

Pesticides, agriculture and the environment



Reducing the use of pesticides and limiting their environmental impact

Collective Scientific Expert Report

Executive Summary of the Expert Report written by INRA and Cemagref
in response to a request from the Ministry of Agriculture and Fishery
and the Ministry of Ecology and Sustainable Development

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Responsible editors :

Claire Sabbagh (INRA, Collective Scientific Expertise Unit)
and Nicolas de Menthère (Cemagref, Information Systems and Communication Delegation)

Contacts:

Philippe Lucas, INRA: *Philippe.Lucas@rennes.inra.fr* ; Jean-Joël Gril: *gril@lyon.cemagref.fr*
Claire Sabbagh, INRA Collective Scientific Expertise Unit: *sabbagh@paris.inra.fr* ;
Gérard Brugnot, CEMAGREF, Expertise Representative: *gerard.brugnot@cemagref.fr*

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The list of authors and contributors to the expert report is shown inside the back cover.

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Collective Scientific Expert Report INRA - CEMAGREF

Pesticides, agriculture and the environment:
**Reducing the use of pesticides and
limiting their environmental impact**

Executive Summary of the Expert Report

Jean-Noël Aubertot, Jean-Marc Barbier, Alain Carpentier, Jean-Joël Gril,
Laurence Guichard, Philippe Lucas, Serge Savary, Marc Voltz (editors)
Isabelle Savini (author)

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Introduction

Advances in plant protection have contributed considerably to increasing yields and ensuring regular production. Easy to obtain and apply, and rather inexpensive, chemical control products have proved to be extremely efficient and reliable in a very large number of cases, on large surface areas. More than in many other countries, French farming has developed production systems based on using these products; it is currently highly dependent on pesticides and France now ranks third in worldwide pesticide consumption. However, today, the systematic use of pesticides is being called into question, with the increasing awareness of their negative impacts, the demonstration of undesirable adverse effects on ecosystems, on non-targeted useful or domestic species and on human health. In its report on "The Health Risks linked to the use of Plant Protection Products", submitted to the Ministry of Environment in 2002, the Committee for Prevention and Precautions (CPP) considered that the presumption of risks to human health was sufficiently serious to justify application of the Precautionary Principle. These risks to human health were further emphasised in the report dated February 12, 2004 from the Steering Committee for the French Environment-Health plan. The development of environmental monitoring has also demonstrated the degree of pesticide dispersion in the environment: the sixth report by the IFEN (French Institute for the Environment) on pesticides in water highlighted the almost total contamination of water bodies by pesticides. These observations argue in favour of increasingly restrictive regulations at both the European and French levels, which cannot be limited to even the most stringent evaluation of pesticides themselves; they will have to take account of how these substances are employed.

A certain number of key events related to current European and French policies have converged to render the question of reduced pesticide use a high priority for government action. In the context of the European Union, reference should be made to Common Agricultural Policy (CAP) reforms and the probable future strengthening of the environmental conditions related to the granting of farm subsidies; changes to the regulations linked to application of Directive 91/414/EC, relative to marketing authorisation procedures for plant health products; implementation of the Framework Water Directive (FWD) which, in order to comply with the objectives of a "good ecological state" for water bodies, will require the definition of action plans, some of them concerning pesticide use. At a French level, an Interministerial Pesticides Plan, and a national Health-Environment Plan (PNSE) have confirmed concerns about reducing pesticide contamination, including their negative impact on human health which was emphasised in the report dated February 12, 2004 issued by the PNSE steering committee.

It is in this context, that the French Ministries for Agriculture and the Environment asked INRA and the CEMAGREF to carry out a collective scientific expert report on the current situation concerning our knowledge of the conditions of pesticide use in farming, the means to reduce their use and to restrict their environmental impacts: What do we know about pesticide use in France? How can these products be better used, and how can space be better organised to restrict contamination? How can practices be changed and production systems modified so that they become less pesticide-dependent?

This expert report excludes aspects relative to human health. It limits itself to the agricultural use of pesticides. Its aim is not to serve as direct methodological support for the approval of products, or for the local operations currently under way aimed at reducing water pollution by crop protection products.

This work has been carried out by a group of some thirty experts from different disciplines (agronomy, soil sciences, hydrology, bioclimatology, ecotoxicology, plant health, economics, sociology, etc.) working in different institutions (INRA, CEMAGREF, IRD and BRGM). This report relies on the current, worldwide, scientific bibliography, based on which the experts have extracted, discussed and assembled those elements relevant to answering the questions asked by the sponsors. The initial questions, formulated during an interactive process between the experts and the sponsors, were laid down in a specification, with which the experts have sought to comply. However, the limitations encountered regarding the existence or availability of data may have modified certain aspects of the report.

This report focuses on analysis and evaluation, and does not conclude with opinions and recommendations for actions to be taken by the sponsors. The experts are responsible for the scientific content of the document, individually in their area of expertise and collectively regarding the coherence of the report as a whole. INRA and CEMAGREF bear responsibility for procedural compliance with the principles of quality which govern the compilation of expert reports.

Collective Scientific Expertise (ESCo): methods and keys to understanding

. The principles of ESCo

The ESCo provides support for public-sector decision-making; its task is to answer a complex question raised by an external sponsor, and to compile a report on the current state of multidisciplinary scientific knowledge based on a world-wide bibliography, highlighting confirmed findings, uncertainties, deficiencies and controversies.

This requires a joint decision as to analysis of the question raised by the external sponsor and the organisation(s) responsible for coordinating the expert report, which leads to the development of a specification. The expert work itself involves plenary meetings of all the experts involved, a report which assembles all the contributions of experts and an executive summary, synthesis for decision-makers and stake holders. Submission of the executive summary to the sponsors is accompanied by a symposium, open to a broader public.

Experts are chosen on the basis of a bibliographical search. The assistance of outside experts may be required, both from France and other countries, as they will guarantee the independence and openness of this work.

. Relying on a variety of bibliographical resources

In theory, the literature examined is limited to scientific articles published in peer-reviewed journals and referenced in international databases; in practice, it is usually necessary to extend the search to include "grey" literature (miscellaneous reports, etc.). Thus the experience of "field experts" can be taken into account, insofar as it has been the subject of articles published in recognised technical journals. The experts also need to deal with a certain amount of raw data, arising in particular from statistical surveys.

. The type of "answers" provided by the "Pesticides" ESCo

The scientific analysis proposed by the ESCo aims to identify, characterise and classify the "problems" raised and their principal determinants, and then to list and evaluate the knowledge and technical resources available (existing, under development, potential, etc.), which could be mobilised to deal with these "problems". This approach does not result in the formulation of "turnkey" solutions.

The ESCo has not aimed to produce an exhaustive catalogue of the pest control methods available and effective for each type of crop and under all regional conditions. It has placed itself at a more global level, trying to adopt a more general approach to the technical aspects of pest control regarding the questions raised by reduced pesticide use.

Nor has the ESCo tried to propose a critical evaluation of operations currently under way¹ and aimed at reducing pollution by pesticides, or to draw up alternative policies to manage the pesticide problem. Nevertheless, by combining the data available on the conditions of application and efficacy of a certain number of generic measures, this expert report can provide analytical tools concerning the actions under way, envisaged or conceivable in France.

. The status of the executive summary

The present synthetic document deals with the principal aspects of the expert report with the aim of applying the knowledge which motivated the commissioning of this ESCo, and it makes reference to current government efforts in favour of reducing the risks linked to pesticide use.

This document may go further than the report itself with respect to interpreting its scientific conclusions and their links with elements in the economic or political context, which are not the subject of research and were not taken into account in the scientific analysis.

In the commissioning letter sent to ESCo, the questions asked by the sponsors were organised according to the classic stages of an action-oriented approach: diagnosis, possible actions and the means to be implemented. These three headings are used in this executive summary.

1. Operations which are the subject of specific evaluations: for example, the monitoring systems on water contamination, the action of regional "plant health" groups and the question of the TGAP (General Tax on Pollutant Activities) were recently the subject of an expert review by the IGE (Inspectorate General for the Environment).

1. Rationale behind intensive farming systems and emerging changes

1.1. Rationale behind intensive farming systems

Before the advent of pesticides, cropping systems were designed to ensure the best compromise between plant health risks and the potential yield of the crop. Gradually, the acquisition of knowledge on crop needs for mineral elements and the mastery of fertilisation, the development after the Second World War of herbicides which could eliminate competition from weeds, and insecticides which protected crops from insect damage, and then, after 1970, development of the first synthetic fungicides to protect growing plants against diseases, profoundly modified cropping systems.

Because they now had the means available to act directly on the principal pests threatening their crops, farmers started to dissociate in their choice of crop management sequence or cultivation system those elements which contributed to achieving the highest yields and those which preserved this potential. This logic led them to adopt farming practices as a function of a yield goal, even though they increased the plant health risk, and then "treating the symptoms" when they appeared.

Pesticides, which were effective, relatively inexpensive and easy to use, contributed to the development of intensive production systems, which also benefited from favourable market conditions and farm prices, and to an under-evaluation of the environmental consequences which need to be managed today.

1.2. Emerging changes

. Increasing concerns about the impacts of pesticides on human health and the environment

Carcinogenic, neurotoxic or endocrine effects of pesticides have been demonstrated in animals. The question of risks to man (consumers, non-farming rural inhabitants exposed to pesticides, those applying pesticides and their families) is thus raised. It has been the subject of considerable controversy, but constitutes a major priority in most Health-Environment reports and plans, which require epidemiological studies in this respect. A scientific expert report has been commissioned on the subject from INSERM (the French Institute of Health and Medical Research).

Furthermore, pesticides are incriminated in the deterioration of the ecological status of surface waters and coastal waters, in reducing the terrestrial biodiversity observed in farming regions and "natural" contaminated environments and, for example, regarding the excessive mortality of bees and reduced hive productivity.

The concerns of the French population² have been expressed in opinion surveys on the perception of risks and safety³. The question of pesticides forms part of broader worries about the environmental impact of farming activities (nitrates, damage and pollution generated by indoor farming, etc.) or the risks related to the use of certain techniques (animal flour, GMOs, etc.).

Acknowledgement of the Precautionary Principle, which now forms part of the French Environmental Charter, provides a conceptual and legal framework for government action on these risks. Indeed, whatever the true risks involved, pesticides may be the source of crises in consumer confidence.

. More stringent European regulatory and legal measures

For more than 20 years, the European Union has gradually been adopting regulations aimed at protecting consumer health and preserving the environment, by laying down standards for contamination (drinking water quality, residues in food products), procedures to authorise the use of potentially dangerous substances and, more recently, obligations concerning the ecological status of different environments.

The main regulations currently in force include:

- Directive EC 80-778 relative to the quality of drinking water, fixing 0.1 µg/l as the limit content for each pesticide and 0.5 µg/l for all pesticide substances in drinking water; if these thresholds are exceeded, the authorities are obliged to intervene (reducing the sources of pollution or improving water treatment processes).
- Directive 91/414/CEE relative to the marketing authorisations for crop protection products. First applied in 1993, this Directive strengthened the toxicological and ecotoxicological evaluation criteria applied in the approval of new compounds, and scheduled the reappraisal of existing products.

² Indeed, this situation was the reason for a "response" from the crop protection product industry, which took the form of information campaigns in the general press and special dossiers in the professional press (e.g. "Crop protection products: restoring the image" in the July-August 2004 edition of *Agrodistribution*)

³ An example is the 2004 Baromètre issued by the Institute for Radioprotection and Nuclear Safety (IRSN) (*Institut de Radioprotection et de Sécurité Nucléaire*): 63% of those questioned classified pesticides as being the source of situations with a high or very high risk; only 12% considered that they were being "told the truth" about pesticides, and 14% trusted the authorities.

- The Water Framework Directive (2000/60/CE): adopted in 2000, the WFD obliges Member States to achieve a "good status" in terms of the chemical and ecological status of all surface waters, and a "good chemical status" for all groundwaters, by 2015.

These dispositions should soon be supplemented. In 2002, the European Commission adopted the Communication entitled "Towards a Thematic Strategy on the Sustainable Use of Pesticides" (COM(2002)349), a document which analysed the situation at the time and proposed measures which could be implemented in the context of this Strategy. In 2005, these proposals have been the subject of a public consultation of all relevant parties, and a draft Framework Directive on Pesticides (DCP) is scheduled to be presented in 2006.

Several European countries have already initiated detailed programmes concerning reductions in the use of pesticides (as early as 1986 in Denmark and Sweden, in 1991 in the Netherlands and in 1998 in Norway, etc.), even though not all of them have produced the desired results (for instance in the Netherlands).

. The question of the viability of pesticide-dependent systems

Questions are also being asked about the agronomic sustainability of "intensive" farming systems, which are confronted by a reduction in the number of pesticide active substances (AS) which are available and effective. This reduction has resulted in:

- the development of pesticide resistance among targeted pests,
- the non-approval of a certain number of older compounds (containing AS which pose (eco)toxicological risks that are deemed too great, or are already present in water, or dossiers which were not re-submitted by companies which estimated that the potential market for the product did not justify the expense). The number of active substances authorised in Europe thus fell from 800 in 1990 to 489 in 2004; in the short term (by 2010), this number will probably decrease further to between 350 and 400 AS,
- growth in the cost of the development and approval of new products, which generates a slowing in the Marketing Authorisations (MA) granted, notably for minor crops.

Weakening of these systems also generates economic problems affecting crops which are both major consumers of pesticides, sensitive with respect to consumers (fresh foods with a "healthy" image, products with a quality label) and subject to crises concerning overproduction and/or strong competition. Fresh fruits and wine are thus exposed to the risks of "health crises", or the loss of export markets to countries where consumers are more sensitive to the environmental conditions of production.

1.3. The French answers

. Legal and regulatory measures

Changes to regulations are linked to the transposition of European Directives into French law (e.g. Law on water and aquatic environments, etc.).

As for reductions in pesticide pollution, emphasis has until now been placed on: the storage and handling conditions of products, the organisation of systems for the collection and disposal of empty crop protection product packaging and containers (EVPP) and unused crop protection products (PPNU) and (currently under preparation) the management of tank residues (to be diluted and spread on the treated field). The Ministry of Agriculture is also trying to develop regulations concerning the mixing of different pesticides in one application.

. Voluntary actions

In addition, public authorities are setting up or backing actions based on voluntary participation, which farmers defend as being the best means of developing more environmentally-friendly farming practices. The actions of the authorities therefore consist in endorsing the development of "alternative techniques", or supplying financial incentives for their adoption.

As an example, reference may be made to the creation of regional "crop protection products" groups, responsible for diagnosing high-risk zones within the region, managing actions to reduce pesticide pollution in pilot watersheds (222 throughout France), Agri-Environmental Measures (AEM) and the french approach of "agriculture raisonnée" (see: Box 5).

. The Interministerial Plan to reduce pesticide-related risks

This plan, which prefigures the French plans which will be required of Member States by the future Framework Directive on Pesticides, should be rendered public at the end of 2005⁴. It summarises and lists, in some fifty "actions", the measures taken or planned at the regulatory or legislative levels (in the context of future Law on water and aquatic environments and the Agriculture Orientation Law) and lays down guidelines concerning the actions which should be pursued and/or developed (e.g. actions by regional "crop protection products" groups).

4. A draft version of this Plan (dated 17/11/2004) was circulated for discussion in early 2005.

1.4. Current challenges and the future calendar

. Implementation of the Water Framework Directive (WFD)

The WFD is being introduced in stages, which in 2005 include an inventory of water bodies and evaluation of their quality. This first phase has revealed that a high percentage of French water bodies may not attain the "good state" targeted, because of their contamination by pesticides. The Directive provides that Member States must, by 2010, have submitted their national plan concerning the measures to be implemented to achieve this good state.

. Changes to the Common Agricultural Policy

The reform adopted in 2003 introduced the notion of cross-compliance, as part of the first pillar of the CAP (making direct aids dependent upon compliance with prevailing Directives and with Good Farming and Environmental Practices); a gradual strengthening of these general environmental requirements is planned. A new equilibrium in favour of the second pillar has also been announced; preparation of the new Rural Development Plan (2007-2012) will be initiated in the near future.

More rapid and abrupt changes should not be excluded either: some Member States are disputing the important share of the CAP in the European Union budget and the distribution of aids among the member states, which suggests that maintaining the CAP until 2013 in the form negotiated by France in 2002 may be called into question in the very near future. The CAP is also under attack because of its internal support system and export refunds in the context of World Trade Organisation (WTO) negotiations, which may lead to changes in the aids granted to farmers and the prices and markets for some agricultural products.

. Implementation of the European Strategy for the sustainable use of pesticides and of the French "Pesticides Plan"

Although draft European Commission directives and regulations, and the final content of the French plan are not yet known, some points appear to have been determined: the implementation of monitoring and control systems on pesticide sales, the development of indicators to evaluate the policies retained, etc.

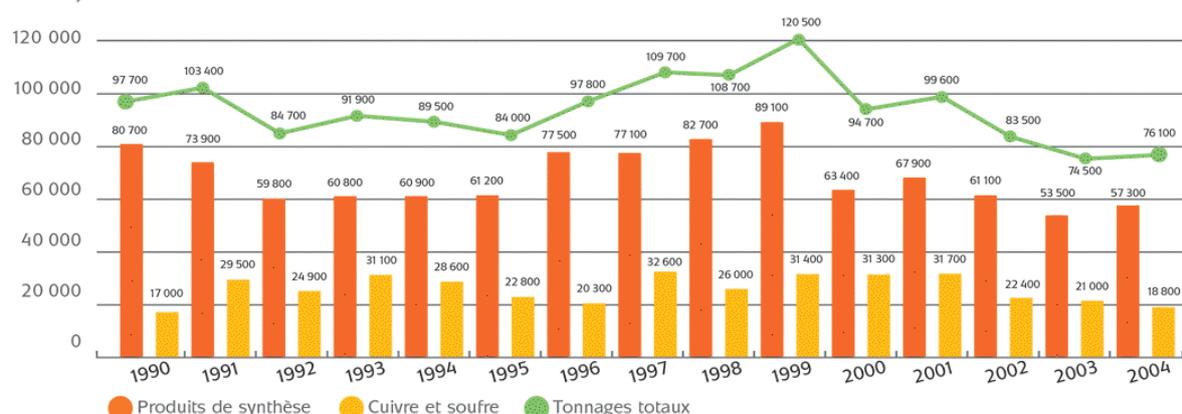
►► The risks associated with widespread pesticide use have been an issue for 20 years now. The measures taken in France until now have mainly concerned the health of users and reductions in occasional pollution caused by poor practices. They still pay very little attention to diffuse pollution and the high levels of pesticide consumption. Reductions in the use of crop protection products are nonetheless emphasised at present in Health-Environment policies, which have been requested by consumer and environmental protection organisations... and implemented in a few, rare, EU countries.

Pesticide use

France ranks third in the world for pesticide consumption and is the leading user in Europe, with a total volume of 76,100 tonnes of active substances sold in 2004. Fungicides account for 50% of this volume, herbicides for 34%, insecticides for 3% and other products for 14%.

Before 1993, when Directive 91/414/CE was first implemented, 800 active ingredients (AI) of plant, mineral or synthetic origin could be used as pesticides in Europe. The review of AI and the obligation to register them on a positive European list has since led to the gradual withdrawal of many products. In 2005, 489 AI, belonging to around 150 different chemical families, continue to be available. They can be broken down according to use into 165 fungicides, 139 herbicides, 95 insecticides, 11 nematocides and 79 other products. These AI are formulated and marketed in the form of commercial preparations or products: approximately 6000 are registered, but only around 2500 are actually sold.

An analysis of consumption data, estimated on the basis of sales figures from the major crop protection product companies, provides an initial understanding of how pesticides are used, and how practices are changing.



Changes to the tonnages of pesticide active ingredients sold in France between 1990 and 2004

(Source: UIPP, "Les chiffres clés" 2004)

Year	1999	2000	2001	2002	2003	2004	Change 2001/2004
Herbicides	42 462	30 845	32 121	28 780	24 510	26 102	-19%
Fungicides including copper and sulphur	63 021	52 834	54 130	44 444	39 317	37 174	-31%
Insecticides	3 612	3 103	2 488	2 316	2 223	2 469	-1%
Other	11 407	7 911	10 896	8 009	8 480	10 360	-5%
Total (excl. Cu and S)	88 874	63 333	67 943	61 167	53 557	57 350	-16%
Total	120 502	94 693	99 635	83 549	74 530	76 105	-24%

Tonnes of pesticide active ingredients sold in France between 1999 and 2004 by major product type. (Source: UIPP)

After slow, sustained growth during the second half of the 1990s, the global quantity of pesticide active ingredients sold started to decline as from 2001, falling from 99,600 tonnes in 2001 to 76,100 tonnes in 2004, or an overall reduction of 24% in the total quantity of pesticides (-16% excluding copper and sulphur). This reduction in consumption mainly concerned fungicides (31%) and herbicides (19%).

At first sight, this trend is encouraging, but must be related in part to:

- the introduction of new compounds which are used at very low doses per hectare, and the prohibition of or limitations on the use of pesticide active ingredients with a high recommended application rate,
- the marked reduction in the use of sulphur and copper products (of around 40%) which, because of their large share in total consumption (nearly 30%), explains a large proportion of the reduction observed.

It is therefore not possible to make a direct link between this downturn in consumption and changes in farming practices to resolutely target a reduction in the use of plant protection products by farmers. For example, the tonnages sold in 2002 were comparable to those seen in the mid 1990s.

Diagnosis

The first stage in this expert report consisted in making an inventory of the knowledge available on the current situation (i.e. the use of pesticides, their effects and the determining factors for their use).

2. Pesticide use is high but poorly described

2.1. Levels of and changes to national consumption

. Global consumption (aggregated data)

The figures available are the annual sales declared by the major pesticide companies and published by the UIPP (French Crop Protection Products Manufacturers Association) in France.

These very global data evidence the extremely high consumption of pesticides in France (90% of them used by farmers). France ranks third worldwide for its tonnage consumption, and is the leading European consumer (with 34% of the total amount in 2001). It still ranks fourth in Europe when consumption is related to the number of hectares cultivated (not including permanent grasslands) with 5.4 kg/ha, behind Portugal, the Netherlands and Belgium.

Reference is frequently made to a downward trend between 1999 and 2003, but this reduction observed in the tonnages sold should be interpreted with caution: 1999 corresponded to record sales (purchased before implementation of the General Tax on Polluting Activities (Taxe Généralisée sur les Activités Polluantes, TGAP in 2000); the development of AI used at very low doses per hectare reduced tonnages, and parasite pressure varied from one year to another (2003 drought), etc. In fact, the tonnages sold increased slightly in 2004.

. Highest consuming crops

A small number of crops (small grain cereals, maize, rapeseed and grapevines), which occupy less than 40% of the utilized agricultural area (UAA) in France, account for nearly 80% of the pesticides sold in the country each year.

Crop	% utilized agricultural area (UAA)	% total pesticide consumption	Comments
Small grain cereals	24%	40%	60% fungicides 35% herbicides
Maize	7%	10%	75% herbicides
Rapeseed	4%	9%	
Vines	3%	20%	80% fungicides
Total	38%	79%	

Land use and pesticide consumption for specific crops

(2000 data. Sources: SCEES, UIPP)

► The quantities of pesticides sold or used do not constitute a sufficient indicator to characterise pesticide consumption and the changes which affect this consumption.

2.2. Crop protection practices

The crop protection practices implemented by farmers are still very poorly known. Very few accessible data exist; those collected by economic actors (surveys conducted by cooperatives, etc.) are not openly available. The only "available" data (which are little-exploited) concerning a range of crops are the "Cultivation practices" surveys carried out by the SCEES (the French Ministry of Agriculture survey and statistics department) in 1994 (for 10 crops) and in 2001 (12 crops), covering 9,000 and 21,000 fields, respectively. As for fruit production, five-year "orchard" surveys have collected some data on crop protection (data from the 2002 survey have not yet been published).

