An economic analysis of the possibility of reducing pesticides in French field crops

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Abstract

The paper aims to study the effects of reducing pesticide use by farmers in the arable sector in France and the feasibility of a policy target of reducing pesticide use by half. The originality of the approach is to combine statistical data and expert knowledge to describe low-input alternative techniques at the national level. These data are used in a mathematical programming model to simulate the effect on land use, production and farmers' income of achieving different levels of pesticide reduction. The results show that reducing pesticide use by 30% could be possible without reducing farmers' income. We also estimate the levels of tax on pesticides necessary to achieve different levels of reduction of pesticide use and the effect of an incentive mechanism combining a pesticide tax with subsidies for low-input techniques.

Keywords : pesticide use, policy incentive, environmental indicators, low-input techniques.

1. Introduction

The harm caused by pesticides to human health and the environment is a major subject of concern which involves some sensitive issues such as drinking water contamination, the health of users and the harmful effects on wildlife and biodiversity. In France, which ranks third in the world (and first in Europe) for the use of plant protection products, a strong social and political willingness was displayed in 2008, in a large social forum tracing objectives of the environmental policy of the country (known as the "Grenelle de l'environnement"). Ambitious targets were set and different measures and incentives are currently being implemented. The objective of reducing, if possible, the use of pesticides by half by 2018 has been announced.

The issue of reducing pesticide use has also emerged in the environmental policy debates in several other European countries, and therefore, in 2009, the European Union (EU) adopted a common framework (directive 2009/128/EC) that requires each member state to submit a 2012 action plan to reduce pesticide use in agriculture. The EU directive gives the policy launched in France a broader perspective.

However the objectives set in 2008 are still under discussion: is the 50% reduction target set in 2008 realistic? What would be the consequences of such a level of reduction on French agricultural production and on farmers' income? What are the economic incentives needed to encourage such a reduction?

Our research was conducted to help answer these questions[1]. The work we present here concerns the French production of field crops. Although the use of pesticides per hectare of crops is not as high as in other crops (fruit, vegetables, vineyards), the territorial extent of field crop production is such that any global reduction of pesticides in France necessarily involves a reduction in the field crops sector. In 2006, field crops represented 80% of the total cultivated land and accounted for 68% of the pesticides used in agriculture. During the last ten years pesticide use in French agriculture has been quite stable, showing no decrease despite a fall in prices for agricultural products relative to input prices. Most of the French production of field crops is grown using intensive conventional techniques. Although some farmers use less intensive techniques, it is difficult to know exactly what proportion of the total field crop area is concerned. The fraction of organic farming in the total field crop area is around 1%. (Butault et al., 2010).

Our analysis relies on a combination of a traditional economic optimization approach and production functions based on agronomic knowledge. In a first step, a group of agronomists studied the feasibility of pesticide reduction in the main French field crops and elaborated for each crop (and several climatic zones) alternative crop management plans to reduce the use of pesticides. In a second step an economic evaluation of the alternative crop management plans and of economic incentives that may encourage their adoption was carried out. To conduct this economic analysis a mathematical programming model was built for the whole French production, divided into eight main regions.

Mathematical programming models have several advantages in the economic analysis of policies designed to modify the environmental impact of agricultural activity. They allow a modification in the production decisions of farmers to be analysed, independently of what has already been observed in

[1] It is part of a large interdisciplinary study "Ecophyto R&D" carried out by the French "Institut National de la Recherche Agronomique" (INRA) in order to answer specifically the three mentioned questions, this study has been done at the request of the French ministries in charge of agriculture and the environment. All the results can be found on the INRA website.

the past. A detailed representation of the production technologies can be embodied in the economic models. It thus makes it possible to study the environmental impacts of agricultural production considering the "joint production" of agricultural outputs and environmental externalities. This explains why this approach has been adopted by many economists analyzing the impacts of agriculture on the environment. (see for instance Mosnier et al. 2008, Peerlings and Polman, 2008, Buysse et al. 2007, Van Calker et al. 2005, Havlik et al. 2005, Falconer and Hodge 2001).

The use of results from biophysical simulation models is often an interesting way of compensating for the lack of data for hypothetical techniques that are not in actual use. Using data generated from agronomic simulation models in mathematical programming models makes it possible to explore a wide range of alternative, including low-input, techniques, for which observed data on farms or experimental data are insufficient (Flichman and Jacquet 2003, Janssen and Van Ittersum 2007). This could have been the approach adopted in our analysis. However, pesticides are not a direct production factor (like water and nitrogen) : their effect is to reduce damage levels and hence production losses due to pests, which is imperfectly embodied in the current agronomic models. Consequently, the economic studies addressing the issue of pesticide use reduction are generally based on data from observations on a few farms, or data from agronomic experiments (Falconer and Hodge 2000, Falconer and Hodge 2001, Kersalears, 2005, Van Calker 2006) . Most of them are conducted at the farm level.

The novelty of our paper is to conduct an economic analysis of the possibility of reducing pesticide use at the national level (i.e. for France) using a mathematical programming model and data from different sources: statistical surveys, experimental data and expert knowledge. The construction of different production technologies by experts is the solution that we have chosen to provide indicators for techniques ranging from low-input to organic production, for which we lacked data in the farm-based surveys.

