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diversifying crop protection




European Crop Protection in 2030

A foresight study

Coordinated by Labussière E., Barzman M., Ricci P.

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SIXTH FRAMEWORK PROGRAMME

This publication is the synthesis of the foresight study “European Crop Protection in 2030”. Launched in July 2007, this foresight exercise is one of the activities carried within ENDURE Network of Excellence. It was funded by the EC, under FP6 Priority 5.

The study was conducted by a panel of ten crop protection experts from four different countries and from a range of scientific disciplines. During more than two years, this expert panel gathered regularly under the management of a project team and carried out an in-depth reflexion on the possible futures of crop protection in Europe at the horizon 2030. They compiled the conclusions from their collective discussions in this document.

Working group
of the ENDURE Foresight study

This study has been carried out from July 2007 to April 2010, by a working group composed of an expert panel (scientific knowledge and expertise) and a project team (foresight methodology and project management).

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FOREWORD

This is an important time for crop protection in Europe. New European regulations adopted in 2009 will place new limits on the use of pesticides, our principal crop protection tools. This has prompted many of us to wonder about the future of pest management. While we are thinking about the next few years, why not think about the next 20? This study invites us to do just that.

A journey into the future is best started from an understanding of where we are today, and how we got here. Bringing together that experience from across European countries and cropping systems, the ENDURE project reveals how pesticide-based crop protection in Europe has evolved from a reaction to pest and disease outbreaks into an integral element of many crop systems, allowing an acceleration of production. Now "locked in" to so many cropping systems, pesticide use has risen, leading to concern about health and environmental effects on the one hand, and an accelerated race against pesticide resistance on the other. Integrated Pest Management (IPM) and its associated cultural and biological control methods, has provided an alternative to pesticide-dominated crop protection. While it has a long history, and very successful application in countries like Switzerland, IPM is still limited on a European scale. Looking across European crop protection, as this study does well with its truly continental team of experts, one is struck by how a region that has in common most of its crops, pest and pest control technologies, can exhibit such a diversity of current crop protection systems.

Such diversity does not make planning for the future easy. Nor do the ambiguities in future global agricultural trends, and what they might mean for Europe and its crop protection systems. Will rising global food demand and prices stimulate Europe to be even more active as a global agricultural trader, or will it create concern for food sovereignty and more locally focused agricultural production? Will Europe direct its future production towards capturing greater global market share, becoming the world's breadbasket as climates change, or will it become a specialist provider of high quality products? Will European populations become more urban and less interested in farming and crop protection issues, or will they populate the rural landscape and celebrate their agriculture *territoires*?

These possible European agricultural futures could greatly influence crop protection in very different ways. Given the long lead period for the development of crop protection systems and technologies, some futures work on crop protection is very timely. This study uses the increasingly popular tool of scenario building, which has the strength of accommodating different, equally likely futures, and the added value of making these futures real through the story lines and actors each scenario creates. The future scenarios which this study carefully creates and analyzes give us much food for thought. Researchers and policy makers interested in European crop protection will find in this book an empowering presentation of the past, present and future of their discipline, and new ways of thinking how it should progress over the coming decades.

Professor Jeff Waage
Director of the London International
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INTRODUCTION

Pierre Ricci

By farming, humans create an ecological niche which is favourable to plant growth and accumulates primary resources. Many organisms including plants, insects, nematodes, fungi, bacteria, and rodents compete with humans over the exploitation of this niche. These organisms – pests in the generic sense – decrease yields, reduce product quality, spoil or destroy harvests. Their irregular occurrence, often linked to climatic conditions, combines with year-to-year climate differences to create large variations in the outputs of crops. These irregularities can disrupt farming economy and, historically, have been a major cause of famines.

Limiting this competition has always been a major concern of farmers. The introduction of **pesticides** during the twentieth century and the development of increasingly diversified synthetic pesticides over the last fifty years changed the face of crop protection. Pesticides are easy-to-use tools that allow farmers to eliminate individual pests during the growing season at the field level and when they become potentially detrimental. Together with fertilizers and plant breeding, pesticides have significantly contributed to the regular high yields and quality achieved by western European agriculture over the last decades.

The advantages provided by pesticides go beyond merely reducing losses. The certainty of having an effective means of control at hand gave farmers unprecedented freedom to rearrange the set-up of their **cropping systems.** In France for instance, winter wheat-based cropping systems shifted between 1978 and 1984 to simplified rotations, high sowing densities, high fertilisation, use of growth regulators, and new high-yielding varieties (see chapter 1.3). These changes generate systems that are inherently more conducive to pest outbreaks and associated damage relative to traditional systems and could not have been adopted without the highly effective degree of crop protection pesticides provide. Not surprisingly, over the same period, total pesticide consumption in France more than doubled, increasing from ca. 40,000 t to nearly 100,000 t. Another example of how European cropping systems have become dependent on pesticide use is the widespread adoption of apple cultivars that are very highly susceptible to apple scab disease. The adoption of these popular cultivars strongly limits the capacity to reduce the number of fungicide treatments.