Very little information is available (quantities, technical efficacy, economic results, etc.) concerning pesticide-saving practices.

. Annual crops

According to the SCEES 2001 survey, the average numbers of treatments were 6.6 for wheat, 3.7 for maize and 6.7 for rapeseed, despite particularly favourable climatic conditions and weak parasite pressure.

Winter Wheat: current production conditions in France

Based on data from the 2001 SCEES survey on "Cultivation practices"⁵

. A strategy which targets high production

In 2001, most wheat was planted after ploughing or deep tillage (17% of land was planted without tillage in 2001, as opposed to a little less than 12% in 1994). This crop received an average of 175 units of nitrogen in 3 inputs, and 6.6 crop protection treatments⁶ (including 2.3 of herbicides); 16% of this land received more than 6 crop protection treatments (excluding herbicides). The average yield in 2001 was 70 q/ha.

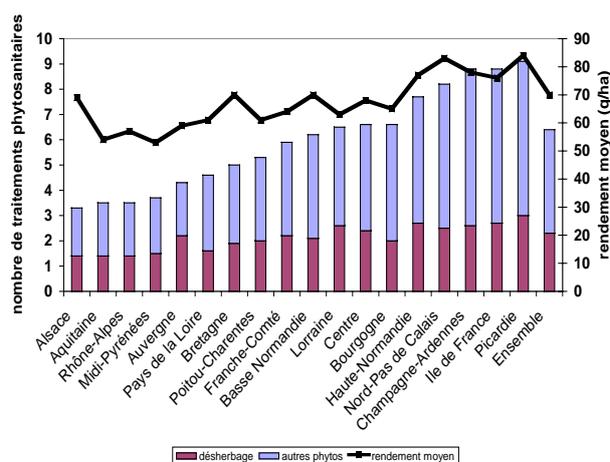
These 2001 data demonstrated an average increase of more than 3 treatments compared with 1994, due to at least one additional herbicide application (to a considerable extent explained by the mild winter and favourable rainfall at weed emergence) and with fungicides. Mixtures of products were used much more frequently, but this was combined with a reduction in the doses per hectare treated with numerous active ingredients (which could be applied at doses much lower than the recommended doses).

Regarding the practices implemented by farmers, the survey also revealed a preponderance of an "intensive production strategy", strongly dependent on pesticide use.

Future strategy concerning the management of winter wheat, based on surface area (Agreste 1996)		
Search for maximum yield	Search for high yield, by integrating techniques to limit costs	Search for a reduction in all expenses, even if yield is reduced
8.5% <i>(5.5 to 16.4%)</i>	84.8% <i>(78 to 92.3%)</i>	6.7% <i>(2.2 to 11.1%)</i>

The figures in heavy type indicate the mean of all regions taken together; the range in italics indicates the amplitude of regional means.

. Correlation between yield and the number of treatments



The SCEES survey in 2001 revealed considerable regional variations in practices concerning wheat, with an average number of treatments ranging from 3.4 in Alsace to 9 in Picardy. The graph demonstrates a link between the level of intensification and potential: regions with a high potential (Champagne-Ardenne, Picardy, Ile de France, etc.) were also those with the highest average number of treatments.

Major variations were also observed within each region.

. Previous crops: a proven simplification of rotations

Comparison of the 1994 and 2001 data illustrated a marked trend towards simplifying crop rotations: a very marked increase in wheat after rapeseed (25% of land planted with wheat in 2001, or +108%) and wheat after small grain cereals (19%; +48%), with a parallel reduction in wheat after "other" crops (-41%). The five crops (small grain cereals, grain and forage maize, rapeseed, sunflower) which accounted for 56% of crops preceding wheat in 1994, represented 74% in 2001.

. Decisions to apply pesticides

The SCEES survey included a question about the reasons for the choice of applying pesticides ("habit", "technical recommendations" or "observations", the answers being non-exclusive). In 1994 (data not published for 2001), farmers stated that in between a quarter and a third of situations, their treatment choices were a matter of "habit", indicative of few changes to their practices (a situation which could be assimilated to a systematic treatment programme). These treatment "habits" varied markedly as a function of crop and region, although these disparities did not necessarily result in practice in the use of different treatments.

5. 4195 fields surveyed corresponding to an extrapolated surface area of 4.3 Mha spread throughout 21 administrative regions. 2001 was a "quiet" year for parasites, but cereal yields were affected by damp climatic conditions, little conducive to implantation.

6. One treatment meant the use of a crop protection product (containing one or more active ingredients), applied during one passage.

The only published national analysis of SCEES surveys concerns wheat and maize crops, and demonstrates a trend towards a reduction in the dose/hectare for each product, but also an increase in the number of treatments per crop, between 1994 and 2001.

The 2001 survey revealed marked disparities between regions, which varied as a function of the crops considered. In wheat, at least (a crop where the average number of treatments ranged from 3.4 in Alsace to 9 in Picardy), a clear correlation was observed between the number of treatments and yield. A more detailed analysis is necessary to understand this variability in protection practices between crops; in particular, a link needs to be established between crop protection practices on the one hand and soil and climate conditions and all crop management sequences on the other.

. Perennial crops

Apple orchards, which are the most prevalent orchards in France, are also the most frequently treated: in 1997, they received an average of 17.6 fungicide treatments and 10.5 insecticide/acaricide treatments each year. Some regional averages were markedly higher with, for example, 24 fungicide applications in Limousin, and 9 to 13 insecticide treatments against codling moth alone in Provence-Alpes-Côte-d'Azur (PACA).

Vines (3.7% of the UAA, 20% of national pesticide consumption and 30% of fungicides) undergo some twenty treatments each year, most of them being fungicide treatments.

2.3. The importance of prescription

Prescription is central to the decisions taken by farmers with respect to pesticide use, and much more important than for other elements in a crop management sequence (tillage, fertilisation, choice of variety, etc.). Prescription is usually laid down by specialists, who thus make independent diagnoses concerning weed control and treatments against diseases or pests. The decision-making tools available (see below) are used to specify the need for a treatment or not, or a date for treatment, but are not designed to create a situation which will prevent certain risks and thus avoid the need for treatments.

Increasingly, advice concerning crop protection is promulgated by sales representatives acting for the cooperatives which sell pesticides, who are therefore interested in both selling more inputs (seeds, fertilisers, pesticides, etc.) and collecting a maximum crop yield, i.e. in maintaining intensive farming systems.

2.4. The question of indicators on the intensity of pesticide use

This question of indicators is recurrent: all discussions on policies to regulate pesticide use refer to the need for indicators to determine guidelines and then monitor their effects. Thus action 27 of the French Pesticides Plan proposes "fixing a target for improved practices, using indicators and based on references concerning good crop protection practices, as well as an in-depth analysis of existing practices".

It is necessary to make a distinction between pesticide consumption indicators and impact indicators, which will be discussed below (see: 3.4.).

. Global indicators

Neither the number of crop protection treatments, nor the quantities of pesticide commercialised or used, constitute reliable indicators to characterise pesticide use and its evolution.

The example of the Netherlands confirms the limitations to this criterion: this country had adopted a programme aimed at achieving a 50% reduction in the tonnages consumed; this goal was attained, but it was subsequently shown that this had mainly been due to the elimination of soil disinfectants used at high doses per hectare.

Similarly, Denmark (see Box 14) adopted a TFI (Treatment Frequency Index) as an indicator to monitor the effects of its policies: the number of approved doses applied on average to the entire UAA in the country, all pesticides taken together. The TFI offers an initial approach to the intensity of pesticide use, as it includes the dose used in its calculation. However, the "environmental profile" of the product is not taken into account (behaviour of compounds in the environment, ecotoxicity).

. Crop protection practice indicators

Today, knowledge of the agricultural practices is limited at best to a statistical analysis of the number of treatments, which clearly does not enable an understanding of the logical thinking adopted, nor identification of the principal management methods used at the level of a cropping system and region. If we are to be able to change crop protection practices, it will be necessary to analyse crop management sequences at the level of the cropping system, and no system currently allows this.

One option could be explored: analysis of the management records⁷ which have been rendered compulsory concerning numerous aspects of farming, and which until now have been little exploited by farmers themselves or their advisors in order to understand and measure changes in their practices.

The recognised need for a clearer understanding of practices is now resulting in discussions on the design of systems such as "observatories of farming practices and production systems"; such projects have been the subject of calls for tender under the ADAR and ADD (Federative inter-agency programme on Agriculture and Sustainable Development, which is managed by INRA).

►► The first obstacle to understanding pesticide use is the weakness of the data available. For example, spatial data necessary to establish a link between pesticide use and environmental contamination, or to identify major sources of pollution, do not exist or are not available. This situation should change because implementation of the European Thematic Strategy allows for the introduction of regulations relative to data collection (defined by Eurostat).

The second obstacle is the lack of simple indicators on pesticide use and changes to pesticide use. The choice of an indicator is closely dependent on its objective (monitoring of the effects of policies, characterisation of use, estimation of impacts, etc.). The closer this goal is to environmental performance (impact), the more important is it that the indicator chosen should include variables on the characteristics of the products used and the environments receiving them. It will thus become less operationally relevant and more complicated to use, which is contrary to the optimum nature of indicators. On the other hand, if an indicator is too simple (e.g. number of treatments per hectare), it requires other descriptors in order to limit erroneous interpretation. Efforts must be made to propose a list of indicators which specifies their relevance as a function of their targeted use and their method of use (including conditions for interpretation).

3. Environmental contamination and ecosystem damage: proven but unequally quantified

In the early 1990s, and particularly because of the impetus given by the integration into French law of Directive EC 80-778 relative to drinking water, surveillance systems on water quality were set up, and numerous scientific and technical studies were initiated to better describe and understand the transfer of pesticides in the environment as well as (to a lesser extent) their impact on organisms not targeted by their use. Scientific references and contamination data are therefore much more numerous with respect to water than on other environmental compartments.

3.1. Environmental contamination

"Contamination" is defined as the abnormal presence of substances or micro-organisms in an environmental compartment. For all synthetic pesticides, reference can therefore be made formally to contamination, including of the soil, even if the presence of pesticides is expected and voluntary (which is not the case, for example, regarding aquatic environments). "Pollution" specifies the presence of substances at levels above that allowed for drinking water in the EU.

. Contamination of surface and ground waters

Inland water bodies are the environments on which the data are the most numerous, and they are the subject of an annual compilation by the IFEN (French Institute of Environment). These data demonstrate the widespread contamination of surface and ground waters by pesticides, and a preponderance of herbicides amongst the most frequently detected compounds (at least at the scale of "water bodies" in the sense employed by the WFD).

Significant contamination can be generated by very low pesticide losses: a leakage of less than 1/1000th of the total herbicide applied to a field may suffice to contaminate the water flowing from that field to a level above that of potability.

However, the data collected do not enable an unbiased quantification of the levels of contamination, or calculation of the exposure of organisms. Indeed, they are:

- highly heterogeneous and difficult to compare, because they are generated by different monitoring networks (with differing objectives: monitoring of drinking water, monitoring of watersheds, etc.), using different analytical methods and different lists of the compounds to be detected,
- not representative, because sampling is infrequent and, in particular, does not enable the detection of pollution peaks,

⁷ In 2001 (SCEES survey on wheat), an average of 85% of farmers stated that they recorded their crop protection practices (95% in field crop regions)

- very incomplete, because the compounds monitored are mainly parent compounds applied at high doses (metabolites or compounds employed at low doses are generally not screened systematically), and because possible interactions between the different substances are not taken into account,
- little suited to ecotoxicological studies, as the presence of a substance is not necessarily indicative of its bioavailability.

As for coastal waters and transition zones, knowledge of contamination is extremely fragmentary or even inexistent for substances other than certain organochlorine pesticides, even though these environments must be taken into account when implementing the WFD.

. Air contamination

Studies by various research groups have been carried out in France since the end of the 1980s, and are still ongoing. Surveillance networks on air quality have started to take measurements, but the data remain fragmentary (occasional monitoring campaigns at different times and in different regions), and the list of compounds monitored is limited.

These early data have provided observations of the presence of pesticides in all phases of the atmosphere, at concentrations which vary over time (sometimes as a function of the season, or linked with periods of application) and space (proximity of sources); even poorly volatile or prohibited substances have been detected.

The methodological problems are numerous: until now there have been no standards for sampling (currently being defined), and there have been problems concerning analytical methods (relatively low concentrations, partitioning between the gas and particle phases, etc.), the interpretation of observations (links with use, correlations with physicochemical characteristics, etc.). Note should be taken of the organisation of national working groups on the subject in recent years.

. Soil contamination

There is no system to characterise soil contamination by pesticides which is similar to the methods used to monitor water and air contamination. Chronic pollution by mineral substances (copper) and the existence of "related residues" (which cannot be extracted using analytical methods) raise the question of the long-term environmental risk, notably in the event of farm land being reallocated for other purposes.

This risk is illustrated by the case of chlordecone, which was used between 1972 and 1993 to control banana weevil in Guadeloupe and Martinique. It remains in the soil, and probably will remain there for several decades, polluting water and contaminating crops in some areas.

. Interpretation of data

The interpretation of contamination data requires identical reference values. For example, in aquatic environments, these are identical for all substances. It is mainly these which are retained for potability standards (generally, 0.1 µg/l for each substance, 0.5 µg/l for all substances), even though their toxicological and ecotoxicological properties often markedly differ. Comparison of these reference values with the Predicted No Effect Concentrations (PNEC) (some of which are still provisional), which were determined when pesticides were evaluated regarding their ecotoxicological risks in aquatic environments, shows that for nearly 20% of substances (31 out of 163, mainly insecticides and herbicides) the PNEC for aquatic environments are 0.1 µg/l or lower.

► It is important, or even essential, to obtain monitoring data on contamination: to estimate the exposure of human populations (air, drinking water) so that a post-marketing system can be implemented for pesticides; to ensure surveillance of the status of water bodies in compliance with the undertakings of the WFD, etc. However, current systems (at an early stage with respect to air, heterogeneous regarding water) do not enable collection of the necessary data⁸.

Furthermore, because the soil is a key compartment (source and sink) regarding other environmental compartments, information on pesticide load in the soil and their evolution is essential.

3.2. Fate and dispersion in the environment

. Compartmental distribution in treated fields

Few references are available concerning losses at application, but it is known that the percentages of AS which do not attain their target (in most cases, plant organs) may be very considerable, depending on the mode of action of the pesticide and the developmental stage of the canopy. For example, when spraying on foliage, these percentages may reach 10% to 70% in the soil and 30% to 50% in the air. During soil fumigation, 20% to 30% may be lost in the air, depending on correct or incorrect compliance with the rules of application.

⁸ Reference should be made to the creation of the Observatory on Pesticide Residues (ORP) (*Observatoire des Résidues de Pesticides*), whose long term missions will be to assemble for exploitation all information and results on pesticide residues in different environments and products consumed by man, to estimate the levels of exposure of populations and identify actions which could improve information systems, notably the type and format of the data collected.

Foliage runoff onto the soil may then concern a small proportion of the pesticide applied to the canopy. Volatilisation following applications to the soil or plants accounts for a few tenths to a few dozen percent of the dose applied, depending on the compound, the soil climate conditions and cultivation practices.

. Atmospheric dispersion

Numerous experimental studies have considered the atmospheric transfers which occur during spray application, referred to as *drift*. The factors involved have been identified (weather conditions, methods of application, e.g. height of sprayer), and this transfer route has been the subject of estimates in product approval procedures. However, because some ambiguity remains as to the actual definition of drift (it is defined as either the difference between the quantity leaving the nozzles and that attaining its target, or as the quantities deposited close to the field), it is difficult to compare their results (because of the use of different sensors) and little knowledge has been acquired on the evaporation of spray droplets. Models of varying complexity have been developed. Specific studies (including the use of modelling) have been developed for certain application methods (for example, spraying by helicopter: see AFSSE expert report) or on the possible dispersion of dust from seed coatings or granules.

In the context of the post-application period, only relatively recently has attention been paid to the dispersion and short-range deposition of gaseous compounds arising from volatilisation, and little information is available at present on this transfer route for pesticides. Models do exist, but few datasets are available to validate them. At a larger scale, the long range transport of pesticides has recently been demonstrated by their detection at sites far distant from any use (mountains, lakes, etc.). However, it is currently difficult to estimate the potential for pesticide transport due to a lack of knowledge on sinks (atmospheric degradation, dry deposition, wet deposition) and gas/particle partitioning (which affects the degradation of compounds and their transportation potential). As for wind erosion from soils or plants, neither its degree nor the factors governing it are known precisely; some authors consider it to be a minor problem, while others think that it constitutes a significant dissipation pathway (and could even be more important than runoff).

. Retention and degradation in the soil

The processes underlying pesticide retention in the soil reduce their mobility and thus, at least temporarily, diminish their transfer to the air or to water. The retention of non-ionised compounds increases in line with the organic matter content in the soil. For other, polar or ionisable compounds, it is more difficult to predict the levels of retention. Nevertheless, it evolves over time and may become almost irreversible, resulting in the development of bound, non-extractible residues, concerning which neither the precise chemical nature nor the potential for subsequent release are known.

The degradation process is a major factor for pollution control in environmental compartments contaminated by pesticides, if it results in total mineralisation (because the metabolites arising from degradation may themselves be pollutant). It depends on the chemical stability of the compound and on both abiotic factors (temperature, moisture) and biological factors (microflora). Repeated treatments of land with the same pesticide may cause the selection of an adapted microflora which accelerates the degradation of that pesticide. The degradation rates of a given compound can vary considerably, and these variations are difficult to predict with accuracy.

Retention and degradation are not independent phenomena: retention conditions the availability of products for their degradation. In practice, it is the combination of retention and degradation which determines the mobility of different substances.

. Transport by runoff and percolation

Water contamination differs as a function of the type of drainage: it is at a maximum in terms of pesticide concentrations with runoff, average for artificial drainage systems, weak to average for lixiviation. Most pesticide losses during runoff or erosion take the form of a solution, particle transport only being important for the most significantly retained pesticides (those which are hydrophobic or little soluble in water). In most cases, a reduction in erosion will have little effect on pesticide losses, so it is important to seek to reduce runoff flow rates.

The maximum risk of surface water contamination corresponds to heavy showers occurring shortly after an application or arrival of the product on the soil, i.e. when the availability of the substance is at its peak in the soil and the surface state of the soil may be degraded: losses during such events may constitute the largest proportion of annual contamination.

As for the contamination of underground water bodies, the risk is mainly linked to rainfall levels, the thickness of the unsaturated zone, interactions between water tables and rivers and the type and rate of flow through the soil and subsoil.

However, the transport in water of some substances may be observed several years after their application, which undoubtedly illustrates the significant risk of a remobilisation of residues strongly retained in the soil matrix. For example, this is the case of chlordecone in the volcanic ash soils of Guadeloupe.

. Hydrological transfers exiting the fields

Water circulation pathways and the transported pesticide quantities between farmed fields and watersheds are diverse, and vary considerably from one water system to another. The contamination of surface water is not solely

due to runoff, and the contamination of shallow or deep groundwaters is not only a result of percolation. Exchanges exist between these different transfer routes.

The dynamics of surface water contamination at the scale of a watershed can quite easily be linked to farming practices, on condition that the latter are clearly identified. However, they sometimes exhibit major temporal variations, and peaks of pollution, which raises the problem of their surveillance. The dynamics of groundwater contamination remain very poorly understood; the mechanisms and response times to a change in pollutant pressure have not been clearly identified.

. Problems encountered in establishing links between different mechanisms, and the current limitations to modelling

Considerable study has been made of the mechanisms of transfer to aquatic environments, but research has often been restricted to the field scale or specific type of environments, or has been focused on a specific process. Thus the principal mechanisms are known, as well as their determining factors, but their expression and relative importance are strongly dependent on environmental conditions, which are often difficult to formalise, particularly when it comes to the biological aspects of degradation. Furthermore, establishing links between all these processes for several compounds and at a scale larger than a field, has proved difficult. These aspects have only been quantified for a set of watersheds, well-equipped with monitoring systems.

Detailed models which describe the global dynamics of pesticides are available, and some of them are frequently used to evaluate risk in the context of product approvals. However, they are often limited to describing processes in the unsaturated areas of soil, and very few datasets are available to calibrate and validate these models. The question of the validation (scientific, through use, etc.) of these models is indeed the subject of much debate.

▶ Although considerable progress has been achieved in recent years concerning models of pesticide transfer, the predictions of these models for long-term evolutions in contamination at larger scales are still limited by considerable uncertainty.

Furthermore, very few data are available to deal with the controversial question of the relative importance of occasional pollution (farmyards, management of spray tank residues, etc.) and diffuse pollution (agronomic applications), whether in terms of environmental contamination or impact.

▶▶ The mechanisms which determine the availability of pesticides in the soil and their transfer to water systems are globally well understood, but it remains difficult to quantify them, both because of our limited knowledge in this area and because of the marked spatial and temporal variations in the reactional sites responsible for retention, the expression of degradation functions and the conditions governing transfer. Consequently, classifying the importance of different mechanisms in a given situation will inevitably be inaccurate, as will any evaluation of the efficacy of corrective solutions proposed following a diagnosis based on this knowledge. Nevertheless, these limitations to diagnoses (performed notably in the context of actions by regional "Crop protection products" groups) do not call into question the overall usefulness of implementing them: they remain essential if we are to propose appropriate techniques.

3.3. Impacts on ecosystems

. Effects on organisms and ecosystems

Gradual removal from the market of the most toxic compounds has eliminated massive mortality rates among non-target organisms. The direct effects which remain are less visible, usually non-lethal and more difficult to detect, but they can weaken populations (lower reproductive performance, increased vulnerability to predation, etc.). Thus pesticide effects may become apparent long after exposure. The direct effects of pesticides may also give rise to indirect effects which are more difficult to detect but may often have major consequences. Modifications to the availability of resources (trophic or other) and competitive relationships are the principal mechanisms generating the occurrence and propagation of these side effects.

The principles underlying the effects on organisms are known, but the effects themselves are difficult to demonstrate in the field, because of their non-specificity and the existence of mechanisms which regulate populations at different spatial and temporal scales (for example, in birds and mammals, it is very difficult to determine population and community numbers, because of the size of the regions they inhabit and their generation time).

. Monitoring of impacts

It is extremely difficult to quantify the true impacts of pesticides and analyse their evolution.

Monitoring networks for the impacts of pesticides on organisms exist, but they are fragmentary and highly specific: they mainly concern wild vertebrates and, to a lesser extent, domestic bees; the probability that an incident will be detected by these surveillance networks has not been determined but is unquestionably small. In many cases, the impacts observed cannot be attributed to a particular pollutant because of the numerous substances present in the environment and the synergistic effects of different pollutants.

Using a physicochemical approach to evaluate environmental quality has numerous limitations, notably because of the occasional nature of the analyses (in both space and time), the efficiency of the analytical methods employed, a lack of data on the bioavailability of the substances detected and uncertainties regarding the causes and extent of intra- and inter-specific variations in the susceptibility of different organisms.

Several complementary biological strategies can be deployed to evaluate the effects of pesticides in natural environments: the measurement of biomarkers, analyses on sentinel species, detection of bioindicators. Despite the very large number of scientific studies performed on biomarkers, these tools are still little employed for routine environmental biosurveillance. Furthermore, the numerous bioindicator tools developed to evaluate environmental quality (notably aquatic), some of which are used routinely, were not designed to demonstrate the specific impacts of pesticides.