We present the method in section 2, distinguishing firstly the data for current activities, secondly the construction of alternative activities and thirdly the model. In section 3 we present the results, in four sub-parts: i) a basic economic evaluation of the four alternative techniques, ii) a comparison of model results with the current situation, iii) the results of the model for different targeted levels of pesticide use reduction, iv) the effect of two policies: pesticide taxation and subsidies for organic farming. Section 4 is devoted to a discussion of the results and to conclusions.

2. Method

2.1. Current activities

France was divided into eight large regions to cover the diversity of soils, climates and pest pressure.

The yields, costs and gross margins for each of the crops and regions were obtained from Farm Accountancy Data Network (FADN) data. This choice was made in order to ensure consistency of our aggregated estimations with national levels of production and areas for each product.

However, FADN data base contains accountancy figures where costs and crops are for the whole farm and are not broken down into the different crops. To obtain costs per hectare for each crop, a standard linear regression model was used (Pollet, Butault 1998). This estimate provides results for pesticides, seed, fertilizer and fuel. The crops taken into account were soft wheat, durum wheat, winter and spring barley, maize, other cereals, sugar beet, potatoes, peas, rapeseed, sunflower, other oilseeds, artificial fodder and other field crops.

Simultaneously, data from a national survey on crop management practices “enquete sur les pratiques culturales” (EPC) (French Ministry of Agriculture, 2008) was used to characterise current agronomic practices in more detail. It covered detailed descriptions of farming practices for 12,900 fields considered to be representative of the French production of field crops. Nine crops are included in this survey (soft wheat, durum wheat, barley, maize, rapeseed, sunflower, sugar beet, potatoes, peas). These crops represent nearly 90% of the area occupied by French field crops.

This EPC survey was conducted in 2006 (the previous study dating from 2001). Thus, the year 2006 was used for all the work. In 2006, yields and production costs were quite close to the average for the period 2000-2006 (Butault et al.2010).

Consistency between the two databases is not complete. The FADN data base is representative of the total professional farm production and inputs use, which is not the case for EPC. However the EPC gave additional information in terms of detailed crop management plans.

In order to characterize the current and alternative techniques, indicators have been used and calculated using the EPC. The Treatment Frequency Indicator (TFI) was used to measure intensity of pesticide use. This indicator is defined as the number of treatments applied multiplied by the ratio of the applied dose per hectare to the recommended dose. (OECD 2001, Pingault et al. 2009). It thus took into account the intensity of treatment, which can be applied in reduced doses or on only one part of the area (e.g. chemical weed control in the row only). Using the EPC survey TFI was calculated from records of each treatment applied to plots compared to recommendations, per class of product: herbicides, fungicides, insecticides and "other"[2] pesticides.

Other indicators were also used, particularly the number of times pesticides were applied (in order to estimate working time), the energy cost and the nitrogen balance. The nitrogen balance (in kg of nitrogen per hectare per year) was defined as the total quantity of nitrogen applied to the field, minus nitrogen exports calculated from the crop yield and nitrogen export coefficients per crop . The energy cost (in gigajoules per hectare per year) took into account the energy directly consumed by agricultural equipment and the indirect energy consumption used to produce fertilizers.

The estimates of costs per hectare of crops from the FADN data provide results in terms of costs per hectare that are not exactly the same but that are consistent with input quantities obtained from the EPC. As an illustration, table 1 shows the link between the TFI (calculated from EPC data) and pesticide values per hectare (calculated from FADN data).

[2] This latter class covers products used against pests like mollusks, and substances that are not, strictly speaking, pesticides, but which have a controlling effect on crop development (cereal growth regulators).

Table 1 –TFI and pesticide costs for each crop in 2006 (average for France)

	TFI	Pesticides Cost €/ha	"Price" of TFI
Common wheat	4.1	133	32.9
Durum wheat	2.8	112	40.6
Barley	3.1	100	31.9
Maize	2.0	88	43.7
Potatoes	16.7	489	29.3
Sugarbeet	4.2	251	59.8
Peas	4.6	216	46.8
Sunflower	2.1	87	42.4
Rapeseed	6.1	203	33.1
Total	3.9	136	35.0

Source: EPC and FADN data. Authors' calculations.

2.2. Alternative activities

In order to construct data for crop management techniques leading to a reduced use of pesticides, a panel of 30 experts from the French national agronomic research institute (INRA) and from national extension services staff worked throughout 2008 separately and in meetings. They were asked to use their personal knowledge and the data provided to them to generate for each crop and each French soil and climatic region, several crop management plans and corresponding yields, from intensive to organic farming.

It was decided to infer an intensive technique (T0) from the EPC data base. In order to obtain a consistent technique from an agronomic point of view, it seemed important to deduce it from fields treated fairly similarly. For this, 30% of the fields that received the most pesticides were singled out from the database and the average practices on these fields, as they were judged agronomically consistent by experts, were considered as defining intensive technology (T0)

It was not possible to apply the same methodology to design low-input techniques because of the low level of adoption by farmers of low-input techniques, which is reflected in the difficulty in identifying agronomically sound practices in the database for the low level of pesticide use.

Thus, departing from the T0 technique, four techniques ranging from "logical farming" ("agriculture raisonnée" in French) to organic farming were defined by experts (Table 2).

