c^2+s_N^2\sigma_\mu^2)\right)\right\}$$

In equation (4), the term () represents the additional risk brought up by the novel management. We now derive the first order condition of equation 4

$$\bar{\pi}_N-\bar{\pi}_c-\alpha s_N\sigma_\mu^2=0 \tag{5}$$

Since $\bar{\pi}_N>\bar{\pi}_c$ S_N can never be equal to zero, according to equation 5, and $s_N=\frac{\bar{\pi}_N-\bar{\pi}_c}{\alpha\sigma_\mu^2}>0$:

The area under the novel technology increases when the profit differential between novel versus conventional crops increases, i.e. when the AEI increases. It decreases when the coefficient of absolute risk aversion increases and when the additional risk associated with the novel technology (σ_μ^2) increases. The maximum is $s_N=\bar{S}$

Case 2: The labor supply is bounded by family labor

The maximization problem can be written as follows:

$$Max_{s_N}\left\{\pi_c(\bar{S}-s_N)+\pi_N s_N-\frac{1}{2}\alpha(\bar{S}^2\sigma_c^2+s_N^2\sigma_\mu^2)\right.$$
$$\left. subject\,to\,l_c s_c+l_N s_N\leq\bar{L}\right\} \tag{6}$$

In equation 6, under risk, the value of area under novel technology s_N depends on the first order conditions, where λ is the marginal value of the labor constraint (equation 7):

$$s_N=\frac{\overline{\pi}_N-\overline{\pi}_c-\lambda\left(l_N-l_c\right)}{\alpha\sigma_\mu^2} \tag{7}$$

In equation 7 (under risk), the area under novel technology is subject to the same conditions as in equation 5 (no risk): it increases when the AEI increases and when the coefficient of absolute risk aversion α decreases. In addition to this, if $\lambda>0$ (the family labor constraint is bounded), and since l_N-$l_c\geq 0$, the area under novel technology s_N is decreased when the differential of labor demand between novel and conventional technology (l_N -lc) is increased. Then, under risk and limited family labor, it's the labor constraint, in addition to risk aversion, that arbitrates for crop acreage and technology choice.

2. An empirical model to simulate adoption decisions under different contracts

In this section, we propose to tackle the problem of adoption of low input practices by empirically specifying the theoretical problem addressed in the first section. This allows us to develop an in-depth analysis of how the analytical model can apply in reality. The model is implemented on a case study of specialized cash crop farm situated in South-western France. The region has been targeted by agro environmental programs to improve water quality, at the river basin scale.

Table 1. **The impact of the new practices on farm management and risk exposure**

Practice	Impact on labor input	Impact on demand of chemical inputs	Impact on risk exposure
No tillage[2]	Decrease in time spent in ploughing and machinery use. Increase in labor productivity if no more time is spent in monitoring weeds.	It depends. Requires a better management of weeds in intercrop-periods, requires implementation of rotations. Possible extra use of herbicides.	Possible decrease in yield variability, especially for winter crops, because of possible loss during the rising step.
Long rotation	Decrease in labor productivity. Decrease in labor-peaks because of crop diversification.	Decrease in chemical treatments replaced by mechanical operations.	Diversification of crop acreage as a way to manage market risks. Yields perceived as more variable.
30% Decrease in pesticide use	Increase in labor demand for mechanical operations. Decrease in labor productivity.	Decrease in chemical treatments replaced by mechanical operations.	Loss of protection for sanitary risks. Yields perceived as unchanged but more variable.

Source: Eausage research project, workshop in Toulouse, June 2009.

The implementation concerns two types of low variable input practices currently supported by the CAP 2nd pillar Agro-Environmental (AE) measures: i) implementation of long rotations, ii) 30% decrease in pesticide application. A third AE measure is tested, which is supporting iii) "no tillage" practices. This last measure is the most adopted AE measure in the region. Its implementation, when accompanied by longer rotations or intermediary crops, in order to better control weeds and sanitary disease, is the component of a global change at the cropping system scale. According

[2] Reference: "Travail du sol simplifié, bilan du suivi 2001-2004", Regional extension services, *Midi-Pyrénées*, Experiments monitored on plots in the 6 counties, in 2 types of soils: sandy clay and clay-calcareous.

Table 2. **The crop pattern of the two different cash-crop farm types in the Midi-Pyrénées region: comparison between the statistical observed farm and the farm modelled**

Share of the area in the river basin[3] **Crop pattern (ha)**	**Farm type 1 (dry cereals, hilly areas)**		**Farm type 2 (irrigated maize, valleys)**	
	35,00%		*17,00%*	
	observed	***baseline***	**observed**	***baseline***
Fallow, buffer strip	15,0	*15*	12,0	*12*
Colza	5,7	*30*	27,3	*27,3*
Soft wheat	43,6	*42*	26,5	*29,5*
Durum wheat	16,7	*15*		
Barley		*0*	3	
Sorghum				
Sunflower	35,8	*15*		
Soybean	8,0			
Maize	20,8	*29*	47,6	*47,6*
Pea, special crops				
grassland	4,4	*4*	3,6	*3,6*
Total Agricultural Area	**150,0**	**150,0**	**120,0**	**120,0**
% of irrigable soil	8%	14%	40%	45%
% muddy clay soils	80%	80%	20%	20%
% sandy clay soils	20%	20%	80%	80%
N^r of Family Labor Units	**2**	**2**	**1.5**	**1.5**