3.4. Integrative approaches

. Relationships between pesticide use, contamination and impacts

With the exception of certain watersheds monitored by regional "pesticide" groups, data on farming practices around the points where contamination is measured are not collected or available. Water contamination measurements are rarely adapted to evaluations of exposure (unknown bioavailability, etc.). In the few studies that have been able to demonstrate a link between pesticide exposure and its effects on natural populations in an aquatic environment, the characterisation of exposure was generally insufficient to determine precisely the concentrations and durations of exposure which induced these biological effects.

► As things stand at present with respect to the studies carried out, it is almost impossible to demonstrate any links between crop protection practices, levels of environmental contamination and impacts on organisms and ecosystems. The best documented cases, where the precise role of pesticides has been demonstrated, mainly concern birdlife, and they required several years of large-scale study.

. Indicators and pesticides

Different indicators of fluxes impacts and risks have been developed in Europe to predict the contamination of different environmental compartments and its impact on various targets. However, at present, no objective data are available to determine whether the output data from these indicators are reliable. Even when the aim is to classify substances with reference to each other, there is no consensus as to the indicator or method to be implemented. These tools, which have often been designed with markedly different purposes in mind, all suffer from a lack of validation in field situations and are the subject of numerous criticisms.

One possibility for the future would be the use of deterministic models of transfer to develop robust indicators, as some pesticide transfer models have benefited from major validation programmes over the past twenty years.

►► Despite the strong and legitimate demand for the development of easily accessible contamination risk and impact indicators, it is necessary at present to remain circumspect as to the use of existing indicators as an aid to decision making. The implementation of true validation programmes concerning the different indicators available at present should nevertheless allow us to overcome this problem in the future. However, the usefulness of indicators as a tool to assist with communication, increase awareness and serve as a basis for discussion already seems unquestionable.

4. Poorly evaluated plant health risks which are enhanced by cultivation systems

4.1. Insufficient evaluation of plant health risks and the efficacy of pesticides

The aim of crop protection is not to restrict the size of pest populations but to reduce the crop losses (both quantitative and qualitative) they may cause. However, some confusion is observed between injuries affecting crops (identifiable by their symptoms), damage to harvests (measurable by quantitative and/or qualitative deterioration in the products harvested) and economic losses to the producer, even though the injury-damage-loss sequence is neither linear nor automatic.

Indeed, in many contexts, injuries do not result in damage nor, obviously, in an economic loss. However, in some cases, a minimal injury can give rise to massive losses. The successive transformations of injuries into damage and damage into loss are thus markedly dependent on the production situation (technical, biological, pedoclimatic, social, economic and cultural contexts).

Evaluating and implementing crop protection methods requires quantification of the damage that predictable injuries may cause if no protection is ensured and, naturally, quantification of the efficacy of the control methods applied to limit these injuries. Unfortunately, the references necessary concerning all crops and production situations in France are far from being available.

Knowledge does exist, and has generally been acquired by comparing treated and untreated situations in order to evaluate injuries, or even damage and, in some cases, by extension, the economic losses due to some of the principal pests affecting major crops. These studies have been performed on {1 pest – 1 crop} couples, under "intensive" cultivation systems which induce high plant health risks. These situations where pesticides were indeed proved necessary, led to an overestimation of the benefits linked to their use. The results cannot be extrapolated to situations or systems which are designed to express slower and less aggressive pest dynamics. Specific experiments are therefore necessary to make a clear distinction between injuries, damage and economic losses, and to evaluate them under conditions where they will not immediately be maximised by the cultivation conditions.

Pesticide treatments may also be used to ensure the health quality of foods. The frequently advanced argument of protection against mycotoxins, which indeed contaminate French cereal crops, needs to be kept in perspective. Control of the fungus by fungicides is very incomplete, and a limitation of risk factors would appear to constitute a more pertinent management method. Indeed, research has shown that the correlation between symptoms of Fusarium head blight and mycotoxins is weak (numerous strains are not toxinogenic, and toxinogenic strains do not automatically produce toxins). Another case, often referred to justify the treatment of seed, is that of ergot of rye (the toxins of which have a severe effect on the human nervous system) and also that of wheat; the few infestations observed in France during the 1960s were in fact linked to the poor control of weed grasses, which play an important role as a relay host in the development cycle of the pathogen.

► The data concerning crop losses (i) currently caused by plant pests and (ii) that plant pests could cause if present-day protection methods were not used, are clearly lacking. This results in considerable problems in evaluating the efficacy of current protection practices and, even more, of new practices.

4.2. Insufficiently differentiated control strategies

Preventive treatments, or those triggered by early symptoms, are common; these practices do not take account of the true risk to the crop concerned or to subsequent crops. Determining the types of risks or the dynamics for the development of pest damage would help farmers decide as to the protection strategy best suited to the type of risk.

. Crop protection strategies and the characterisation of risk

The notion of risk, when applied to plant protection, makes a simple classification of pests according to two criteria: the extent of damage (limited or severe) and the frequency of this damage (low or high). The four cases thus defined require different protection strategies.

Risk of:	Chronic epidemic	Occasional epidemic
Limited damage	Management strategy aimed at reducing recurrent damage and increasing system viability.	Cases which do not require a particular strategy if the damage is slight and infrequent.
Massive damage	Context where the immediate viability of the system is in question, where it is necessary to reconsider plant production as a whole.	Management strategy aimed at preventing the epidemics themselves.

Characterisation of the risk associated with the development of a pest population and crop protection strategies

. Control strategies and the biological cycles of pests

Methods for management of pest populations can be placed in two principal categories: those intended to reduce initial populations, x_0 (at the beginning of the plant cycle) and those designed to slow the apparent rate of population growth, r (during the plant cycle). The relative usefulness of these methods depends on the pest cycle (monocyclic or polycyclic) and its mode of infestation, which determines whether the population in year n depends to a major extent or not at all on that of year $n-1$ (see Box 4).

4.3. Cropping systems which increase plant health risks

. Health risk factors

A pest will develop more freely if it encounters continuously favourable conditions in the time and space it will occupy during its cycle.

Pests "take advantage" of the nutrients supplied by the crop (e.g. weeds), of dense and homogeneous crop stands (e.g. diseases) and of the disappearance of their natural, competing enemies (e.g. arthropods).

Control strategies and biological cycles of pests

The rate and amplitude of pest population development depend both on the initial populations (x_0), those present at the time of sowing and the pest multiplication rate (r) during the life of the crop. The availability of an efficient treatment product often means that these parameters are used to predict the dynamics of pests and that treatment is only applied when a "harmfulness threshold" is reached. Another approach consists in reducing, as far as possible both x_0 and r , preventively.

The control of initial pest populations (x_0) is particularly effective for population management when there is a high degree of polyetism (in polyetic epidemics, dynamics during a season are strongly dependent on those during the previous season, because of the residual population it generated) and when the dynamics are monocyclic (a single reproduction phase of organisms during a season). A limitation of x_0 will also have a marked, but lesser effect, when the dynamics are polycyclic, with a high level of polyetism.

This reduction in x_0 will be particularly effective against soil-borne diseases or weeds; it can be achieved by biofumigation or by burying crop residues in the first case, and by false seedbed in the second.

A reduction in the reproduction (r) of the pest population will be particularly effective when the degree of polyethism is low (whatever the seasonal dynamics, mono- or polycyclic), and moderately effective when the degree of polyethism is high, when the seasonal dynamics are polycyclic.

This reduction in r may result from a variety of actions: use of partially resistant varieties, restrictions on mineral inputs which render the plant population less vulnerable to infections, management of the plant population structure, etc. In fact, practically all cultivation practices are, to varying degrees, likely to affect the dynamics of pests.

It is of course possible to combine the measures aimed at reducing x_0 to levels which keep r at low values.

	Low polyetism	High polyetism
Monocyclic dynamics	actions on x_0 : 0 to + actions on r : +++ (e.g. slugs)	actions on x_0 : +++ actions on r : + (e.g. many weeds, nematodes, pathogens affecting above-ground organs, surviving in the soil)
Polycyclic dynamics	actions on x_0 : 0 actions on r : +++ (e.g. obligatory parasites of above-ground organs, such as wheat rust, apple codling moth)	actions on x_0 : + actions on r : ++ (e.g. cereal aphids, downy mildew of vineyard, take-all of wheat, apple scab)

Typology of pest dynamics (according to two levels of polyetism crossed with two types of dynamics during a plant cycle) and management methods.

Levels of control (0 to +++) of populations achieved by actions on x_0 and r , and examples of pests exhibiting these dynamics.

Examples:

- In the case of take-all of wheat, rotation with non-host crops which will reduce the quantities of inoculum in the soil will suffice to maintain the risk at a low level. In the case of wheat followed by wheat, any measure which can reduce this initial quantity of inoculum (management of inter-crop period and/or its efficiency (tillage) will have beneficial effects on the severity of disease.

- With respect to wheat leaf diseases such as rust, it is possible to reduce the multiplication and dispersion of inoculum to a significant extent by cultivating associations of cultivars with different resistances in the same field.

- In apple orchards, the elimination of leaves in the autumn (by removal or burial) can significantly reduce (up to 95%) emission of the ascospores which are responsible for initial scab infections the next year, and consequently the incidence and severity of the disease affecting foliage and fruits.

- Sexual confusion methods enable the effective protection of apple orchards against codling moth, on condition that all farmers in the same region use them at the same time, although prior insecticide application may be necessary to reduce the initial populations.

. Perennial crops

Perennial crops (vines, fruit trees) which have been in place for many years, are usually concentrated spatially in production regions where they are dominant or almost the sole crop. Pests thus benefit from particularly stable and favourable conditions. Repeated use of the same pesticide substances to control infestations therefore favour the appearance and development of treatment-resistant populations.

. Annual crops

Current technical and economic changes (see Box 3, concerning wheat) are tending to increase the risk of plant health problems:

- the specialisation of production systems results in a shortening of crop rotations and the application of crop sequences including plants with the same biological cycle (winter cereals, for example), thus favouring the appearance of weeds, as well as pests and diseases surviving in the soil,
- the search for maximum potential yield leads to the use of a high seeding rate (which favours the appearance of fungal diseases) and high levels of fertilisation (from which weeds also benefit),
- reductions in production costs through economies of manpower and energy lead to an abandonment of ploughing (which previously enabled the deep burial of weed seeds and pathogenic spores, etc.).

Furthermore, the development of international trade has subjected agricultural products to a risk of the introduction of new pests which may develop all the more rapidly if they encounter the favourable conditions referred to above. A good example is the corn root worm (*Diabrotica*), where efforts are being made to prevent its spread from outbreaks in the Ile-de-France region since 2002 and in Alsace since 2003.

4.4. The successful use of control methods is often not sustainable

Farming is faced with the question of the sustainability of pest control methods (as human medicine is with that of antibiotics), and more broadly all methods of "total" control. The appearance of resistance to the active substances employed has led to losses in efficacy and an increase in the doses applied and will, in the long term, result in the abandonment of some products, which may generate a plant protection stalemate in some cases. The prospects for innovation are not hopeful regarding the systematic replacement of all the compounds which have become ineffective.

. Pest resistance to pesticides

The existence of resistance phenomena was demonstrated as early as 1928. The repeated use of new AS has generated the appearance and rapid spread of resistance: there have recently been cases of rapid circumvention within a few years.

With respect to fungicides, the strobilurins (which inhibit a mitochondrial complex) appeared to have a bright future in numerous crops, but soon came up against problems of resistance concerning major parasites such as Septoria leaf blotch of wheat, downy mildew on grape or apple scab which may rapidly restrict the usefulness of these products. Regarding insecticides, codling moth is a good example of a pest which can rapidly develop cross-resistance to AS belonging to different chemical families. The appearance of herbicide resistance is a problem which has been known in France for many decades; the first cases of resistance to triazines were detected in the 1970s. More recently, since the 1990s, resistance has developed to grass herbicides (family of "fops", "dimes" or substituted ureas).

In France, resistance at present mainly concerns a majority of the key pests damaging fruit crops (scab, mites, various species of aphid, psyllid, leaf miners, codling moth). In grape vines, resistance has been observed among plant-eating mites, while against downy mildew, there are no longer any compounds with curative effects which do not encounter resistance problems. The same applies to field crops: all plants are concerned by resistance.

. Limited prospects for innovation

The prospects for agrochemical innovations in the medium-term appear to be limited, in a context which is much affected by the rising development and registration costs for new products, which is hardly motivating for the companies concerned. The new fungicides announced in the medium term do not include any new family with a broad spectrum of action, but some agents are likely to be introduced, including against mildew. No herbicides with a novel mode of action have been introduced for several years, although a few new products have been proposed, belonging to known chemical families.

The situation differs regarding insecticides and acaricides, because a certain number of new AS should be introduced onto the market between now and 2010: neurotoxic agents, and particularly nicotinoids (delayed by the lawsuit brought against imidaclopride) and toxins extracted or modified from micro-organisms (e.g. emamectine, etc.). New insect growth regulators are currently being approved. New insecticides and acaricides, with novel modes of action, are expected in the longer term.

Voluntary approaches involving pesticide-saving practices

French "Agriculture raisonnée"

"Agriculture raisonnée" (AR) is a global approach to farm management which aims to reduce the negative effects of farming practices on the environment, while not detracting from the economic profitability of a farm. Sixteen of the 98 points in the national reference document on AR concern crop protection.

However, the undertakings made by farmers in this respect (apart from recording their practices) do not go far beyond compliance with national and regional regulations. For example, the crucial undertaking consists in "only using products which benefit from a marketing authorisation and which are approved for the uses considered, and complying with the recommended application rate".

The aim of AR is that 30% of farms⁹ should become certified between now and 2008. By the end of September 2005, or 18 months after the operation was launched, 1019 farms already belonged to the scheme. They are very unevenly spread throughout the country and in different crops: 36% (374) of them are vineyards in the Languedoc-Roussillon region.

Agri-Environmental Measures (AEM)

Assessments made halfway through the European Rural Development Programme (RDP) showed that France devotes to the environmental axis (forests and LFA included) 56% of the contributions received under the European Agricultural Guidance and Guarantee Fund (EAGGF). This situates France midway down the list of European countries, but much lower than some German Länder, the United Kingdom, Ireland, Finland, Sweden and Austria. Under this programme, AEM constitute the most important measure and the principal tool to improve the environment.

Only a limited number of contracts have been finalised concerning AEM (not including organic farming) which directly concern the use of pesticides (measures 08 and 09; less than 5% of the utilized agricultural area in France). Nearly 80% of the land covered by such contracts corresponds to small changes in practices. Thus AEM do not take account of farms where practices are the least compliant with the specifications, and thus probably the most pollutant. To this problem of adverse selection is added the fact that the contractual arrangements concern globally unambitious measures, and insufficiently targeted zones where the stakes are particularly high. Overall, the half-term evaluation of the RDP admits that the effects of AEM on environmental preservation have probably been very limited.

Integrated farming

The proportion of land officially registered for integrated farming (Box 6) covers 0.4% of the utilized agricultural area in France (Agra CEAS Consulting, 2002). France thus counts as one of the European countries least committed to this type of production, far behind Denmark (23%), Austria (18%) and the United Kingdom (10%).

Integrated farming is mainly applied in arboriculture. In 1997, 12% of French fruit tree growers stated they employed this method. However, French Integrated Fruit Production (IFP) is generally judged as being undemanding. Some specifications place priority on communication, and often, in terms of plant health, deviate from IOBC recommendations. As an example, IFP regulations in Northern Italy are much closer to the IOBC directives, and initiatives concerning commercial exploitation have been much more successful than those launched in France.

Organic farming

In 2004, organic farming in France concerned 11,000 farms (3% of the total) and 540,000 hectares (2% of the UAA). After strong growth in recent years, French organic farming is now stagnating, and is markedly less important than it is in other European countries (12% of Austrian UAA, 6% in Italy in 2002). Organic-farmed land is mainly devoted to forage and pasture; cereals only cover 82,000 hectares.

Although the market for organic products is limited by a difference in consumer prices which may be considerable (both production costs and those of collection, processing and distribution are higher, because of the small volumes involved), production is also limited in France because the aids granted in the context of a CAD, or Sustainable Farming Contract) are restricted to the conversion phase.

The figures referred to in recent reports commissioned by the EU (Box 6) on the proportions of integrated and organic farming in Member States should be considered with care (data already old, only taking account of land benefiting from official guarantees, etc.). However, it is clear that France is only weakly involved in these types of farming. While countries such as Denmark and Austria have developed both integrated and organic farming sectors, in France there is practically no intermediate between mainly intensive conventional farming and organic farming, which only concerns a very small proportion of the UAA.

⁹ In 2003, France counted a total of 590,000 farms, 367,200 of them run professionally.

For some pests (viruses, phytoplasmas, bacteria), no pesticide treatments exist or are authorised, which renders preventive measures essential.

. Adaptation of pests to resistant varieties

The adaptation of pests also concerns the genetic resistance of varieties, notably with total resistance, and these mechanisms are particularly rapidly circumvented by pests if the varieties are used repeatedly and in large quantities.

There are numerous examples, but that of rapeseed can be considered in more detail. During the 1990s, phoma stem canker-resistant varieties, with a specific resistance gene (*Rim 1*) were introduced onto the market. They were remarkably successful: between 1996 and 1999, the surfaces planted with rapeseed varieties possessing this gene increased from 19% to 44%. At the same time, strong selection pressure on the pathogenic populations led to an increase in the frequency of the corresponding virulence allele (*avrLm1*) and, within a few years, to the loss of efficacy of these phoma stem canker-resistant varieties.

4.5. Current approaches to pesticide-saving practices

These approaches include: the rational use of pesticides, Integrated Pest Management¹⁰ (which combines different control strategies), integrated production¹¹ (protection of crops integrated in the design of the cropping system) and organic farming (which prohibits the use of any synthetic chemical pesticide).

. Current Decision Support Systems (DSS)

Tools have been developed for many years to help farmers manage their decisions concerning crop treatments. These tools are developed and/or circulated by technical institutions, the Plant Protection Department of the Ministry of Agriculture (which circulates "Farm Warnings"), Chambers of Agriculture and the distributors of crop protection products. They take a variety of forms, but their principal objective is usually to better rationalise the use of pesticides.

Most of these systems are based on coupling biological models predictive of the evolution of diseases or pest populations as a function of climatic conditions, with rules to trigger treatments according to a harmfulness threshold.

The models do not usually include parameters related to cultivation practices, except as an element to adjust output variables in order to take account of different agronomic situations. Harmfulness or intervention thresholds are generally determined for so-called "intensive" cultivation conditions. Efforts have been made (particularly by technical institutes) to adjust these thresholds to the diversity of agronomic situations observed, notably by supplementing Farm Warnings, relevant at the level of a region, by decision-making rules which integrate the risk factors linked to the management method and the cultivation history of the field.

Most of these tools are based on achieving a technical optimum, and quite logically result in high-input management systems. They generally only consider the {1 crop - 1 pest} couple, and therefore neglect interactions between different pests. Finally, they only very rarely take account of the environmental impacts of treatments.

. General contractual approaches

These individual approaches, applicable to the entire country (Box 5) are of two types:

- global approach at the farm level, comprising a coherent series of undertakings which define a type of production: "integrated farming", integrated pest management and organic farming (Box 5).
- more specific measures, proposed in the context of the agri-environmental measures which form part of the second CAP pillar. AEM offer a catalogue of several hundred measures, some of which concern pesticides, either directly (replacement of herbicide treatments by mechanical or thermal weeding, of soil disinfection with physical processes; adoption of integrated control methods, biological control; implementation of grassed buffer strips, etc.), or indirectly (diversification of crops in the cropping plan, implementation of grass cover under perennial ligneous crops).

European comparisons (Box 6) place France among those countries which have little developed both integrated production and organic farming. Countries where organic farming covers a markedly larger proportion of the UAA (Austria, Italy, etc.) ensured this development by mobilising European subsidies for AEM as early as 1992, while France chose to allocate these subsidies to more specific measures which had little effect on reducing pollution from farming. Although very numerous, the measures included in global farming contracts, the CTE (contrat

¹⁰ "Integrated Pest Management: a system to control harmful organisms using a series of methods which comply with economic, ecological and toxicological requirements, priority being given to the deliberate implementation of natural limiting elements, while respecting tolerance thresholds", OILB/SROP, 1973

¹¹ "Integrated Production/Integrating farming : a farming system for the production of foods and other high quality products which uses natural resources and regulating mechanisms to replace inputs harmful to the environment and thus ensures sustainable farming in the long term," OILB/SROP, 1993.

territorial d'exploitation, or territorial farming contract) and then the CAD (contrat d'agriculture durable, or contract for sustainable farming) paid little attention to pesticide use.

As for global methods, two approaches are possible: specifications with few limitations but accessible to a large number of farmers, and more stringent specifications, adoption of which will necessarily be limited. The first option is generally preferred in France (with relative success in terms of adoption).

. Local collective operations

These principally concern the 222 pilot watersheds monitored by regional "pesticide" groups, where all the farmers concerned are encouraged to modify their plant protection practices, depending on the problems identified locally (water potability thresholds exceeded concerning a widely-used pesticide compound, etc.).

The 2003 report on these operations showed that at that time, a diagnosis had only been completed in 45% of watersheds, and only 88 of these watersheds had developed or implemented such action plans; it was therefore too early to be able to evaluate the usefulness of this approach.

▶▶ If cropping systems are to be rendered less dependent on pesticides, it will be necessary to modify the structure and the spatial and temporal organisation of plant cover (within and outside fields) in order to create less favourable conditions for pests and thus reduce health risks.

The approaches currently proposed, which do not call cropping practices or cropping systems into question do not resolutely target this objective.

▶▶ Solutions must be found at a local level, as a function of the environmental and yield goals targeted. The principles for implementation exist, as to a certain number of means, which will need to be combined. The tools to accompany implementation of these new production methods still need to be designed, or at least their parameters still need to be established.

5. An economically rational level of pesticide use

The great majority of the studies consulted were based on mathematical formalisations of the behaviour of the concerned agents, i.e. should be considered in the context of (neo)classical microeconomics. These studies highlight the specific mechanisms governing pesticide use by farmers and generally put forward proposals as to the implementation of regulation mechanisms on pesticide use. The few studies published have only evaluated the importance of these mechanisms in some precise cases, such a specific crop in a given region or country, usually the United States. Thus, although the economic determinants of pesticide use are well known, quantification of their effects is very fragmentary. This is due to both a lack of data necessary for this quantification and to the fact that these studies are not always of scientific interest. Quantification is usually linked to the demands of public authorities.

5.1. Economic rationale for the use of pesticides

From an economic point of view, the current level of pesticide use in France is based on their technical efficacy (notably in production systems which are specialised or have high yield goals) and on their relative profitability (in the broadest sense) when compared with alternatives to chemical control.

. Price elasticity and the dependence of farming on pesticide use

The technical dependence of conventional production systems on pesticide use results economically in the low elasticity of pesticide demand, considering their price.

Although it is generally accepted that the low cost of pesticides favours their use, it is often more difficult to acknowledge that higher prices for these products would tend to encourage reductions in their use, because of this low price elasticity.

Thus, if the price of pesticides were to rise markedly and abruptly, farmers would probably decide to modify their pesticide use only slightly (and would then wholly suffer from the effects of such price rises). However, in the medium term, a variety of means would be available to them to adjust to this price rise: a reduction in the surface areas of crops consuming the highest levels of pesticides; a lowering of their objective yields, requiring lower levels of crop protection; adopting the pesticide-saving practices which are available. In the long term, they could modify their production choices and cropping systems more markedly. Their pesticide use would thus tend to decrease under the effect of this price rise. The price elasticity of pesticide use is therefore low in the short term, high in the medium term and very high in the long term.

▶ The dependence of farming on pesticide use is more marked in the short term than in the long term. And it will decrease to a greater extent if the farmer has alternative methods available to protect his crops.