Table 2 Crop management techniques and data used

	Description / Strategy used	Data sources
Current practice	"Average" current practices	Survey on the crop management practices (French Ministry of Agriculture, 2008)
Technique 0	"High-pesticides" current practices	Survey on the crop management practices (French Ministry of Agriculture, 2008)
Technique 1	Logical farming: Each intervention is based on observation and treatments are triggered in relation to thresholds.	Data and references from Extension institutions : At national level (Arvalis, Cetiom) and at regional level (Chamber of Agriculture for the regions Normandy, Poitou-Charente, Burgundy and Ile de France) Farmers data from the 'Farre' network (survey of 20 farmers, 340 plots)
Technique 2	Integrated production: the application of a strategy based on a coherent combination of non-chemical agronomic methods and chemical means in order to restrict the use of pesticides. (without changing crop rotations)	Field experiments and trials data available at a national level for : "Integrated production of wheat (25 sites for 2003-2007, Bouchard et al. 2008), "Integrated production of rapeseed network INRA-Cetiom (40 sites x years for 2004-2007 for North, West and Centre). Long-term "La Cage" INRA experiment (1997-2007) for rapeseed, peas and wheat. Networks of Integrated Production farms. Expert knowledge.
Technique 3	Integrated system: Similar principles as technique 2 with modification of crop rotations.	Collective expertise, networks of farms (Burgundy, Eure, Picardy), Long-term "ICP managing self-propagating crops" trial, INRA Epoisses. Expert knowledge
Technique 4	Organic farming	Arvalis (Villarceaux trial), Agence Bio 2006 statistical data, CasDAR RotAB expertise, network of wheat plots under contract in Rhône Alpes (records from 2002 to 2007), group expertise

Source: Guichard et al. 2009

Technique T1 refers to the crop management plan most recommended by extension services. It uses a calculated quantity of pesticides, chemical intervention being based on pest and disease observations, and assumes the use of decision-making tools to determine the quantity of inputs to use.

Techniques T2 and T3 refer to sustainable farming also called integrated farming in Europe, in reference to the principles of integrated pest management (International Organisation for Biological and Integrated Control, 1973). Following these principles, technique 2 is mainly based on non-chemical agronomic methods (e.g. modifying sowing dates and density, mechanical weeding) supplemented by chemical methods. Technique 3 enables greater reductions in the use of pesticides. It is based on the same principles as technique 2, but it also relies on changes in crop rotations. Lastly, Technique 4 corresponds to organic farming practices.

To estimate the performance of crops managed with Technique 2, the agronomists based their calculations mainly on the experimental data obtained in multi-site and multi-year trial networks of different teams from INRA. For crops not well represented by trials, group knowledge was used, supplemented by the expertise of other people consulted on a more individual basis.

Compared to Technique 2, Technique 3 introduced reasoning based on crop succession (e.g. although wheat after wheat is possible in Technique 2, it was excluded from Technique 3 because of the biotic pressure it generates). Although the effect of crop succession on input use has been widely studied by agronomists, large scale experimental data are not yet available. In this case, the experts' group used available data and their expertise in an approach inspired by prototyping procedures (Rossing et al. 1997, Lançon et al, 2007 and 2008; Vereijken, 1997).

Finally, Technique 4 corresponds to the specifications for organic farming. The data available in experimental trials and reference organic farms were on too few geographical sites to be extrapolated to the whole of France. However these data were reviewed by the expert group and used in particular for the construction of technique 3, but do not enable a sound technique 4 to be constructed for all cultures and the different French regions. For this purpose, the FADN data were finally the only source to be used, as a sub-sample of organic farms (300) exists in the field crops farms sample[3]. The information on some indicators was thus missing for this technique.

All in all, the knowledge obtained from very diverse origins (e.g. statistical data, multi-year experimental systems, field observations with farmers or in experiments, agronomic knowledge) was progressively built up, consolidated and formalized, resulting in technical matrices for each crop and each region. Validation of these matrices took different forms, based on the procedures proposed by Bockstaller (Bockstaller et al, 2003). Quantitative validation of all the figures by field measurements was obviously impossible given the lack of experimental data. However, the proposed data were submitted to scientific expertise on each element of the proposed technique (e.g. the reasons behind the effect of techniques on the reduction of pest and disease populations were first discussed and then their effect in reducing the damage). In this respect, although the quantitative reliability is not the same for all the techniques (and diminishes from Technique 2 to Technique 4), the group debates and discussions act as a guarantee of their relevance.

The consistency between the different crop management alternative and the aggregated FADN data (production, yields, input costs) was obtained by keeping the FADN data as the reference and applying the reduction estimated by the agronomists' group for the different alternative management schemes. Finally results for the different parameters for each crop and region were obtained. Annex 1 to 4 give an illustration of some of them for wheat.

2.3. Model

Techniques 0, 1 and 2 do not assume any modification of rotations. Techniques 3 and 4, however, are based on modifications of rotations and therefore of land use.

The purpose of our modelling exercise is to focus on changes in techniques. For this reason the fraction of the different crops in regional land use is fixed and only a change of technique to one assuming land use modification (T3 and T4) produced a modification in crop areas. Thus, the model simultaneously determines the technique used for each crop in each region and the fraction of regional land farmed using the techniques without land use modifications (T0, T1 and T2) with technique T3 and in organic farming (technique T4).

