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Technical and Economic Analysis of Farming Systems Engaged in Agri-Environment-Climate Measures for Pesticide Use Reduction in Burgundy (France)

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TECHNICAL AND ECONOMIC ANALYSIS OF FARMING SYSTEMS ENGAGED IN AGRI-ENVIRONMENT-CLIMATE MEASURES FOR PESTICIDE USE REDUCTION IN BURGUNDY (FRANCE)

Key-words: pesticides, agri-environmental measures, farming systems, durability.

Mots clés: pesticides, mesures agro-environnementales, systèmes d'exploitation, durabilité.

Abstract:

The European Union has created agri-environmental measures so that some of the European farmers may commit to reducing their environmental impact in exchange for financial compensation. However, little is known about the impact of such measures on farms recently engaged, like the "agri-environment-climate measures" (AECMs) specifically targeting pesticide use. The aim of this study is to reveal how AECMs and/or pesticide reduction have impacted farms which have actually engaged their production systems in the *Nièvre* region (Burgundy, France). For this, farmers were interviewed on their practices, results and constraints, and technical and economic data from their farm records were analyzed. All farms have reduced their phytosanitary Treatment Frequency Index through risk acceptance, adaptation of crop choices and/or reliance on soil preparation; however half of them have implemented a relatively low-input system not due to AECMs. AECMs did not lead the majority of farmers to really think differently about their practices. Upon engagement, the farms were overall both less reliant on pesticides and more profitable economically than the regional average. Under AECMs, their annual profit would have decreased without the AECM subsidies, but so would have their debt ratio compared to regional references. In the future, their farming systems (with their lower pesticide use) should be able to subsist without AECM subsidies, all the more so as the AECM period was not perceived as a bad experience by farmers. To keep reducing pesticides, farmers have technical, economic and political concerns, with weed control as a main challenge. For an average farm of *Nièvre*, engaging in an AECM would probably have required more effort, and the discoveries made in this study illustrate some possible strengths and weaknesses of agri-environmental policies.

Résumé:

L'Union Européenne a créé des mesures agro-environnementales pour permettre à une partie de ses agriculteurs de s'engager à réduire leur impact environnemental en échange de compensation financière. Cependant, l'impact de telles mesures sur les exploitations récemment engagées, comme les « mesures agro-environnementales et climatiques » (MAEC) visant l'usage des pesticides, est peu connu. Cette étude a pour but de révéler comment des exploitations ayant engagé leur système de production en MAEC ont été impactées par ces mesures et/ou par la réduction des pesticides, dans le département de la Nièvre (Bourgogne). Pour cela, les agriculteurs ont été interrogés sur leurs pratiques, leurs résultats et leurs contraintes, et à partir de leurs documents d'exploitation leurs données technico-économiques ont été analysées. L'ensemble des exploitations ont réduit leur Indice de Fréquence de Traitement phytosanitaire par la tolérance des risques, l'adaptation des choix culturaux et/ou le recours au travail du sol ; cependant la moitié ont appliqué un système relativement économe en intrants sans que cela soit dû aux MAEC. Les MAEC n'ont pas conduit la majorité des agriculteurs à vraiment avoir de nouvelles réflexions sur leurs pratiques. Au moment de s'engager, globalement les exploitations étaient à la fois plus économes en pesticides et plus rentables que la moyenne départementale. Durant leur période en MAEC, leur profit économique annuel aurait baissé sans les subventions MAEC, mais leur taux d'endettement aurait fait de même comparé aux références départementales. A l'avenir, leurs systèmes d'exploitation relativement économes en pesticides devraient être capables de subsister sans les subventions MAEC, d'autant que les agriculteurs n'ont pas vécu leur période en MAEC comme une mauvaise expérience. Pour poursuivre la réduction des pesticides, les agriculteurs ont des contraintes et inquiétudes sur les plans technique, économique et politique, la maîtrise des adventices constituant l'un des principaux défis. Pour une exploitation moyenne de la Nièvre, s'engager en MAEC aurait probablement demandé plus d'effort d'adaptation, et les résultats de cette étude illustrent de potentielles forces et faiblesses des politiques agro-environnementales.

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1. Introduction

Among the global issues related to industrial agriculture, pesticide use has been reported to have several major detrimental effects such as decline in bird and insect populations, apparition of resistance in pests and elevation of cancer risks for workers and consumers especially in developing countries (Horrigan et al. 2002). In rich countries such as the United Kingdom and France, recent epidemiological studies have indirectly associated exposure to pesticides through food consumption with higher risk of cancer, in particular non-Hodgkin lymphoma (Bradbury et al. 2014; Baudry et al. 2018). Pesticides are also screened in groundwater for health hazards related to drinking water consumption (Ali and Jain 1998). In addition, the benefit-cost ratio of pesticide use on national economies is under question (Bourguet and Guillemaud 2016).

In the face of such outcomes, the European Union (EU) has created political measures – called AECMs, for "agri-environment-climate measures" – that allow some farmers to implement practices supposed to be more eco-friendly, in exchange for financial compensation and on a voluntary basis. These AECMs are a component of the current version (2015-2020) of the EU Common Agricultural Policy, and some of them aim at mitigating pesticide use. Their design and implementation differ from one European region to another. In order to help establish the relevance of this kind of initiatives from politicians and farmers, scientific research can determine whether they have positively impactful effects on environmental protection, health preservation, food production and economy, and whether they are durable. As part of this effort, researchers can investigate how agri-environmental schemes and pesticide reduction affect farming systems overall, by looking at technical results, farm economy and social dimensions.

Scientific literature about the impacts of AECMs (or just AEMs for "agri-environmental measures", before 2015) on the organization and economy of farms engaged is scarce, especially when it comes to agri-environment(-climate) measures which are recent (after 2010) or specifically targeting pesticide use. Some sparse results have emerged from past AEMs, the latter being context-specific just like AECMs. For Darnhofer and Schneeberger (2007), AEMs in Austria (where a great majority of farmers was engaged in various AEM types) were economically attractive for farmers and did not require them to significantly change their practices, which were more extensive compared to the rest of the EU. Unay-gailhard and Bojnec (2016) found that in Slovenia AEM adoption by farmers was positively correlated with hired labor on their farms, suggesting that more ecological practices required higher work quantity. In a model of a scenario with more AEMs for dairy farms in Dutch policy, Helming and Schrijver (2008) found a decrease in the number of dairy cows per ha, in the gross margin per ha, in national milk production and in nitrogen pollution; thus AEMs would lead to more extensive practices. Similarly, farms participating in agri-environmental schemes in Germany between 1989 and 2002 have shown a reduction in their land use intensity and production per hectare (Osterburg 2005). Finally, Arata

and Sckokai (2016) found that former agri-environmental schemes led to an income loss for farmers that was not fully compensated by AEM payments in all countries, including France.

Regarding research on pesticide use reduction (regardless of AECMs), a national network of demonstration farms, called DEPHY, was built in France in the last decade with support from the government. Across a sample of about 1000 field crop and mixed crop-livestock systems from that network, there was no visible impact of phytosanitary treatment frequency index (TFI) – that is, approximate level of pesticide use based on registered rates of application – on farm productivity, economic performance and working time (DEPHY 2014). Similarly, based on data from 946 non-organic field crop farms from DEPHY, Lechenet et al. (2017) estimated that the majority of field crop farms could reduce their TFIs by an average of 42%, with no negative effect on farm productivity and profitability, provided that they implement some alternative pest management techniques such as crop diversification, adoption of crop varieties resistant to diseases, mitigated fertilization or mechanical weeding (*Figure 1*). Although the selection of farms to build the network (see for instance Petit et al. 2012) was constrained by antagonistic objectives (Guichard et al. 2017), these results give support to the conclusions of Lamichhane et al. (2016) asserting that pesticide reduction can be achieved in many parts of Europe without significant losses in crop yields.

Furthermore, farmers organizations have conducted their own research, like farmers from the CIVAM network in France who have been testing low-input cropping systems for the last three decades and who also have contributed to designing and testing agri-environmental schemes in preparation of the 2015 Common Agricultural Policy. Apparently, their low-input systems yield positive results regarding production, economy, ecology and social, but adoption of their technical specifications (more demanding than those retained for AECMs) by test farmers has proved complicated (Réseau Agriculture Durable 2012).

***Figure 1* : A demonstration show of several spiked harrows for mechanical weeding at a farmer meeting in the *Nièvre* region, France.** Farmers seeking to reduce their reliance on pesticides may face trade-offs regarding cost of technology, technical performance, formation requirement, working speed, fuel consumption, etc. Photo by L. Delsalle, 03/29/19.

The present study is intended to contribute to these research fields by bringing to the light detailed results from farms **that have actually engaged in current AECMs for pesticide reduction** with five-year contracts in the *Nièvre* region (Burgundy, France). The aim of this study is to reveal how AECMs and/or pesticide reduction have impacted the farms, on their technical, economic and social dimensions. Specifically, the driving questions for this work were the following:

- Has the adoption of AECMs for pesticide reduction led farmers to change their production systems, and/or to think differently about their practices? What changes have been induced?
- In what state are the farming systems finding themselves under AECMs, especially with regard to technical mastery, farm economy and working life quality? Will they be able to subsist, especially with their lower pesticide use, once the AECM contracts (and subsidies) come to an end?
- What needs and constraints do farmers have to continue farming with lower reliance on pesticides?

To perform this study, quantitative data about crop years 2012-2013 to 2018-2019 were collected in addition to qualitative data, for 13 farms having started their five-year AECM contracts between 2015 and 2017.

2. Materials and methods

2.1. Setting for the study

The study site is a 25 km-wide rural area located in the northern part of the *Département de la Nièvre* in central France (appendix 1). There is one dominant soil type: superficial calcareous clay soils; the region enjoys moderate relief and oceanic climate. Agriculture is the main land use, with field crop farms and mixed crop-livestock systems raising cattle, sheep or pigs. The area includes five water catchment drainage basins which are vulnerable to pesticide pollution (superficial soils, karst systems); the latter sometimes exceeds European drinking water standards at the catchments (Delsalle 2015).

In reaction, the organizations in charge of the catchments (municipalities and a water agency) are implementing a program to mitigate water pollution. Among others, they have proposed AECMs for pesticide reduction to the farmers cultivating on the drainage basins. These measures gradually require farmers to get TFIs below 40% of reference TFIs for herbicides, and below 50% of reference TFIs for the other phytosanitary products together, over the four crop years following the start of the contracts. Thus, as the AECM contracts start in May, a farm that engaged in 2015 will face gradual restrictions on TFIs from crop year 2015-2016 to crop year 2018-2019, and it is specifically during this period with TFI restrictions that this study will consider the farm to be "under AECM". The reference TFIs are based on the 70^{th} percentiles of TFIs achieved (per crop) by the farms of Burgundy in 2014. The annual subsidies for these AECMs in Burgundy range from about 60 €/ha to about 190 €/ha, depending on the AECM.