. "Over-use" of pesticides and little use of pesticide-saving practices

A gap is often observed between the level of pesticide use recommended by plant protection experts and that actually employed by farmers, who frequently schedule systematic treatments. Such "over-use" (higher than the "optimum") thus represents wastage and does not comply with the postulate for the rational use of agents. Economists have thus sought to reveal this and understand the reasons for the limited use of more pesticide-saving practices, such as those observed in countries where these have been encouraged.

This research has demonstrated the importance of some of the characteristics of pesticide-saving practices:

- they generate indirect costs: increased working times, purchase of specific services (tests, advice, etc.) and, in some cases, costs linked to an increased variability in production,
- they require more knowledge (training and experience that the economists group under the heading of human assets) than conventional cultivation practices, which are generally based on well-established routines,
- they are (or at least are considered as) more risky.

These explanatory factors have been formalised and introduced into microeconomic models. Thus the information necessary to manage treatments is considered as an input variable, the cost of which can be evaluated (purchase of data or advice, cost of working time devoted to field observations, etc.).

The question of risk is taken into account via the definition of "risk aversion", which leads the farmer not to choose to maximise his expected profit, but to insure himself against the risk of a drop in income, or yield (e.g below a critical threshold). This behaviour may result from individual preferences, but it is often linked to specific constraints (reimbursement of loans, need to ensure forage supplies for a herd, etc.). Risk averse farmers tend to use pesticides at a level above that which could achieve the maximum expected profit. They are particularly inclined to over-use pesticides if the price of the product to be protected is high (market gardening, arboriculture, viticulture, etc.).

► The refinement of microeconomic models makes it easier to understand the factors which determine decisions to use pesticides, amongst which the relatively low price of pesticides remains predominant.

. Non-economic reasons

It has been shown that some farmers adopt techniques which are more environmentally-friendly, even though they are less profitable. These particular choices should be compared with those of consumers who purchase "ecological" products, which are more expensive than standard products. However, farmers who are ready to "sacrifice" part of their income to adopt practices more in line with their values or preferences, are few in number. It is clear that although farmers have become aware of pollution problems, this is not sufficient to ensure that a spontaneous solution will be found to pollution of agricultural origin. This remark also applies to consumers.

5.2. Costs and risks related to pesticide-saving practices

. Direct and indirect costs of pesticide-saving practices

These costs correspond in particular to:

- the purchase of information or detailed advice, or specific equipments, etc.,
- the time devoted to training, the acquisition of general information, the observation of fields and the processing of these data, as well as to technical interventions (mechanical weeding takes more time than spraying with herbicide). The opportunity cost of this increased labour can be high, particularly on farms devoted to stock rearing or having multiple activities (pluriactivity).

. Risks and uncertainties

Pesticide-saving practices may generate "objective" risks, such as those linked to diagnosis errors. However, an increase in production risks, which may be linked to an increase in the variability of yields, remains controversial. This effect seems to depend on the situation: crops, adoption of cropping systems which reduce crop protection risks, etc.

The subjective dimension of risk must also be taken into account: these are the risks perceived by the farmer, who may, in particular, overestimate the plant health risk and thus the risk linked to using fewer pesticides. In practice, it is difficult to distinguish between what is due to risk aversion (unchangeable, individual preference) and an excessively pessimistic or uncertain assessment of the possible benefits of a new technique (that could be corrected by adequate information).

. Specific costs during the adoption phase

In the case of complex practices which need to be adapted locally, the costs of initial investments (training, purchase of special equipment, etc.) should be supplemented by the costs of experimenting and adapting the new practices to the specific conditions on the farm. Indeed, these "learning costs", which correspond to a reduction in profits during the transient phase of mastery of and adaptation to the new technique, and can be determined by the difference in profits between a farmer who has just adopted the technique and one who is experienced in it, are rarely evaluated.

Integrated and organic farming systems in Europe

Unlike the United States, the EU and France have not initiated studies or surveys aimed at compiling an inventory on the use of integrated pest control methods, or more generally on the use of integrated farming techniques.

In 1986, the European Union launched the Competitiveness of Agriculture and Management of Agricultural Resources (CAMAR) programme, which concerned a network of tests being carried out in ten European countries; this programme was subsequently replaced by the Agro-Industrial Research (AIR) programme. These efforts do not seem to have borne fruit, if we are to judge from recent assessments made at the request of the European Commission (Agra CEAS Consulting, 2002). These practices appear to concern less than 3% of the European utilized agricultural area (UAA) (levels between 1995 and 1998).

In Europe, the principles of Integrated Crop Protection are only really applied to a few, highly profitable crops: fruit arboriculture, greenhouse crops and viticulture. In most other cases, farmers are still at the stage of optimizing chemical control.

	Surface areas: integrated farming (1000 ha)	Surface areas: organic farming (1000 ha)	Total Utilized Agricultural Area (TUAU) (1000 ha)	% of TUAU as integrated farming	% of TUAU as organic farming
Germany	225	546	17 327	1.3	3.0
Austria	608	272	3 423	17.8	7.9
Belgium	7	21	1 382	0.5	1.5
Denmark	637	158	2 764	23.0	5.7
Spain	39	381	29 377	0.1	1.3
Finland	14	147	2 150	0.7	6.8
France	133	370	30 169	0.4	1.2
United Kingdom	1 554	579	15 858	9.8	3.7
Greece	0	27	3 465	<0.1	0.7
Ireland	19	27	4 434	0.4	0.6
Italy	159	1 040	15 256	1.0	6.8
Luxembourg	nd	1	127	nd	0.8
Netherlands	30	32	1 848	1.6	1.7
Portugal	58	48	3 942	1.5	1.2
Sweden	157	174	3 109	5.1	5.6
EU-15	3 641	3 823	134 631	2.7	2.8

Sources: Agra CEAS Consulting (2002), IPTS (2004)

Agricultural areas concerned by integrated farming (1995/1998) and organic farming (2000)

The land area registered as being used for integrated farming is thus generally small, except in some Member States such as Austria and Denmark, and to a lesser extent in the United Kingdom or Sweden. It should be noted that Member States with high levels of integrated farming are also those with the highest levels of organic farming. Only Finland and Italy have high proportions of organic farming without high proportions of integrated farming.

However, these figures should be analysed with caution. Indeed, the term "integrated farming" does not comply with a standard in the EU, as it covers systems which, in practice, may not be equivalent. Similarly, only those farms registered officially (such as for AEM co-funded by the EU), or producing high-quality (labelled) products, are listed as users of integrated farming techniques. These figures may therefore underestimate the actual use of these practices. Finally, although they are included in recent reports (2002 and 2004), these data are old, and the situation may have evolved markedly since they were collected.

These costs and risks combine to restrict the scope of farmers who might adopt innovative, pesticide-saving practices at an early stage. The only farmers who will be ready to do so are younger members of the profession (for whom a new practice could generate considerable cumulated profits), the best trained (for whom the initial investment in training and learning are the lowest), those with the largest farms (who can then devote fields to trials), those whose farms benefit from good financial health (which allows a certain degree of risk-taking) or those who are not risk averse and/or are keen to adopt new techniques.

5.3. Methods which could encourage the use of pesticide-saving techniques

Identifying the curbs on adopting practices which require fewer pesticides has led countries committed to such policies to implement a variety of actions.

. Development of diagnostic services

The existence of paid diagnosis services allows farmers who have insufficient time and/or training to achieve this themselves, to delegate the scouting of their crops. Private-sector crop protection advisors, who can scout for any infestations, already exist in the United States, Canada and the United Kingdom.

The effects of diagnosis have been the subject of particular study in the United States, where in the 1970s and 1980s, programmes were implemented to develop this practice, involving private-sector crop scouting services. However, scouting does not always result in a reduction of pesticide use. In this context of more extensive farming than in Europe, where preventive chemical protection is not very profitable, the diagnosis of infestations can enable judicious, and thus more widespread treatment (having determined that this is necessary), or it may lead to action being taken against pests which were previously undetected.

. Organisation of an insurance system

Taking account of the attitude of farmers towards risk has led to the suggestion that crop insurance could be a useful instrument to reduce pesticide use. Thus the United States has set up a highly-subsidised crop insurance scheme. This system raises two types of problem:

- It is running a considerable financial loss: reimbursements for damages paid to farmers exceed the premiums they pay. The difficulties encountered in designing a non-loss-making harvest insurance scheme mainly arise from the "moral hazard" question (insured farmers are not encouraged to implement the methods they would usually employ to protect their harvests), and adverse selection (insuring particularly those with the highest risks). The US system is in fact more similar to a subsidy system than to a true insurance scheme: in some years, the premiums only cover a third of reimbursements.

- Although harvest insurance reduces pesticide use in the simple case of a single crop with pesticides being the only input, this is far from being the case in the multi-output and multi-input cases. In some American States, harvest insurance has increased pesticide use, because it has increased the area of land growing pesticide-consuming crops. In all cases, it is important to remember that in theory, the financial insurance of crops can only eliminate that proportion of pesticides used to control yield variations (the remainder being, on average, profitable).

In fact, harvest insurance schemes are less and less considered as useful instruments to reduce pesticide use, at least in the United States. However, they can still be recommended as instruments to stabilise farm income, which was their initial objective. Furthermore, the main drawbacks of this instrument were highlighted for annual crops. These drawbacks may be less serious in the perennial crops cases.

. General training and information on new techniques

For many farmers, adopting pesticide-saving techniques requires prior investment in training. American studies on this question, and the fact that countries which are "ahead" in the area of pesticide regulation have all implemented training (and advice) policies, tend to confirm this point.

In addition, it is essential to provide prior information on the benefits expected from the new technique, rectifying if necessary any over-estimations of the risks and reducing the uncertainties about the effects which will result from the techniques.

▶▶ The ratio between pesticide prices and those of agricultural products or other inputs (labour, fuel, etc.) still seems to favour conventional cultivation practices, and thus the use of pesticides.

Changes to practices which allow a reduction in the "technical dependence" of agricultural production on pesticides are based on the use of particular types of input, notably knowledge and information in general. Adopting a pesticide-saving practice constitutes an uncertain and relatively major investment, not in terms of capital assets but in human assets and working time.

If, when calculating the comparative profitability of integrated pest management and systematic plant protection, the cost of the time spent by the farmer in monitoring his crops, the cost of his training in screening or the cost of

any diagnostic errors are neglected, this will lead to an artificial over-estimation of the profitability of integrated crop protection.

Box 7

Expenditure on pesticides

Expenditure on pesticides per hectare are six times higher in the setting of market gardening than with field crops. However, their share in total operating costs and gross farm income is inversely proportional. Indeed, for market gardeners and fruit producers, expenditure on labour is much higher than on the purchase of crop protection products. Overall, expenditure on pesticides only represents a small proportion of farm income.

	Technical and economic orientation of farms					
	Cereals and protein-rich seeds	All field crops	Market gardening	High-quality wine	Other viticulture	Fruit and other permanent crops
Expenditure on pesticides (€/ha of UAA)	121	131	685	398	287	410
Share of pesticides in operating costs(1)	10.2%	9.4%	2.7%	3.8%	9.2%	6.0%
Share of pesticide expenditure in gross farm income	10.2%	9.4%	2.7%	3.8%	9.2%	6.0%

(1) costs of supplies (fertiliser, seed, pesticides, etc.) + labour + work contracted out + equipment maintenance and repair.

Level of expenditure on crop protection products by French farms in 2002, as a function of different technical and economic orientations

Pesticides account for around 50% of operating costs for field crops, and 10% in viticulture.

6. Regulation policies which are difficult to justify and implement

6.1. Cost-benefit analysis of pesticide use is unfeasible

Theoretically, any public policies to regulate pollution must be based on general cost-benefit analyses, i.e. in this setting, an economic evaluation of all costs (to both farmers and society) of all the benefits (to farmers, other economic agents in the agri-food sector, consumers and society) of pesticide use.

Indeed, government authorities are keen to obtain such analyses, which has generated the development of economic tools which can place a price on all these elements.

. Economic evaluation of "external effects" is very difficult

In principle, market costs and benefits are the least difficult to evaluate: the costs of care given to individuals suffering from poisoning, the cost of treatments to render pesticide-contaminated water drinkable, the cost of restoring ecological environments, etc. Some elements already pose problems: purchases of bottled water or of organically farmed products are not attributable to the problem of pesticides alone.

The question is even more difficult with respect to all non-market costs and benefits (the value of environments or biodiversity for future generations, etc.), which economists try to determine using indirect approaches, and notably by estimating the "willingness to pay" of individuals concerning an improvement in or lack of deterioration of environmental quality, through the observation of how the environment is used (recreational fishing, etc.) or by direct questioning techniques based on contingent scenarios.

Furthermore, as seen above (cf. 4.1.), even the benefits of pesticide use to agricultural production are difficult to evaluate if no references are available on the possible performance of the systems which would be designed to reduce plant health risks.

Given the complexity of the problem, the uncertainties surrounding some of the effects of pesticides and the ethical nature of some of these effects (effects on human health, responsibility towards future generations, etc.), a cost-benefit analysis of pesticide use is not practically viable.

6.2. A "locked-in" system?

The hypothesis of a "locked-in" system has been raised by some economists. In a strictly economic sense, this term refers to the impossibility of changing a system, even though the alternative has been proved to be more profitable, a condition which may not hold here. Nevertheless, the term can be used to reflect the combination of factors which makes it very difficult to change from the current system.

The determining factor remains the profitability of pesticides (cf. 5.1.): in the current economic context, economic rationale will encourage the use of pesticides.

Dependence on pesticides may also be increased by factors external to the farming sector:

- the demands of consumers and/or the distribution sector with respect to the appearance and storage of fresh fruits or vegetables, which tends to encourage the use of pesticides,
- the preponderance of a crop protection advisory sector which is dependent on pesticide sales and thus tends to favour their use,
- the fact that the distribution of seed, pesticides and fertilisers, and the collection of crops, are often ensured by the same companies, reinforces the previous point. The reluctance of these companies to distribute varieties which are hardy or resistant to certain pests is often suggested as constituting a brake on the spread of pesticide-saving practices.

Some recent studies have analysed the importance of individuals who combine the roles of plant health advisor and pesticide salesman to the use of these inputs (and they confirmed the expected effects). More numerous studies have sought to evaluate the willingness to pay of consumers regarding products guaranteed to be free of pesticide residues. However, these potentially important roles of agricultural supplier, product processor and consumers concerning the use of pesticides are still little studied in the economic literature.

Socio-cultural factors may also explain the problems encountered in adopting alternative production systems: problematic acceptance of redefining the profession of farmer (as a gardener of nature) and thus accepting a new professional identity based on the acquisition of new skills; loyalty to individual values and to the liberal view of farming which refuses attempts at any organisation, control or regulation of their activities by third parties; idea of "clean fields" (without weeds or disease) and yield as a presentation to society and a guarantee of reliability and skills; isolation, which hinders conversion to practices where the pooling of information, or risk taking, are important factors; rejection of the ideology which sometimes accompanies the promotion of new practices or systems ("ecologists", "environmentalists" considered as "illegitimate" in the social and technical world of farmers).

►► It cannot be expected that escape from this system will be based on a global cost-benefits analysis which, we have seen, is not feasible. Only political choices based on enhancing the proven, harmful effects of pesticides on the environment and/or on referring to the Precautionary Principle concerning the long-term effects of these products, will be capable of modifying this currently dominant system.

Furthermore, this political objective must result not only in intervention at the level of farmers (pesticide users) but also at the level of "locked-in" areas, which constitute the downstream demand for "perfect" products, advice given by the companies selling pesticides, etc.

Potential technical actions

These technical actions aim to limit the dispersion of pesticides in the environment and reduce pesticide use. Classically, it is considered that this second objective can be pursued: by "managing" the application of these products, and/or by applying a combination of control methods with partial effects, qualified as "alternatives", alongside (integrated protection) or instead of standard chemical control methods.¹²

7. Reducing pesticide dispersion in the environment

Many of the actions mentioned here have frequently been proposed, particularly to reduce the contamination of water. Nevertheless, whether their efficiency can be guaranteed remains unclear.

Pesticide transfer results from a very strong interaction between the properties of compounds, environmental characteristics, climatic conditions and farming practices. Although the processes involved are quite well understood, their quantification remains highly inaccurate, except in some intensively instrumented experimental situations. The transfer models available allow testing of scenarios for changes in practices or the introduction of corrective management measures. They may be useful as a decision-making aid, and to compare the efficiency of management measures. However, validation of their predictions is a difficult point, requiring considerable investment in experimentation, particularly at the scale of a watershed. As a result, it does not seem simple to validate the efficacy of the elementary measures proposed, and thus obviously, that of a combination of these measures.

7.1. Adapting the use of crop protection products to environmental conditions

Marketing Authorisations (MA) for crop protection products are delivered at a national level, so that any evaluation of the risks on which the MA is based must guarantee an acceptable level of risk in that country, i.e. under (almost) all environmental conditions. However, such risk evaluations are performed using a standard scenario of product use, which does not therefore take account of the different types of environments associated with specific risks. This method may give rise to either an under-estimation of risks to certain environments, or to a decision (justified in high-risk zones) not to authorise a product at the national scale. This may create a "crop protection vacuum", where more harmful products may be used in zones with a lower risk.

► Taking account of environmental conditions when evaluating risks prior to granting MAs would have the advantage of responding more specifically to environmental protection needs and would offer more flexibility in the response to plant protection needs.

7.2. Reducing losses at application

A reduction in losses during application, or immediately afterwards, can be achieved by improving the properties of commercial crop protection products and their conditions of application.

. Improving the properties of active substance preparations

Formulations of active substances, and the possible addition of adjuvants during preparation of the spray mixture aimed at improving product efficacy, may have negative or contradictory effects on the risks of losses. For example, increasing the adhesion and wettability of foliage treatment products can reduce runoff from the leaves but may favour volatilisation.

It is possible to adjust inert substances or adjuvants to improve the properties of preparations: optimising the size and density of drops to limit losses due to droplet volatilisation, increasing the rate of leaf penetration, increasing the resistance to abrasion of granules and seed coatings, etc.

. Improving application techniques

Technological developments in equipment can achieve considerable advances in quality. Thus the simple replacement of traditional spray nozzles by air injection nozzles can significantly reduce quantities of the finest droplets (the most likely to be dispersed by the wind) and thus drift. However, optimisation of these processes remains difficult.

12. The expert report includes a chapter which summarises the technical options and resources to be implemented to attain three "types of objectives" (see Box 23): Type "T" (for transfer): limit pesticide transfers; Type "R" (for rational): reduce pesticide consumption through their more rational use; Type "S" (for systems): reduce pesticide consumption by using cultivation systems which diminish plant health risks. Sections 7, 8 and 9 correspond respectively to the technical aspects of these types, T, R and S.

As for the equipment currently in service, technical checks on its operation constitute prerequisites which are necessary but far from being sufficient. Indeed, despite it being more difficult to achieve, it is the optimisation of adjustments which will result in the greatest economies in pesticides.

. Compliance with application conditions which limit losses

Treatments should be prohibited during very windy conditions, very dry conditions, at very low or very high temperatures, depending on the type of pesticide, or when rain is forecast. For compounds which are highly volatile just after application, it may also be possible to issue recommendations concerning the best time of day for application in order to limit the importance of losses, once the mechanisms involved in this process are fully understood.

Periods of application must also take account of the type and state of the soil. Indeed, a certain number of mobile substances can be transferred rapidly: by runoff, or in winter, on saturated, hydromorphic soils; by preferential runoff on dry, fissured clay soils.

Compliance should be ensured with recommendations concerning incorporation of the product in the soil, which is effective in reducing the volatilisation of some compounds.

► It is possible to limit losses through a combination of complementary technical improvements, concerning the properties of commercial preparations and the techniques and conditions of application. For example, it is possible to limit drift by acting on formulations or the adjuvants added during preparation of the spray mixture, the type of nozzles, adjustment of the sprayer and meteorological conditions.

► These improvements, which increase the proportion of product reaching its target and staying there, will therefore enable a reduction in the doses applied.

Experiments on crops such as grape vines have showed that with optimum adjustments and compliance with the conditions of application, it is possible to reduce the approved dose by 15% or even 30%, without any loss in efficacy.

7.3. Reducing transfers within and out of the field

Because pesticide transfer by surface runoff is generally more significant than that which occurs due to lixiviation in the soil, it is usually advantageous to promote infiltration – unless the local diagnosis indicates the need to protect water tables (or drainage networks) rather than surface waters.

Organic matter plays an essential role in the retention of numerous active substances and in microbial degradation activity, so practices which increase humus levels in the soil should be encouraged.

According to these principles, the following should be considered as favourable to reducing transfers:

- maintaining plant cover: planting of an intercrop; growing grass between rows of perennial crops or even annual crops (maize), if competition with the main crop is not prohibitive,
- leaving crop residues on the soil if the field is not ploughed,
- applying organic amendments to soil, etc.

7.4. Intercepting pollutant flows

It is possible to reduce transfers towards water through adaptations which facilitate the infiltration of runoff containing high levels of pesticides. The best-known system is that of buffer zones, consisting of grassed (or wooded) strips.

. Grassed buffer strips (GBS)

Their effectiveness has proved highly variable (from nearly 100% of pesticide interception to very low levels). Because the effectiveness of a GBS is mainly based on its infiltration capacity, it is markedly reduced if the GBS is saturated (frequent in hydromorphic zones during the winter), or if it intercepts a concentrated flow. A GBS may even have a negative effect if it facilitates infiltration towards a susceptible alluvial water body.

The effectiveness of a GBS depends on its position in the watershed, local environmental conditions (soil, subsoil, etc.) and its maintenance; only a precise, local diagnosis of the functioning of the system, and the implementation if necessary of systems for the dispersion of runoff, can guarantee this efficiency.

. Other systems

- Wooded strips, hedges. Their usefulness is based on the same idea of retention and infiltration as GBS; added to this are a barrier effect when the hedge is combined with a bank, and an effect on atmospheric dispersion.

- Ditches. Maintaining controlled vegetation in ditches favours the retention of compounds in the hydrographic network during transfer to surface waters. The effects expected can range from significant (in the case of low runoff flow rates), to probably minor (in the event of heavily-polluted, high flow rates). The gains from this action when compared with its cost (investment in ditching equipment, working time, etc.) cannot be evaluated from the data currently available.

- Wetlands. These environments are likely to allow the retention and degradation of some pesticides; however, the scientific findings are insufficient to evaluate the final degree of compound degradation, according to their characteristics and local physicochemical conditions. Orienting wetlands towards a buffer function may, however, compromise other environmental functions (biodiversity, refuge, etc.) which indeed justify their conservation.
- Spatial distribution of crops. Alternating winter crops and spring crops (or even grasslands) on slopes and valley lines reduces the surface areas contributing to runoff during periods of high rainfall in the spring or summer, and allows runoff from higher fields to be intercepted by a lower field with good infiltration. Such measures require coordination between those farming the same watershed.

▶▶ Although a vast array of techniques is available to reduce pesticide transfers, these techniques are far from being wholly mastered (in particular, there is a frequent lack of local experimentation which would enable adaptation of these techniques to a wide variety of local conditions). For the same reason, it is necessary to perform local diagnoses on the conditions affecting pesticide transfers. Even the best-known techniques are still relatively infrequently employed (with the exception of GBS).

▶▶ Nevertheless, particular attention should be paid to environmental assessments of these practices, and all their effects must be considered. For example, grass between rows of a perennial crop improves soil infiltrability, but its destruction may require a post-emergence herbicide applied at levels higher than those necessary for a pre-emergence one to maintain bare soil.