The contribution of pesticides to crop production is therefore equivocal. Entomologists were the first to observe that a chemical treatment against one pest could unbalance the population regulation occurring within trophic chains and cause outbreaks of new pests. They proposed to manipulate these regulations in order to restore the natural **biological control** of potential pest populations, instead of directly destroying them. In 1978, the catastrophic outbreak of the brown rice plant hopper in Indonesia demonstrated the unsustainability of intensive systems exclusively relying on chemical control. This event led FAO to promote **Integrated Pest Management** (IPM). This concept stresses the need to use a wide array of convergent control methods and recognizes the importance of the choice of cultivar and fertilisation rate to prevent build-up of pest populations.

In Europe, systems relying on chemical control have been challenged by the ability of pests to acquire **resistance to pesticides,** leading to partial or total loss of pesticide effectiveness. Managing pesticide use to delay the appearance and expansion of resistant populations has become a major concern for industry, research and regulatory services. Occasionally, farmers have been left within a technical impasse with a chemical solution no longer available. Until now, these challenges have generally been overcome by the agrochemical industry which has produced a steady flow of innovation thanks to sustained high R&D investments (currently 2 billions Euros per year). Recently, the commercial prospects of developing new pesticides are however less favourable. Average pesticide

life-time is decreasing (e.g. the few years needed for *Septoria* to acquire widespread resistance to strobilurins). New forms of resistance that cross over different families of active ingredients have appeared. And industrial data show that it now takes more time and more money to bring new compounds to the market.

The criticism around the use of pesticides has actually mainly emerged from civil society, i.e., from outside the mainstream agricultural sector, and has been voiced by environmental protection organisations. The cumulative effects of decades of large scale use of pesticides on ecosystems have become conspicuous: residues in surface and groundwater are ubiquitous, soils are sometimes durably contaminated, and pesticides are held partially responsible for decreasing biodiversity in rural areas. Consumers are increasingly worried about residues in food. In recent years, investigations on the impact of pesticides on human health have confirmed cases of serious diseases contracted by farmers over many years and linked to the handling of pesticides without proper protection.

Policy makers at a national level have unequally addressed these societal concerns over the last twenty years by diverse regulations aiming at pesticide use-and-risk reduction. The elaboration of a better coordinated and more encompassing legislation at the European level has been undertaken in 2006 with the adoption of the *Thematic Strategy on the Sustainable Use of Pesticides* by the Commission. The result has been a legislative 'pesticide package' adopted in 2009 which introduces increased restrictions on the registration and on the use of pesticides, including the mandatory adoption of IPM principles by European agriculture before 2014 (see chapter 1.1).

In the course of the discussions on the 'pesticides package' at the European Parliament, the mainstream farming community voiced its concerns that restrictions on the range of available pesticides and on their use would jeopardise the competitiveness and profitability of European agriculture thus compromising its ability to face worldwide stakes: feeding an increasing population together with delivering renewable energy and other non-food products. Now that the outcome of this debate has been somewhat frozen into legislation, the challenge is to reconcile in practice the goal of agricultural production with the new rules for a safer approach to crop protection. Precisely, the *ENDURE Network of Excellence* was launched to investigate how crop production in Europe could reduce its use of plant protection products and adapt to these new constraints.

The ENDURE Network brings together more than 300 researchers in the fields of agronomy, biology, ecology, economics and the social sciences from 16 organisations in 10 European countries. The project is funded for four years (2007-2010) by the European Commission's Sixth Framework Programme, priority 5: 'Food Quality and Safety'. Considering the need to provide farmers with solutions achievable on the short term, ENDURE examined how farming practices could be improved to reduce and optimise pesticide use in existing farming systems by making a better use of current knowledge and resources. ENDURE focussed on nine key crop-pest **'case studies'** and took advantage of its transnational position to compare the situations in different Member States (see chapter 1.2). The results show that significant progress can be achieved by sharing local experiences acquired in the different countries and by testing their potential for broader European level implementation. Besides these opportunities, the analyses also identify the bottlenecks that make some changes difficult within the current farming systems.

Indeed, because current cropping systems developed assuming free access to chemical control, if farmers want to significantly reduce their dependence on pesticides on a longer term, they will have to **redesign their cropping systems** in order to make them less vulnerable to pests. Developing methods to design and assess such innovative systems and developing the toolbox for their implementation is at the core of the research activity of the Network. However, ENDURE social scientists show that **transitions towards more sustainable crop protection strategies** are not possible if only farmers are involved (see chapter 1.3). Over the last fifty years, farmers and the other components of the socio-technical agrifood system (advisors, researchers, input producers and providers, crop collectors and processors, retailers, consumers, and policy makers) have become highly interdependent and have gradually adjusted to each other to create a coherent but 'locked-in' system. In order to allow for more sustainable solutions, these stakeholders now have to engage in coordinated changes. A shared a vision of possible alternative coherent systems is a prerequisite to such change.