Over about 100 eligible farms on the study site, 15 are now engaged in such AECMs, two of which engaged only a minority of their crop surfaces and were consequently excluded from the study. All the remaining AECM farmers except one took system AECMs, i.e. a new type of French agri-environmental schemes that engages the whole farm, including – to some extent – the management of livestock. Thus, the mixed crop-livestock system AECMs for herbivores (9 farms engaged) promote meadows and self-sufficiency on fodder, while the field crop system AECM (3 farms engaged) demands some level of crop diversity in space and time. Technical specifications are summarized in appendix 2. Six study farms engaged in 2015, four in 2016 and three in 2017.

The subject farms had no organic surfaces when engaging in AECMs and they do not use irrigation. Their characteristics are detailed in appendix 3. Their sizes range from 50 to 460 ha, with 1 to 3.5 man work units (MWU) – 1 MWU being equivalent to one person working full time. The 9 mixed crop-livestock systems raise suckling cows and two also have a few sheep; they have between 50 and 200 livestock units (LU). None of the farms sell their main productions on a farm shop or to local consumers.

Farm quantitative data were collected from technical and economic farm records, and for qualitative data the farmer in charge of each farm was interviewed individually (interview guide in appendix 7). An outline of the methodology was presented at a farmer meeting before starting data collection. The study was carried out in spring and summer 2019. One farmer could not be interviewed.

2.2. Assessment of the changes in the production systems in relation to AECMs

In the interviews, following some general questions about the farm farmers were asked to summarize the changes they had made in their farming systems since the start of their AECMs. They would then be interrogated on the evolution of their different farming practices one by one, namely: crop rotations, cropping plans, choice of varieties, pest management and weed control, application of organic fertilizers, application of mineral fertilizers, soil preparation, sowing, management of crop residues, cover-cropping, animal rations, use of cropland surfaces for forage production, and livestock management in general. For each category, the farmers were asked what practices (and associated decision criteria) they used to have before the AECMs, what practices/criteria they have now, and whether they would (also) have done differently if there had been no AECMs. This allowed to identify evolutions (including stagnations) induced or partly induced by AECMs, and non-AECM-induced evolutions. Then, in order to have an overall estimation of the level of impact of AECMs on the production systems, farmers were asked to select the level of effort (none / a little / quite some / really much) that their AECM engagements had required from them to adapt their practices. Finally, they were asked if their engagement in AECMs had changed the way they think about their farming practices (open question), and if they were already committed to reducing pesticides before engaging.

Moreover, these qualitative data were complemented with quantitative data about farming practices available in technical farm records: cropping plans, phytosanitary treatments and mineral fertilizer applications are regularly documented by farmers and organizations providing them technical support. From this data, indicators of practices were calculated for several crop years before AECMs (three crop years per farm) and under AECMs (one to four crop years, depending on engagement date and available data). Thus, for each farm and crop year, the part of cropland (permanent grassland and non-cultivated surfaces are not included) dedicated to each crop was calculated, as well as the part dedicated to annual winter crops (the dominant crops) and the part dedicated to legumes to assess crop diversification, which may be used to foster low-input pest/weed management. TFIs (total and per type of phytosanitary treatment, at farm and crop levels) were calculated to assess how the use of pesticides has evolved with AECMs (explanations for calculations of TFIs in appendix 4). Similarly, the quantities of nitrogen (N), phosphorus (P) and potassium (K) applied with mineral fertilizers at farm level were calculated to identify changes in fertilization practices – which can be affected by cropping plans, or affect crop vigor, weed development etc. For each indicator, the mean of the observations (observation: result for one farm, one crop year) under AECMs and the mean before AECMs were calculated.

To better apprehend the relations between cropping plans, TFIs and quantities of fertilizers, Pearson correlations were tested at a 5% significance level – a few minor indicators had less than 30 observations and they were not tested. As these practices can be affected by the practices of the previous campaigns, correlations between indicators with a one-year or two-year time lag were also included.

2.3. Assessment of the state of the farming systems under AECMs

After looking at how the production systems changed, this study sought to further appraise the impact of AECMs and/or pesticide reduction by assessing the state of the AECM farming systems. For this, this study sought to collect and calculate farm results which condition, for most of them, the durability of the production systems.

2.3.1. Collection of qualitative results

Firstly, the interviews were used to collect qualitative results, starting with the social dimension. Following the part where farmers are interrogated about the changes in their production systems, they were asked what these changes had brought them on a positive side and on a negative side, all in all (open question). Later they were led to reveal how their working time repartitions – both in time during the year and between farming activities – had evolved in the last few years, and if/how this had been affected by AECMs and/or the techniques that they had adopted to limit pesticide use. Similarly, they were asked if they felt that they had more work, less work or as much work since they had engaged in AECMs. Then they were asked if they thought that their amount of holidays would be different without the AECMs. Finally, farmers were led to recall the different things affecting their professional life quality, before being asked if their professional life quality had decreased, increased or remained the same since they had engaged in AECMs.

After the social-oriented results, farmers were asked about technical results, weed levels and yields in particular. For each result, farmers were asked how it had evolved, how it could be explained and if AECMs and/or the techniques that they had adopted to limit pesticide use had had an effect. Irrespective of current yields, weed level can be of particular importance since a high weed level can leave a seed stock that will make weed control even more difficult in the following years.

2.3.2. Choice of quantitative indicators

Then, this study sought to assess the state of the AECM farming systems through quantitative indicators, especially regarding economics. Both scientific and grey literature was explored to choose indicators of the durability of the production systems. The indicators that were retained (*Table 1*) are mainly based on Grailhe et al. (1998), IDEA (2006); Angevin et al. (2009); Figari et al. (2009); Delaire (2016); Deytieux et al. (2016); Lechenet et al. (2017); Réseau CIVAM (2018).

The first indicator, stocking rate, is an indication of the profile of the livestock system (rather extensive or rather intensive) and of self-sufficiency on fodder. As forage surfaces are promoted by AECMs in this study, we will check whether the stocking rate of the farms under AECMs is lower. Then, veterinary costs will help us see if animal health may have been affected by AECMs and/or pesticide

***Table 1* : Quantitative indicators selected for the assessment of the state of AECM farming systems, and their formulas.** GP: gross product; OP: operating costs; MC: mechanization costs; EBITDA: earnings before interest, taxes, depreciation and amortization; OI: (net) ordinary income; EI: (net) extraordinary income; FC: financial costs.

Indicator	Calculations, AECM subsidies included	Calculations, AECM subsidies removed
Stocking rate (LU/ha)	$\frac{Number\ of\ livestock\ units}{Forage\ area}$	-
Veterinary costs (€/LU)	$\frac{Veterinary\ costs}{Number\ of\ livestock\ units}$	-
Gross margin (€/ha)	$\frac{GP + due\ AECM\ subsidy - OC}{Utilized\ agricultural\ area}$	$\frac{GP - OC}{Utilized\ agricultural\ area}$
Economic efficiency	-	$\frac{GP - OC}{GP}$
Semi-net margin (€/ha)	$\frac{GP + due\ AECM\ subsidy - OC - MC}{Utilized\ agricultural\ area}$	$\frac{GP - OC - MC}{Utilized\ agricultural\ area}$
EBITDA before labor costs (€/MWU)	$\frac{EBITDA + labor\ expenses}{Number\ of\ man\ work\ units}$	$\frac{EBITDA + labor\ expenses - AECM\ OI}{Number\ of\ man\ work\ units}$
Available income (€/FWU)	$\frac{EBITDA + AECM\ EI - FC}{Number\ of\ family\ work\ units}$	$\frac{EBITDA - AECM\ OI - FC}{Number\ of\ family\ work\ units}$
Debt ratio (%)	$\frac{Debts}{Assets}$	$\frac{Debts}{Assets - all\ AECM\ net\ income\ up\ to\ now}$
Relative farm size (ha/MWU)	$\frac{Utilized\ agricultural\ area}{Number\ of\ man\ work\ units}$	-
Adjusted accounting price of the farm (€/MWU)	$\frac{Assets\ exclusive\ of\ land}{Number\ of\ man\ work\ units}$	-

reduction, through differences in fodder for instance. Then, a set of indicators was used to get a good idea of the economic durability of the AECM production systems: margins, EBITDA, available income and debt ratio. Gross margin represents a profit directly yielded by the production system (semi-net margin is more complete as it integrates mechanization costs, but the estimation of those is more approximate) but does not represent the ultimate farm profit. EBITDA integrates costs more external to the production system (labor costs, land rents, some taxes, insurances, …) as well as most farming subsidies; in this study labor costs were negated so as to assess EBITDA regardless of whether the work is done only by the farmer family or also by employee. "Available income" additionally integrates what the farm pays to the bank (financial costs: annuities and short-term financial costs) and is an approximation of the annual

"true profit" of the farm and the farmer family. Debt ratio goes further as it is an indicator of current farm economic health as determined by current and past results, but it is least directly related to the subject production system. Relating margins to land surfaces and livestock quantity together – taken as "natural production units" – was tested during this study, but it was found to be less relevant than just margins per hectare in our case (see appendix 5).

These economic indicators were calculated both with and without income related to AECM subsidies in order to see how much these weigh in farm profit. All these indicators are taken at farm level, meaning that they are directly affected by animal production (9 of the 13 farms have livestock), which is not directly related to AECMs or pesticide reduction. As a matter of fact, it was assumed that crop production and animal production were intertwined (through nutrient fluxes, trade-offs for farm organization, …) and this assumption was checked in the interviews. However, the interviews also revealed that the farmers involved did not significantly change their livestock management over the study period – outside minor changes in forage due to AECM requirements previously mentioned; thus we may assume that variations in the economic indicators will be primarily related to crop production.

As for the remaining indicators, economic efficiency is an indication of the reliance of the production system – irrespective of AECM subsidies – on external inputs (pesticides, fertilizers, seeds and fodder mainly), which represent operating costs. Relative farm size is an indication of employment and of how much land (and livestock) each person has to take care of. Finally, accounting price of the farm gives an idea of how much successors would need to spend to take over the farm in its current state, thus it is related to the durability of the production systems in a longer time perspective. This indicator was adjusted by negating the value of the land owned by the farm, so that farm price is not affected by the proportions of rented land versus owned land.