▶▶ It is probably illusory to hope for the total elimination of pesticide transfers in the environment, and particularly in the most vulnerable settings; limitations to pesticide use thus appear to be essential if the aim is to achieve a significant reduction in environmental contamination. Because the relationship between reducing pesticide use and reducing contamination is very probably not linear, reductions in use should certainly be substantial in order to guarantee an effect, whatever the pedoclimatic and agronomic conditions.

8. Optimising pesticide use

Optimising pesticide use consists in making the good decision of treatment in function of an objectively measured necessity in a specific situation. Optimising pesticide use leads to tactical decisions that are taken only after crop establishment.

8.1. The different ways to optimise pesticide use

As the first step in reducing pesticide use, chemical applications can be optimised at various levels.

. Conducting less frequent crop spraying

This can be achieved through risk assessment (see 4.5.), which, it should be recalled, generally takes into account the risk of an epidemic but very rarely the risk of yield losses.

. Reducing the doses applied per unit of surface area by better targeting the spray

Reducing the basic doses, primarily with respect to herbicides and spraying to prevent foliar disease, consists in 1) adjusting the intensity of the spray to the type, state (stage, abundance) and spatial distribution of the pests targeted or 2) using a precision spray method, for instance, against weed or disease patches, by sensor-controlled spray systems or through adjustments made by the user.

Local spraying results in a lower dose per hectare. In weed control, for instance, it is possible to significantly reduce the quantity of herbicide applied (by 2/3 in grapevines and some annual crops such as maize) by spraying only under rows, as either grass is sown between rows or this soil is weeded mechanically.

Fungicide and insecticide applications can be better targeted, for example, at fruit or leaves. Deposition on leaves is optimal when spraying row by row. It is therefore possible to reduce the dose depending on plant stage, especially in the early stages of plant growth.

These different options generally require more specialised spraying systems and extremely fine tuning of sprayers.

. Spraying only when conditions are favourable

Keeping informed of meteorological conditions enables farmers to predict the development of pests and the effectiveness of spraying at a given time (see 7.2.). Optimum climatic windows must be defined for each product, outside of which spraying would be ineffective. The quality of the application thus depends on the organisation of work on the farm and the possibility of taking action under the best conditions.

. Choosing the right product to reduce environmental risks

Choosing the "right product" requires that farmers have the "right information", which is rarely the case at present. However, multicriteria decision-making tools for the choice of pesticides are currently being developed. One such tool is *Decid'herb*, a joint project involving INRA, the French Technical Institute for Cereals and Forage (*Arvalis - Institut du vegetal*) and the French Technical Centre for Oilseed Crops (CETIOM). *Decid'herb* takes into account both environmental and economic impacts of choosing one herbicide over another.

. Preventing the development of pesticide resistance

Several options exist for the preventive management of resistance: alternating active substances in time or space and/or combining them, limiting the number of applications per active substance or family of active substances, and avoiding spraying repeatedly with very low doses of the same active substance.

It is sometimes necessary to set up refuge areas that allow susceptible populations to develop without pesticide application. This prevents resistance from spreading and allows farmers to implement, on a temporary basis, alternative methods for pesticide use, even if they are less effective.

► In order to assess risk and choose the product best suited to a given risk situation, farmers must not only improve their ability to diagnose and identify pests but also be sufficiently informed as to determine which pesticides are likely to be effective given the risk but have little negative impact on human health and the environment.

8.2. Conditions and limitations of implementation

The obligations of farmers as set out in the "Agriculture Raisonnée" reference documentation are as follows: to keep informed (subscription to a journal and technical consulting services independent of marketing) and seek training, to carry out observations on representative fields and keep a record of practices (activities on each field and trigger factors).

. Recording practices

This point is included in the "Agriculture Raisonnée" reference documentation and is made mandatory (in theory, as from 1st January 2006) by Regulation no. 852/2004 relative to the hygiene of foodstuffs. However, none of the references provides for a particular use of the recordings, whereas they should be regarded as a management chart by the farmer to record his/her practices and any changes.

It is important to go from simply observing an obligation that can be "checked off", that the farmer or his/her advisor can easily provide information for, in order to make these recordings a management tool for farmers (product choices, changes in parasite pressure and pesticide use, etc.).

. Scouting

The effectiveness of scouting techniques depends on the cultivation practices used. With respect to European field crops, scouting is useful because ineffective pesticide applications are thus avoided. However, in more intensive cultivation systems, there is a relatively high rate of potentially damaging infestations. Farmers therefore have less incentive to use scouting systems, as they are less likely to give them an opportunity to save on pesticides.

► It is difficult to ensure that a commitment to carry out scouting has been followed through on (if it is not done by an external company); therefore, such a commitment does not guarantee a reduction in pesticide use.

. Theoretical flexibility and practical limitations

While demanding "Agriculture Raisonnée" methods can considerably lower pesticide use, they also:

- Require prior training in which some farmers are probably not prepared to invest.
- Require monitoring of fields that is all the more demanding if the cultivation system is "intensive" and implies high plant health risks. Such monitoring may not be compatible on farms with an extensive surface area per worker.
- Represent a risk, which is higher for more expensive farm products (e.g. wine) and specialised farms, etc.
- May not be "sustainable", as maintaining pest populations just below the threshold of tolerance for a given crop does not prevent the development of residual populations (weed seeds, pathogenic fungus spores, etc.) likely to damage future crops (and which will no doubt require more intensive pesticide applications).

►► With respect to field crops, while rationalising all types of treatment should in theory result in a significant reduction in the quantities of pesticides applied (see Box 11), the agronomic sustainability of the system (in the absence of any measure aiming to reduce plant health risks) is probably limited. In the long-term, it would no doubt be more effective to first seek to reduce plant health risks preventively, and then rationalise chemical control.

As far as cultivation systems are concerned, especially perennial crops, for which the options for reducing risks are more limited, "Agriculture Raisonnée" is not likely to significantly decrease the number of treatments.

Box 8

GMOs and pesticide use

Genetic engineering, defined simplistically here as the creation of transgenic varieties that are totally resistant to pests, is the prime example of an alternative to pesticide use. The environmental argument in favour of reduced pesticide use has in fact been used in debates on GMOs.

Despite the many issues and controversies raised by GMOs, little has actually been published in the way of research. Most studies rely on results from the United States, which have seen significant development of GM crops since 1996. The interpretation of these results sometimes differs, particularly with respect to changes in pesticide use as a result of GM crops.

GMOs currently grown in the world are based on two very different rationales: pest resistance and tolerance to a broad spectrum herbicide.

Pest-resistant GM crops

*Pest resistance is obtained through the plant's synthesis of a pesticide compound. The varieties currently on the market contain genes from the bacterium *Bacillus thuringiensis* (Bt), which renders them resistant to lepidoptera (e.g. driedfruit moths, borers). This is expected to result in the elimination, or at least a reduction in, insecticide sprays against targeted pests.*

US data shows, apart from regional differences, a reduction in the number of insecticide sprays against the targeted pests, a less significant decrease in the quantities applied, and the abandonment of particularly toxic compounds (organophosphorus compounds).

Some authors question the benefits of this strategy which consists in mimicking the mode of action of pesticides, that is, favouring a unique, harsh mode of action in order to destroy a particular pest, and raise the issue of the adaptation of the targeted organisms and thus the sustainability of the method.

GM crops that are tolerant to glyphosate, a broad spectrum herbicide

Tolerance to a broad spectrum herbicide with a theoretically more favourable (eco)toxicological profile and low persistence allows the herbicide to be used without putting the crops at risk. Commercialised varieties are tolerant to glyphosate (active substance in Roundup). The expected results are a reduction in the total quantity of herbicides applied and in the number of active substances, and thus in the variety of potential pollutants.

However, questions remain as to the overall impact of this technique:

- While glyphosate has a more favourable ecotoxicological profile than the selective herbicides it has replaced, a larger treated surface area would imply an increase in glyphosate content in water resources.*
- GM plant regrowth management and their dispersion outside of the field would require additional herbicides.*
- The widespread use of glyphosate would stimulate the appearance of resistant weeds.*

Here, too, the data shows differences amongst the regions, but, on average, no reduction, or, in some cases, a slight increase in the quantity of herbicides used.

Evaluating the effects of using these GM varieties is complicated by the various changes made to crop sequence management. Using these varieties which facilitate post-emergence chemical weed control also implies the abandonment of mechanical weeding and the development of zero-tillage, which can increase some plant health risks and thus the total consumption of pesticides.

▶ *Transgenic varieties are potentially interesting for certain types of resistance that are difficult to exploit via standard routes of selection, or in order to combat pests which have already been subject to many pesticide applications or which farmers have no means (viruses, etc.) to control.*

▶ *Current examples have not always demonstrated a significant reduction in pesticide use.*

9. Reducing pesticide use

Cutting back on pesticide use implies searching for alternative pest control methods and designing cropping systems that reduce plant health risks.

9.1. Exploiting crop pest resistance

. Advantages of genetic improvement

It is important to distinguish resistance, whether partial or total, from tolerance. The genetic resistance of a variety prevents, delays or reduces the effectiveness of a given pest's reproduction cycle. A variety known as "tolerant" remains susceptible, but its morphological characteristics make it less vulnerable to damage by a given level of pest infestation.

Varietal improvement consists primarily in developing disease resistance, e.g. cereals that are resistant to rusts, Septoria leaf and glume blotch, powdery mildew, eyespot, Fusarium head blight, etc. There are also several types of pest resistance or tolerance: grapevine grafting onto phylloxera-resistant rootstock, etc.

However, no varieties have been selected for their competitiveness with weeds. Organic farmers are now looking into cereals that have faster and more extensive soil cover so as to choke out weeds.

Transgenesis, because it theoretically provides vaster sources of usable genes, and because it speeds up the process of transferring these genes to already-top quality varieties, may be seen as a means of obtaining varieties requiring less pesticide. The few applications that currently exist include resistance to a few pests and, in a completely different rationale, total tolerance to a herbicide that can be used without danger for the crop. Using GM crops raises the issue of acceptability by society, but also environmental consequences and their actual contribution to reducing pesticide use (see Box 8).

. Implementation

The fact that, in just a few years, pests are able to bypass major-gene resistance demonstrates the advantages of partial and polygenic resistance, as well as that of diversifying, in time and space, the types of resistance used to delay pest circumvention. One method involves a combination of varieties, sowing a mixture of varieties carrying different resistance genes, the effectiveness of which depends on the combination of several modes of action (barrier effects, spore dilution, stimulation of defence mechanisms, etc.).

The genetic resistance of a plant may be accompanied by a slightly lower potential yield, which may compromise its registration in the official varieties catalogue. The commercialisation of multi-resistant varieties of hardy wheat whose potential yield is slightly lower than that of varieties from the same generation which although more productive are also more susceptible, was made possible only because the CTPS, or French Permanent Technical Committee for Seed Selection, now gives "bonus" points for disease resistance.

There are specific limitations on using the varieties with the highest levels of resistance in perennial crops: the lifespan of the crop stand, regulatory issues (for grapevines, Appellations of Origin are associated with a certain grape variety), and marketing (difficult to introduce a new fruit variety on the market).

9.2. Promoting non-chemical pest control

. Biological control

Biological control agents include predators, parasitoids, pathogens (e.g. fungus, bacterium or virus) and competing pests. It is important to distinguish 1) pest control through the introduction and acclimatisation of a new species in the environment; 2) release in large numbers (inundative release) or small numbers (inoculative release) of the pest's enemy; and 3) environmental manipulation that favours the pest's enemies that are naturally present (auxiliaries).

However, it is also crucial to assess the risks involved in introducing auxiliary organisms, which could attack species other than the one targeted.

Biological control is mainly used against pests such as insects (controlled by predators, parasitoids and diseases), phytophagous mites (controlled by predatory mites) and nematodes (controlled by nematophagous fungi). Biological control agents are often used against a narrow spectrum of pests, and are usually susceptible to pesticides.

Biological control rarely deals with disease, although a biological control agent was recently approved as a soil treatment against sclerotinia stem rot (for legume crops, rapeseed, soya, sunflower, etc.).

Little use is made of biological control in field crops. Only the trichogram against the European corn borer is used on large surface areas. The agent against sclerotinia stem rot was only recently marketed.

Current effectiveness of various pest control methods – examples

. Pest control: winter wheat

Major pest groups	Current abundance of pests	Current effectiveness of pest control methods				
		Chemical control	Resistant varieties	Biological control	Physical control	Cropping system
Pathogenic fungi (<i>broadly speaking</i>) <i>Septoria leaf and glume blotch, rusts, Fusarium head blight, take-all, eyespot, and powdery mildew</i>	+++	++ (1)	+++	-	+ (4)	++ (6)
Weeds <i>Fox-tail and rye-grass primarily</i>	+++	++ (2)	-	-	++	+++ (7)
Viruses, viroids and mycoplasmas <i>Barley yellow dwarf virus</i>	+	+ (3)	-	-	+ (5)	-
Insects <i>Aphids, flies and wireworms</i>	+	++	+	-	+	+
Nematodes	+	-	+	-	-	++ (8)
Slugs	+	+	-	-	-	++ (9)

1. Application target: seeds or growing crops.
2. Application timing: pre-sowing, pre- or post-emergence.
3. Control of aphids, which are vectors of viral diseases.
4. For instance, regrowth management through dethatching can have consequences on the summer survival of wheat leaf rust (*Puccinia triticina*).
5. For instance, the management of summer regrowth through dethatching can impact on the cycle of aphids, which are vectors of viral diseases.
6. Soil-borne diseases are particularly sensitive to the interactions of soil tillage and preceding crops, the date and rate of seeding, and nitrogen fertilisation (dose and type).
7. The planting season is the ideal time to prevent certain weeds from emerging at a given time of the year. Tilling the soil and, more particularly, ploughing, is an effective way of managing weed seed stock.
8. Reducing the rate of return of cereals and adjusting the seeding and tillage dates enables control of nematodes.
9. For instance, burying crop residues hinders slug development.

. Pest control: fruit arboriculture

(in general, including stone fruit)

Major pest groups	Current abundance of pests	Current effectiveness of pest control methods				
		Chemical control	Resistant varieties	Biological control	Physical control	Cropping system
Fungi (<i>broadly speaking</i>)	+++	++	+	-	-	++
Bacteria	++	-	-	-	+	++
Viruses, viroids and mycoplasmas	+++	+	+	+	-	++
Mites	+	++	-	+	-	-
Insects	+++	++	-	+	-	-
Nematodes	+	-	-	-	-	+
Weeds	+	+++	-	-	-	+++

Biological control is more prevalent in legume crops, especially those grown under shelter (80% of tomatoes). However, experience has shown that biocontrol can be made inefficient when insecticide has to be used to eliminate a new emerging pest.

In orchards, there have been a few successful acclimatisations. A recent example that is the most-often cited is the introduction of phytoseiids (mites which prey on mites). Development technicians have been the main actors in France; they have accompanied these introductions by backing the recommendations of the IOBC (International Organization for Biological Control of Noxious Animals and Plants) and technical institutes (ACTA, CTIFL) on the thresholds of intervention with chemical acaricides.

► The need for formulated agents for biological control has not yet been met, despite the scientific results demonstrating the effectiveness of these products.

Developing new biological control agents is difficult for several reasons, including 1) the costs of registration for what is often a small market; 2) technical constraints for reproduction of the agent at a commercial scale and for survival during distribution; 3) a potentially higher frequency of application and therefore increased costs for the farmer; and 4) vulnerability of the agent to environmental conditions.

For example, releasing *Anthocoris nemoralis* (flower bugs) to control pear psylla or *Harmonia axyridis* lady beetles to control various species of fruit tree aphids were evaluated during the 1990s. Uncertainty about the conditions for the method's effectiveness, as well as the exorbitant costs of producing these auxiliaries, did not allow for practical utilisation.

. Biotechnical control

Biotechnical control involves the use of biological events and products, but no living organisms. Here are a few examples:

- Sexual confusion, which consists in disrupting insect mating by massively diffusing sexual pheromones; this method is currently used in maize, grapevines and orchards.
- Induction of plant resistance using elicitors that stimulate natural defence mechanisms. Interest has been revived in these long-established mechanisms over the last 10 years; applications, however, remain limited. One of the first applications was a product registered in Europe against wheat powdery mildew and tobacco mildew. Several disadvantages have been observed, including partial effectiveness (which requires the product to be combined with a fungicide), action that is not targeted enough, the necessity of preventive application, and a "physiological cost" for the plants which needs to be more precisely evaluated.

. Physical control

Physical control includes all techniques whose principal mode of action does not involve any biological or biochemical process. For example:

- Mechanical weed control (tillage, mowing, mulching, manual weeding, flooding) and insects (physical barriers against entry, such as nets, plastic film, etc.).
- Thermal control of pests and weeds by lethal heating or lowering the temperature to below freezing. Thermal weeding (hot water, flaming or infra-red) is being studied in organic farming. Another example is soil disinfection by solarisation, which consists in the sun heating the soil, which has been covered by clear plastic sheeting.
- Electromagnetic control of weeds, using an electrical current, has not been extensively developed due to the high costs involved; this is therefore not yet an option.

► Most non-chemical control methods and the genetic resistance of the most sustainable crops are only partially effective against pests.

They are therefore at a disadvantage when compared with chemical control, which because it is effective and reliable, is used as a reference, often implicitly. Other methods are rarely tested in adequate conditions: either they are tested outside of a real production context (as is the case with biological control) or their effectiveness is assessed using a control that is chemically protected rather than a totally unprotected control.

9.3. Reducing pest-related risks

Reducing the risk of infestation consists in making conditions less favourable to pests, in time and space, using the characteristics of the plant community as well as the crop rotation systems and their spatial organisation.

. Cultural control

Cultural control may be defined as changing the cropping system in order to prevent or hamper the development of pests. It may include:

- Rotating crops with different cycles and/or from different botanical families in order to prevent the establishment of weeds with a development cycle that matches that of the crop, and to break the cycle of animal pests and pathogens.
- Managing the crop stand (e.g. date and rate of seeding, fertilisation, irrigation) in such a way as to create unfavourable conditions for the development of pests such as pathogenic fungi, or to get round it by shifting the

Case study: Low-input hardy wheat

A better understanding of field crop physiology and the functioning of agrosystems have resulted in the development of new, less intensive crop management sequences. These sequences were studied by INRA in the 1980s and 1990s. They produced revealing results for wheat, sunflower, sorghum and rapeseed.

Reducing inputs requires **setting a lower yield goal than the potential yield**. In the case of wheat, this can involve seeding later or at a higher rate and reducing early nitrogen fertilisation. Doing so reduces the risk of lodging, and the risk of pests and pathogens, which in turn implies less pesticide treatments and growth regulators. Setting a lower yield goal can also lead to choosing varieties based on criteria other than maximum yield, particularly the variety's resistance to disease, which can further reduce inputs.

As early as the mid-1980s, experiments were conducted comparing two crop managements whose yield goals differed by 15 q/ha, and showed that it was possible to reduce yield without affecting gross margins. A lower yield goal led to a reduction of some 40% in crop costs. This was achieved as follows: 10% to 15% less nitrogen fertiliser, 40% less seed, 70% less fungicides and 100% less regulators.

During the 1990s, these early results were confirmed in a number of regions by INRA and various Chambers of Agriculture within test networks, and on experimental stations and farms. Research also showed that low-input crop management sequences were all the more advantageous as the price of wheat decreased: at FF125/q (i.e. roughly €19/q, the price of wheat in the early 80s), intensive crop management was the most profitable; at €10/q, low-input crop management generated considerably higher margins, on average. The variability of yield and margins did not increase with less inputs, because a controlled decrease in lodging and disease was also observed for the same system.

Low-input crop management has gained further credibility in recent years due to the marketing of **multi-resistant hardy varieties**. The potential yield of these varieties is 5 to 10 q/ha less than varieties of the same generation which are more productive but susceptible. In 1999, a network of crop management tests was set up for hardy varieties, by INRA, ITCF (Technical Institute for Cereals and Forage) and private selectors of the Economic Interest Group "Club des Cinq" at the initiative of INRA. Its aim was to test the agronomic and economic performance of different combinations { variety x crop management }.

Sequence	1	2	3	4
Price of wheat = €137/t				
Isengrain	78%	75%	51%	15%
Oratorio	48%	63%	69%	45%
Price of wheat = €91.5/t				
Isengrain	51%	57%	57%	33%
Oratorio	45%	57%	72%	72%

Sequence 1: unlimited potential yield and inputs

Sequence 2: ITCF recommendations 2000

Sequence 3: reduced yield goal and inputs

Sequence 4: same as System 3 but decrease in N (30 kg/ha less); 0 fungicides; 0 regulators

Isengrain: standard variety (productive and susceptible to disease)

Oratorio: hardy variety (less productive but multi-resistant)

Comparison of the economic benefits of the different "variety x crop management" combinations

% of tests (33 tests, 3 years, throughout France) where the Variety x Crop Management generates a better gross margin
(Hardy Wheat Varieties Network, 2000 to 2002)

The results over 2000-2002 demonstrate that the benefits of a hardy variety combined with a less intensive crop management increase when the price of wheat decreases. Regardless of the price of wheat, the hardy variety, Oratorio, achieved better scores for a less intensive crop management.

In addition, by choosing a good variety and changing fertiliser fractioning, it may be possible to maintain the same protein content in the seed. The main problem with the hardy varieties is that they are still relatively unknown on the market, perhaps because the seed distribution circuits are also those that distribute fungicides.

The sowing of mixtures of different varieties with complementary resistance is also a promising solution, as combinations of varieties regularly produce higher yield and protein content than pure varieties.

cycles of susceptible crops (for instance, avoiding late seeding of winter rapeseed so that it is not exposed to the *Leptosphaeria maculans* spores (causal agent of phoma stem canker) released in its earliest stages, which are the most susceptible).

- Managing the inter-crop period, for instance, sowing an intercrop between two commercial crops (to reduce nitrate leaching) or tillage, to reduce the stock of weed seeds and inoculum.

- Combining crops, for instance a cereal and a grain legume.

. Spatial organisation of crops

There are very few scientific references on the spatial organisation of crops beyond the field level. This type of organisation aims to limit the spread of pests via the crop rotation system, by creating a "mosaic" of crops, and by breaking up the agricultural landscape.

The methods used against different types of pests are as follows:

Weeds: 1) Reduce seed production by limiting emergence, 2) Increase crop competitiveness, harvest before maturity, and 3) Reduce weed capacity to germinate by deep burial (ploughing).

Decisions about crop sequence, alternating the depth of tillage and seeding dates result in conditions that hinder the development of the species most adapted to a given cycle. This was confirmed during infestations of foxtail that was resistant to herbicides of the "fops" family (aryloxyphenoxypropionates), which can be controlled by modifying the entire cropping system: total exclusion of this herbicide family, introduction of spring crops in the sequence, moving forward the seeding dates for autumn crops and ploughing.

Pathogenic fungi: 1) Reduce primary inoculum, 2) Limit contamination by managing less dense canopy, which results in a less favourable microclimate and 3) Use resistant varieties.

Soil-borne diseases: Destroy post-harvest residue. Airborne diseases: 1) Prevent by shifting crop cycles (susceptible stages) so that they do not correspond to spore dispersion periods and 2) Reduce the receptiveness of the plant cover by creating an unfavourable microclimate, for instance, by reducing the density of the crop stand or by reducing nitrogen fertilisation.

Choices have to be made depending on the dominant risk: for instance, a dense crop stand will better choke out weeds, but it will also favour fungal diseases.

9.4. Towards the "zero pesticide" objective

Stopping the use of synthetic pesticides involves a combination of consistent practices to keep the potential pressure of pests down to the lowest level. It also requires major changes in cultivation systems and the spatial organisation of these systems.