Source: chambre régionale d'agriculture Midi-Pyrénées Sicomore, RA 2000.

to technical literature and discussions with regional experts, its adoption increases production risks perceived by farmers in so far as sanitary risks can be increased by tillage removal, because weed and sanitary management needs to be adapted[2]. Thrice practices have consequences on three topics on farm: labor input, demand for chemical inputs (pests, nitrogen) and exposure to climatic risk (table 1). As mentioned in this table, the different farm practices have different consequences on risk and farm management. According to agronomists, there is no clear demonstration of the impact of pesticides on the degree of yield variability (notably because yield level has many determinants interacting with each other), but many theoretical and empirical studies in economics assume that pesticides, while reducing infestation levels and pest damage, decrease the yield variability (Hall and Norgaard, 1978; Feder, 1979; Antle, 1988). Interviews with regional experts lead us to assume that both reducing the quantity of pesticides by 30% and implementing long rotations (implying also a decrease in the level of pesticides, by 20 to 50%) would preserve crop yields on average while increasing yield variability by 15% (more or less, depending on the crop). Also, because of lack of

[3] Source: Recensement agricole 2000 according to a typology elaborated by Cemagref-team inside the Concert'eau project, 2008.

knowledge concerning the consequences of the "no tillage" practice on yield variability, and considering the experience reported by extension services in the Midi-Pyrénées[2,3] region, this practice is also considered, in this paper, as yield-risk increasing (preserving average yield)[4].

We develop a static mathematical programming model of crop choice. The decision variables are: the area in the different crops, given a limited total agricultural area and the labor demand per period, considering the implemented technology. If the labor demand exceeds the family labor resource, occasional labor can be hired.

In our model, we aim at accounting as precisely as possible for the consequences of the implementation of the above three different practices in terms of risk management and labor organisation. In order to represent farmers' risk attitude, we chose a Constant Relative Risk Aversion (CRRA) Utility function. While the relative risk aversion remains constant (the indifference between risky payoffs is not disturbed when all payoffs are

Table 3. **Main economic and agronomic data for the different possible crops (*conventional practices*)**

	soft wheat (dry)	**durum wheat (dry)**	**sunflower (dry)**	**rapeseed (dry)**	**soybean (irrig)**	**maize (dry)**	**maize (irrig)**
Impossible precedent crop	0	0	rapeseed	rapeseed	0	0	0
Yield [5] *(tons/ha)*							
Mean	5,5	5,5	2,4	2,8	3	7,5	8
Standard deviation[6]	0,83	0,9	0,39	0,1	0,262	1,5	1
Standard deviation if novel practices (+15%)	0,9545	1,035	0,4485	0,115	0,3013	1,725	1,150
Mean price *(€ /ton in 2005)*	100	145	210	180	190	110	110
Operating costs *(€/ha)*							
Inputs	289	359	205	296	120	388	388
machineries	136	136	170	126	161	164	224
Specific crop premium *(€/ha)*	74	114	80	74	74	74	122
Gross margin* *(€/ha)*	**199**	**416**	**209**	**156**	**363**	**347**	**390**

*Not including the Single Farm Payment: Normal: 320 €/ha, Fallow: 340 €/ha

[4] This assumption is based on a workshop organized in June 2009 with 15 participants of the Eausage-PSDR project: researchers, teachers in agronomy (from agricultural high school and research institute in Toulouse), farming experts from extension services in Midi-Pyrénées. They were asked to assign a value of mean yield and yield variability to the main crops cultivated in the Midi-Pyrénées region (maize, wheat, sunflower) under both conventional and integrated practices. The precise crop management, considering the precedent crop, inventorying the different farm operations, was also detailed with them.

[5] The yield is varied according to Cropsyst model simulation considering different possible crop precedent.

[6] Representing climatic risk observed in the past 4 years in the whole region, source Chambre régionale d'agriculture Midi-Pyrénées.

multiplied by a positive constant), it exhibits a decrease in absolute risk aversion with an increase in wealth (Hardaker and Lien, 2007) (eq. 7).

The expected income is calculated based on case studies of two cash crop farm-types in the Midi-Pyrénées region. For these farm-types, the production function is defined by a mathematical programming (MP) optimization model, in which a set of activities (both conventional and novel practices) is competing with each other under a set of constraints. The MP is drawing a relation *f* between the outputs (quantities *y* produced in the different crops) and the levels of inputs (Land S, Labor L and the vectors x_C and x_N of areas under conventional and novel practices): $y = f\ (x_c, x_N, L, S)$

The data used to calibrate the parameters of the MP model and to run it come from surveys conducted in Southwestern France. We begin by briefly specifying the MP model. We then describe the data and discuss the model calibration.