2.3.3. Analysis of the quantitative indicators

These indicators were calculated for several crop years under AECMs (one to four crop years, depending on engagement date and available data) and before AECMs (three crop years per farm). First, each indicator was calculated for each farm, each crop year, based on data available in farm economic records (accounting documents); and then it was matched against a reference value representing an average result of the farms of the *Nièvre* region (most of them are not engaged in AECMs or organic agriculture), for the corresponding crop year and farm type – rather field crops-specialized, rather suckling cows-specialized or rather mixed. The difference was calculated as percentage of the reference value, except for indicators of annual profit (margins, EBITDA before labor costs, available income) since for them the raw difference (how much money?) is more of interest. The reference values were provided by the main farm accounting organization in the region (Cerfrance Alliance Centre). This allowed to see how the AECM farms are compared to the others for a given indicator, by calculating the mean of the differences between the study farms (when under AECMs) and the reference values. A one-sample t-test or a Wilcoxon

signed-rank test (on one-sided hypothesis) was used to assess whether the mean difference (t-test) or the median difference (Wilcoxon) is different from zero at two significance levels: 20% (based on farmers' judgement and interest) and 5%. As sample size under AECMs was small, the Shapiro-Wilk test was used to check normality at a 20% significance level, before choosing between t-test and Wilcoxon test. Calculating an indicator with or without income related to AECM subsidies did not change the reference value used for comparison.

Similarly, the difference between the average result "under AECMs", raw or expressed as a mean difference with reference values, and the average result "before AECMs" was calculated, so as to know if/how the fact of being under AECMs and/or using (supposedly) fewer pesticides may be associated with a change in the results of the subject farms. This study compared differences with reference values (instead of just raw results) so as to remove effects that external factors such as changes in weather or market prices can have on farm results. Pearson correlations (including correlations with indicators of change of practices, and time lags) were also tested at a 5% significance level to further analyze the results.

2.4. Appraisal of the evolution perspectives of the subject farms

To assess whether the production systems implemented by the farmers under AECMs, with their lower pesticide use, will be able to subsist once the AECM contracts come to an end, it was also necessary to ask farmers what are their intentions about it. Specifically, they were asked at the end of the interviews:

1. *If an identical AECM contract were again offered to you: would you take it?*
2. *And when your present contract comes to its end, without any new AEM, would you keep the farming system that you implemented with the AECM?*

They were also asked what evolutions they considered for their farms.

As for the needs and constraints faced by the farmers to continue farming with lower reliance on pesticides, this study did not seek to investigate them in depth. The farmers were merely asked what they would need for that, and what would be their problems (in general, and technically) regarding switching to organic.

3. Results and discussion

3.1. Changes in the production systems in relation to AECMs

3.1.1. Practices before engagement

To begin with, here is a summary of the initial farming practices which used to be applied on the farms before their engagement in AECMs, based on the interviews (and some farm technical data). At that time, farmers mainly grow three winter crops: wheat, rape and winter barley; they also have a few additional crops such as sunflower, corn or legumes. For most of them, crop rotations are based on a rape-wheat-barley succession, and their choices of varieties are based on productivity first. Before sowing, farmers commonly use stubble ploughing once or several times and then traditional plowing; such a soil management contributes to eliminating weeds. All farms sow a majority of seeds treated with pesticide. Weeds, fungal diseases, insects and slugs are fought with conventional phytosanitary products, in a preventive way (especially with fungicides) and/or in a curative way (especially with insecticides and slug pellets). All farms use mineral fertilizers. Upon harvesting of cereals, straw is removed in exchange for manure from animal production. A majority of farms have cover crops (only before spring crops), sowing them in summer and destroying them three months later. The diet of cattle and sheep is based on pastures, fodder crops and straw, and is completed with purchased concentrates. Two farms diverge from the group: one has a more simplified system (fewer crops and field interventions) and one practices conservation/integrated farming.

3.1.2. Changes as reported by farmers

Under AECMs, farmers have increased their use of three main strategies to reduce pesticide use, according to the interviews: accepting the risk of not applying some phytosanitary treatments, adapting crop choices to reduce the need for phytosanitary treatments, and relying on soil preparation to fight weeds. Five farms have increased their use of all three techniques, five farms have increased their use of the first technique and one of the other two, one farm focused on crop choices and one farm hardly changed anything in their production system. Mixtures of crops from different varieties or species (outside pastures and cover crops) and mechanical weeding (between crop planting and crop harvest) were used by one or two farms each, and no farmer reported having re-planted bushes or trees and/or using auxiliaries, or permanent soil cover.

Table 2 shows in more details the evolutions which occurred in the AECM production systems according to the 12 farmers interviewed. For each kind of pesticide treatment, most farms have reduced product application through the above-mentioned strategies, due to AECMs (or partly) for 5 farms (spraying of herbicides), 6 farms (spraying of fungicides and insecticides), or 7 farms (non-organic slug

***Table 2* : Evolutions in the production systems under AECMs as reported by farmers.** Numbers show how many farms have decreased, maintained or increased each farming practice. Italic bold numbers are for evolutions which are at least partly due to AECMs.

Farming practice category	Farming practice or technique	Decrease	No change (or none reported)	Increase
Phytosanitary treatments	Reliance on herbicides	9	3	-
		5	***1***	-
	Reliance on fungicides	8	4	-
		6	-	-
	Reliance on insecticides	10	2	-
		6	-	-
	Reliance on slug pellets (non-organic)	9	3	-
		7	-	-
	Reliance on seed treatments	8	4	-
		7	-	-
	Reliance on growth regulators	6	6	-
		5	-	-
	Selection of phytosanitary products to lower TFIs (organic products excluded)	-	10	2
		-	-	***2***
Crop choices	Cultivation of spring crops	1	2	9
		-	-	***4***
	Cultivation of alfalfa and/or clover	-	4	8
		-	-	***5***
	Use of starter crops alternative to rape	-	4	8
		-	-	***5***
	Use of more resistant varieties	-	9	3
		-	-	***1***
Fertilization	Manure application	-	9	3
		-	-	***1***
	Use of mineral fertilizers	3	9	-
		1	-	-
Soil preparation	Traditional plowing	4	7	1
		-	-	-
	Stubble ploughing	2	7	3
		-	-	***2***
Other	Delay before sowing of winter cereals	-	7	5
		-	-	***2***
	Straw harvesting	-	10	2
		-	-	-
	Cover cropping (regardless of spring crop quantity)	-	8	4
		-	-	-
	Use of forage produced on farm	-	7	2
		-	-	***2***

pellets, seed treatments). For slug pellets, the main strategy for reduction was to replace them with organic-certified slug intoxication products. For growth regulators, half of the farms reduced or stopped their use, in great part due to the AECM contracts which allow their use only on barley; and the other farms did not use to spray growth regulators before AECMs anyways. Lower reliance on phytosanitary products was motivated in part by AECMs and/or environmental concerns and in part by cost reduction.

On the other hand, two farms at least reduce their TFIs not necessarily through pesticide use reduction but rather through manipulations with the choice of products (organic excluded), based on their formulations and registered rates of application, under guidance of the advisor technicians. It cannot be said here whether this technique reduces environmental impacts.

Then, a majority of farms adapted their choices of crop species under AECMs, due to AECMs (or partly) for half of them. They have increased the cultivation of spring crops (mainly spring barley and sunflower), which disturb weed cycles. They have increased the cultivation of alfalfa and/or clover (low-input leguminous crops which can be declared as temporary pastures), and although the nine mixed-crop livestock systems had requirements on pasture surfaces, the main reason for this adaptation was pesticide reduction. Finally, they have sought to replace rape – a highly-treated crop, especially with insecticides – with alternative starter crops (mainly legumes, sunflower and corn); three farms had already stopped cultivating rape before AECMs. Only three farms have increased their preference for varieties more resistant to diseases and/or lodging.

Most farmers did not report a change in their fertilization practices, and AECMs had almost no impact on this. AECMs did not affect much soil preparation either, farmers mainly use the same techniques as before anyways; most changes are adaptations to crop choices. However, some farmers have delayed the planting of winter cereals to mid-October so that they can eliminate more weeds with soil preparation. AECMs had reportedly no impact on straw harvesting and cover cropping (regardless of spring crop quantity). And although a majority of the nine farms raising livestock reported cultivating more legumes (as fodder crops), which could reduce the need for concentrates for nitrogen nutrition, they hardly notice a difference in total forage production and animal rations. A last interesting point is that when farmers did not increase or decrease the use of some practices (because they already had a lower-input system for instance), AECMs did not contribute to maintaining the practices.

When asked about the level of effort that their AECM engagements had required from them to adapt their practices, three farmers answered “none”, seven said “a little” – for three of them it was mainly about checking that they fulfill TFI requirements, two said “quite some” and no farmer answered “really much”. Thus, it has not been too difficult for the farmers to adapt to AECM requirements, which is also part of the reason why they have engaged. Overall, AECMs have really driven three farms towards a lower-input system, they have rather assisted three other farms in their transition towards a lower-input system, and six farms would have implemented a lower-input system regardless of AECMs. After observation of the data (detailed in appendix 6), the evolutions do not clearly vary according to farm type, AECM type, or engagement date.

Finally, five farmers declared that their engagement in AECMs did not change the way they think about their farming practices, even though two of them modified their production systems because of AECMs. Three farmers said that they were just more careful with pesticide use due to AECMs, but these are farmers who said that they would have implemented the practices that they used even without AECMs. And four farmers reported that AECMs had opened them to alternative reflections and practices, for instance working more at the crop rotation level to reduce pesticides.