. Organic farming

Organic farming, which by definition does not use synthetic chemical inputs, has maintained the use of a few pesticides based on plant extracts (which does not necessarily mean they are harmless) and mineral substances (copper and sulphur as fungicides, the accumulation of which poses a problem in the soil). The existence of organic farming proves that production is possible in these conditions. However, it is difficult to develop, especially for perennial crops. Organic farmers produce low yields on average (36 q/ha for wheat), but which can also be respectable (e.g. nearly 70 q/ha for wheat), whilst being limited by the non-use of synthetic fertilisers.

. Designing new systems

Potential solutions also include "zero-pesticide" or nearly "zero-pesticide" systems, with the option of using synthetic fertilisers and pesticides from time to time – just as organic farming allows the occasional use of allopathic veterinary treatments and IFP allows the occasional use of pesticides – even if it means taking away the "organic farming" label from harvests that have been sprayed.

As with organic farming, these systems should combine several approaches that minimise plant health risks and available protection strategies with partial effects. Such systems would be especially useful in susceptible areas that require pesticides to be eliminated entirely or nearly entirely (see above).

9.5. Alternatives to chemical control

. Alternative Strategies and Techniques

The concept of "Alternative techniques", which suggests the existence of solutions that simply replace pesticide use, with all the advantages of effectiveness without the drawbacks of disturbing the environment and poor sustainability, hardly seems appropriate. Crop protection is not based solely on specific technological advances, but rather on the implementation of a wide range of technical, biological and economic know-how. Incorporating these into control methods is not necessarily easy. Deploying a natural enemy in a cropping system or implementing a new crop sequence is not as simple as spraying soil or crops.

Case study: Crop protection in field crop systems

The objective of this study was to illustrate, using a given production situation, the implementation of a series of measures designed to limit the use of pesticides in a cultivation system. Due to a lack of scientific references on this type of unconventional cultivation system, the study was carried out using specialists' statements only. It is based on an initiative of the ADAR (French National Association for Agricultural Development) project entitled "Systèmes de culture innovants" (innovative cultivation systems) developed by a group of experts from Chambers of Agriculture and technical institutes, among others. It was then complemented by the evaluation of the agronomic, environmental and economic performance of the cultivation systems proposed, and information on work time.

Subject

The example chosen was a winter rapeseed-wheat-barley rotation on "poor soil" (pebbly, clay- and lime-rich soil) in a northern region of France. Based on an initial "standard" situation with crop management systems that are dominant in today's farming landscape, three alternative cultivation systems were set up that limited the use of pesticides. The first system aimed at reducing pesticide use without changing the rotation. This reduction, which was limited by the initial rotation (short rotation, 100% winter crops), was based on the differentiated management of weed control and pesticide use. The second system aimed at a much more drastic reduction in pesticide use and ruled out all pesticides that posed major risks for the environment or human health. Meeting this objective involved making significant changes to the cropping system, including diversifying and extending the rotation. The third scenario increased constraints on means of action with a view to eliminating all pesticide use.

Results of the analysis

A comparative analysis of the 4 systems based on environmental and economic criteria showed that:

- Drastically reducing pesticide use without changing the rotation or doing away with simplified tilling, can considerably improve the environmental performance of the sequence. This was achieved by cutting down the frequency of applications by nearly 75% (in number of approved doses/ha, regardless of the active substance involved), and active substance per hectare and per year from 5,055g to 700g (i.e. 86% less in terms of quantity applied), using mechanical weed control methods and less insecticides. These improvements are probably only sustainable over a few years. It is very likely that this type of alternative strategy on short rotations will produce a weed seed stock that will rapidly become uncontrollable unless the strategy changes to include a considerable amount of herbicides.

- Switching to an Integrated Pest Management strategy, based on extending and diversifying the crop sequence, gives considerable freedom to the farmer. It allows for very low quantities of active substance (less than 5g/ha/year), thereby producing almost zero environmental risk and therefore similar results to a "zero pesticide system".

These alternative systems do not produce the same yields as conventional systems and imply significant variability of yield in some susceptible crops (e.g. rapeseed). This irregularity due to uncontrollable parasite-related incidents results in high variability of these systems from year to year in economic terms, which nevertheless on average produce nearly the same results as standard systems.

Operational costs are considerably lower in alternative systems, due to less pesticide use. On the other hand, significantly more time is spent working in the fields (on average: from 6.3hrs/ha to more than 9hrs/ha in the first case, not including observation time) because mechanical control replaces chemical control. In addition, observation time is necessary for training and informing oneself; this increases with the number of crops.

Conclusions

In examining the conclusions drawn from this study using specialists' statements, it is important to remember that it was conducted based on experts' knowledge about a particular situation, in a given environment, without scientific references on the quantification of the interactions amongst cultivation systems and biological components in the field or the effectiveness of alternative strategies. Despite these preliminary reservations, the case study demonstrates the broad scope of the approach. It shows the need for a more in-depth analysis of the consequences of different scenarios in terms of functioning of the farm, and other environmental impacts (energy, CO₂ emissions, etc.).

Nevertheless, the integration of methods for controlling crop enemies has two major advantages:

- It almost always leads to reduced harm to the environment, due to the fact that limiting the damage is no longer exclusively based on chemical control.
- The diversification of selection pressure by these methods can make them more sustainable than other individual control methods broadly applied over several years, such as pesticide application or the use of a variety with total specific resistance. Less pesticide use also results in better effectiveness as it defers the appearance of pests' resistance.

In fact, for all plant production, instead of turning towards "alternative solutions" for pesticide use, it would be better to develop a different way of thinking about protection and, more generally, production. This would result in less vulnerable crops, more effective (technologically speaking) and efficient (with respect to the economy, environment, society and long-term performance of systems) protection. This strategy is understood in the concept of *Integrated Crop Management*.

. Limitations of charters and "Good Practices"

The current fashion is to propose guides, charters and references for Good Farming Practice (GFP) to orient plant protection practices, and to evaluate them. This type of tool does not appear to achieve more than simple awareness on major-risk practices.

These charters and references are necessarily designed for very broad applications, which do not take account of the diversity of farming situations. They are generally represented as basic GFP lists, which integrate little of the interactions among techniques, which are in fact determining factors in integrated approaches that aim to reduce pesticide dependence in cropping systems and often decisive in the environmental impact of the systems.

Making a decision to work according to integrated protection or production methods is fundamentally different from the sequential implementation of basic GFP. The interactions between technical choices and the necessary adjustments to make depending on the diversity of situations should therefore be incorporated into the preparation of guides.

. Consequences for research

The concept of "integrated protection" can be integrated at two levels. The first is vertical: It is the combination of cultural, genetic, biological, physical, biotechnological or chemical methods to control a given pest population. The second is horizontal: Instead of seeking to control a particular crop enemy, it is the pest profile that is to be controlled. These two levels of integration require significant research.

What is more, most research projects on crop protection are conducted at the crop cycle and field scale, whereas the underlying processes often occur over several years or beyond the field scale. Broadening these scales will require major methodological changes, including working out a solution for collecting and exploiting data. Given these conditions, it is quite clear that modelling will be at the forefront of methods implemented to take account of these new scales. Thus, the development of crop management methods, adapted to the diversity of environments and varieties, will have to rely increasingly on mathematical models on crop functioning. These models do not have the practical limitations of experiments (costly trials in the field which cover a wide range of soil climate and technical and economical situations) and allow for testing of a vast number of scenarios that simulate the effects of modifying crop sequence management and cultivation systems.

▶▶ The principles of non-chemical protection are widely-known for the most part (e.g. knowledge of cycles, qualitative effects of the major techniques). However, at present, insufficient research has been done on their coherent integration into a crop management sequence, or, more generally, into cropping systems, for a wide range of objectives and constraints.

Field crops offer the most immediate flexibility for less pesticide-based pest management, whereas grapevines and market garden crops offer the least flexibility (Box 12).

▶▶ The testing of partially effective methods cannot be carried out by comparison with a pesticide. Such methods must be tested as elements of a strategy in which other partially-effective methods are also combined, in the particular production situation that the strategy has been designed for. Estimating the efficacy of these techniques therefore requires that experiments be carried out in the appropriate conditions.

▶▶ Rather than "control of crop enemies", it is rather the preservation of "the health of cultivation systems" that must be considered. The issue of the health status of crops must therefore be a crucial element to take into consideration in designing cropping systems.

Flexibility with respect to different types of crops

. Field Crops

Field crops offer the most immediate flexibility for less pesticide-based pest management. For instance, it is possible to modify cropping systems in the following ways: to extend rotations and organise cropping plans in such a way as to hamper the establishment and growth of pest populations; to use varieties that are less susceptible to disease and/or combinations of varieties; to set lower yield goals, thus allowing for later seeding and lower seeding rates, and less fertilisation; and to till the soil and alternate winter and spring crops, which reduce the emergence of weeds. Specifically for wheat-based systems, research on cultivation systems has shown that it is possible to reconcile both income and less chemical inputs. (see Box 10).

. Perennial Crops

Perennial crops are more difficult, because it is not possible to make rotations to disrupt pest cycles, and because these systems usually involve restrictions for using the most resistant varieties. However, there are crop stand management methods that can help limit the development of disease and pests. Sowing grass between rows (as long as the grass is not too competitive with the crop) allows for a reduction in herbicide use and the maintenance of auxiliaries. It also has the advantage of improving soil resistance and reducing erosion and run-off.

In fruit arboriculture, sexual confusion methods, when "rationalised" at the production level, can produce significant results, just as managing the landscape ensures the maintenance of auxiliaries. Pruning and elimination of primary sources of inoculum (leaves on ground) are other ways of reducing the abundance of certain diseases.

In viticulture, there are limited possibilities for implementing alternative methods. However, a distinction needs to be made between the following: pathogenic agents, which can be controlled through reducing the vigour of plants; and pests (insects and mites), which can be controlled using biological or biotechnical methods, where the maintenance of auxiliary fauna can in the majority of situations ensure the prevention of damage. Pilot experiments and demonstration of methods within regions have shown that pesticide-saving techniques would result in 30%-50% less pesticides in viticulture.

Surveys of wine growers have shown that the number of treatments applied is not proportional to the objective risks (as evaluated by Farm Warnings, for example), but tends to depend on the prestige of the wine, i.e. its sales price (which determines the financial resources available and an insurance strategy based on a predetermined application schedule), even though these farms often benefit from high-level technical management and could better optimise their protection programmes.

. Vegetables

Given the significant amount of labour generally required for vegetables, the cost of pesticides accounts for little in total production costs. In addition, farmers' aversion to risk is even higher as vegetables have high added value and as symptoms found in the harvested organs can result in considerable financial loss in the currently highly competitive market. Chemical control thus appears to be the simplest, most effective and cheapest method for managing vegetable crop enemies. The diversity of vegetable crops also increases the difficulty in developing standard alternative methods for chemical control.

These crops cover a wide range of production methods: vegetables in the open field, open-air market garden crops, protected crops (greenhouse or high tunnels) in the field or out. These crops have different structural levels of dependence on pesticides. For crops in the field, alternatives to fumigation to control soil-borne pests are not always available. When they are, they are more difficult to implement and their effectiveness varies. They include rotation management (insertion of "purifying" crops in the sequence) and crop management sequences (rationalising fertilisation and soil conditioners, adaptation of drainage and irrigation, etc.) and biodisinfection (combination of organic soil conditioners and solarisation). However, for years now, greenhouse crops have enabled the implementation of integrated crop protection strategies against airborne pests through the combination of resistant varieties and healthy plants during planting (preventive method), physical control of inoculum and pests (entrance locks, insect-proof nets, foot baths), micro-climate management, fertigation management and introduction of biological control agents.

In field crops, reducing pesticide use involves the acceptance of a lower yield goal. In the case of products such as fruits or vegetables, it may be necessary for consumers to accept flaws in the appearance of products which do not affect the quality of their taste or nutritional value.

Means

As a general cost-benefit analysis of pesticide use is not a practical proposition (see 6.1.), the role of economists is limited to evaluating the effects of varying decreases in pesticide use that could be imposed by the public authorities and of the various instruments available, including effects on 1) farmers' income and pesticide producers' and distributors' income, 2) consumer purchasing power, 3) the environment and human health and 4) the government's budget.

Most economic research on pollution regulation therefore more or less concerns the definition of instruments that will enable the achievement of goals at the least cost for society. Much of the research done on pollution regulation is theoretical. Even if it is not specific, this research has produced results that are directly usable for the case of pesticides. The design of (economically) efficient regulatory instruments is always based on the same major principles.

Therefore, systematic studies on the use or regulation of pesticides are commissioned by national institutions (or higher) that are considering public action (e.g. ministries, the European Union). As such, they are published in expert reports rather than as scientific publications on specific issues, that is, on original problems (economic mechanisms or econometric methods).

10. Principles and instruments for a pollution regulation policy

10.1. Principles

Several major principles, which form the basis for economic analysis, are behind the decision for a pollution regulation policy:

- **Only intervene when necessary.** From an economic point of view, the public authorities must only intervene when a given problem cannot be resolved spontaneously, that is, in a market economy. This is the case with pollution, as there are no mechanisms, or too few of them, that enable the "victims" of pollution to change the choices made by those who pollute, towards less emissions.
- **Deal as directly as possible with the source of the problem.** Since any active compound used is a potential pollutant, whether it is dispersed into the environment or remains on the crop, regulations must aim at reducing the use of pesticides and encouraging the use of the least toxic and ecotoxic products available.
- **Adapt the conditions of intervention to the goal.** Instruments of regulation must be all the more coercive or motivating as the goal is a priority. For instance, human health goals justify relatively "firm" means of intervention with respect to the level of product toxicity. This principle also requires adjusting a given instrument (e.g. tax rate, levels of standards, specifications of an agro-environmental contract) to the goal and/or using instruments designed for each particular situation.
- **Choose instruments with the best properties** (see evaluation criteria, Box 13): lowest implementation and management costs, long-term effects, etc.

10.2. Instruments

. Types of instruments

The principal types of instruments used in the case of pesticide pollution are:

- regulatory, restrictive approaches,
- instruments with economic incentive (market-based): equal taxation of pesticides for all farmers, subsidies for the adoption or utilisation of pesticide-saving practices that are adjusted according to the pollution reduction objectives, and soil climate conditions and/or production system conditions.

All measures that provide an incentive to reduce pesticide use can be effective on one of two levels, and preferably, both:

- Direct influence: Increasing the relative cost of using pesticides or introducing regulatory limits on pesticide use;
- Indirect influence: Lowering the relative cost of using alternatives to pesticides or introducing regulatory instruments that aim to increase the use of alternatives.

. The difficulty with a cost-benefit analysis of regulatory instruments

As part of its "Thematic strategy on the sustainable use of pesticides", the European Commission commissioned a study¹³ on the socio-economic impacts of the proposed measures. The report, delivered in 2004, attempts to

13. *Assessing the impacts of the specific measures to be part of the Thematic Strategy on the Sustainable Use of Pesticides*, 2004.

assess the costs and benefits of the introduction (at the scale of the EU with 15 or 25 Member States) of a few regulatory instruments, the majority of which are standards (restrictions on aerial spraying, identification of zero-pesticide areas, technical inspection of sprayers, etc.). The report provides an interesting assessment of the administrative costs associated with the instruments. However, it uses on a basic accounting approach, which does not take account of the economic mechanisms involved, and therefore does not mention certain costs and benefits. Furthermore, the calculations in the report are based on particular case studies, the results of which have then been extrapolated to produce figures at EU level. This method can result in serious sampling and extrapolation biases. These problems were in fact emphasised in the Commission's comments on the report by external experts (provided by Commission).

Box 13

Criteria for comparing the different instruments for pollution regulation

. Administrative costs of implementing the instruments

While often ignored in theory, administrative costs are a decisive factor in practice, and are now recognised as such in the definition of regulatory instruments for agricultural pollution.

These costs, incurred by the regulator (the government or the institution which the government designates for regulation purposes), include: costs of developing (e.g. expert reports, negotiation of instruments) and testing measures (e.g. follow-up of practices and compilation of data collected), information-related costs, cost of managing the implementation of the instruments (e.g. tax collection, subsidy payments, delivery of authorisations) and costs associated with the inspection/penalty systems.

As a general rule, the more individualised a instrument is and the more inspections it requires, the higher the costs associated with it will be, and therefore the less it ought to be used on a large scale.

. Feasibility and credibility of inspections

Standards and other regulations are often not observed as they should be with respect to environmental protection, as is true for road safety or income tax. It is therefore necessary to establish a sufficiently deterrent system of checks and penalties. Failing to do this implicitly favours an underestimation of environmental problems, as those who do not follow the rules will not feel they have committed a serious offence.

Environmental regulations pose particular problems. The deterrent nature of an inspection cannot be due solely to the frequency of checks or the extent of the penalty. Since doing harm to the environment or breaching a contract can only justify, from a legal perspective, penalties equal to the damage done, it is crucial to set up frequent checks, which is costly from an administrative point of view.

This criterion argues in favour of "zero-pesticide" measures, as they are much easier to enforce than "rationalised chemical protection" systems.

The politically controversial question about checks and penalties can also lead to consider as an option a code of good practices, which emphasises the goodwill and honesty of those targeted.

. Long-term incentive

Certain regulatory instruments can represent the same type of incentive over the short- to medium-term but have very different long-term effects. For example, as long as farmers observe the clauses of the contracts they have previously signed, they have no incentive to further reduce their use of pesticides. However, if, over the short- to medium-term, a tax achieves the same reduction of pesticides used, the incentive will continue to exist over the long-term, with respect to pesticide use, supply of the products and consulting on reduced pesticide use.

. Flexibility

The different instruments available allow varying degrees of flexibility to farmers in the solutions to be adopted to reduce pesticide use. This is one of the advantages of a tax, as it leaves farmers a choice in the methods they adopt to reduce pesticide use. The other instruments appear coercive and tend to "lock in" farmers' behaviour.

. Consequences and acceptability

The financial consequences of the regulatory instruments for pesticide use dictate, to a significant extent, their acceptability by the different agents concerned.

10.3. Spatial differentiation of measures

While the widespread contamination of the various compartments of the environment by pesticides suggests the overall reduction of their use, specific goals have to be set and instruments chosen and calibrated to achieve minimum objectives for the entire country.

However, pollution-related problems are more serious in some areas than others. Certain areas are more subject to (e.g. more pesticide transfer due to soil climate conditions, presence of heavily polluting farms) or susceptible to (e.g. ecologically vulnerable environment, activities that are incompatible with certain levels of contamination) pesticide-related pollution. These areas include: ecologically important areas (e.g. Natura 2000 areas), sources of drinking water, or areas with major conflicts over use of the environment, such as peri-urban areas, fish-farming areas or catchment areas used in the production of mineral water.

Implementation of the European Water Framework Directive (WFD) via the systematic search for bodies of water whose quality would be compromised by pesticide pollution, will help in identifying new "vulnerable" areas. These catchment areas will require the design and application of measures aimed at restoring water quality.

While moderate measures have been taken to reduce the effects of pesticide pollution in the least vulnerable areas, a more considerable, rapid and/or targeted decrease in pesticide use in the most vulnerable areas will require local adaptation to the measures or additional instruments.

The local nature of farming activities and their concentration in a given area are important factors in the regulation of farming-related pollution, and all the more so when the objectives for environmental protection are ambitious. The implementation of stringent measures for environmental protection can result in changes in production methods, or even in the crops themselves in the most vulnerable areas with a high concentration of polluting activities. This aspect of regulation is a difficult one, politically speaking, but it is nevertheless essential.

- In a country the size of France, it appears necessary to combine several instruments in order to:
- Resolve a problem that is not identical throughout the country, either by adjusting the level of instruments locally or by using some instruments only in specific cases.
 - Make the most of the respective advantages of each of the instruments available, some being more recommended than others in a given situation (e.g. global or local intervention).

11. Regulatory instruments

11.1. Regulation of (eco)toxicity of plant protection products and contamination thresholds

The main instrument is clearly the registration procedure for plant protection products, a fundamental step in controlling the toxicity/ecotoxicity of products introduced on the market. This instrument is widely recognised as necessary, even if its practical implementation is often the subject of debate. Thus, the recent reinforcement of ecotoxicity criteria, which increased the cost for pesticide registration, may have negative effects. For instance, it is noticeable that recent applications for registration have been mainly for large-market crops.

Specific changes could nevertheless be considered.

. Risk assessment and specified use for approval

The analysis of environmental risks (see 3.) has shown the need for several improvements:

- Updating of the criteria and tests to ensure the prior evaluation of ecotoxicological risks, in order to adjust them to changes in the chemical nature and action modes of new compounds, incorporating any new information on consequences for organisms and ecosystems, etc.
- More specific conditions for product use, including restrictions according to the type of soil, weather conditions, type of sprayer, etc.
- Taking account of the atmospheric compartment. The *Focus Air* group is currently working on this aspect; a report including an outline of the modelling tools available and an evaluation plan is soon to be published.
- Taking greater account of interactions between active substances and the inert substances and adjuvants, which can significantly alter the ecotoxicity of formulations.
- Development of post-registration follow-up, which is necessary to ensure the evaluation of ecotoxicological risks and the identification of any adverse effects that were not identified prior to the marketing authorisation.

. Clarifying decision on a new substance given the risks and benefits

Many questions have arisen about how decisions are made, in the current system, concerning the risks and benefits (as assessed by various entities) of a new product. The new law on agricultural orientations should include the creation of a national agency for plant inputs, or ANIV, under AFSSA, the French Food Safety Agency.

ANIV will be responsible for assessing risks and benefits, which should make the decision more transparent. Registration will remain the responsibility of the Ministry of Agriculture.

► It is important to observe the effects of regulations on choices made by pesticide producers. The more demanding a registration procedure is, the less companies will be motivated to create new products and to apply for a marketing authorisation for crops that represent a small market (risk of orphan crops). Establishing stricter conditions of use (e.g. banning use in certain areas), as long as they can be effectively enforced, may enable the authorisation of more products in areas that do not present any particular risks.

. Regulation of Contamination

Until now, maximum contamination standards existed only for drinking water supplies. Now, the same issue has arisen with respect to the environment, with the introduction of water quality standards, within the framework of the WFD, which should be identical to those for potability.

It seems (see 3.1.) that for certain substances, the concentrations which are predicted to have no effect, as determined during the ecotoxicological risk assessment for aquatic environments, are lower than the threshold of 0.1 µg/l. The introduction onto the market of active substances that require much lower doses than older substances, challenges the relevance of current thresholds.

11.2. Regulations concerning conditions of use

. Technical checks of sprayers

Voluntary checks started in 1995 resulted in the inspection of some 20,000 machines in service. Of these, 40% were in good condition, 40% required repair as soon as possible, and 20% required repair before use. These conclusions suggest that mandatory periodic checks of sprayers would be beneficial; they have been provided for in the Water Law project.

Although keeping equipment in good working order is necessary, it alone is not sufficient to reduce losses of pesticide during application. Drift, for instance, depends considerably on the appropriate settings of the equipment and application timing (weather conditions).

. Restrictions on application of mixes

The Ministry of Agriculture has attempted to limit the application of pesticide mixes by firstly establishing a positive list of authorised mixes; this was later replaced by the list of banned mixes. The restrictions are founded on non-association rules of products which have earned certain a reputation of risk rather than on an understanding of interactions between the active substances and their effects on organisms. In any case, it is not possible to contemplate acquiring information on all the possible combinations of active substances, breakdown products and adjuvants.

. Licence for application

In France, only those applying pesticides on behalf of third parties are currently obliged to obtain an authorisation. Requiring all pesticide users to sign up for training and obtain certification has been proposed in the framework of the European Thematic Strategy. Nothing seems to argue against this type of project, at least not in principle. A number of countries (e.g. Denmark, Italy) have already established the requirement of such a licence, or have at least made training of all professional pesticide users mandatory.