For technique 0, technique 1 and technique 2 the current land use observed in the FADN is kept constant. For Technique 4, current land use for farms in the FADN organic farming sub-sample was used. For Technique 3 the group of experts suggested possible rotation systems, but this data was also difficult to extrapolate to a national level. Upon consultation, the group of experts considered that Technique 3 was linked to systems half-way between conventional farming and organic farming. They

[3] We have to mention the fact that the results from the FADN organic sample from 2002 to 2006 seem to overestimate crop yields. For wheat, for example, the national observed yield is 49 quintals per hectare (against 69 quintals in conventional farming) whereas the group of experts estimates it as being more probably between 40 and 45 quintals.

thus concluded that land use in each region was an average of the land use for each of these two production modes.

Land use corresponding to the different techniques was established for each of the eight regions using FADN data. As an indication, the distribution of crops in the total arable land in France is given in Annex5.

Thus, the first variant of the model is written:

Maximizing $\sum_{c, S, R} [X_{c, S, R} . MB_{c, S, R}]$, (1)

Subject to constraints:

$\sum_{SA}[X_{C, SA, R}] = \sum_{C,SA}[X_{C,SA,R}].A_{C,R}$ ....(2) For techniques T0,T1,T2, the fraction of each crop (area) in the regional land use remains the same as that observed in the initial land use.

$X_{C, SM, R} = \sum_{C} X_{C,SM,R}.ASM_{C, SM,R}$ ....(3) For techniques T3 and T4, the fraction of each crop (area) follows the land use constructed for T3 and observed for T4

$\sum_{C,S} [X_{C, S, R}] = SAU_R$ ....(4) For each region, the total cultivated area is equal to the region's area.

With:

S: {T0,T1,T2,T3,T4} the set of all techniques,

SA={T0,T1,T2} techniques with no change in rotations,

SM = {T3,T4} techniques with supposed modifications in rotations

R = all regions (eight regions)

C = all crops (15 crops)

$GM_{c, S, R}$ gross margin per crop, technique, region

$A_{C,R}$: fraction of each crop in the current area (observed land use)

$ASM_{C,SM,R}$: Share of each crop in the area in organic farming (T4) and in T3.

SAU_R: farming area of each region for field crops (including artificial fodder)

At this stage, it is important to clarify the nature of the model and in particular the question of its calibration against observed data. Indeed the use of a mathematical programming model for assessment of policy impacts generally requires that the model adequately reproduces the observed behaviour (of farmers or the agricultural sector) before being used in simulations of changes in the economic context. But when data are insufficient to characterize the existing situation, the calibration by econometric methods or methods of positive mathematical programming can be hazardous. (for an extensive discussion of this point see Buysse et al. 2007). Thus, when dealing with innovations and new technologies in agriculture, most authors are using normative mathematical programming (Falconer and Hodge 2000, 2001, Kersalears, 2005, Van Calker 2006, Buysse et al. 2007). In this sense, a normative model is not designed to prescribe what should be done; rather it enables us to explore the performance capacities of new technologies and to shed light on the consequences of their generalization. That is the approach we chose here because we did not have enough information on the current distribution of acreage between the different techniques we study and on motivations of farmers to adopt or not adopt these techniques.

The model was used in three stages. Initially, it enabled us to determine the choice of technique for each crop and each region and the corresponding land use, with the objective of maximizing the gross margin (equations 1 to 4). The model solution was then compared with the current situation.

Secondly, a constraint was introduced in terms of the desired average reduction in pesticide use at national level and the level to be reached was established in ascending order between 10 and 50% .

$$\sum_{c, S, R} [X_{c, S, R} . TFI_{c, S, R}] \leq MaxTFI . \sum_{c, S, R} [X_{c, S, R}], \qquad (5)$$

With MaxTFI given as being equal to 10%, 20% etc. 50% of the current TFI at a national level.

Finally, the model was used to determine the levels of public incentives capable of achieving the desired reductions in pesticides. A taxation system with a uniform redistribution of the tax revenue to farmers was analysed alone and in combination with a subsidy for organic farming (equations 2 to 4 and equation 6). In this case the objective function is as follows :

Maximizing

$$\sum_{c, S, R} [X_{c, S, R} .GP_{c, S, R} - X_{c, S, R} .(1+t).CPest_{c, S, R} - X_{c, S, R} .RCWP_{c, S, R} + X_{c, S, R} .AidComp + X_{c, 'N3', R} .OrgAid] \qquad (6)$$

With:

$GP_{c, S, R}$: gross product per crop, technique, region

$CPest_{c, S, R}$ pesticide costs per crop, technique, region

$RCWP_{c, S, R}$ other costs per crop, technique, region

t: tax on the price of pesticides (as a %)

OrgAid: aid per hectare of organic farming

AidComp: aid per hectare compensating for reduced taxation (equal to taxation revenue and distributed per hectare cultivated.)