2.1. Structure of the Mathematical Programming (MP) model

The optimisation model is based on the maximization of the expected utility of income over one period. Yield risk due to climate variability is assumed to be the only source of risk[7]. The yield risk is supposed to be normally distributed, on the basis of the mean and variance of yields statistically observed for the different conventional crops in the region during the past four years. In table 3, the yield per crop is reported: mean and standard deviation. These statistics have been calculated according to the yields observed on several plots of similar soil types, belonging to 110 farms of the Midi-Pyrénées region during the four past climatic years (data provided by the regional extension services[8]). In the GAMS program, 100 states of nature are randomly generated according to these distributions (mean, variance) and with respect to the covariance between the yields of the different crops. As mentioned before, we assume that under thrice novel practices, the yield variability is increased. A higher variability of yield standard deviation (expanded by 15%) is simulated (table 3).

Considering that yield is the only source of risk, the vector of net incomes by state of nature *k,* $R_{k,}$ is calculated and $U(R_k)$ is a vector of utilities weighted by $w_{k,}$ the probability per state of nature (Lambert and Mac Carl, 1985; Lien

[7] Unlike the analytical model, we voluntarily ignore market risk in order to focus on the risk of implementing new farming practices. However we do not ignore the brake on adoption entailed by a context of sharp, rapid, unpredictable increases (or decreases) of cereal prices.
[8] From regional extension services: Chambre régionale d'agriculture Midi-Pyrénées, références technico-économiques en systèmes de grandes cultures, Résultats 2001, 2003, 2005, 2007. Statistic values are computed when the number of plots per crop is over 20.

and Hardaker, 2001). We assume all states of nature to be equally probable. The utility function is of CRRA type, it is given by eq. 7[9]

When r > 0 and $r \neq 1$ $U(R_k) = \left(\frac{1}{1-r}\right) * (R_k)^{(1-r)}$

When r = 1 $U(R_k) = ln(R_k)$

Rk: expected income for the state of nature k; r: coefficient of relative risk aversion.

Equation 7

The net income is divided into two parts: market returns and subsidies; x_C represents the area under conventional crop management; x_N is the area under novel crop management; y is the yield per crop for every state of nature k; p is the market price of crops; w is the variable cost per hectare of crop. Fixed costs are noted FC. The subsidies from CAP first pillar are introduced[10]; the coupled subsidy per hectare of arable crop is noted s and the decoupled Single Farm Payment is noted D. It is distributed to the whole farming area $\bar{S}$. Also, an Agri Environmental Incentive (*AEI*) is allocated to areas cropped under novel practices x_N [11] (eq. 8).

$$R_k = \sum_{C,N} [x_c(y_{C,k}p_C - w_C + s) + x_N(y_{N,k}p_C - w_N + s + AEI)] + \bar{S}D - FC \tag{8}$$

The main constraints of the MP model are related to agronomic and economic resources (land, irrigation, labor and rotation), according to the structural features described in table 2. The constraints also rely on policy and environmental restrictions: i) *land*: the composition in the different soil types (muddy-clay soils and sandy-clay soils, which are less fertile) is different in both farm-types; ii) *irrigation*: the share of irrigated land is linked to the farm type location, higher in valleys than in hilly areas (table 2); iii) *rotation*: for each crop, a set of possibility of previous crops is identified and the share of area of each crop is limited by the total area of its previous crops (table 3). The mean yield and its variability per crop/precedent according to the type of soil is assessed thanks to the Cropsyst crop growing model for conventional management and according to regional references (Belhouchette *et al.*, 2009); iv) *labor*: the labor resource on farm is composed of family workers and possible extra seasonal workers that are costly. The labor supply in days

[9] First, the CRRA utility function is increasing in r if r < 1 but decreasing if r > 1. Therefore, dividing by 1-r ensures that the marginal utility is positive for all values of r. Second, if r- > 1, the utility function converges to $\ln(r_k)^2$.

[10] According to the CAP subsidy scheme included in the Mid Term Review reform (2005-2008); crop direct payments are partially decoupled (75%), the rest of the subsidies are distributed inside a decoupled Single Farm Payment (SFP).

[11] This optional achievement for farmers who wish to obtain the AEI subsidy is modelled by the use of a binary variable and a RMINLP solver. The use of RMINLP enables attaining a feasible integer solution. In this case the integer restriction is relaxed.

per month depends on both family holidays and bad weather conditions (with a probability that bad weather day happens during holidays). Labor needs and family labor availability are reported monthly. For input-saving-practices, mechanical operations are a substitute for chemical treatments: They are more labor intensive at some "peak periods" (tab. 4 and 5); v) *CAP cross compliance*: in order to receive the specific crop premium a rate of 10% set-aside for cereals, oilseed and protein crops is imposed; in order to receive the entire amount of the Single Farm Payment per farm, 3% of the area allocated to cereal, oilseed and proteins crops have also to be converted into buffer strips.

Table 4: **Time spent per type of farming operation (for a single operation)**

	In hours per hectare
Soil preparation (tillage)	1,4
Remove of stubbles	0,7
Sowing	1,9
Fertilizer operation	0,5
Pest treatment	0,2
Harrow	1,1
Harvest	1,2
Straw-press	0,5

Source: Regional coop of machinery, CUMA-Midi-Pyrénées.