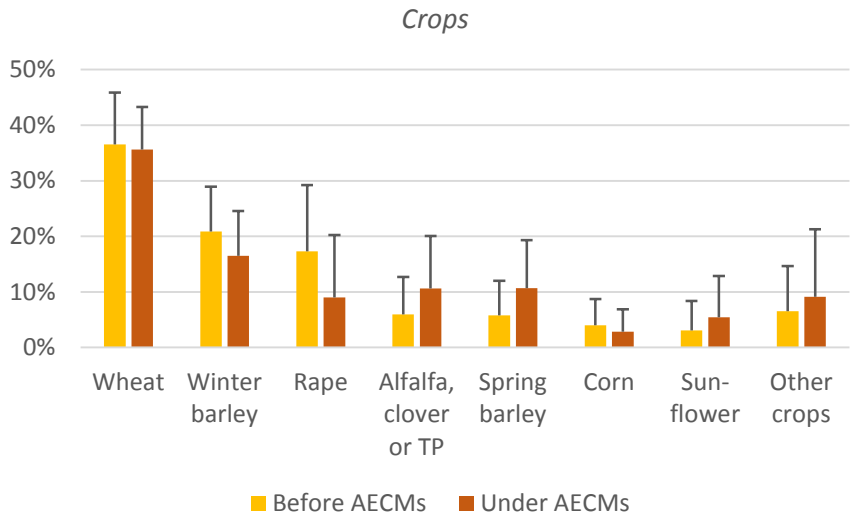
3.1.3. Quantitative indicators of change of practices

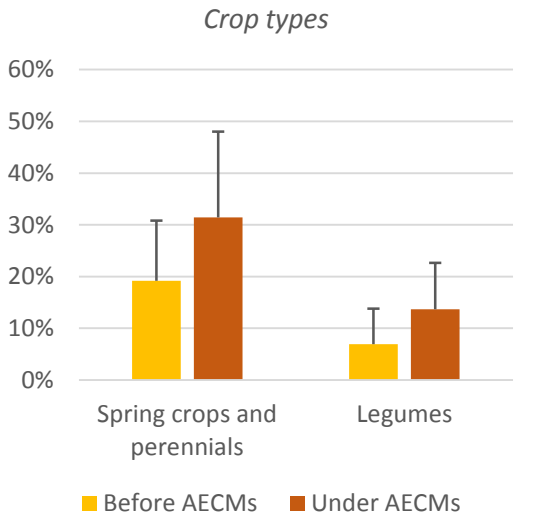
Regarding the quantitative assessment of changes in the production systems following their engagement in AECMs, the results are summarized in *Figure 2*. We can see that they are consistent with the changes reported by the farmers during interviews. Thus, the part of cropland dedicated to spring crops (mainly spring barley), perennials (alfalfa / clover / temporary pastures) and legumes (alfalfa, clover, pea, …) has rather clearly increased, at the expense of winter barley and rape, which is supported by negative correlations. The decrease of farm TFIs was even more consistent between farmers (total TFI decreased in all farms, -38% each farm on average). Farm TFIs and TFIs on commonly treated farm surfaces (which excludes temporary pastures, alfalfa and clover) have a very similar evolution, showing that farm TFIs were not mainly reduced directly by growing more "low-input crops" (crops outside commonly treated surfaces), but rather by reducing the TFIs of the main treated crops. This is supported by correlations.

Outside non-organic slug pellets and growth regulators, which were almost completely forsaken, insecticides are the type of treatment which was most suppressed (-66% at farm level), especially on wheat (-56%) and rape (-53%). Insecticide TFI on commonly treated surfaces was about 50% correlated with part of cropland dedicated to rape in current and previous crop years, suggesting that the strong reduction in rape surfaces (-47%) reduced both immediate needs for insecticides and later insect pressure. The same effect can be observed with fungicides, but more strongly. Fungicide TFI was most reduced on wheat (-41%). Herbicides are the type of treatment which was least suppressed (-27% at farm level), they were mainly reduced on rape (-19%) and wheat (-16%). Herbicide TFI on commonly treated surfaces was not correlated with the current or previous relative surface of any crop or crop type, suggesting that crop diversification (including with spring crops and perennials) was not enough to control weeds. The farms who reduced herbicide TFIs most did not have a similar evolution in their practices (crop choices, reliance on soil preparation, risk acceptance, …); the same can be said for total TFI. Finally, among the main crops seed TFI was most reduced for spring barley (-61%), rape (-40%) and then winter barley (-20%), with a 32% reduction at farm level.

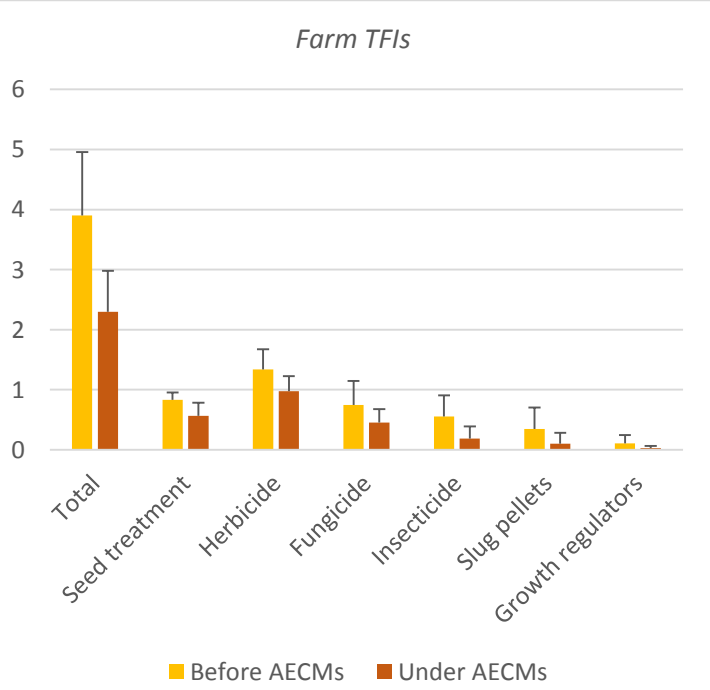
While most farms were not at the end of the period with gradual contract restrictions on TFIs at the time of this study, on average the TFI for herbicides (0.97) and the TFI for other phytosanitary products (1.32) under AECMs have been below the end targets (respectively 1.2 and 1.8). Weather conditions, which were not advantageous to insects and fungi in the last years in the area, probably helped

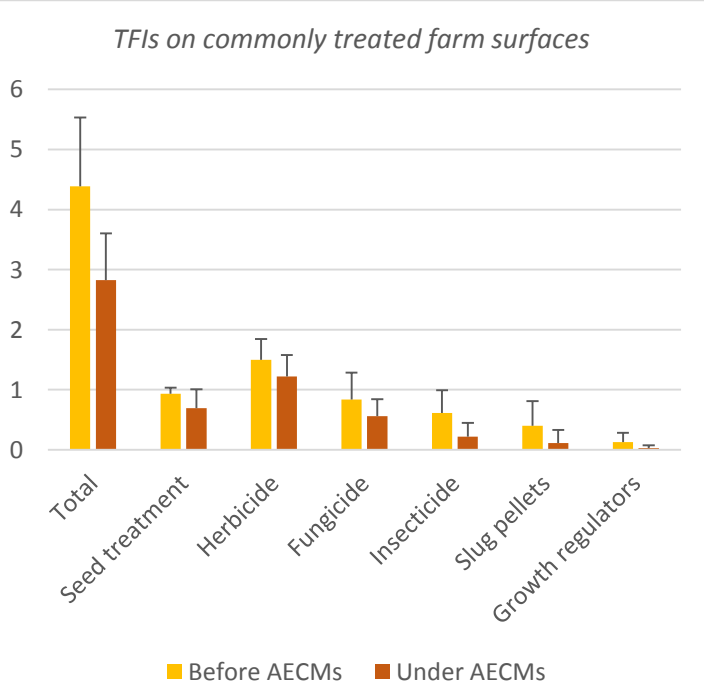
a. Cropping plans: average part of cropland dedicated to different crops and crop types. TP: temporary pastures.

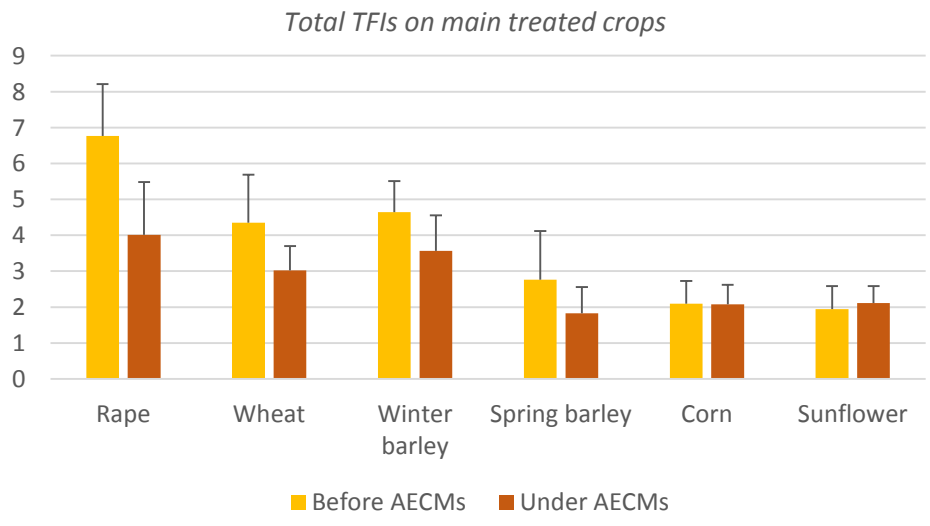




b. Phytosanitary treatments: average Treatment Frequency Indexes (TFIs)







c. Fertilization: average quantities of nutrients applied with mineral fertilizers. N: nitrogen; P: phosphorus; K: potassium.

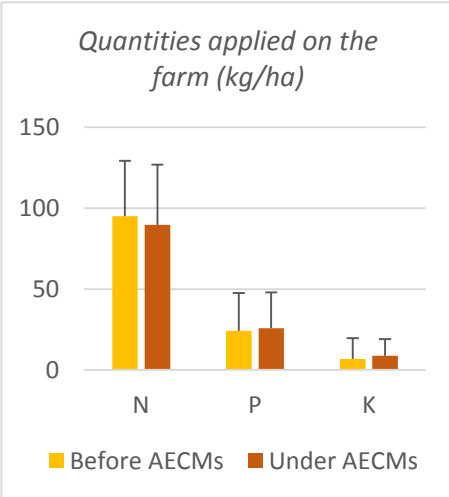


***Figure 2* : Evolutions in the AECM production systems based on technical records.** Segments on top of the bars show standard deviations.

reducing insecticide and fungicide TFIs. Interestingly, the strongest drop in farm total TFI (-60%) occurred with a farmer who said that the main thing he/she had changed was to select phytosanitary products which yield a smaller TFI for a same treatment. Another farm declares permanent pastures (normally excluded from TFI calculations) as temporary pastures, causing total TFI to be divided by 2.5 both before and under AECM.

As for fertilization practices, the use of mineral fertilizers did not change much. N fertilization has decreased by 6%, a modest evolution that was however consistent between farms and rather consistent with the increase of legume cultivation. On the other hand, the evolutions in phosphorus and potassium application were more variable. Correlations indicate that mineral fertilizer application tends to decrease when there is (and when there has been) an increase in the cultivation of "low-input crops" and legumes, a decrease in fungicide TFI on commonly treated crops and a decrease in rape cultivation (highly fertilized crop). There was also a weak positive correlation between N fertilization and spring barley cultivation (less fertilized than winter barley), and there was no correlation between mineral fertilization and herbicide TFI.