3. Results

3.1 Economic comparison of the different techniques

The question of what could be done in order to decrease the total pesticide use in France could simply be answered without using the model by calculating aggregated indicators for each technique. Doing that we can see what would happen if the all France production would be cultivated in technique 1, 2, 3 or 4. (table 3)

Table 3 Implementation of each technique to all France compared to current situation

	Production (valued at 2006 price)	Gross Margin (2006)	TFI
	€/ha	€/ha	
Current	891	485	3.8
T0	933	455	5.4
T1	917	498	4
T2	834	480	2.5
T3	785	460	1.9
T4-organic price	581	341	0.2
T4 standard price	651	272	0.2

This calculation provides a first assessment of the relative value of the different techniques. We can see that the intensive technique (the 30% "most intensive") produces an average margin that is less than that observed for France in 2006.[4] Technique T1, which is based on a more "reasonable" use of inputs, produces a higher margin than Technique 0, and is close to the national average, both in terms of margin and TFI. The low-pesticide input techniques, T2 and T3, produce a lower TFI (as much as –50% for Technique 3), accompanied by a reduced margin. The organic farming margin was calculated, on the one hand, from prices currently observed on organic farms and, on the other, from the prices of conventional products. We can see that in both cases, margins are distinctly lower than for the other techniques. We can see also that the total agricultural production would not decrease if all the arable land is cultivated in T1, but would decrease quite considerably (-12%) if all the arable land area is cultivated in T3.

Based on this initial observation, we attempted to analyse how a combination of these techniques, which may be chosen differently depending on the region and the crop (which the previous analysis did not take into account), could produce a reduced TFI with the lowest possible margin reduction. We also wished to observe the results on the other indicators (production volumes, other environmental indicators) and to study the effect of taxes and subsidies that can be used to achieve this objective.

3.2 Economic optimization of the choice between production techniques

The first result from the model was obtained by maximizing the gross national margin without constraints on the use of pesticides. This optimized situation is calculated from prices for 2006 and 2007. It is presented in Table 4 in comparison with the current situation.

[4] This result is consistent with prices for 2007, €829 for T0, against €837/ha on average.

Table 4: Observed situation and optimization results using prices for 2006 and 2007 (France)

	2006 prices		2007 prices	
	Current	**Optimized**	**Current**	**Optimized**
Production (€/ha)	891	900	1244	1282
Margin (€/ha)	485	511	837	876
% of land use				
T0	(30%)	6%		6%
T1		59%		81%
T2		36%		13%
T3				
T4	(1%)			
TFI	3.79	3.44	3.79	3.79
HerbicideTFI	1.4	1.36	1.4	1.46
FungicideTFI	1.29	1.12	1.29	1.23
InsecticideTFI	0.64	0.58	0.64	0.63
N-Balance (kg/ha)	26.5	24.4	26.5	25.65
EnergyCost (GJ/ha)	11.7	11.8	11.7	11.92

Based on the prices for 2006, the model provides a solution in which the phytosanitary pressure (TFI) is reduced by 9% compared to the current situation, in spite of a 1% increase in total production and an average margin increase of €26 per hectare (i.e. 5%).

With prices for 2007, the optimized situation generates the same TFI as in the observed situation but with a national production increase of 3% and a national average margin increase of 4.6%.

Several elements explain these results. Firstly, we can see that the areas devoted to intensive techniques (T0) represent only 6% in the model solution (both with prices for 2007 and 2006) whereas, by construction, they represent 30% of current areas. This reflects the fact that for most crops, alternative techniques are technically more efficient than the intensive technique.

Besides, we see a significant difference in the distribution of techniques T1 and T2 between the two price scenarios. With 2006 prices, a considerable fraction (36%) of areas is devoted to T2 whereas the figure is only 13% with 2007 prices. In this latter case, technique T1 is dominant. The explanation lies this time in the differences in the economic efficiency between techniques. In T2 the yield is often slightly lower than in T1 and reduced production costs do not compensate for the reduction in gross product when prices are high. On the other hand, with prices like those observed in 2006, technique T2 is more profitable for many crops. Finally, we can see that in both price scenarios, the model does not show cultivated areas in the most low-input systems (T3 and T4). The calculation of gross margin for organic products took into consideration the prices received for farmers in organic farming. Thus even taking into account the difference in price between products from organic farming and other products, organic farming appears to be generally less profitable than the other techniques.

The other environmental indicators are all more favourable in the model solution than in the current situation. However, the reduction in herbicide TFI is less (-3% with 2006 prices) than the average TFI reduction, due to a greater difficulty in reducing herbicide use without changing the crop rotation. The nitrogen balance also improves, which is a positive aspect, as this indicator provides information on the potential nitrate pollution, which is also a major environmental issue in France. The only slightly undesirable effect is on the energy cost which does not vary with prices for 2006, and increases slightly in the optimized situation with 2007 prices.

3.3 The feasibility of different levels of pesticide reduction

In this part, we are interested on what could be the most efficient way of combining the different techniques in order to achieve different levels of pesticide reduction. To perform this analysis we simply introduce into the model a constraint on the average level of reduction in pesticide use to be reached at a national level. The results are presented in Table 5.