Table 5. **Indicators of input pressure for the different crops (fertilizers and pests)**

	Number of fertilizing operations/ha/year	**Number of pest operations/ha/year**	
		(conventional)	*(30% pesticides)*
Soft wheat	4	5	3
Durum wheat	3	6	3
Maize	3	3	3
Soybean	1	2	1
Sunflower	2	2	1
Colza	4	7	4
Buffer-strip, fallow	0	0	0

2.2. Farm types and source of data

In the river basin called Gers Amont, belonging to the Adour-Garonne watershed located in the Midi-Pyrénées region, agro-environmental programs have been targeted to 700 farmers on a total area of 37,000 ha. Our model is run on two farm-types representative of two types of areas inside this river basin, with different cropping systems. The farm-type 1 is specialized in dry cereals, located in the driest and most hilly areas of the river basin and where the main crop rotation is dry durum wheat followed by sunflower and represents about 35% of the total area. The farm-type 2 is specialized in irrigated maize and located in valleys where the main rotations are maize/maize or maize/soft-wheat or maize/soybean and it represents 17% of this total area (tab. 2). The rest of the area is composed of mixed crop-livestock farm types.

The model is calibrated according to three sources of data: i) the French National Farm Survey (RA 2000[12]), ii) the regional database Sicomore belonging to the regional extension services, iii) direct interviews with farming experts from the studied area.

The yield data for the baseline model are estimated thanks to the Cropsyst crop-growing model, it accounts for the different possible precedents of each crop and for the soil quality[13] (Belhouchette *et al.*, 2009). The labor requirements per crop and per month are calculated according to the time spent in the different farming operations (tillage, fertilization, fungicides, insecticides, herbicides, harvesting), according to the type of machinery used[14] (tab. 4). Some indicators of environmental outputs per crop, according to the frequency of fertilizer and pest operations are implemented for each kind of crop (tab. 5).

2.3. Model calibration

The calibration of the model consists in comparing the predicted acreages allocated to the different crops to those observed in both farm types. The calibration step consists in marginally varying the different exogenous parameters of the MP model in order to minimize the deviation between the observed and the simulated land use, operating a sensitivity analysis to these variations.

Structural features (total agricultural area, percentage of muddy-clay and sandy clay soils, percentage of irrigable area, number of family workers) are exogenous parameters to farmer's decision that can affect land use opportunities and that can be slightly varied from the initial reported value during the calibration process (tab. 2).

Also, the coefficient of relative risk aversion r_r, which has not been experimentally elicited in both farms, is estimated during the calibration. Thus, land use decisions enable to assess risk preferences, through a revealed preferences approach (Wiens, 1976; Chavas and Holt, 1996). Several possible values of the coefficient r_r distributed on the interval [-2, 2] are tested.

[12] A survey carried out every ten years to collect information on all farms. The most recent census available for this study was in 2000. This survey is presented on the official website of the statistics of the French Agriculture Ministry: http://www.agreste.agriculture.gouv.fr/enquetes/structure-des-exploitations/

[13] The simulations account for the previous crop in the rotation, the soil type, and the presence of irrigation.

[14] Reference: Regional cooperative for machinery, CUMA.

This interval corresponds to values of CRRA obtained in lottery games from "strongly risk loving"(-2) to "strongly risk averse"(2), according to Holt and Laury (2002). The elicited CRRA coefficient is then the one that minimizes the sum of absolute deviations between the predicted and the observed land uses. The indicator used to validate the model is the Percentage of Absolute Deviation (PAD)[15], which measures the gap between the observed and the simulated acreage. As a result, in table 2, the difference between "observed" and "baseline" columns are due to this calibration process.

The price situation and CAP regulations in 2005 are used as a baseline for calibration (tab. 2). We considered a reasonable ability of the model to simulate real crop acreage with an error tolerance less than 20%[16] for both farm types.

Finally, the value retained for r_r is 0.7 for both farm-types (tab. 6). This value of relative risk aversion seems credible considering the wide range of values obtained in the literature (for a review see Couture *et al.*, 2010). This level of CRRA corresponds to a "very risk averse" attitude according to Holt and Laury (2002) and to a "rather risk averse" attitude according to Hardaker *et al*. (2004).

Table 6. **Results of the three scenarii: level of incentives, rate of adoption and change in labor use**

	Scenario 1 (no-tillage)	Scenario 2 (long rotation)	Scenario 3 (-30% pesticides)
Farm-type 1 (hilly area, wheat/sunflower rotation)			
Maximum rate of area converted (%)	87[18]	100	87[17]
Level of AEI (€/ha)	20	130	120
Gross Margin-variation (€/ha)	+ 26	+ 69	+ 111
Labor variation (Δnr hours/yr)	- 19	- 4	+ 54
Farm-type 2 (plain irrig. area, specialized in maize)			
Maximum rate of area converted (%)	87	100	87
Level of AEI (€/ha)	20	130	140
Gross Margin –variation(€/ha)	+ 65	+ 67	+ 127
Labor variation (Δnr hours/yr)	- 11	+ 10	+ 84

[15] The PAD is used as an indicator to evaluate the representativeness of the model by calculating the crop pattern variability: $\mathrm{PAD} = \frac{\sum_{i=1}^{n}|\bar{X}_1 - X_i|}{\sum_{i=1}^{n}\bar{X}_1}$ with $\bar{X}_1$ value observed and X value simulated.