► Regulations associated with actual practices raise the issues of enforceability, of the possibility of demonstrating breaches that are not necessarily blatant offences, and of the relevance/effectiveness of the regulations if they set obligations of means.

11.3. Local standards and/or bans on pesticide use

In the most vulnerable areas, more stringent standards of use are called for, such as pesticide quotas (mandatory regulation of quantities) or total bans (of an active substance, type of area, etc.).

. Standards or quotas for pesticide use

Analysis of administrative costs shows that quota systems are expensive to manage. They involve considerable amounts of information to be transmitted between farmers, pesticide vendors and the regulator, in order to define a standard that is appropriate for the soil climate conditions and the characteristics of the farm, as well as to enforce the standard. Such a system tends to exclude the broad application of standards and quotas for pesticide use on a large scale and instead to favour measures that ban certain pesticides (no quotas for use), as they are easier to enforce (it is difficult to check whether or not a given pesticide has been used within the limits provided). Quota systems have the additional disadvantage of setting a certain level of pesticide consumption, which is contrary to the very principle of integrated crop protection.

These instruments should therefore be reserved for use in vulnerable areas or only in the event of acute problems.

Regional prefects ("préfets") currently have the option of issuing orders that limit the local use of a pesticide, in order to protect drinking water resources (in the event that use goes beyond that permitted by potability standards).

In the event of environmental damage that is considered unacceptable, more drastic measures should be envisaged which at a local level might call into question certain types of production. Laws on listed facilities are generally well accepted because they allow for a preliminary identification of polluting or potentially dangerous production activities. The same reasoning can be applied to organise the later identification of polluting activities, especially when these are established without taking into account their impact on the environment or when conflicting uses have changed (for instance, in peri-urban areas). Such bans must be accompanied by support for farms that comply with the established restrictions.

. Spatial restrictions and the conditionality of EU support

France has chosen to plant grassed strips along streams as a Good Farming and Environmental Practice provided for in the CAP. This ensures both the existence of a non-treated area and, at least in the majority of cases, protection of the stream against runoff containing high concentrations of pesticides. This measure also has the advantage of being easy to enforce.

12. Economic incentives to reduce pesticide use

The demonstration (see 5) of the influence of the low relative price of pesticides on their current level of use leads economists to believe that it is necessary to reduce the profitability of pesticides in order to diminish their consumption.

12.1. Decreasing the economic attractiveness of pesticides through taxation

For problems such as pesticide pollution, applying economic efficiency criteria shows that there are substantial advantages to regulation by taxes.

. Advantages of a tax

The main advantage of a tax on pesticides is that it would result in a direct increase in the relative cost of their use, thereby lessening their attractiveness for farmers. It also has the following benefits as a regulatory instrument:

- Because it involves low development and management costs, and more particularly, less inspection costs, taxation has a significantly lower administrative cost than other instruments (subsidies for use of pesticide-saving practices, standards or quotas for pesticide usage).
- Taxes can be adjusted depending on the levels of toxicity and ecotoxicity of pesticides, which can help direct the choices of pesticide users and producers.
- Taxes can be introduced gradually, according to a predetermined timeline or as use is reduced, which allows farmers to anticipate the effects of the taxes and to organise their farming and/or method choices to minimise consequences on the present situation and attempt to prevent them in the future.
- Taxes impose no technical requirements on farmers, leaving them to choose the technical methods they prefer to adopt.
- By reducing the profitability of chemical control, taxes encourage farmers to seek out pesticide-saving practices and can also motivate the creation of a market for plant protection consulting.
- Taxes are good incentives in the long term. They are a clear indication and a necessary incentive for developing alternative methods to chemical control (leading to innovations).

Lastly, a tax has the advantage of generating budgetary resources, even if these are sometimes overestimated.

. Level of taxation

The low administrative costs associated with taxation make it an attractive large-scale instrument. It should therefore be used to achieve the objective of reducing pesticide use set for regions outside of vulnerable areas. However, in order for the tax to fulfil its role, that is, achieve the goal of environmental regulation, its level must produce sufficient incentive and be calculated according to the objectives set. A tax system must be introduced in the context of discussions and negotiations aimed at defining a preliminary objective to reduce pesticide use.

A low tax would bring in revenue but would have no effect on the consumption of the taxed product (as has been the case with the TGAP established in France in 2000; see Box 14).

Taxes can easily be distinguished for various levels of toxicity and ecotoxicity with respect to active substances. This in turn can help orient current pesticide use and development of new pesticides in the future. On the other hand, a regional differentiation of tax rates, in order to modulate the effect of the tax, is difficult. Its enforcement would imply exceedingly high costs (to prevent farmers in low-tax regions from buying pesticides and selling them to farmers in highly taxed regions).

. Tax revenue: Amount and re-distribution

Although it is not its main objective, a tax generates revenue, which the government can use as it sees fit. No economic arguments have been put forward that show that the revenue generated by the tax must be used to finance measures in the same industry (the principle of a “user fee”¹⁴). However, at a political level, it is clear that “returning” those funds to the industry sector which first provided them facilitates the introduction of the tax itself.

If the decision is made to use the tax revenue to finance measures in the sector being taxed, it is crucial that the amount of the user fee not become determined by the initiatives to be financed. Indeed, representatives of this sector having to pay the tax are likely to seek to lower the fee by minimising the actions to be financed.

Box 14

Taxes on Pesticides

. General Tax on Polluting Activities (TGAP) in France

The TGAP was established in 1999 and, in 2000, was extended to “antiparasitic products for use on farms, and other similar products”.

The tax is applied to the first delivery of a product on the French market. It is thus collected from 12,000 to 13,000 distributors in France. The tax is based on a given product's proportion of substances classified as dangerous. These substances are organised into seven categories, each with a specific unit tax (€0 to €1,677/tonne) according to their ecotoxicological and toxicological properties.

Over the 2000-2003 period, the tax brought in an average of €32m per year, i.e. less than 2% of pesticide expenditure in France. The tax is therefore not substantial compared to the price of pesticides and it can hardly be expected to modify the behaviour of farmers.

. A pesticide “user fee”

The French Law on water and aquatic environments provides for the replacement of the TGAP with a user fee, to be collected by public water agencies according to the quantity of pesticides used. The fee in question will distinguish just two levels of toxicity for humans (no environmental objective) and part of the revenue collected will go to farmers who implement techniques to reduce pesticide pollution of the water.

The fee will not be much higher than the TGAP. Expected revenue is €40m, or 2.2% of pesticide sales over the 2003-2004 period (€1.7b). The fee would thus cover less than the sole cost of treating pesticide-contaminated water for drinking, which the public water agencies estimate to be between €50m and €100m – a sum which is expected to rise as the substitution strategy adopted when a particular water supply becomes excessively contaminated is reaching its limits.

The low fee and the fact that less than 30% of revenue collected will be redistributed to pesticide-saving farmers give reason to think that this new measure may well also fail to be an incentive.

Case studies abroad

In Denmark (see Box 15), the tax was low (3%) when introduced for the first time in 1986. In 1996, it went up to 13% for herbicides and fungicides and 27% for insecticides, and again in 1999, to 33% and 54% for the same products, respectively.

In Norway, taxes are differentiated according to the toxicity of the products. They are much higher on products designed for amateur gardeners.

. Taxation and income of farmers

Placing a tax on pesticides puts the onus of pollution regulation on farmers and pesticide producers and distributors.

14. In the French administrative meaning, taxes are entered into the government's general budget, whereas a specific use is designated for the income from user fees.

If the government wishes to compensate the effects of the tax on farmers' incomes (in order to better distribute the social costs of regulation or for other reasons), it is important that they choose instruments that do not take away the incentive of the tax. For instance, deciding to impose a low tax in order to minimise effects on farmers' incomes is tantamount to reducing environmental goals.

Reducing pesticide use and providing support to farmers are two distinct goals. If the government decides to use taxes to satisfy the first goal, the best way of also achieving the second is to compensate farmers directly (subsidies based on number of farmed hectares if seeking to ensure the use of the land, and subsidies based on active workers if seeking to preserve farmers' jobs, etc.). The advantage of these compensations is that they are in line with the principle of "cross-compliance" of European aids and also with WTO rules.

12.2. Supporting pesticide-saving practices

It is important to distinguish (temporary) subsidies for the adoption of a technique and subsidies (unlimited time) for utilisation of that technique.

. Disadvantages of subsidising the utilisation of practices with minimal pollution

Although technically speaking, in the short term, placing a tax on a practice to be discouraged and providing a subsidy for an alternative practice to be encouraged are equivalent, economic efficiency criteria argue in favour of taxation. Subsidising the use of practices that produce minimal pollution (voluntary regulation of quantities) have several disadvantages: high development costs, difficult and costly enforcement, little incentive and risks of negative impacts in the long-term.

These subsidy contracts for the use of good farming practices are established on a case by case basis, and are therefore very expensive (they must be uniform, and are therefore unnecessarily restrictive for some farmers and useless for others). An expensive inspection/penalty system must be set up subsequent to the signing of the contract.

The incentive associated with these subsidies is limited to use of subsidised practices, the list of which is further limited to practices that are easily verifiable. They provide little incentive in terms of developing innovative techniques to reduce pesticide use, as the subsidised practices are predetermined. Such subsidies can also have perverse effects in the long term because they make the subsidised industry more profitable; this in turn can lead to (if the inputs are also associated with subsidies) a growth in the industry which can eventually generate more pollution than the initial situation.

Using these instruments as the basis for pesticide pollution regulation, that is, as a global measure, over the entire country, seems hardly relevant. Indeed, they seem more appropriate for particular situations such as vulnerable areas (see below).

. Advantages of subsidising the adoption of innovative practices

Because pesticide-saving practices must be tested and then adapted at the local level, their adoption generates specific costs, in terms of observation time, risk-taking and/or loss of income (see 5). Without government intervention, the adoption of innovative practices may be slow and of a limited extent, even when the practice itself is recognised as effective.

Government intervention is justified when innovative practices produce benefits for society and when their adoption exhibits network effects. The government may then subsidise the adoption phase for these practices, thereby jumpstarting the process of spreading the new practices (as the first farmers to try the new practices will serve as examples and help spread information to their neighbours and colleagues). These aids can also be distributed to collective organisations such as agricultural development groups.

It is important to remember that subsidising the adoption of innovative practices (as recommended by the EU) is only justified when temporary. Subsidies must not be provided when the practices in question are sure to prove profitable once mastered; in other words, farmers will no longer need support after reaching "cruising speed". Permanent subsidies are a completely different question.

. Contractual approaches in sensitive areas

When the situation does not substantiate the local establishment of strict standards, or, more specifically, the banning of pesticide use, contractual approaches may be used. Contractual measures that give farmers the right to compensation are permitted by the EU, since they require farmers to make efforts beyond that required elsewhere.

This approach applies to practices that are not profitable in existing market conditions, even when mastered. Permanent public support may be appropriate if the practices imply social benefits that are not compensated by the market, as is largely the case with the quality of the environment.

The instruments available range from individual contracts co-financed by the EU within the framework of AEM (Agri-Environmental Measures) to collective approaches, for example, when it becomes necessary to reduce the concentration of pesticides in a river (e.g. based on watersheds).

The subsidies for moderate to demanding pesticide-saving practices remain expensive, even when applied only at the local level.

Thus, the administrative costs of the European agri-environmental measures are estimated to be equal to the subsidies paid out to farmers (for every €1 paid to farmers, €1 must be spent by the institutions in charge of the measures). Analyses have shown that this is due to 1) the great number of contracts offered, 2) the fact that each contract is signed by few farmers; and 3) the relative novelty of the system. A greater number of farmers willing to adopt the practices would allow a better distribution of certain overhead costs and the learning effect could be exploited once there was more experience with these contracts.

A contractual approach could also be implemented privately, when it is in the pollution “victim's” interest to help the polluter reduce emissions, and when that entity has the necessary means to do so. This was the case with the water company, Vittel, when it organised and financed conversions to organic farming in the area supplying its groundwater, in order to stop the rise of nitrate levels. Vittel S.A. implicitly recognised that the farmers had a “right to pollute” and, via the contracts it offered them, bought back this right. This reasoning is similar to that used by the EU in the compensation of farmers’ attempts to comply with that requested when it goes beyond basic respect of general regulations. Here, the compensation was given by Vittel, rather than the public authorities, as the company is the main beneficiary of the efforts made by the farmers.

Locally implemented instruments are all the more effective (and their setting-up costs all the lower) when global instruments play their designated role. The system of taxing has the effect of reducing the subsidies (or compensation) to farmers for adopting the contracts proposed locally.

►► Taxation offers several advantages (low administrative costs, flexibility, incentive in the short- and long-term), which make it the instrument preferred by economists. In order to be effective, it has to set truly deterrent rates, which may be reached gradually, but according to a predefined and credible timeline.

Taxation also stimulates the supply of pesticide-saving practices and alternative methods to chemical control. In this way, taxation is a stimulus for any measure aimed at achieving the adoption and utilisation of pesticide-saving practices.

Taxes thus tend to render subsidies for utilisation of pesticide-saving practices useless. However, such subsidies can be helpful when used temporarily to encourage and accelerate the adoption of innovative practices or in a more permanent way, in a contractual framework specifically for vulnerable areas.

The main disadvantage is the high costs involved for farmers, although it may be possible to directly supplement their income in certain cases (e.g. non-viability of crops or farms that society wishes to maintain). In addition, the tax is not sufficient on its own; other, more global measures relative to the technological and economic environment are also necessary.

13. Global actions tackling the technological and economic environment

13.1. Support for organisation of the technological environment

The development of a technological environment that is conducive to the technical efficacy of a given production sector can have a considerable impact in terms of competitiveness and environmental protection. The public authorities have an important role to play in regulating pesticide pollution, both in agronomic research and agricultural consulting.

. Funding agricultural research

Government intervention is justified when certain innovations take on the characteristics of a public good, and are therefore less attractive to private companies for production. For instance, it would be difficult to register a patent on cultivation practices (e.g. development of low-input crop management) which would provide their designers with a percentage of the profits associated with their use. Private-sector companies are not always prepared to invest in innovations with limited markets (e.g. biological control for a minor crop) or exploratory research (e.g. genetic improvements using new criteria). Public research therefore has a crucial role to play in designing and developing pesticide-saving protection techniques and cultivation systems.

It is also important to communicate information about the expected effects of techniques developed in this way. If farmers know that pesticides will be heavily taxed or strictly regulated in the future, they will seek out pesticide-saving practices; however, they will only adopt them if they are convinced that there are potentially significant economic gains associated with their use and few uncertainties about their effects.

. Financing certain types of consulting and training

While changes in regulations and the economy may favour the emergence of private-sector consultants on crop protection, this consulting will probably only involve farm-specific advice. Information at a larger spatial scale is

difficult for a private company to assess (the farmers in question should in that case join forces and share the purchasing cost). That is why the production and communication of infestation forecasts on a small regional farming scale have traditionally been carried out by regional plant protection departments (SRPV) via "Farm Warnings". However, there are other options, for instance, providing subsidies to private companies, technical organisations or farming groups, to ensure the communication of land data and thus contribute to the production of public information.

The fundamental role of agronomic knowledge about the implementation of pesticide-saving practices also calls for government investment in instruments which encourage the initial and continuing training of farmers (development of agricultural education, funding of specific training programmes and financial aid for private training).

At present, the proposals outlined in the Pesticides Plan emphasise the protection of the pesticide user and training for prevention of exposure-related risks, and do not provide for training that would involve new crop protection methods.

13.2. Working on relations between the agricultural industry and the upstream and downstream industries

The measures above concern the use and quality of pesticides only and are mainly designed for farmers. It would also be interesting to bring other industries into the equation and to develop more global initiatives.

. Relations with consumers and food distribution

Support for more environmentally-friendly agricultural methods can be provided at farm-level, but can also consist of measures aimed at developing specific markets: quality label policies, consumer awareness campaigns, development of specific marketing channels, agreements between the government, mass distributors and processors, and so on.

One such measure has already been applied in the Netherlands, California and England and it is being considered in the rest of the United States as well as in Denmark. These countries are introducing and promoting a variety of ecolabels to encourage consumers to express their preference for products made using truly environmentally-friendly agricultural practices.

Organic farming is potentially interesting in this context. If bans on certain pesticides are imposed locally, organic farming would offer an alternative to those farmers. It is already being used by various stakeholders on the market (e.g. Vittel water company) and institutions (cities like Munich) to protect water resources.

Organic farming presents several advantages. Firstly, it is carried out according to a transparent set of specifications. Secondly, its products are not subject to the same requirements as standard products, particularly in terms of appearance and storage duration for fresh products. Thirdly, it can, to a certain degree, self-finance itself if its products are valued on the market. Finally, export options may exist, particularly to Scandinavian countries, Germany and Switzerland. An additional benefit of developing organic markets is that it gives consumers an opportunity to demonstrate their preferences and to participate in financing pollution-reducing policies through the purchase of more expensive products.

. Relations with the agri-food industry

The initiatives taken by several major companies in favour of organic products or, to a lesser degree, integrated farming products, illustrate the fact that mass distributors may have an interest in this area, especially in terms of image. Partnerships with distributors are necessary, in particular, due to the role of pesticides in the storage and appearance of fresh produce.

In the same vein, processors of farm products can influence the crop protection practices of farmers by adjusting their specifications. Here, too, agreements could be signed between the government and processors. Unfortunately, it is difficult to estimate the impact of these agreements, as the issue has not been looked into sufficiently.

. Relations with agricultural suppliers

It is important to clarify the role of pesticide vendors with respect to crop protection advice, and to further analyse the proposal that companies that sell pesticides could make up for losses in product sales by providing consulting services.

The example provided by human medicine, where advice on and the prescription and sale of medicines are provided by different entities, is an interesting one that could be used in pesticides. Thus, pesticides could, as at present, be sold by supplier cooperatives or private companies, and "prescribed" by entities independent of pesticide sales (possibly by Chambers of Agriculture, the SRPV (Services Régionaux de la Protection des Végétaux) or FREDON (Fédération Régionale de Défense contre les Organismes Nuisibles), both regional organisations against harmful organisms, or private consulting firms), while the role of consulting would be assigned to technical institutes, research organisations or the specialised press.

The Danish experiment

Denmark has set up the most ambitious measures for reducing pesticide pollution in the EU. Its goal was to eliminate the least environmentally-friendly pesticides and to limit use of all others. Launched in 1986, the Danish action plan is now in its third phase.

In 1986, the first action plan was developed with two goals: to make the procedure for approval of compounds more demanding, and to cut total pesticide use in half over 10 years. At the end of that period, 213 compounds had been reviewed: 105 were not presented for approval, 30 were banned or more strictly regulated, and 78 were approved. Over the same 10-year period, sales of active substances went down by 40%, mainly due to the replacement of old products by new substances, which were active at lower doses, and agricultural area decreased by 11%.

The number of applications was measured using the Treatment Frequency Index, or TFI: average number of approved doses applied over the entire country's UAA, all pesticides included. No significant changes were observed in the TFI with the first plan.

The action plan included research, consulting, obligatory training programmes for all pesticide users (2 days for personal users and 2 weeks for farmers who sprayed pesticides outside of their farm), and taxes on pesticides. The taxes were low at the beginning (3% in 1986). In 1996, taxes on herbicides and fungicides rose to 13% and on insecticides to 27%; the same taxes rose again in 1999, to 33% and 54%, respectively.

In 1997, the Danish government created the Bichel Committee to estimate the consequences of the varying decreases in pesticide use in Denmark, including conversions to organic farming. In its conclusions, submitted in 1999, the Committee affirmed that the total elimination of pesticide use would result in major restructuring of the agricultural industry and a decrease of 40% to 60% in cereal acreage, but that reducing the number of applications by 30% to 40% could occur without major economic impacts on farmers.

The TFI stood at 2.67 in the early 1980s, edged down to 2.5 in 1999 and dropped to 2.04 in 2002 (after the application of the second action plan). The third action plan (2004-2009) has set the goal of lowering the index to 1.7 by 2009.

The principal instruments used are additional consulting to farmers to help them reduce pesticide use, development of model farms and group information, and additional alert systems and decision support systems. To complement the consulting, Danish authorities have set up firm measures, including banning the use of certain compounds, taxes and agreements with the industry, and more flexible measures, such as distribution of a list of "inadvisable" active substances, promotion of "clean" products, information campaigns on how consumers can avoid undesirable substances, and green labels. The measures, which are of an economic nature, allow the agricultural industry the choice of which methods to use in order to satisfy them.

► *The Danish policy is exemplary with respect to its coherence. It is a real case and uses, to a large extent, the instruments established by the CAP. Aside from the conditions of its implementation (step-by-step, expertise, measurable objectives, etc.), the Danish policy is founded on three cornerstones:*

- *It implements various instruments, each of which is set up to meet one or more objectives at an appropriate scale.*
- *It is based on various instruments with synergistic effects.*
- *It uses instruments the level of which can be adjusted according to the choices made by society.*

The Danish policy is a model that can be used as long as adaptations are made for the situation in question.

13.3. Connections to agricultural policy and other environmental policies

Until now, the regulation of pesticide pollution has been considered in an isolated fashion. However, it is evident, at least for some crops, that measures aimed at reducing other farming-related pollution should be closely linked to measures for the regulation of pesticide use, due mainly to the association between fertilisation and crop protection at an agronomic level. It seems that insufficient research has been done on the benefits of coordinating policies regulating the different types of pollution of agricultural origin.

. Changes to the CAP

Changes made to the CAP can have an impact on the production choices and yield goals of farmers, and thus on crop protection issues. They also offer attractive opportunities.

The CAP reforms adopted in 2003 will no doubt influence pesticide use. It is important to study the possible impact of changes in the payment of the aids provided for in the so-called "first pillar", which are now largely dissociated from production (yield and crop rotation systems). The reform will curtail support to the bigger farms, in particular, to (irrigated) maize crops. In this way, the reform will also reduce any interference between crop support and environmental policies. Furthermore, direct payments will ensure a steady income to producers of field crops, thus enabling them to accept certain risks. As far as reducing pesticide use is concerned, the reform may have positive or negative effects, especially because it is likely to result in major changes in crop rotation systems.

The most recent reforms to the CAP have promoted the multifunctionality of agriculture (especially its role in maintaining rural areas and quality of the environment) in order to justify continued agricultural support. Multifunctionality must be taken into account when setting objectives for environmental regulation rather than after objectives have already been defined, and instruments are being chosen for this regulation (in order to potentially argue against instruments that might have negative effects on other aspects of multifunctionality).

Preparation of the next Rural Development Programme (RDP) and the likelihood of stricter application of cross-compliance measures in the future may provide an opportunity for designing measures that better meet pesticide-reducing objectives.

Article 69 of the CAP reform offers the possibility of supporting environmentally-friendly agriculture, including organic farming, which is only entitled to a conversion aid in France.

. Risk management in agriculture

The European Thematic Strategy provides for the development of insurance schemes against potential crop losses in order to minimise preventive applications.

The broader question of risk management in agriculture has been the subject of a number of reports in recent years. Two options exist: a system based on contracts per crop and type of risk, as exists in the United States, or shared insurance schemes (e.g. multirisk and multifarm contracts, signed by as many farmers as possible), to take account of climatic risks, but which could be extended to other risks, including plant protection (which depend on climatic conditions, to a greater or lesser extent).

The second option should be further explored, but it is important to recall that while insurance schemes necessarily result in greater stability of operating income, by definition, their profitability (or, at the very least, financial equilibrium) and effect on pesticide use are far from certain. The US is proof of this, even if the approach used was in fact the first option, and even if European and American cultivation practices are considerably different for certain productions.

Insuring crop harvests could play an important role for special crops (especially perennial crops). Nevertheless, this approach would only significantly reduce pesticide use if the percentage of pesticides used to reduce production variability was already high.