Table 5: Current and optimized situation with prices for 2006 and 2007, with a constraint on the level of pesticide reduction

	Situation		**Reduction in the use of pesticides**				
	Current	**Optimized**	**-10%**	**-20%**	**-30%**	**-40%**	**-50%**
		With 2006 prices					
TFI	100	91	90	80	70	60	50
Production	100	101.0	100.8	99.1	96.0	92.5	87.7
Margin	100	105.3	105.3	105.2	103.7	100.3	95.4
Technique as % of total area							
T0		6%	6%	6%	1%	1%	0%
T1		59%	57%	38%	23%	8%	1%
T2		36%	38%	56%	71%	40%	18%
T3						46%	68%
T4					5%	5%	13%
		With 2007 prices					
TFI	100	100	90	80	70	60	50
Production	100	103.1	101.3	99.4	96.9	94.0	89.4
Margin	100	104.6	104.0	103.0	101.4	98.8	95.1
Technique as % of total area							
T0		6%	6%	5%	1%	0%	0%
T1		81%	60%	45%	30%	19%	15%
T2		13%	35%	51%	55%	30%	6%
T3					14%	50%	71%
T4						1%	8%

As we have seen, with 2006 prices the model solution produced a reduction of 9% in the use of pesticides. For reductions of up to 30%, targets can be achieved without completely disrupting production systems: achieving these levels mainly necessitates a switch from “logical” agriculture (T1) toward crops managed in integrated production (T2). Beyond this level, the changes required are more substantial. To reach a target of 50% reduction, “logical agriculture” disappears almost completely and integrated production with (T3, 68%) or without changes in crop rotation (T2, 18%) becomes the dominant mode of cultivation. Organic production (T4) develops on 13% of the areas.

With 2007 prices for a pesticide use reduction target of 50%, "logical" production (15%) resists best, while organic farming drops to 8%.

We can see that for a target reduction of 50% in the use of pesticides, production drops by 12% from its current situation whereas margins drop by only 5%. This is due to the efficiency gain in the solution generated with the model. Compared to the optimized solution, margins drop by 9%.

3.4 Levels of taxation in order to achieve pesticide reduction targets

Here we present the effect of a tax applied on pesticide price. In this simulation, tax receipts are returned uniformly to farmers according to the size of farms. This measure is therefore neutral in terms of budget equilibrium and the full product of the tax goes back to the farmers. It compensates for the reduction in revenue caused by the tax.

Table 6: Effects, with 2006 prices, of a taxation system with uniform redistribution.

	Situation		**Reduction in the use of pesticides**				
	Current	**Optimized**	**-10%**	**-20%**	**-30%**	**-40%**	**-50%**
Associated tax rate	0%	0%	0%	16%	101%	138%	182%
Tax revenue (€millions)	0	0	0	199	1086	1280	1378
Redistribution: € /ha				17	94	110	119
Production	100	101.0	101.0	99.2	95.8	92.7	88.2
Margin before redistribution	100	105.3	105.3	101.7	84.2	77.4	70.6
Margin after redistribution	100	105.3	105.3	105.2	103.4	100.1	95.0
Technique in % of total area							
T0		6%	6%	5%	2%	2%	0%
T1		59%	59%	39%	15%	4%	1%
T2		36%	36%	57%	70%	38%	18%
T3					8%	52%	66%
T4					5%	5%	15%

Table 6 presents the tax levels associated with each pesticide reduction target. We can see that the level increases very steeply. With 2006 prices, a reduction of nearly 10% is achieved with a zero tax level, as a result of a gradual reduction in the previously analysed inefficiency. A level of 16% is sufficient to produce a reduction of 20%. But the level reaches 100% for a reduction target of 30% and 180% for a target of 50%.[5]

Because of high tax rates, margins before redistribution drop steeply, 16% for a 30% target reduction in the use of pesticides, and 30% for a target of 50%. After redistribution, the drop in margins for a target of 50% is only 5% compared to the current situation and 9% compared to the optimized situation.

[5] With 2007 prices, in order to reach a reduction of 50% the tax rate rises as high as 250%.

In fact, the results of this tax with redistribution are very close to the results obtained with the previous model (Table 5), which provided the optimal solution in order to satisfy the constraints for a reduction in the use of pesticides. This demonstrates that the distortions introduced by this taxation system are quite low. Compared to the solution obtained with the constraint of reducing pesticides by 50%, the taxation system is slightly more in favour of systems with low pesticide input: organic farming represents 15% (against 13% in the previous model). The drop in production is therefore slightly greater and margins are slightly lower than in the model with optimisation under constraint.

Taxes do not affect the different systems in the same way. For a pesticide reduction target of 30%, the tax and redistribution combined would have a neutral effect on the margin of low-input techniques (T2), whereas it would translate into a margin loss for intensive farming (T0) and a gain for integrated production systems (T3) and organic farming (T4). But we have to bear in mind that with a reduction target of 50%, the taxes would be paid mainly by low-input production (T2) whereas integrated production systems (T3) and organic farming (T4) would be indirectly subsidized.

3.5 The effects of a tax combined with a subsidy for organic farming

In this scenario, we test a combination of a pesticide tax and a subsidy targeted on low-pesticide techniques. As a 20% area in organic farming in 2020 is one of the goals announced in the current pesticide reduction plan of the French government, we illustrate this tax plus subsidy mechanism through a tax combined to a subsidy to organic farming.

Table 7 provides the results of subsidies to organic farming combined with a tax in a scenario where €140/hectare is paid for organic farming. Initially, in order to compare this with the previous system we suppose that the tax revenue is used both to finance organic farming subsidies and as a supplementary aid that is distributed uniformly for all hectares. The results are still presented for different pesticide reduction targets.

Table 7: Effects, at 2006 prices, of a taxation system with uniform redistribution and a subsidy for organic farming.