[16] This does not really correspond to a benchmark because no consensus exists on the statistical method to be adopted to assess the quality of a model. Since our approach does not really aim to achieve aggregated results, we can tolerate a PAD under 20%.

[17] Representing climatic risk in the past 4 years in the whole region, source Chambre Régionale d'agriculture Midi-Pyrénées.

[18] This percentage corresponds to the maximum area convertible when removing the area set aside (10%) and the buffer strip area (3%).

3. Scenario simulations and results

Three *scenarii* are run corresponding to the implementation of three novel farming practices supported by Agro-environmental Incentives (AEIs).

The *"no tillage" practice (scenario 1)* requires the remove of tillage operations usually dedicated to soil preparation, permitting a decrease in machinery operations. In the model, two types of techniques ("tillage" and "no-tillage") are specified and each crop can be supplied according to both techniques. An extra premium is associated with the "no-tillage" activity. The level of this premium is endogenous and corresponds to the minimum incentive required to switch from "tillage" to "no-tillage".

The *"long rotation" practice (scenario 2)* consists in cropping a rotation of four different crops over five years. This practice leads to a decrease over five years in the use of pesticides because the introduction of varied crops throughout the rotation results in the prevention of pest resistances. A new constraint concerning the total number of crops is introduced in the model. This constraint is related to a binary variable, which also activates the AEI parameter.

The "reducing pest" practice (scenario 3) concerns the implementation of an "integrated" practice, leading to a 30% decrease of pesticide applications for all crops. To compensate for the reduction in pesticide use, farmers have to run extra mechanical soil operations replacing pest applications (extra harrowing...), so we assumed, according to the agronomic literature and to experts, that farmers should replace one pest treatment by three harrowing operations. For integrated techniques, the environmental pressure of farming operations is overall decreased (tab. 5).

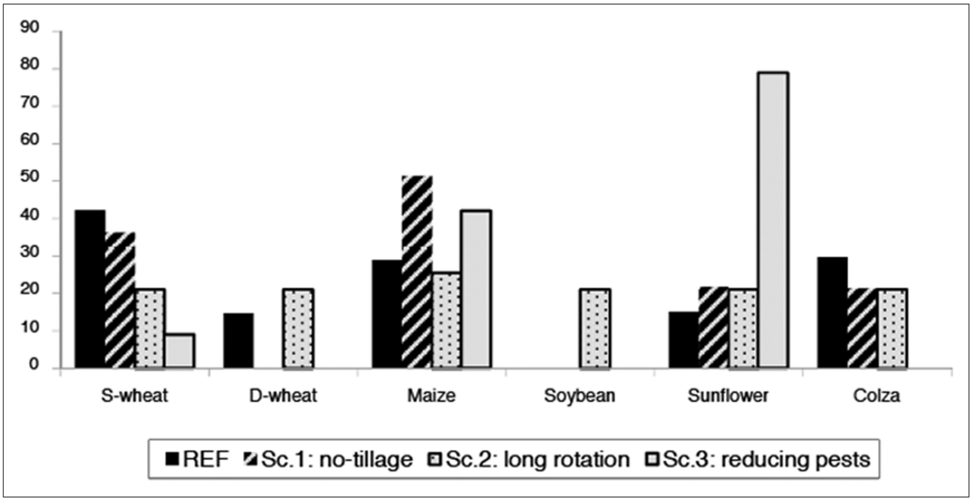
In the model, the attribution of specific AEIs is subject to compliance with the new practice, thus the value of the AEI has to be sufficient to allow the new practice to enter the crop pattern. The AEI is a parameter in the model (eq. 8). We test the minimum level of AEI that allows achieving full contracting into novel practices. To do so, several values of AEI are distributed and tested on an interval from 0 to €150 per ha. The full contracting rate corresponds to 87% for the "no tillage practice" (scenario 1) and the "-30% of pesticides" (scenario 3), removing the area set aside (10%) and the buffer strip area (3%). It corresponds to 100% of the total agricultural area for the "long rotation" (scenario 2). The values of AEI vary from €20 (in scenario 1-no tillage- for both farm types) to €140 per hectare (in scenario 3 for farm-type two) (table 6).

In the following paragraphs we propose to analyze the results of the different scenario simulations according to three main performance criteria: i) the global changes in farm acreage and time organization, ii) the indirect environmental impact and iii) the income change and the sensitivity of farmer's adoption decision according to the level of incentive compared with the level of risk premium calculated per crop.