3.2. State of the AECM farming systems

3.2.1. Social and technical results from interviews

The following part of the results deals with the social side of the study farms, starting with the effects of AECMs and/or pesticide reduction on working times. Pesticide spraying is the one main farming activity on which farmers have got less work, cited by 7 farmers over 12. On the other hand, farmers reported to have got more work with soil preparation (4 farmers), paperwork (3 farmers) and field observation (2 farmers). Four farmers reported that they had got more work in spring / late winter and/or less work in autumn / late summer, the workload becoming more constant within the year. This was due to the cultivation of spring crops or clover (mowed in May), and to the decreased cultivation of winter crops like rape. The rest of the farmers said that the annual repartition of working time had not changed.

In the end, eight farmers said that they had as much work as before since they engaged in AECMs. Two farmers said that they had more work due to increased soil preparation, which is slower than pesticide spraying, and one farmer said that he/she had more work because the farming activities had become less concentrated in summer and fall, so he/she could do fewer things at once (this is a field crop farmer who had the largest cropland to take care of). One field crop farmer said that he/she had less work due to cultivation of alfalfa and clover (harvested by another farmer for forage), and decreased cultivation of rape. All farmers said that their amount of holidays would have been the same without AECM.

Regarding professional life quality, farmers found that AECMs and/or the techniques that they have adopted to limit pesticide use have yielded more positive outcomes than negative ones. Only one or

two farmers found no positive outcome, the others all cited different advantages (new way of thinking, increased autonomy, better interaction with others, …), in addition to reduced pesticide use which was cited as a positive outcome by seven farmers (mainly those who had changed their production system the most). Only three farmers found negative outcomes (stress related to paperwork and controls, increased work, disrupted cropping plans). Ultimately however, the level of professional life quality was deemed unchanged by all farmers except one (increased level).

On the technical side, 4 farmers said that they had not got more weeds than usual, and 6 farmers said that they had got more, due to weather (5 farmers), decreased availability of effective herbicides on the market (2) and/or reduced herbicide use (1). As for yields, 10 farmers said that they were not particularly different than usual (or they could not tell due to high variability) and they do not think that the level of yields was changed by AECMs and/or the evolutions that they have implemented in their production systems in relation to pesticide reduction. A decrease in yields, due to reduced pesticide use and/or increased resistance, was noticed by 2 farmers. Five farmers at least, while noticing more weeds, did not notice a change in yields. All these results on weeds and yields do not seem to be related to the different profiles of evolution in practices (see section 3.1.2.).

3.2.2. Quantitative results from farm records and regional references

Now, we will deal with the state of the study farms under AECMs as described by some quantitative indicators, detailed in *Table 3*. There were not as many data available for this as for the evolutions in farming practices (section 3.1.3.). The data upon which the results are based are from 5 farms for stocking rate (over 9 mixed crop-livestock systems), 6 farms for veterinary costs, 10 farms for margins and economic efficiency, 11 farms for EBITDAs, available income, debt ratio and adjusted accounting price of the farm, and all 13 farms for relative farm size. Due to the little number of data for stocking rate and veterinary costs, we cannot draw strong conclusions about them, except that farm results seem similar to reference values and to results before AECMs.

The indicators of profit show contrasting results, although their evolutions were consistent between farms (each of these indicators evolved in the same direction for at least 8 farms). Without counting AECM subsidies, margins have somewhat dropped under AECMs, with an average decrease of about 85 €/ha compared to reference values. This result is difficult to explain: gross margin (or the difference to reference values) was not correlated with TFIs, except that there were weak positive correlations with insecticide TFI (current and two years before) at farm level and current fungicide TFI on winter barley. Regarding crop surfaces, weaker correlations indicate that the increase of legume cultivation and the reduction of rape cultivation were related to a reduction of current gross margin compared to reference values, slightly compensated by the increased cultivation of sunflower. There were also weak positive correlations with potassium application in current and previous crop years – which

would have tended to increase gross margin compared to reference values. The decrease in mean gross margin primarily comes from a decrease in mean gross product; operating costs did not substantially decrease on average (-16 €/ha), despite the reduction of pesticide use, hence the decreased economic efficiency. From all these observations, we can make several hypotheses to explain the decrease of mean gross margin compared to reference values: cultivation of less lucrative crops (legumes instead of rape), increased damage to crops (insects, fungi on winter barley) following pesticide reduction, use of more expensive phytosanitary products (e.g. slug pellets replaced by organic products), decreased investments in for instance farm equipment.

While without counting AECM subsidies, gross margin has decreased by about 16,800 €/MWU on average, EBITDA before labor costs has decreased by only 13,000 €/MWU and available income was reduced only by 5000 €/FWU (with 0.9 FWU for 1 MWU). It looks like the AECM farms have reduced fixed costs such as mechanization costs (-2800 €/MWU), and their investments so as to have fewer financial costs. Correlations indicate that a slight increase of relative farm size (+ 9 ha/MWU for each farm on average) helped maintaining EBITDA. In the end, in spite of an inferior gross margin, available income under AECMs is not significantly different from reference values (high variations) and debt ratio (+ 3.9 pt) did not increase as much as in reference values. Debt ratio and relative farm size (or their differences to reference values) were about 50% positively correlated. We can deduce from the evolutions that before AECMs, the study farms had a gross margin per ha lower than reference values on average, but a higher EBITDA per MWU before labor costs (with a higher surface per MWU), a higher available income per FWU and a lower debt ratio. If we now include AECM subsidies, the loss in margins is negated, available income has increased by 10,000 €/FWU compared to before, and debt ratio is only 2.3 pt higher than before.

As for adjusted accounting price of the farm per MWU, its evolution was variable between farms, ranging from -14% to + 33%; the evolution of the difference to reference values was similarly variable. On average however, the study farms are rather expensive compared to reference values, hinting that it could be more difficult for successors to take over these farms as they are. This is probably related to a greater relative farm size; within the sample there are strong correlations between the two indicators. However, for the four farmers closest to retirement, adjusted accounting price of the farm is below reference values.

Overall, without the AECM subsidies the farming systems under AECMs seem to be less profitable than before, but still profitable enough to live on. According to Grailhe et al. (1998), the first determiners of the risk of bankruptcy are debt ratio and then available income, both of which appear to be good enough in our case especially if we include AECM subsidies. This suggests that the study farms have a good capacity to make investments. In addition, maybe that it takes a few years for newly implemented practices such as crop diversification to improve soil fertility and pest control, and for farmers to really master new practices. No farmer appeared to be alarmed by their economic situation when asked about it. Still, a low gross margin and for instance a rebound in pest pressure could further

***Table 3* : Indicators of state of the farming systems under AECMs.** Evolution, in percentage points (pt) or euros, refers to the mean difference to reference values, under AECMs as compared to before AECMs. For instance, the stocking rate of the study farms is 14% higher than reference values on average under AECMs (based on 9 observations), but it was only about 12% higher before AECMs. LU: livestock unit; MWU: man work unit; FWU: family work unit; inc. : including.

Indicator	Mean	Standard deviation	Obser-vations	Mean difference to reference values	Evolution
Stocking rate	1.26 LU/ha	0.12	9	+ 14 %	+ 2 pt
Veterinary costs	70.0 €/LU	23.5	11	- 3.2 %	- 2.7 pt
Gross margin (/ha)					
inc. AECM subsidies	441 €	160	19	- 21 €	+ 26 €
no AECM subsidies	331 €	160		- 131 €**	- 84 €
Economic efficiency	0.43	0.25	19	- 24 %°°	- 22 pt
Semi-net margin (/ha)					
inc. AECM subsidies	87 €	147	19	- 41 €*	+ 24 €
no AECM subsidies	- 22 €	147		- 151 €**	- 86 €
EBITDA before labor costs (/MWU)					
inc. AECM subsidies	42,050 €	23,520	20	+ 4432 €	- 2234 €
no AECM subsidies	32,396 €	19,133		- 5222 €*	- 11,751 €
Available income (/FWU)					
inc. AECM subsidies	24,046 €	25,681	20	+ 13,200 €**	+ 9103 €
no AECM subsidies	8673 €	21,918		- 2173 €	- 6107 €
Debt ratio					
inc. AECM subsidies	31 %	23	20	- 43 %°°	- 10 pt
no AECM subsidies	33 %	22		- 41 %°°	- 7 pt
Relative farm size	141 ha/MWU	66	29	+ 19 %°	- 13 pt
Adjusted accounting price of the farm (/MWU)	398,304 €	235,144	20	+ 28 %°	- 12 pt

*Mean difference to reference values significant at 20%.
**Mean difference to reference values significant at 5%.
°Median difference to reference values significant at 20%.
°°Median difference to reference values significant at 5%.

deteriorate farm profit in the future. To ensure the durability of their farms with relatively low pesticide use, farmers may have to consider other evolutions like renewing some of their equipment, relying more on crop auxiliaries, switching to organic, contributing to the development of local markets…

3.3. Evolution perspectives of the farms that engaged in AECMs

All 12 interviewed farmers declared that if an identical AECM contract were again offered to them, then they would take it, probably or without hesitation. They said that they had no particular issue with their contracts, except that there were delays in the payment of AECM subsidies. But if there is no such agri-environmental measure again when their present contracts come to their end, one farmer said that he/she will use more pesticides again to improve yields; the others said that they will keep a farming system similar to what they had under AECMs (with relatively low pesticide use) and/or reduce pesticide use further. Five farmers talked about increasing crop diversification (mainly with legumes as protein crops) and two of them talked about testing mechanical weeding with spiked harrow (see *Figure 1* page 7) in the future. Two farmers seriously consider switching to organic (but it is mainly not a consequence of their engagement in AECMs) and one farmer retired during the study and handed over his/her land to an organic farm.

When it comes to the possibility of reducing pesticides further or even switching to organic, it appears that the main issue for our farmers is weed control. They would need to master new techniques (especially with mechanical weeding) and rely more on plowing. However, these techniques can be complicated to implement on the dominant soil type, which is superficial and somewhat stony. Compared to herbicide spraying, these techniques consume more fuel and take more time. They may also require farmers to invest in expensive machinery. In addition, some farmers were concerned by the level of weeds that they had seen on organic farms in the area, but they acknowledged that some organic farms have "proper" weed management.

While 11 farmers cited weed control as a constraint to reduce pesticides, none specifically cited the control of insects or fungi (maybe in part because pressure was rather low in the last years). Regarding other constraints, two field crop farmers and one livestock farmer reported the lack of good market outlets to diversify cropping plans (especially with protein crops, which can be related to the decrease of margins); two livestock farmers said that switching to organic would require them to reduce the part of cropland dedicated to cereals, implying that there farms would no longer be self-sufficient for straw production. And six farmers at least appeared to believe that growing food without pesticides is just unnecessary or a bad idea (fewer options for pest control, not enough feeding the population, health risk posed by pest).