▶▶ The measures mentioned here are clearly not the only ones available. However, these appear to have characteristics and a certain coherency which make them economically efficient. The Danish example demonstrates that a regulation policy based on a set of measures combining tax-based incentives and various support measures to implement pesticide-saving practices is in fact achievable.

▶▶ It is important to distinguish vulnerable areas, which necessitate more significant reduction of pesticide use and therefore the introduction of additional instruments. These situations may call for more stringent measures.

▶▶ In light of the complexity of the issue of pesticide pollution, it is crucial to adjust the timeline to environmental objectives. More ambitious goals for reduced pesticide use will require longer-term policies. It is necessary to give the various agents (farmers, pesticide producers and dealers, technical organisations, research organisations, consulting firms, etc.) time to find the best solutions to regulatory and economic changes. That said, establishing a regulation policy should be a rapid and firm process.

Three types of objectives

Based on the bibliography used, it is possible to set out potential methods for improving the current situation, in terms of reducing the use of pesticides and their impact on the environment, through three objectives, in order of increasing ambition.

. **Objective Type "T"** (for Transfer): To curb pesticide transfer.

At this level, which assumes that pesticides are being used, initiatives are required that aim to limit contamination by pesticide products and their impacts. To meet Type T objectives, corrective actions are needed which i) do not in theory involve reducing pesticide use further than the recommended doses, ii) promote optimum crop management for the environmental plan, within the range of commonly-used cultural practices, and iii) recommend specific changes to the landscape or the use of natural buffer zones.

In terms of actions to be implemented, Type T objectives cover four sub-objectives: Adapt the use of pesticides to environmental conditions; Limit dispersion during pesticide application; Limit transfers likely to occur after application in the field; and Trap any leaks beyond the field.

Type T objectives rely on known techniques, which are established in experimental farms or by an often small number of farmers, and which remain slow in spreading. As effective as they are, the measures involved are limited in cases of significant pesticide use or particular soil climate conditions. On the other hand, even if the relationship is not completely linear, lower ambitions may be appropriate as pesticide use is progressively reduced.

. **Objective Type "R"** (for Rational): To reduce pesticide consumption by further rationalising their use.

Treatment decisions are increasingly more rational; however, rationalising pesticide use is not independent of the amount of information available on the health of crops, available decision support systems, or the economic climate and decision-makers' management of risk. All of these are elements that it is possible to influence through technical means or socio-economic instruments.

This objective can be broken down into six sub-objectives: Better understanding the relevance of the treatment or the treatment programme; Choosing the best adapted product; Targeting and improving treatment efficacy; Better managing risks of resistance; Improving knowledge of practices and advice; and Promoting self-evaluation of practices and advice.

Some information is already available and can be applied. To facilitate this, it appears necessary to 1) encourage less use of pesticides via the introduction of a tax at a sufficient level as to act as a deterrent, and 2) to support any changes in training, information-provision or consulting that contribute to the rational use of pesticides, no doubt through new organisations that will be less dependent on the marketing of pesticides.

. **Objective Type "S"** (for Systems): To reduce pesticide consumption through cultivation systems that limit plant risks.

Crop protection strategies are based on the choice of cropping systems that reduce the risk of pest development. These cropping systems need to be designed at the local or regional level, according to soil climate properties and pest profiles. More ambitious pesticide-reducing objectives will require more significant transformation of current systems. Many elements can contribute to these low-parasite-risk cropping systems: the choice of less susceptible varieties, plant cover management that is unfavourable to pests, combined strategies for weed control with respect to some annual crops, sowing grass between rows of perennial crops, biological control, inter-crop management, rationalising sequences and/or crop combinations, land coordination (crop mosaic, rural planning and development), etc.

These objectives are ambitious but no doubt necessary, at the very least in the most pesticide-sensitive areas. Deadlines must be set for these objectives and accompanying measures should be considered. Here, too, a tax on pesticides may be just what is required to raise awareness and prompt change towards other cropping systems; in that case, interventions will be needed to ensure the stability of farmers' income, establishment of experimentation-demonstration platforms, organisation of consulting entities to ensure a smooth transition, and the mobilisation of research and development to design and promote the necessary innovations.

At its most ambitious, this type of objective involves designing pesticide-free cultivation systems (**S+**).

► The three types of objectives provide a framework for analysing existing knowledge and the technical, social and economic means available as well as their conditions for implementation to achieve the different objectives. They do not represent alternatives, nor are they successive stages in a general action plan, which is not the goal of this report.

It seems likely that the last objective type will have to be eventually met in the majority of situations. Nevertheless, at least in the beginning, the degree of strictness, as defined locally, according to local stakes and priorities, will determine which type of objective is most appropriate.

Conclusions

1. Dependence of the agricultural industry on pesticides

Production systems are all too often designed to maximise yield potential, assuming that plant health problems will be dealt with later through the simple use of pesticides. This reasoning has led to the development of specialised, intensive cropping systems, which in fact stimulate the development of pests. In these conditions, which maximise health risks, pesticides understandably appear necessary and extremely effective.

In addition to this technical aspect, pesticides are relatively low in cost, compared to other production factors and agricultural productions themselves. On the other hand, the most effective pesticide-saving techniques, which are more complicated to implement, generate significant direct and indirect costs, mainly related to the acquisition of information needed for their implementation.

The technical and economic dependence of agriculture on pesticides is also reinforced by distributors' and consumers' demand for flawless products that can be stored over long periods of time as well as the fact that plant protection advice, the selling of inputs and collection of crops are carried out by the same entities.

2. Proven and plausible risks

Environmental risks are inextricably linked to the nature of pesticides, which are by definition toxic for some living organisms, even at low doses, and therefore necessarily have effects on non-targeted organisms and ecosystems. The effects are known and include the death of organisms, and direct, non-lethal effects on reproduction or predatory behaviour, which in turn have indirect, deferred effects on food chains, biodiversity, etc. Demonstrating this in the field is nonetheless difficult, as the monitoring systems currently in place are insufficient, the nature of the biological effects is not specific enough, and there is a combined effect of many factors (e.g. multiple types of pollution, physical breakdown of the environment).

The agricultural industry currently faces:

- The waning effectiveness of pesticides due to massive use, which increases the probability of resistance amongst targeted pests. In France, all types of production (field crops, fruit arboriculture, grapevines) are currently faced with resistance problems, which concern the majority of pesticide chemical families;
- An economic risk associated with the competitiveness of products of more environmentally-friendly types of farming, which many consumers from various European countries are increasingly turning to.

Risks to **human health** (which are not examined in this expert report) appear sufficiently plausible to be mentioned in all the Health-Environment reports and plans, and also to justify epidemiological studies and the commissioning of an expert report from INSERM, the French Institute of Health and Medical Research.

3. Lack of data makes diagnosis difficult

The use of pesticides is not well known. Published data consists of aggregated national pesticide sales; no regional breakdown of these data is currently available. Knowledge about pesticide practices remains limited, in large part, to statistical analyses of the number of applications, which do not take account of interactions between different techniques, and without understanding their determining factors. It is difficult to estimate the levels of pesticide use because the damage that pests cause, or could cause in the absence of any protection, are poorly quantified outside of intensive systems.

Environmental contamination and impacts are difficult to quantify. Even for water bodies, the best monitored environmental compartment currently available, measurement systems do not enable an exact quantification of contamination or any changes in contamination. Existing data on air are fragmented, and inexistent for soil, both of which nevertheless play a central role in the retention and transfer of pesticides to other environments.

In addition, the monitoring systems that might identify the effects on organisms and ecosystems are not sufficiently developed. In these conditions, there are rarely the data necessary to establish a causality relationship between pesticide use, a characterised contamination of the environment and an environmental impact.

Information about both pesticide use and its impact is lacking or uncertain. To get round this, it is necessary to introduce systems for collecting long-term information, coordinate existing systems (e.g. water contamination), make use of non-exploited data (e.g. farmers' recording of their practices) and data that has not been thoroughly analysed (e.g. SCEES survey). Subsequently, it is crucial to define relevant indicators in order to monitor the changes in plant protection practices and their impacts.

The information currently available does not enable an overall cost-benefit analysis of pesticide use, based on which it would be possible, ideally, to develop a regulation policy. This situation does not preclude cutting back pesticide use as an objective of voluntarism.

4. Use of pesticides must decrease in order to limit impact

Although existing knowledge is lacking in some aspects, it nonetheless prompts action. Knowledge about the fundamental mechanisms is sufficient and the conceptual frameworks exist, to provide a preliminary estimation of the benefits and risks expected, if any, with a given initiative or set of initiatives which emphasise crop protection with less pesticides and/or reduce the impacts of pesticide use.

. Top priority: Reducing the dispersion of pesticides into the environment

The large-scale implementation of proposed corrective measures will probably contribute to improving the situation. As the effectiveness of these measures is nevertheless dependent on climatic factors, which are uncontrollable, they alone will not be able to ensure a significant decrease in pollution. Consequently, a considerable reduction in pesticide use appears indispensable to achieve the ambitious objective of reducing pollution.

. Optimising Pesticide Use: An impact not be overestimated

For quite a long time now, technical institutes and consulting organisations have sought to promote methods to supervise chemical control of numerous pests. This would eliminate some routine treatments, and, more importantly, would likely reduce the doses applied and the potential consequences, through the choice of a better-designed product and observation of conditions that ensure improved effectiveness. The opportunities to reduce pesticide use nevertheless appear limited in cropping systems that generate significant crop pest and disease risks. In addition, the practices involved are expensive and include constant monitoring of fields, which implies significant working time and qualified workers, the risk of significant losses in case of poor diagnosis, risk for the next crops if the fact of not applying treatments results in the maintenance of residual pest populations, etc.

. "Alternatives" to chemical control: no turnkey solutions

Farmers are interested in alternative techniques that are as easy to use, effective and cheap as pesticides, as well as more technically sustainable, which allow them to achieve their high yield goals. Unfortunately, there is no technique that matches those specifications at the present time.

The total genetic resistance of certain varieties to pests, an ideal substitute, has proved to be just as vulnerable to the targeted pests' circumvention techniques as pesticides. This is often the case with all total control techniques, whether chemical or biological. Physical techniques, such as mechanical or thermal weed control, avoid this risk, but represent more working time (and energy) than spraying, and are not a viable solution for large surface areas (as is the case for protection nets). Other techniques, such as partially-resistant varieties, biological control or tillage, are only partially effective. They are effective against pests when combined, and as long as cropping systems and management of the crop state reduce the risk of pest development. There is a wide range of methods available, and the optimum combination is determined based on the production situation.

. Integrated production is a must

"Alternative techniques" on their own thus do not appear appropriate. Instead, alternative strategies should be used for crop protection, based on the gradual implementation of several major action principles, foremost amongst which is the prevention of plant health risks. This is the aim of integrated production, which reintegrates, on new scientific and technical bases, the management of pests into the layout of cropping systems, or production systems. This management method considers the health of cultivation systems rather than control of crop enemies.

This approach goes beyond that of good farming practices, as listed in codes, charters and references, which are defined for areas that are too vast to take account of the diversity of production situations and which do not generally take account of interactions among techniques.

Organic farming has demonstrated that it is possible, albeit difficult, to forego the use of synthetic pesticides. Other potential solutions include systems that would tend towards zero-pesticide approaches, without forbidding the use of synthetic fertilisers and the occasional use of pesticides in the event that non-chemical preventive and curative measures have failed.

5. The means necessary for a pesticide-reducing policy

. Instruments available

- **Regulatory instruments.** These could include stricter criteria for pesticide approval, the development of post-approval follow-up, obligations such as periodic technical inspection of sprayers, and the introduction of a general licence for application and local restrictions on pesticide user in vulnerable areas.

- **Economic incentives** for adopting pesticide-saving practices. Because support systems for the use of preferred techniques are costly to develop and enforce, and because they are not incentives in the longer term, they must be temporary and reserved for the adoption phase of these new techniques. A complementary option that is both affordable and viable in the long term is the introduction of a **tax** on pesticides. The tax must be high enough, as

proven by Danish experience, to provide sufficient incentives, including in the long term. Direct income support, determined according to the situation, may prove necessary in order to compensate farmers' financial losses.

- **Additional measures** to facilitate switching over to other plant protection strategies. There is a wide range of strategies available: specific training for farmers and consultants in more complex strategies for protecting crops, promoting the development of consulting (public or private) in crop protection, independently of pesticide sales, encouraging the active involvement of technical institutes and agricultural development groups, consumer awareness initiatives for the potential impact of reducing pesticide use on health and the environment, etc.

. A policy that must be far-reaching and gradually introduced

A policy for reducing pesticide use must have access to combinations of measures in order to meet its objective at the lowest possible cost for society; it must also take into account the differences in local situations.

Vulnerable areas (protected perimeters for extraction and collection of drinking water, ecologically important areas, peri-urban and fish-farming areas, catchment areas for water supplies, the contamination of which requires intervention) may necessitate the adoption of more restrictive measures, together with specific compensatory support.

If an ambitious policy for the reduction of pesticide use is chosen, its implementation must be planned out in such a way as to allow the economic agents to adapt to the new situation. For instance, a tax could be gradually introduced to give farmers time to adjust their production systems to reduced pesticide use. At the beginning, it could also be accompanied by subsidies for the adoption of less polluting methods.

. The need for a preliminary socio-economic expert debate (a French "Bichel committee")

Before introducing an ambitious policy to regulate pesticide pollution, a preliminary "diagnosis" of the situation is needed. While the identification of vulnerable areas seems far advanced today, many aspects require improvement, for example: inventory and evaluation of pesticide-saving practices, prediction of the effects of given instruments on pesticide use, production levels and farmers' incomes, and evaluation of the impact on the various economic agents. This type of analysis is necessary to identify the decisions at stake when setting environmental goals, especially to reduce pesticide use, and when determining the amount and form of compensatory support to be granted to farmers, if this is shown to be useful and in line with society's expectations.

An expert debate is needed that would not only be science-based, but would also rely on experts in the field, to collect data and hear out representatives of the economic interests involved (segments of the agricultural industry, supply sector, etc.) and consolidate all this information. In Denmark, this preliminary diagnosis was established in two years by a group of experts referred to as the "Bichel Committee"; their experience is a worthy example.

. Research needs to be developed

The necessary diversification of pest control methods requires significant research (see Box 17), particularly on the functioning of agrosystems. This involves research in the following areas: physical environment, ecology of complex systems (populations, communities, landscapes) and agronomic engineering, in order to produce management options. It is also important to pursue fundamental research on the short- and long-term fate of the products in the environment and on the biology of plant/pest and pest/auxiliary interactions. In addition, it is essential to promote multidisciplinary projects that combine biotechnical disciplines with the social sciences in order to respond to questions about the functioning of agrosystems, the rules for designing management strategies, conditions for their social and economic acceptability, the evaluation of their sustainability and their environmental impact. Lastly, regardless of the technical initiatives chosen, it is crucial to emphasise the need to develop experiment networks, to take account of the great diversity of local situations and for the sake of demonstration.

. Extension to the EU: Beneficial but not indispensable

The establishment of European groups of experts have enabled scale economies at EU level by combining the work of researchers who are faced with similar problems, despite differences in national contexts. This cooperation between Member States could be beneficial if extended to other areas as well. For instance, the introduction of a taxation system at EU level would significantly reduce the costs of enforcing the system and would prevent the distortions of competition within the EU related to its introduction. However, while cooperation at EU level appears advantageous, it is not necessary. A policy of pesticide-pollution reduction is legitimate in a country of the size of France.

Research priorities

. Role of public research

Over the last 30 years, crop protection has been largely based on the use of pesticides, with innovations coming almost exclusively from private research, via pesticide manufacturers.

Public research has either:

- supported this evolution by furthering biological research on targeted pests (cycles, dynamics, harmfulness, adaptation to selection pressure), thereby allowing for more rational use of active substances, or
- invested in research likely to result in alternative control methods (plant/microorganism interactions and genetic control, ecology of populations and communities and biological control, agronomy and cultural control, etc.).

With the exception of highly resistant varieties, the proposed alternatives are generally partially effective and should be combined with the aim of complementary action, or used in situations with less parasitic risk.

It is most unlikely that a mono-sector research structure, such as the agro-pharmaceutical chemical industry, will produce innovations with a systemic aspect, both in their design and economic use.

Public research is therefore a driving force in the acquisition, organisation and operational use of knowledge that is needed to design new means of action and strategies in which they will be effective, in collaboration with private research and development.

Research: Directions to take or to pursue

The abovementioned goals involve the following:

- Continued research on the physicochemical and microbiological mechanisms that determine the fate and transfer of pesticides in different compartments (soil, water, air), at different spatial scales.
- Research combining the characterisation of environmental contamination (presence and bioavailability of substances) and the evaluation of ecotoxicological effects at different levels (biological, spatial and temporal), in order to better understand the mechanisms involved in the propagation of effects between levels of biological organisation, improve post-approval follow-up of substances and identify the most critical situations requiring specific management measures. This research is particularly relevant in an integrated protection context, where a multifactorial analysis would enable weighting the impact of pesticides as compared to other control methods.
- Development of research on the functioning of agrosystems combining the physical study of environments, the ecology of complex systems (populations, communities, landscapes) and agronomic engineering, and which take a spatialisation approach to cultivation systems in order to produce management options.
- The need to pursue fundamental research in biology, e.g. on pest/plant and pest/auxiliary interactions, and to further analyse the role of the mechanisms involved in the system operation and their dependence on environmental conditions.
- Strengthening of research partnerships between biotechnical and socio-economic disciplines to better anticipate or break down barriers to the development of innovations in these areas.
- Development of economic research on the potentially important roles of agricultural suppliers, and processors and consumers of agricultural products in the use of pesticides (application of results of industrial economy research or contract theory).
- Continued research on indicators that would enable diagnosis and the evaluation of the effectiveness of public policies at various levels in space and time. This research must include phases of vulnerability analysis and validation in the field .

Support of mission-oriented research

- It is important to continue **developing and making operational validated models for pesticide transfer in the environment**, and to continue and multiply the experiments on corrective techniques, with a twofold objective of adaptation to the diversity of situations and demonstration, on the basis of a classification to include the fate of pesticides and the agricultural and soil climate conditions in which pesticides are used.

- Further research needs to be done on biological control, with a particular focus on **the conditions for maintaining the biological agents following introduction, and the reproduction and effectiveness of the agents**. Research projects based on agronomics, population ecology and landscape ecology should be encouraged.
- It is important to continue the research being performed on variety selection in the private sector and to **encourage public selection especially in the early design of resistant breeding stock for crops which cover a surface area that does not justify private investment, or resistant genes of neighbouring species that require more significant genetic research**. More generally, selection should include a vast number of criteria: resistance (even partial) to pests, the possibility of cultivating them in low-input systems with lower parasitic risk.
- It is important to promote, through calls for tender involving major resources, **multidisciplinary projects on agrosystems, rules for designing management strategies, conditions for their social and economic acceptability, evaluation of their sustainability and their environmental impact**. It would be useful to develop decision support systems that take account of interactions between factors that can be used for non-intensive systems.
- It is essential to build **databases** on pesticide use by farmers in order to quantify the economic and technical factors determining their use, and consequently, to quantify the effects of potential regulatory instruments. These data will be used in existing and future models and statistical techniques. They will also be used for the indicators developed for public policies.
- It is important to support the creation of **experimental platforms that are correctly set up to be representative of farming situations and designed for a multicriteria evaluation of the effectiveness of integrated protection systems**.

AUTHORS AND EDITORS OF THE EXPERT REPORT

► Experts

Responsible for scientific coordination

Jean-Joël GRIL, Research Engineer, CEMAGREF Lyon
Philippe LUCAS, Research Director, INRA Rennes

Authors and contributors

Anne ALIX, IR*, INRA/SSM Versailles: Ecotoxicology of terrestrial and aquatic ecosystems, evaluation of impacts and risks
Jean-Noël AUBERTOT**, CR*, INRA Grignon: Agronomy of field crops, cropping systems, integrated pest management
Jean-Marc BARBIER, IR, INRA Montpellier: Agronomy, technical practices and behaviour of farmers, decision analysis
Enrique BARRIUSO, DR*, INRA Grignon: Fate of pesticides in the soil
Carole BEDOS, CR, INRA Grignon: Pesticide transfers to the atmosphere
Marc BENOIT, DR, INRA Mirecourt: Dynamics of cropping systems and production systems, organic farming, agricultural development
Bernard BONICELLI, DR, Cemagref Montpellier: Pesticide application techniques, pesticide dispersion, evaluation and optimisation of equipment and practices
Philippe BONTEMS, DR, INRA Toulouse: Theory of contracts applied to the environmental economy, industrial economics
Thierry CAQUET, CR, INRA Rennes: Aquatic ecotoxicology
Alain CARPENTIER, CR, INRA Rennes: Economy of agricultural production, evaluation of environmental assets, econometrics
Michel CLERJEAU, Professor, ENITAB / INRA Bordeaux: Plant health protection of grapevine, evaluation of fungicides
Christophe DAVID, Research Professor, ISARA, Lyon: Agronomy, organic farming
Philippe DEBAEKE, DR, INRA Toulouse: Systemic agronomy, field crop strategies, low-input systems, integrated weed control
Robert DELORME, DR, INRA Versailles: Knowledge and evaluation of plant health products and active substances, toxicity of insecticides, insecticide resistance
Igor DUBUS, IR, BRGM Orleans: Modelling of the fate and transfer of pesticides in the environment, risk evaluation
Vincent FALOYA, IR, INRA Epoisses: Agronomics of field crops, integrated cultivation systems, farming practices
Chantal GASCUEL, DR, INRA Rennes: Hydrology, soil and landscape structures in farmed drainage basins
Jean-Joël GRIL, IR, Cemagref Lyon: Diffuse pollution, corrective measures
Laurence GUICHARD, IR, INRA Grignon: Agronomics of field crops, evaluation of farming practices and cultivation systems
Marie-Hélène JEUFFROY, CR, INRA Grignon: Agronomics of field crops, organic farming
Anne LACROIX, IR, INRA Grenoble: Environmental economics, diffuse pollution, integrated crop management systems
Ramon LAPLANA, DR, Cemagref Cestas: Evaluation of agri-environmental policies, integrated regional management
Stéphane LEMARIÉ, CR, INRA Grenoble: Economics and strategies of agricultural supply companies
Philippe LUCAS, DR, INRA Rennes: Plant pathology, epidemiology, integrated crop management
Françoise MONTFORT, CR, INRA Rennes: Soil-borne parasites in field vegetables, crop protection within cropping systems
Philippe NICOT, CR, INRA Avignon: Diseases in greenhouse market garden crops, alternatives to pesticides in market garden crops
Bernadette RUELLE, ICGREF*, Cemagref Montpellier: Crop protection and the environment
Benoît SAUPHANOR, IR, INRA Avignon: Fruit arboriculture, insecticide resistance and alternative protection methods
Serge SAVARY, DR, INRA Bordeaux: Ecology and biology of pests: pest control strategies
Nadine TURPIN, IGFREF*, Cemagref Clermont-Ferrand: Environmental economy, regional economics
Marc VOLTZ, DR, INRA Montpellier: Transfer of pesticides to soils and water systems

► Collective Scientific Expertise Unit (UESCo), INRA

Annie CHARTIER, IR, INRA Versailles: Information researcher
Claire SABBAGH, IR, INRA PARIS: Unit Head, Manager of the ESCo
Isabelle SAVINI, IE*, INRA Paris: Editorial compilation and coordination.

* DR: Direct or of Research; CR: Research Attaché; IR : Research Engineer; IGFREF : Engineer, Rural, Water and Forest Engineering; ICGREF : Civil Engineer, Rural, Water and Forest Engineering; IE: Design Engineer

**In heavy type: scientific coordinator