3.2. Changes in crop patterns and time organization

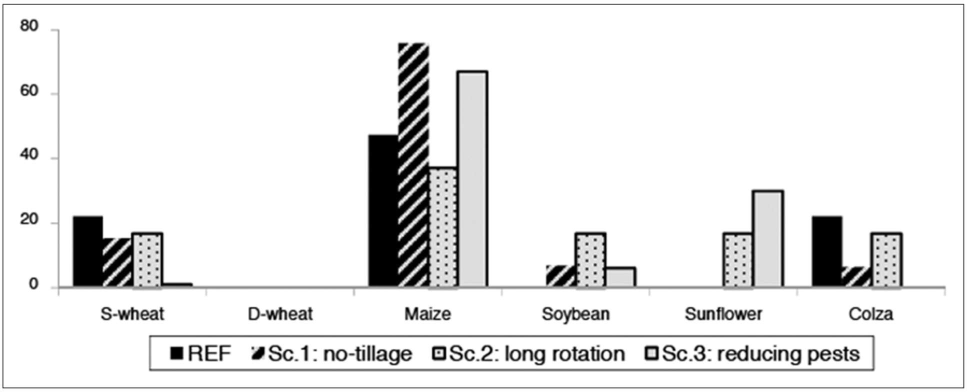
The results obtained for each scenario are compared to the baseline-calibration situation.

Figure 1: **crop pattern (in ha) according to the different *scenarii*, farm-type 1 (dry cereals)**



In scenario 1 the crop pattern of both farm-types is slightly changed (fig. 1 and 2); the remove of tillage decreases the global labor needs (by 19 hours/yr for farm-type 1 and by 11 hours/yr farm-type 2, see tab. 6). Thus, farmers can re-allocate their labor time and reduce labor peak periods in order to grow more profitable crops (fig. 3 and 4): for both farm-types, a decrease in the area of winter crops (soft and durum wheat) is observed; they are replaced by oilseeds and maize areas.

Figure 2. **Crop pattern (in ha) according to the different *scenarii*, farm-type 2 (irrig. Maize)**



In scenario 2 the rotation lengthening has a greater impact on the cropping patterns of the farm-type 2 (irrigated maize) than on the farm-type 1 (dry cereals) since, in farm-type 1, a wide variety of crops is already and traditionally cultivated in order to face amplified yield risks in dry and hilly areas. In farm-type 2, new crops (soybean and sunflower) appear in the crop pattern under sc. 2 (fig. 1 and 2).

In scenario 3, an analysis of the labor demand per month shows a high increase during spring (April, May) reaching 48% in farm-type 1 and 84% in farm-type 2 (fig. 3 and 4). This is consistent with the replacement of pesticides treatments with mechanical operations and with the assumption of decreasing labor productivity under the new practice. A change in crop patterns of both farm-types, greater than in the previous *scenarii*, is observed. In farm-type 1, only three sorts of crops remain; the soft wheat area is reduced while the area with maize and sunflower is greatly increased. Durum wheat and colza are removed (fig. 1). In farm-type 2 changes are similar: soft wheat is decreased while maize and sunflower are increased (fig. 2). This result is consistent with

Figure 3. **Time consumption (per month) according to the different *scenarii*, farm-type 1**

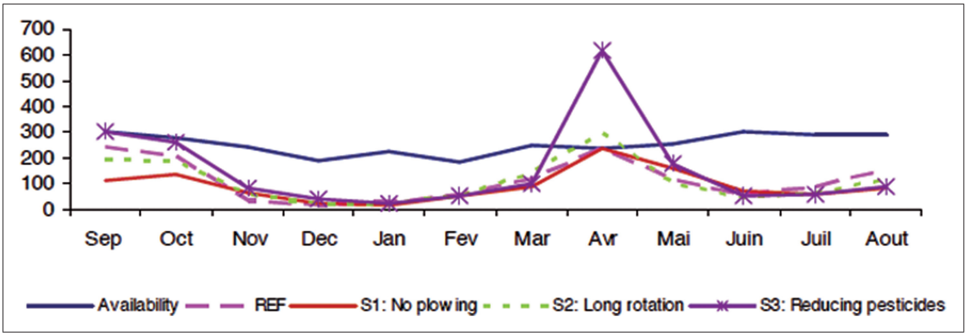
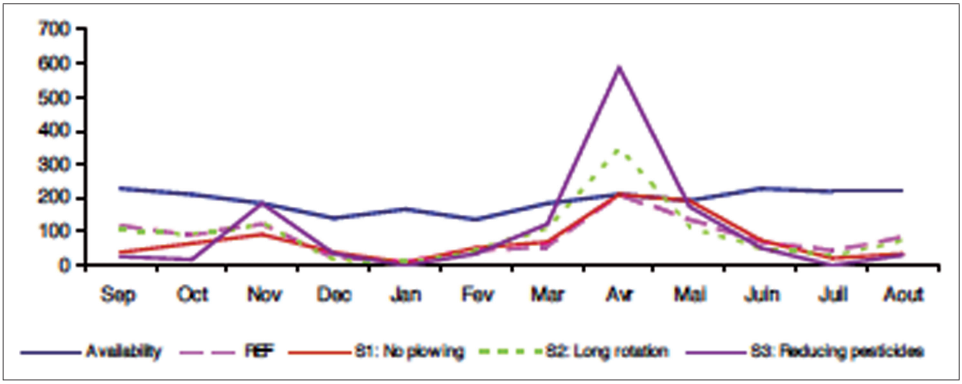


Figure 4. **Time consumption (per month) according to the different *scenarii*, farm-type 2**



the modeling assumptions: crops, which generate the most profitable expected gross margins (and with lowest yield variability), and which allow a better labor allocation (maize, sunflower) are preferred to the others. With riskier yields and an increase in labor needs due to the reduction of pesticides use, farmers try to concentrate their efforts and time availability on crops that have the highest profit.