The fact that farmers avoid growing labor-intensive crops (e.g. corn) on distant parcels, and prefer to grow a given crop on parcels close to one another (especially if the farm is large), is an additional constraint to reduce pesticide use by diversifying crop rotations. The additional working time induced by soil preparation, mechanical weeding, pest monitoring, reliance on crop auxiliaries or even alternative marketing also implies that farmers may need to consider a production system with a smaller scale if they want to further reduce pesticides with increased technical and economic mastery. Within the study sample (section 3.2.2.), relative farm size (per MWU) was positively correlated with EBITDA before labor costs

(per MWU) but also with debt ratio (and adjusted accounting price of the farm, per MWU), and it was not correlated with margins (per ha) or available income (per FWU).

Finally, changes in weather can be both constraints and driving forces to implement alternative practices, thus there were crop failures with rape for crop year 2018-2019 due to drought around sowing.

3.4. Validity, possible extrapolations and limitations of the study

Not too much value should be granted to one elementary result in this study, due to some level of imprecision. Thus, to ask farmers to describe or explain their practices, results and opinions, open-ended questions were used so as not to restrict the farmers' answers, but they could have omitted some details. Above all, the quantitative results calculated from farm records contain multiple approximations originating from recording by farmers, technicians and accountants, from calculations by researchers, from some inhomogeneity and unavailability of data sources and from rules of calculation. While crop surfaces are rather precisely recorded (strong administrative follow-up) and do not require much process for calculations, TFIs are probably the most questionable indicators especially due to indiscriminate rules of calculation (seed treatments always count for 1, two active ingredients applied together count for 1 treatment, …). A more representative index of phytosanitary treatment, accounting for quantities of active ingredients, has been proposed to the French government (Guichard et al. 2017).

Another debatable point is that for a given type of quantitative result, the mean was based on all corresponding observations indiscriminately (except when specified per farm in the text). This means that farms with more observations available (especially under AECMs) have more weight in the means; results from farms with fewer observations were deemed less representative. This method may be relevant for indicators which are quite variable from one year to the next for a given farm (like the indicators of annual profit, relative surfaces of crops such as spring barley, …), but it may be less relevant for more stable indicators (like debt ratio or relative surface of wheat). It was necessary to look closely at the data to spot tendencies concealed by overweighting observations, like the non-reduction of debt ratio among the study farms.

This being said, the results allow drawing tendencies. With this study, we discover that farms actually engaged in AECMs for pesticide reduction have indeed reduced pesticide use through risk acceptance, adaptation of crop choices and/or reliance on soil preparation, which was not perceived as a bad experience by farmers. And that apparently, their annual economic profit would have decreased without the AECM subsidies but not to such an extent that their farming systems will not live on without these subsidies. This applied to a group of 4 field crop farms and 9 mixed-crop livestock systems with suckling cows, whose production systems were under AECMs in the last few crop years in the rural *Nièvre* region. Before engaging, these farms were mostly less reliant on pesticides and more profitable than the corresponding regional average. Thus, it can be hypothesized that compared to the study farms,

the average farm of *Nièvre* tends more to use more pesticide than "necessary" and that reducing pesticides would not lead them to become less profitable, which is in accordance with findings from DEPHY (see Introduction). However, reducing pesticides to the extent required by AECMs would certainly have demanded more effort from them, which can explain the relatively low rate of participation in AECMs among eligible farms – especially field crop farmers who cannot directly use pastures and fodder crops for meat production. Finally, the technical specifications of the contracts are adjusted to the considered area according to proportions of cultivated crops, and the AECM subsidies (in euros per hectare engaged) in Burgundy are below the French average, so AECMs may have a quite different impact in other agricultural/administrative regions, with different market outlets as well.

4. Conclusion

In the northern part of *Nièvre*, central France, 4 field crop farms and 9 mixed-crop livestock systems have engaged their production systems in AECMs for pesticide reduction. With this study, farmers were interviewed and technical and economic data from their farm records were analyzed, in order to discover how such farms could be impacted by AECMs and/or pesticide reduction. It has been found that total Treatment Frequency Index has decreased in every farm, often clearly ahead of contract end requirements, but half of the farms were reportedly affected in their practices by AECMs only in a minor way (e.g. fewer seed treatments) and would have applied a relatively low-input system regardless of AECMs. Each type of phytosanitary treatment (herbicide, insecticide, growth regulators…) was reduced by a majority of farms, in great part due (or partly due) to AECMs. For this, farmers combined different strategies: more accepting the risk of not applying a phytosanitary treatment, adapting crop choices (less rape, more spring crops, more legumes, …) to reduce the need for phytosanitary treatments, and more relying on soil preparation to fight weeds (delayed sowing, stubble ploughing, …). Fertilization practices did not change much, nor did livestock management (minor changes in forage). Overall, farmers said that their engagement in AECMs had required little effort from them to adapt their practices, but four of them declared that AECMs really had brought new reflections for them about their practices.

Overall, farmers said that they had the same work quantity and annual repartition as before, but there were some variations between farmers. Minor random variations aside, labor force was unchanged. Farmers reported more positive outcomes than negative ones for them from AECMs and/or the techniques that they had adopted to limit pesticide use, nevertheless their level of professional life quality was reportedly almost unchanged. There was no clear effect on the levels of weeds and yields, however annual economic profit was decreased if we do not include AECM subsidies. This loss was probably due to several different factors (such as low investments, cultivation of less lucrative crops, some damage from insects, …); it does not too much endanger the durability of these farming systems with lower pesticide use all the more so as debt ratio was really kept relatively low even without AECM subsidies, which really compensated the annual losses anyways. Before engaging, these farms were mostly less reliant on pesticides and more profitable than the corresponding regional average, so the average farm of *Nièvre* could probably reduce pesticides without any loss of profit. As for the study farms, reducing pesticides even more may require to reconsider the design of the farm systems further; in any case their farming systems should be able to subsist once the AECM contracts (and subsidies) come to an end. The study farmers do intend to keep farming with relatively low pesticide use – and they would take an AECM contract again if they had the opportunity.

The main constraint faced by farmers to continue farming with lower reliance on pesticides is apparently weed control. The dominant soil type is superficial and somewhat stony, which makes increasing plowing for weed control more complicated in a short-term perspective and maybe even more detrimental in a long-term perspective (erosion). Farmers may need some alternative equipment and/or

agro-ecological techniques for soil preparation. Growing more legumes could be one of the easiest ways for farmers to reduce herbicides and other pesticides further, but for that they need to have the possibility to use/sell them properly, or be compensated. Farmers may overcome their constraints with some technical assistance and/or financial support. While the study farms have relatively large surfaces with relatively low gross margin per ha, a relatively smaller production system may make it easier for them to reduce pesticides with increased technical and economic mastery. When it comes to stopping pesticide use, farmers have technical, economic and political concerns that may have to be addressed further.

About the relevance of the studied agri-environmental schemes, this study has illustrated the fact that TFIs are relatively indiscriminate indicators which can be a flaw in French/European agri-environmental policies, although TFI requirements did lead some of the farmers to reduce their reliance on pesticides. Although the subject farming systems will probably be maintained without AECM subsidies, the latter were a driver for half of the farmers to risk relying less on pesticides, and they can help farmers to make investments possibly needed to maintain their farming systems in the future. However, this study does not say whether / how much the observed decrease of treatment frequency can in fact be related to an improvement in ecosystem preservation, human health or drinking water quality. Also, while the purpose of AECMs is to mitigate practices harmful to the environment such as pesticide application, the farms that rely more on these practices are less likely to engage in such agri-environmental measures. Agri-environmental schemes may need to dedicate additional support to specifically assist these farming systems on the way to sustainability.

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Conflict of Interest: This study was carried out as a paid internship at the municipality of Clamecy which is part of the local agri-environmental program for water protection.

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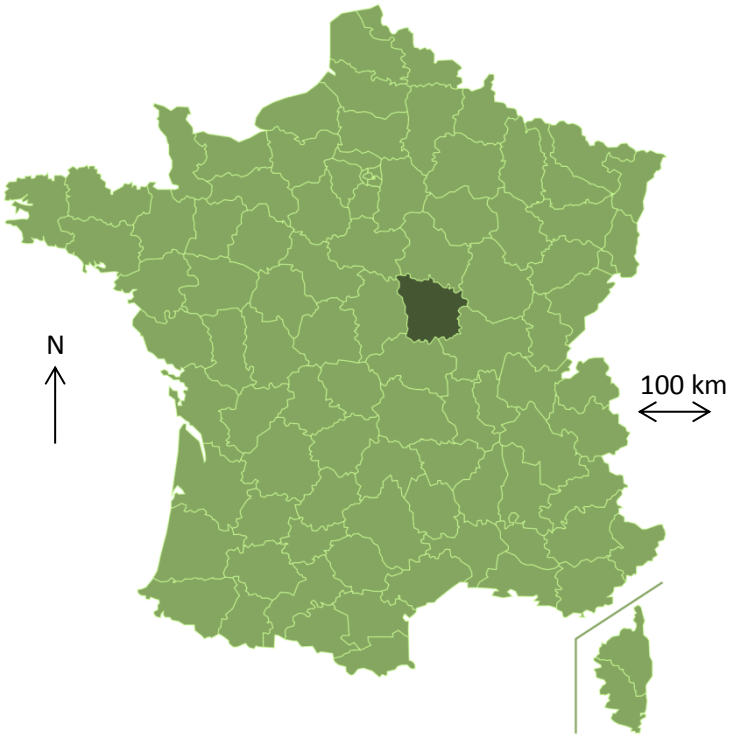
Appendices

Appendix 1: Localization of the *Nièvre* region within France



Map from https://en.wikipedia.org/wiki/Ni%C3%A8vre (10/04/19).

Appendix 2: Summary of the technical specifications of the AECM contracts involved in this study

Source: Lison Delsalle (2017) Les MAEC sur les BAC, issue 11. Regarding TFI reduction requirements, the end target is 1.2 for herbicides; for non-herbicide it is 1.8 if the farm has livestock and 2.0 if it does not. For a farm engaged in (May) 2015, "the first crop year" refers to 2015-2016.

Mixed crop-livestock system AECMs for herbivores

- The whole farm is engaged and it must have at least 10 livestock units.
- Purchase of concentrates limited to 800 kg/LU (cattle) or 1000 kg/LU (sheep).
- Farmer must attend appointments about nitrogen management.
- Use of growth regulators is forbidden except on malt barley.
- Gradual restrictions on herbicide and non-herbicide TFIs.
- If field crops (corn excluded) are less than 33% of farm Utilized Agricultural Area (UAA):
    - pastures must reach more than 60% of farm UAA;
    - silage maize must amount to less than 22% of farm forage area;
    - AECM subsidies shall amount to about 74 €/ha each year.
- If field crops (corn excluded) are more than 33% of farm UAA:
    - pastures must reach more than 35% of farm UAA;
    - silage maize must amount to less than 15% of farm forage area;
    - AECM subsidies shall amount to about 60 €/ha each year.