	Situation			Reduction in the use of pesticides			
	Current	**Optimized**	**Org. Subsidy**	**-20%**	**-30%**	**-40%**	**-50%**
Organic farming subs. (€/ha)			**140**	**140**	**140**	**140**	**140**
Associated tax rate	0%	0%	0%	5%	31%	60%	138%
Tax revenue (€millions)	0	0		59	339	555	1047
Redistribution: € /ha					17	18	56
TFI	100	91	86	80	70	60	50
Production	100	101.0	99.0	97.7	96.3	92.6	88.9
Margin before redistribution	100	105.3	106.0	104.8	99.6	94.8	82.5
Margin after redistribution	100	105.3	103.5	103.4	103.2	98.5	94.1
Technique in % of total area							
T0		6%	5%	5%	5%	2%	1%
T1		59%	53%	39%	23%	20%	3%
T2		36%	33%	57%	64%	57%	32%
T3							40%
T4			8%	8%	8%	21%	24%

We can see that the organic farming fraction increases in all situations and reaches 24% when associated with a pesticide reduction target of 50%. This has the effect of reducing the tax needed to reach such a level of pesticide use reduction. So that, with 2006 prices, the tax is only (compared to the figures obtained without organic farming subsidies) to 60% for a 40% pesticide reduction and 138% for a 50% pesticide reduction.

For lower tax levels, the tax revenue is insufficient to finance the organic farming subsidy, as indicated in table 7 by the figures showing that the margin after redistribution is lower than before redistribution. For a pesticide reduction target of 30%, a tax of 31% produces a revenue that is sufficient to finance a subsidy to organic farming at a rate of €140/ha and to offer a supplementary flat-rate compensation. We can see that for pesticide reduction targets of 30 to 50% the level of the margin after redistribution is scarcely any lower than in the system with a tax only. The two systems are thus very similar in terms of budgetary balance.

If the tax alone constitutes an interesting mechanism because of its non-distorting nature, the system of subsidizing organic farming may be preferable if we consider that the objective of reaching a certain degree of organic farming is a priority, for reasons such as the protection of certain sensitive zones (such as catchment areas for drinking water).

Budget equilibrium was chosen as a framework insofar as it enabled us to clearly isolate the question of pesticide reduction and to compare the efficiency of two different policy mechanisms as regards this reduction. But in the agenda of the renegotiation the CAP after 2013, subsidies for organic farming could probably be financed through other funds. Furthermore, the simultaneous choice of the level of subsidies for organic farming and of the level of tax depends very largely on priorities in terms of both level of pesticide use reduction and organic farming development. Although linked, organic farming and reduced pesticide use have specific different functions. The last simulation (table 8) illustrates how different combinations of tax level and organic farming subsidy level could achieve the same level of reduction in pesticide use, with different effects on the land fraction that would be devoted to organic farming.

Table 8: Tax needed in order to achieve a TFI reduction of 40%, associated with different levels of subsidy for organic farming.

	Situation		**Amount of the subsidy for Organic Farming (€/ha)**					
	Current	Optimized	0	100	140	180	220	260
tax rate	0%	0%	138%	101%	60%	42%	30%	21%
Production	100	101	93	93	93	93	92	92
Technique in % of total area								
T0			2%	2%	2%	4%	4%	4%
T1			4%	19%	20%	20%	21%	22%
T2			38%	58%	57%	55%	52%	50%
T3			52%	0%	0%	0%	0%	0%
T4			5%	21%	21%	21%	24%	24%

(*) The margins indicated include the subsidy for organic farming that is not covered by the tax revenue when the revenue is insufficient.

Table 8 gives results for the level of tax which, when associated with different subsidy levels for organic farming, would result in a target pesticide reduction of 40%. We notice that the same result, in terms of pesticide reduction, can be achieved with different tax/subsidy combinations for organic farming. For a subsidy of €220/ha of organic farming, there would need to be a tax of 30% in order to achieve a reduction of 40%.

4. Discussion and Conclusion

We have concentrated on studying the means of reducing pesticide use on field crops in France, and we have produced several different results that need to be discussed.

Our results demonstrate ways of reducing the use of pesticides for field crops without necessarily incurring considerable income losses for the producers. They show that we could reduce the use of pesticides by about 10% by decreasing the level of inputs without significant production loss. A more general adoption of integrated agriculture techniques could take us further and produce a reduction of 30% with a reduction in production but without affecting farmers' incomes.

One of the first comments is that, on average, the intensive technique (used in 30% of the most intensive plots in the farming practices survey) appears to be less efficient than techniques using smaller quantities of inputs. This result leads us to question the reason for the intensive use of pesticides in some of today's farms, given that prices for the period 1998-2006 were the same or lower than those for 2006. Other authors (Falconer and Hodge 2000, Carpentier 2005, Butault al. 2008, Loyce et al. 2009) have obtained comparable results either for the efficiency of low-input techniques or on the non-adoption by farmers of low-pesticide-input techniques.

Farmers' risk aversion is often cited as the reason for this situation. At present, few studies quantify this effect and no clear conclusions can be drawn from them (Carpentier 2005).