3.2. Consequences in terms of environmental indicators

The consequences in terms of environmental outputs due to the observed changes in the acreage are assessed here through three indicators: crop diversity, number of fertilizer operations and number of pest treatments (fig. 5 and 6).

Scenario 1

In farm-type 1, the "no tillage" practice has a very little impact on the environmental indicators. The increase in maize area and decrease in winter crops induce a reduction of acreage diversity and a rather stable level of fertilizer and pest consumption per hectare (fig. 5). In farm-type 2, the number of crops is slightly increased but the sharp increase in maize area to the detriment of wheat and colza induces an increase in the mean number of pest operations *per* hectare (fig. 6). Thus, this contractual measure remains rather controversial in terms of environmental impact.

Figure 5. **Agro-ecological indicators for the farm-type 1 in the three *scenarii***

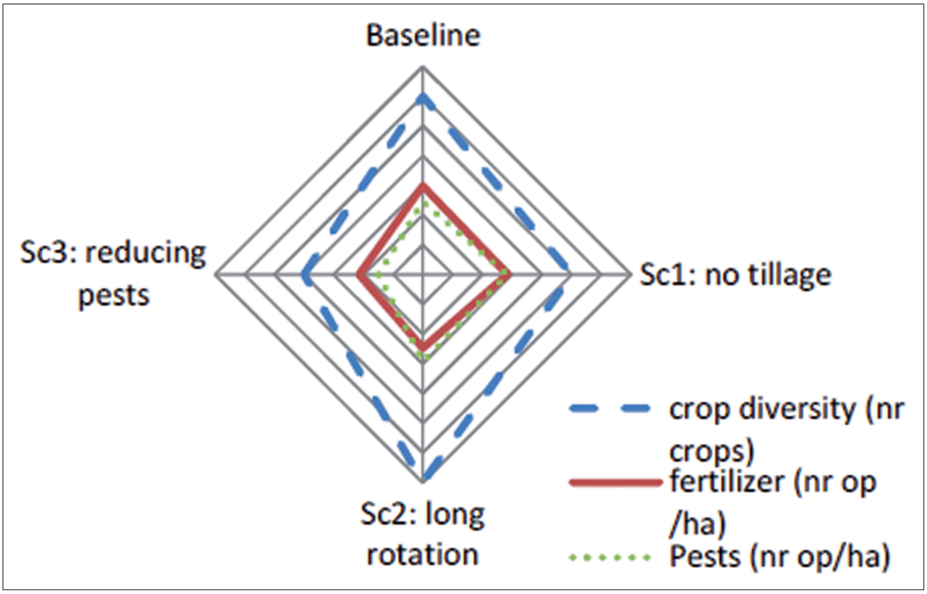
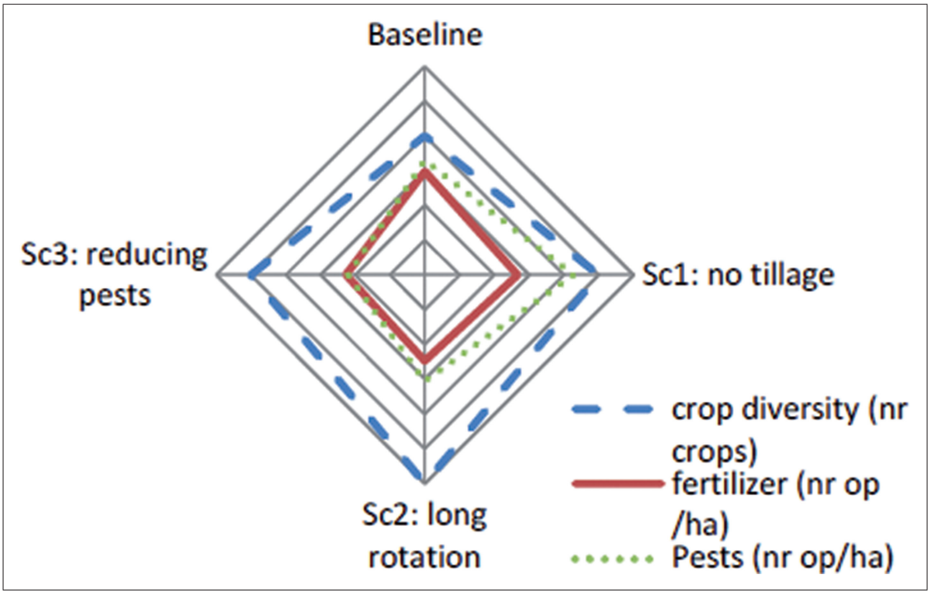


Figure 6. **Agro-ecological indicators for the farm-type 2 in the three *scenarii***



Scenario 2

In farm-type 1, the "long rotation" practice is increasing the number of crops in the acreage, but the starting point was already rather satisfying (6 different crops). The introduction of soybean in the acreage (with lower fertilizer needs, see tab. 5) induces a slight decrease in fertilizer pressure per hectare. The pest indicator is unchanged (fig. 5). In farm-type 2, the environmental balance of the new acreage (decrease in maize area, appearance of sunflower in the rotation) is improved for the three indicators (fig. 6).