Field crop system AECM

- Arable land must be more than 70% of farm UAA and the farm must have less than 10 livestock units.
- At least 70% of the arable land is engaged.
- No crop should represent more than 60% of farm UAA in the first crop year; no more than 50% afterwards.
- The farm should have at least 4 crops (each representing more than 5% of farm UAA) in the first crop year, and at least 5 afterwards.
- Cultivated legumes should represent more than 5% of farm UAA.
- A given parcel cannot have a same crop during 3 successive crop years (2 successive crop years for straw cereals).
- Farmer must attend appointments about nitrogen management and should not fertilize legumes.
- Use of growth regulators is forbidden except on malt barley.
- Gradual restrictions on herbicide and non-herbicide TFIs.
- AECM subsidies shall amount to about 166 €/ha each year.

Localized AECM: Gradual reduction of the use of phytosanitary products

- Only arable surfaces can be engaged; corn, sunflower and temporary pastures cannot be more than 30% of the surface engaged.
- Farmer must attend appointments and a formation about the use of phytosanitary products.
- Gradual restrictions on herbicide and non-herbicide TFIs.
- AECM subsidies shall amount to about 190 €/ha each year.

Appendix 3: Characteristics of the study farms upon engagement in AECMs

Farm	Farm type	Year of engagement	AECM	Surface (ha)	Labor force (man work units)	Livestock	Quantity of livestock units	Annual amount of the AECM subsidy
A	Mixed crop-livestock system	2015	Mixed crop-livestock system AECM for herbivores	310	3	Suckling cows	176	28,038.58 €
B	Field crop farm	2015	Field crop system AECM	124	1	None	-	19,592.72 €
C	Mixed crop-livestock system	2015	Mixed crop-livestock system AECM for herbivores	164	1	Suckling cows	124	12,145.42 €
D	Field crop farm	2015	Field crop system AECM	93	1	None	-	15,441.72 €
E	Mixed crop-livestock system	2015	Mixed crop-livestock system AECM for herbivores	128	1.5	Suckling cows, sheep	49	11,873.84 €
F	Field crop farm	2015	Field crop system AECM	56	1	None	-	9,094.01 €
G	Mixed crop-livestock system	2016	Mixed crop-livestock system AECM for herbivores	242	1	Suckling cows	197	14,676.67 €
H	Mixed crop-livestock system	2016	Mixed crop-livestock system AECM for herbivores	194	1.8	Suckling cows	192	11,608.32 €
I	Field crop farm	2016	Localized AECM: Gradual reduction of the use of phytosanitary products	214	1.1	None	-	26,586.00 €
J	Mixed crop-livestock system	2016	Mixed crop-livestock system AECM for herbivores	199	1	Suckling cows	(unknown)	14,584.80 €
K	Mixed crop-livestock system	2017	Mixed crop-livestock system AECMs for herbivores	432	2.5	Suckling cows	(unknown)	32,169.84 €
L	Mixed crop-livestock system	2017	Mixed crop-livestock system AECM for herbivores	168	2	Suckling cows	106	10,157.28 €
M	Mixed crop-livestock system	2017	Mixed crop-livestock system AECM for herbivores	327	1	Suckling cows, sheep	143	19,951.80 €

Appendix 4: Rules of calculation for TFIs (translated from DEPHY 2014)

For a *(non-organic)* phytosanitary treatment, the Treatment Frequency Index is the ratio between the rate of application during the treatment and the registered rate of application for the product and the crop involved. If the treatment is done only on a portion of the parcel, then its TFI is proportionally reduced.

If several uses are registered for the treatment (i.e. several pests targeted with different registered rates of application), then TFI calculations shall use the smallest registered rate. Consequently, the TFI associated with a given treatment can be greater than 1 if the targeted pest is not very sensitive and requires a high rate of application.

The TFIs of the different treatments from the harvesting of the previous crop to the harvesting of the considered crop are cumulated to obtain the crop TFI. If there are several successive crops within one crop year, the sum of their TFIs gives the annual TFI. On an area containing different crops, the TFI of the cropping system is the average of the annual TFIs *(weighted according to crop surfaces)*.

Appendix 5: Expressing margins with a "natural production unit"

Regarding margins, we commonly find results per hectare in the literature and accounting practices. This implies that margins are mainly correlated with agricultural land surfaces. Here, I argue that livestock represents a primary mean of production just like agricultural land used for cash crop production; and that consequently, margins should perhaps be related to land surfaces and livestock quantity together, taken as "natural production units" (NPUs). Using economic references for the region during the study period (see section, 2.3.3.), the average contribution of 1 hectare in cash crops to gross margin (*x* €/ha) was estimated with field crop systems (FCS), and then the average contribution of 1 livestock unit to gross margin (*y* €/LU) was deduced with mixed crop-livestock systems (MCLS). The calculations were:

$$x = \frac{FCS\ gross\ margin}{FCS\ agricultural\ area}\ ;\ y = \frac{MCLS\ gross\ margin - x \times MCLS\ cash\ crop\ surfaces}{MCLS\ livestock\ quantity}$$

It happened that the two contributions were 98% similar on average (respectively 487€/ha and 475€/LU), so in this study one hectare in cash crops and one livestock unit would have represented 1 NPU each. But then, Pearson correlations were tested (at a 5% significance level) using the 52 observations with gross margin, utilized agricultural area and number of NPUs available, only to find that in the sample gross margin was more correlated with utilized agricultural area than number of NPUs. Still, the concept of NPU is perhaps relevant in other settings, e.g. with farms with less surface and more livestock.

Appendix 6: Evolutions in the production systems under AECMs as reported by each farmer

Farm	A		B		C		D		E		G		H		I		J		K		L		M	
Evolution (decreased or increased use)	**-**	**+**	**-**	**+**	**-**	**+**	**-**	**+**	**-**	**+**	**-**	**+**	**-**	**+**	**-**	**+**	**-**	**+**	**-**	**+**	**-**	**+**	**-**	**+**
Phytosanitary treatments																								
Reliance on slug pellets (non-organic)	X		X						X		X				X		X		X		X		X	
Reliance on fungicides	X		X		X		X		X								X				X		X	
Reliance on herbicides	X		X		X		X		X						X		X				X		X	
Reliance on insecticides	X		X				X		X				X		X		X		X		X		X	
Reliance on growth regulators	X		X						X				X				X						X	
Reliance on seed treatments	X		X				X		X				X		X		X		X					
Selection of phytosanitary products to lower TFIs		X										X												
Crop choices																								
Cultivation of spring crops		X		X		X				X		X	X			X				X		X		X
Cultivation of alfalfa and/or clover		X		X				X		X						X				X		X		X
Use of more resistant varieties		X		X																				X
Use of starter crops alternative to rape		X		X				X		X						X				X		X		X
Fertilization																								
Manure application				X												X								X
Use of mineral fertilizers			X				X																X	
Soil preparation																								
Stubble ploughing		X													X			X	X					X
Traditional plowing				X	X								X						X				X	
Other																								
Delay before sowing of winter cereals		X								X				X								X		X
Cover cropping (regardless of spring crop quantity)										X						X		X				X		
Straw harvesting								X								X								
Use of forage produced on farm		X																				X		

Appendix 7: Interview guide used with farmers in this study (translated from French)

Preliminary information

First, some general questions about your farm.

History of the farm:

Part of the farm land that you own:

And part that you rent:

Is it a simple individual farm or is it an enterprise (then who are the associates?)?

Do you live on the farm?

Who lives with you?

Who else works with you on the farm? What is the work quantity for each of you? What tasks are assigned to each?

-> number of man-work units :

Have you got a job beside the farm? *(What about the other associates?)*

(Does your spouse have a job beside the farm?)

Do you take part in project or programme with agricultural organisations?

What is the main reason that led you to engage in AECM? Are there other reasons?

(How) did the people living with you contribute to your decision to engage in AECM?

(Which breed do you have?)

(What kind of animals do you produce? How old are they sold? What weight do you want them to reach?)

(How many animals of each type do you have?)

(During which period of the year do your animals give birth?)

(During which period of the year do you sell your animals?)

How do you get supply for:

seeds:

fertilisers:

phytosanitary products:

(feed:)

(straw:)

Do you exchange straw with manure?

How do you market your productions? Have you got any particular marketing strategy?

(How) do you store your productions?

Which of your productions is/are the most important to you?

What kind of soils do you have on your farm? What are the advantages and drawbacks of these soils for you?

Do you have relief constraints on your farm? (How does this affect your work concretely?)

Identification of potential production systems to segregate

Now, I am going to ask you questions in order to see whether we should break down your farm into several parts to perform its technical/economic analysis.

Before the AECM period, did you have several distinct rotations (crop successions)? Which rotation was assigned to which parcels? What was the interest of each rotation?

Regardless of crop rotations, do you treat some parcels differently from the others (due to distance, soil type, relief, neighbourhood, localised AECM, ...)? What are the differences in treatment for these parcels?

(Do you assign some parcels to cash crop production exclusively, and other parcels to feed production for your livestock exclusively? Or are cash crops always in rotation with the other crops?)

(On which part of your permanent pastures do you practice mowing?)

(On which of your parcels do you spread your manure?)

(Can it happen that you give feed produced on your farm to your livestock while they are grazing? Or that you give to your livestock part of your harvest that you initially wanted to sell?)

(Does it happen, especially during work-intensive periods, that you have to choose between taking care of the crops properly and taking care of the livestock properly?)

AECM and modification of practices

Now, we will try to see in detail, farming practice after farming practice, if and how the AECM changed them. I will ask about your previous and current practices, about the role played by the AECM, and about your decision criteria (regarding when to intervene, where, how, at what intensity...).

But first, can you summarise the changes you made in your system since you engaged in AECM?

How did you modify your **crop rotations** since you are engaged in AECM? Why did you do these modifications? What are your crop rotations now?

What are the differences in your overall **crop choices** (crop and assigned surface) between now and before the AECM?

Before the AECM, did you use to make your crop choices more at the parcel scale or at the farm scale? What about now?

If there had been no AECM, would you (also) have done differently regarding crop choices?

Varieties

Before the AECM, how did you use to choose your varieties?

And now how do you choose your varieties?

(For which crops was there a change?)

If there had been no AECM, would you (also) have done differently regarding choice of varieties? *(If there was a change, why?)*

Pest management

Regarding phytosanitary products, we will talk about it in detail later with each TFI.