Another reason that has been analysed by certain authors relates to the brakes that upstream and downstream enterprises apply to the dissemination of low-pesticide or low-input techniques (Wilson et al., 2001, Vanloqueren et al., 2008). This has also been shown to be an important obstacle to the dissemination of low-pesticide techniques in the case of French field crops (Barbier et al. 2010)

A reduction of 50% in the use of pesticides would involve profound changes in cultivation systems toward integrated production systems with longer rotation periods and the development of organic farming. This would translate into a reduction in the total production volume, but also a modification in the nature of products, some being reduced more than others because of the modification in land use. Production of potatoes, sugar beet and oilseed rape would decrease considerably. This drop in the production of rape raises in particular the question of the compatibility of a policy aimed to reduce pesticides with the biofuel policy which in France relies largely on the development of biodiesel based on rapeseed oil. Conversely, other crops should increase in order to take their place in the cropping systems, particularly leguminous plants. This also raises the question of the consequences on the markets and on the ability of supply chains to adapt themselves to such changes.

Our results concerning necessary tax levels in order to achieve a significant reduction in pesticides demonstrate that the tax must be very high. It would be over 100% for a reduction of 30%. This result tends to confirm several economic studies on this question that also suggest low price elasticity of the demand for pesticides (see Carpentier et al., 2005).

In terms of policies, different conclusions can be drawn from these results. In order to achieve a 10 to 20% reduction in pesticide use, the policies required should relate mainly to extension and training services, the role of institutions responsible for advising farmers being of central importance. Achieving higher reductions in the use of pesticides presupposes setting up other economic incentive or regulatory instruments. If pesticide taxation is probably the most efficient way to achieve reduction in pesticide uses, level of taxes should be high enough for a taxation mechanism to be effective. In this regard a policy that combines tax and subsidies for low-inputs technique could be considered as a second best choice.

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ANNEXES

Annex 1 soft wheat-Treatment Frequency Indicator

	Current	T0	T1	T2	T3	T4
Centre-Poitou	3.6	5.2	4.1	2.4	2.0	0.0
Ile de France-Champagne-Bourgogne	4.7	6.5	4.7	2.5	2.0	0.0
Limousin-Auvergne	2.6	4.5	2.8	2.5	1.9	0.0
Lorraine-Alsace-Franche Comté	3.5	5.0	3.7	2.0	1.7	0.0
Midi -Pyrénées-Aquitaine	2.3	3.9	2.4	2.2	1.7	0.0
Nord Ouest	3.4	4.9	3.9	2.3	1.9	0.0
Nord-Picardie-Normandie	5.0	6.9	5.0	2.7	2.1	0.0
Sud Est	2.5	4.3	2.7	2.4	1.8	0.0

Annex 2 Soft Wheat Yield (t/ha)

	Current	T0	T1	T2	T3	T4
Centre-Poitou	6.39	6.83	6.66	6.10	6.10	4.53
Ile de France-Champagne-Bourgogne	7.09	7.42	7.38	6.65	6.65	5.02
Limousin-Auvergne	5.59	6.02	5.90	5.35	5.35	3.96
Lorraine-Alsace-Franche Comté	6.70	7.10	6.90	6.30	6.30	4.70
Midi-Pyrénées-Aquitaine	5.60	6.00	5.90	5.40	5.40	4.00
Nord Ouest	6.63	7.09	6.91	6.33	6.33	4.70
Nord-Picardie-Normandie	7.89	8.25	8.21	7.40	7.40	5.59
Sud Est	5.57	5.99	5.88	5.33	5.33	3.94

Annex 3 Soft Wheat Gross Margin with 2006 prices (€/ ha)

	Current	T0	T1	T2	T3	T4
Centre-Poitou	378	353	386	405	425	363
Ile de France-Champagne-Bourgogne	499	474	541	533	564	516
Limousin-Auvergne	292	262	309	275	294	196
Lorraine-Alsace-Franche Comté	438	422	451	454	471	334
Midi-Pyrénées-Aquitaine	369	351	389	354	369	387
Nord Ouest	384	372	395	408	424	344
Nord-Picardie-Normandie	556	525	603	600	635	517
Sud Est	287	248	303	278	301	270

Annex 4 Soft Wheat Gross Margin with 2007 prices (€/ ha)

	Current	T0	T1	T2	T3	T4
Centre-Poitou	841	848	869	848	868	787
Ile de France-Champagne-Bourgogne	991	989	1054	995	1026	967
Limousin-Auvergne	651	648	688	619	637	525
Lorraine-Alsace-Franche Comté	959	973	991	943	959	808
Midi-Pyrénées-Aquitaine	812	828	857	778	792	790
Nord Ouest	809	827	839	814	830	734
Nord-Picardie-Normandie	1015	1005	1080	1031	1065	940
Sud Est	639	628	675	616	639	593

Annex 5 Crop share in % of the total French arable land.

Crop	Current, T0,T1, T2	T3	T4
Soft wheat	39.3	37.2	35.1
Durum wheat	3.8	2.2	0.6
Spring barley	4.4	3.7	3.1
Winter barley	9.7	7.8	6
Maize	11.1	10.8	10.5
Other cereals	5.4	12.4	19.4
Potatoes	1.3	0.8	0.4
Sugarbeet	2.8	1.9	1
Peas and beans	2.6	5.4	8.2
Sunflower	4.9	4.5	4
Rapeseed	11.7	7.9	4.1
Other oilseeds	0.5	1.4	2.4
Other major crops	1.5	1.7	1.8
Artificial fodder	1.1	2.3	3.4
Total	100	100	100