Scenario 3

The implementation of "integrated" practices is beneficial for all indicators in both farms, except for the crop diversity in farm-type 1 (fig. 5 and 6). As seen before, the number of crops is decreased in farm-type 1, because of a different time allocation along the cropping cycle since peak periods are increased due to more numerous mechanical operations replacing chemical treatments.

3. 3. Income change and level of incentive

For both farm-types, the expected income is increased in all *scenarii*, compared with the baseline. This increase is due to both the level of associated incentives and, in some cases, to the decrease of labor or machinery costs (tab. 6). The increase in gross margin, which can be observed in all *scenarii* for both farm-types (+6% to +27% depending on farm-type and scenario), results from the AEI compensation (in its two components) and also from changes in acreage decisions. It also reflects an increase in the risk premium.

In *scenario 1 (no tillage)* a 20 €/ha premium results in about 87% of the total area using no-tillage practice for both farm-types (tab. 7). This premium is lower than the amount currently programmed in the Agro Environmental Scheme (about 30 €/ha).

In *scenario 2 (long rotation)*, the income increase due to the adoption of the new practice is higher than in the scenario 1 for both farms (tab. 6). This is mainly due to the amount of additional premiums received in response to the compliance with the long rotation (130 €/ha) and to the additional income from the new crops (soya, durum wheat, sunflower). The level of incentive resulting from our simulation is rather close to the premium currently given to farmers (138 €/ha). In farm-type 2, which is a farm specialized in maize, this premium allows farmers to face additional costs caused by the introduction of new crops, especially the expense of extra occasional labor during labor-peak periods.

In *scenario 3 (reducing pesticides)*, a substantial increase in income is observed for both farm-types (tab. 6). The levels of AEIs are different in the two farm-types: 120 €/ha in farm-type 1 and 140 €/ha in farm-type 2. These different levels can be explained by different labor availabilities between both farm-types (2 farming units in farm-type 1 and 1.5 in farm-type 2). Under reduced pesticides practices the labor productivity is decreased and, with lower family labor resource, the farm-type 2 is penalized. In April, both farm-types face a large increase in the labor peak-period due to the replacement of pest treatments by mechanical operations (fig. 3 and 4). To overcome this peak period, they have to hire occasional labor, which is costly. This partially explains the higher level of incentive for farm-type 2.

Conclusion, discussion

The simulations performed with a MP model under yield risk, for two different cash crop farm-types of Southwestern France, and three different alternative practices supported by the CAP green payments highlight different results. Depending on different agronomic contexts, different levels of Agro-Environmental Incentives can be efficiently targeted to the implementation of new farming practices. The level of incentives depends on farm characteristics (degree of specialization), labor allocation and also on farmers' perceptions of yield risk. The implementation of new farming practices can give to farmers the opportunity to re-allocate their available time towards more profitable crops, and thus to avoid the effect of decreasing marginal labor productivity associated with the adoption of low-input practices. However, when labor is reallocated, acreage may change and the resulting environmental indicators (crop diversity, fertilizer and pest mean pressure per area) are thus not moving all in the same direction under the different scenarii. The scenario of "no-tillage" practice has been tested. While it is the most adopted agro-environmental scheme in the region, it has contrasted impacts on the different environmental indicators due to labor reallocation. Thus, the results confirm that the quantity of labor required to change farming practices probably constitute the main obstacle to the adoption of innovative farming practices since it changes the spread of labor peaks throughout the year. Since the new farming practices are labor intensive, the marginal cost of changing varies according to the balance between labor needs and labor resources per month in the different farm types. Finally, an interpretation of the gap between the level of the efficient incentive obtained by simulation for each farm-type and the current levels of premium proposed to farmers is proposed. This gap can also be interpreted as an extra risk premium for farmers whose perception of yield variability is increased.

With respect to the actual debate regarding the CAP reform, our results suggest that in order to encourage farmers to adopt alternative practices, it might be relevant to review the content of the green payment schemes in order to take into account not only yield risks and mechanization costs, but also labor costs (quantity of labor required, possibility or not to reallocate labor and level of skills required). It seems also justified to implement environmental incentives that cover more than one year.

The change in farming practices is a gradual process, which requires a good knowledge of agronomic factors. In the early years of the adoption process, farmers can support additional costs such as weeding and other mechanical operations. The sanitary problems entailed by the novel practices (weeds, depletion of soil structure, . . .) could have heavier impacts on yields than those considered in our simulations. Considering this additive yield risk in the middle run, the current amount and the five years duration of the environmental contract duration probably correspond to a sufficient length to reach a better knowledge of the practice and to get back a "normal" soil microbial activity and yield level.

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