Overall, before the AECM, what techniques did you use to use for pest management and weed control?

What were your decision criteria to use these techniques?

And now, what techniques do you use for pest management and weed control overall?

What were your decision criteria?

(For which crops was there a change?)

If there had been no AECM, would you (also) have done differently regarding pest management? *(If there was a change, why?)*

Do you think that you would have used more phytosanitary products without AECM?

Spreading of organic fertilisers

Before the AECM, did you use to spread organic fertilisers? What kind of organic fertiliser?

What was your spreading plan?

And now, do you spread organic fertilisers / what kind / what plan?

(For which crops was there a change?)

If there had been no AECM, would you (also) have done differently regarding organic fertiliser spreading? *(If there was a change, why?)*

Compost

Did you use to compost before the AECM? What and how?

And now do you compost? What and how?

If there had been no AECM, would it have changes anything? *(If there was a change, why?)*

Mineral fertilisation

Before the AECM, what kind of mineral fertilisers did you use to use? What was your spreading plan?

And now, do you use other types of mineral fertilisers? Have you modified your spreading practices?

(For which crops was there a change?)

If there had been no AECM, would you (also) have changed your mineral fertilisation practices? *(If there was a change, why?)*

Irrigation

Before the AECM, did you use to irrigate and how?

What were your decision criteria to irrigate a crop?

Has your irrigation system evolved since then? What about your decision criteria?

(For which crops was there a change?)

If there had been no AECM, would it have changed anything regarding use of irrigation on your farm? *(If there was a change, why?)*

Soil preparation

Before the AECM, what tilling (or no-till) techniques did you use to have?

What were your decision criteria?

Have these techniques evolved since then? What about your decision criteria?

(For which crops was there a change?)

If there had been no AECM, would you (also) have done differently regarding soil preparation? *(If there was a change, why?)*

Sowing

Before the AECM, what were your strategies for sowing?

What were your decision criteria?

Have your sowing strategies evolved since then?

If there had been no AECM, would you (also) have changed your sowing strategies? *(If there was a change, why?)*

Crop residues

Before the AECM, what did you use to make of your straw cereal residues? How and why?

Have you made changes in your management of residues since then?

If there had been no AECM, would you (also) have done differently regarding management of residues? *(If there was a change, why?)*

Cover crops

Before the AECM, did you use to grow cover crops? During which period of the year? What did you use to do with them?

What were your decision criteria regarding cover crop harvesting/destruction?

And now do you grow cover crops? During which period of the year? What do you do with them?

What are your decision criteria regarding cover crop harvesting/destruction?

If there had been no AECM, would you (also) have done differently regarding cover crops? *(If there was a change, why?)*

Feeding

What are the rations for each type of animal?

Have these rations changed compared to before the AECM?

If there had been no AECM, would you (also) have adopted different rations? *(If there was a change, why?)*

Beside pastures, what is the part of your **cropland dedicated to feed production** for your livestock?

Has this part changed compared to before the AECM?

If there had been no AECM, do you think that this part would (also) have changed? *(If there was a change, why?)*

At what time of the year do you take your **animals to pastures**? And at what time do you bring them back into the barn?

If there had been no AECM, would it (also) have been different? *(If there was a change, why?)*

Other animal husbandry practices

Other than rations and grazing period, have you made changes in your livestock management since you engaged in AECM?

If there had been no AECM, do you think that you would (also) have made changes in your livestock management (outside rations and grazing period)? *(If there was a change, why?)*

Do you see anything else that we may have not talked about in your production system? Other changes in your conduct of crop management? *(e.g. soil improvers, harvesting, ...)*

If yes:

Before the AECM, how did use to do?

What were your decision criteria?

And now, how do you do it?

What are your decision criteria?

If there had been no AECM, would you (also) have done differently?

With the AECM, do you observe more your fields to better manage your crop, or do you use monitoring tools?

Think about all these changes of practices that you have mentioned: all in all, what did they bring you on a positive side and on a negative side?

Your overall feeling is that engaging in AECM has asked from you:

- no effort to adapt your practices
- a little effort to adapt your practices
- quite some effort to adapt your practices
- really much effort to adapt your practices

Would you say that your engaging in AECM has changed the way you think about your farming practices? (Were you already committed to reducing pesticides before engaging?)

Other results

Now, your feeling about the results of your practices.

During which periods of the year is the **workload** at its highest, and during which periods is it at its smallest?

Has this working time repartition evolved in the last few years? How would you explain it?

On which activities did you get more work?

On which activities did you get less work?

On the whole, would you say that you have more, less or as much work since you engaged in AECM?

Do you think that the AECM or the techniques that you have adopted to limit pesticide use could have had an (other) direct or indirect effect on your work quantity?

Do you sometimes take holidays? How many days a year?

Do you think that this would be different without the AECM?

In your work, what is it that you find good and bad for your **professional life quality**? (life quality can include things such as working conditions, stress, pride taken from the job, ...)

In the end, since you engaged in AECM, you find that your professional life quality has decreased, increased or remained the same?

How have your **yields** evolved since you are in AECM? Now how do you fare compared to the average? How do you explain these results?

Do you think that the AECM or the techniques that you have adopted to limit pesticide use could have had an (other) direct or indirect effect on your yields?

Has the AECM changed the type or number of **field operations per parcel** that you carry out every year?

How do you think that your **herbicide TFI** has evolved in the last few years? How do you explain it?

How do you think that your **insecticide TFI** has evolved in the last few years? How do you explain it?

How do you think that your **fungicide TFI** has evolved in the last few years? How do you explain it?

How do you think that your **anti-slug TFI** has evolved in the last few years? How do you explain it?

How do you think that your **seed TFI** has evolved in the last few years? How do you explain it?

How do you think that your **growth regulator TFI** has evolved in the last few years? How do you explain it?

How has your **stocking rate** evolved in the last few years? How do you explain it?

Do you think that the AECM or the techniques that you have adopted to limit pesticide use could have had an (other) direct or indirect effect on the stocking rate?

What level of **veterinary costs** do you think you have? Did it change in the last few years? How do you explain it?

Do you think that the AECM or the techniques that you have adopted to limit pesticide use could have had an (other) direct or indirect effect on your veterinary costs?

How do you think that your **fuel consumption** has evolved in the last few years? How do you explain it?

Do you think that the AECM or the techniques that you have adopted to limit pesticide use could have had an (other) direct or indirect effect on fuel consumption?

Now, do you get more **weeds** than before on the whole? To what extent? Do you know why?

Do you think that the AECM or the techniques that you have adopted to limit pesticide use could have had an (other) direct or indirect effect on weed level?

In your opinion, how is your farm performing **economically**? And how do you think that this has evolved in the last few years? How do you explain it?

In your opinion, how did the AECM (and your practice adaptations) affect your economic situation?

For the economic analysis of your farm, is there something in particular that you would like us to calculate for you?

If the farmer finds himself/herself in difficulty: If you see that your farm really is in trouble, have you got ideas to rebound?

Future of the farming system

Now, the future of your farm.

Do you consider switching to organic? Why? On a technical aspect, what is it that would hinder your conversion?

Do you see anything else that you would need to keep reducing pesticide use, if you wanted to keep reducing it?

Does the AECM contract include things in particular that bother you? And things that you appreciate?

If an identical AECM contract were again offered to you: would you take it? *If not:* Why ?

And when your present contract comes to its end, without any new AEM, would you keep the farming system that you implemented with the AECM? Otherwise which evolution do you consider? Why ?

Would you try new techniques, or use some different equipment?

Have you got any other objectives or projects for the future?

In how many years do you consider handing over your farm?

Do you have plans to hand over your farm?

Do you wish to find a successor?

What future would you want for your farm once you have handed it over?

Complementary information for the economic analysis

Now, I would need some information to help me do the economic analysis of your farm.

Do you know in detail when you received (OR counted in advance) the AECM payments, and the amounts?

In the last few years, have there been any periods where the weather was particularly advantageous or disadvantageous for your productions?

Did you hire employee in the last few years / did the number of employee change?

What about the other workers (if there are any)?

-> Evolution of the number of man-work units:

Have you done a big investment or a big sale in the last few years?

Did you start (or stop) renting or renting out anything in particular?

What farming machinery do you possess?

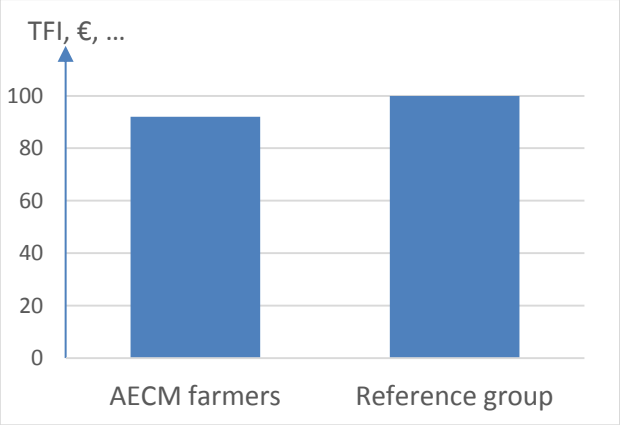
Do you use additional farming machinery? From where?

Do you delegate some tasks to an Agricultural Works Company or to other farmers? Which tasks?

Is your farm associated to another business run by you (farm shop, ...)? In order to help me do my economic analysis, I need to know if it happens that you do loans between the farm account the account of the other business OR your personal account.

Choice of the significance threshold of the results

For my technical/economic analysis I intend to compare AECM farmers' results with the results of reference groups. Either on the whole, or according to farm typology. *(Show graph)*



The gap between your results and the reference result can emerge from a mere random variation, or from a true technical difference between your farms and the reference. I am thus going to do a statistical analysis to work out the probability that the gap does not come just from chance and that the two results are fundamentally different. What level should this probability reach so that you would consider the results to be significantly different?

→ Probability of true difference greater than ...

Farmer's relation to his/her job (bonus)

Now, questions about how you relate to your job.

How did you become a farmer?

Why do you choose to farm (and raise cattle)? What do you like about this job?

According to you, what is it to do one's farmer job well (or badly)?

Do you participate in agricultural organisations?

Do you participate in non-agricultural organisations/associations?

Do you sometimes receive public on your farm?

Do you work in mutual assistance with people who are not part of your farm?

What do you do to improve your knowledge and your know-how?

Auto-evaluation (Excel file): *can be done now, or during the second meeting (if we have one), or the farmer does it alone and may send it to us when finished, or we don't do it.*

Ending

Would you be interested by a second meeting with myself or Lison to discuss the results of our technical/economic analysis of your farm?

Would you be really interested by inviting an organic farmer or a small-scale farmer for this second meeting so that you may compare your techniques and/or your results?