ENDURE developed the present foresight study to contribute to this vision. We selected five scenarios that illustrate *contrasting options in crop protection* and in which the stakeholders have different roles to play. We explored the scientific breakthroughs needed to support these options and what they mean in terms of **research avenues** in crop protection. Looking twenty years ahead leaves precisely the time laps needed to convert new research questions into implemented innovations.

We also derived some considerations for **policy makers,** indicating that the successful implementation of the Thematic Strategy on the Sustainable Use of Pesticides within a competitive agriculture will require more than mere enforcement of the 'pesticides package' legislation and will also depend on other decisions, some of them seemingly remote from the pesticide issue.

Indeed, we must not overlook the fact that several **contextual factors** will largely influence what options will be taken for crop protection. Macro-economic factors and policy choices, both at the global and European levels are certainly major drivers. Their consequences for agriculture have been examined in several recent foresight studies and investigating these aspects was beyond our goal. Nevertheless, we did select different contexts and characterized the main features of the agricultural system that these contexts would determine in Europe. We have then embedded crop protection options in the contextual frame that looked the most supportive and coherent with each of them.

The five scenarios selected in this study do not seek to depict the most probable future of crop protection in Europe. Instead, they present rather extreme situations, especially in that they are supposed to apply to the EU as a whole. Considering extreme situations helps to clarify and highlight the relationships between variables and to **stimulate reflection and debate,** which is precisely the purpose of this foresight exercise.

1 CROP PROTECTION IN EUROPE: CURRENT STATE

1.1 | LEGISLATIVE EUROPEAN FRAMEWORK – CHANGES IN EUROPEAN LEGISLATION AND THEIR IMPLICATIONS

Silke Dachbrodt-Saaydeh, Marco Barzman

Introduction

Over the past 20 years, European pesticide legislation has been subject to radical change. The legislation was developed mainly at the national level through the review of the approval of pesticide products and the withdrawal of dangerous products and since 1991 at the European level regarding active ingredients. The growing awareness of risks to human health and the environment related to pesticide use led to a critical assessment of pesticides. National legislation focused on the mitigation of risks, hence phasing out the most harmful active substances. Major concerns were related to contamination of water resources used for human consumption, possible adverse effects on ecosystems, e.g. non-target species and effects of exposure to residues in water, soil and air. Consumer concerns grew and the demand for an environmental friendly agricultural production and food safety were increasing at the same time (Sabba and Messina, 2003).

The newly adopted European pesticides legislation is responding to this increasing awareness and need to reduce the risks posed by the use of pesticides. It provides for the first time in European history a harmonised approach to regulate the authorisation of plant protection products as well as the use phase of pesticides. The provisions of the Regulation ensure a high level of safety of products for human and animal health and the environment. The Framework Directive emphasises integrated pest management for the first time with harmonised European general principles of integrated pest management and the ambitious promotion of alternative techniques and approaches including non-chemical alternatives. The implementation of those principles, the change toward farming systems less reliant on pesticides and the production of sufficient and reliable yields at acceptable costs are the challenges European agriculture is facing. This will elicit a process drawing from a diversity of solutions and will create a demand for innovative solutions and their combination into IPM strategies in the years to come.

Historical overview

The Community regulatory framework concerning pesticides focused particularly on the placing on the market of plant protection products and on the end of the life cycle of active ingredients. With the 6th Environmental Action Programme (European Commission, 2002) the European Parliament and the Council developed a framework calling for seven thematic strategies for priority environmental problems including pesticides.

In 2006, the European Commission adopted the *Thematic Strategy on the Sustainable Use of Pesticides* (2006a). The objectives of the Thematic Strategy were to minimise the hazards and risks to health and the environment from the use of pesticides; to reduce levels of harmful active substances including through substitution of the most dangerous ones with safer (including non-chemical) alternatives; to encourage the use of low-input or pesticide-free crop farming; to improve controls on the use and distribution of pesticides. To achieve the set goals, a process was initiated revising *Directive 91/414/EEC* (European Commission, 1991) and putting forward the *Proposal for a Directive establishing a framework for Community*

action to achieve a sustainable use of pesticides (European Commission, 2006b) and the *Proposal for a Regulation of the European Parliament and of the Council concerning statistics on plant protection products* (European Commission, 2008a). The ambition was to integrate all three legislative dossiers into a single package, the so-called "pesticides package".

This initiated an important change. For the first time in European legislation the dossiers provide the framework for regulating the entire life span of plant protection products from authorisation and placing on the market, addressing the risks in the use phase and statistics monitoring pesticide sales and use.

The Regulation

The final text of *the Regulation concerning the placing of plant protection products on the market* (European Commission, 2009a) was adopted in September 2009 and provisions will apply from June 2011. The goal of the Thematic Strategy to reduce the levels of harmful active substances elicited a comprehensive review process of the Directive 91/414. Provisions including: the mutual recognition for plant protection products dividing the EU into North, Centre and South zones; comparative assessment for substances; criteria for approval of active substances; a simplified evaluation and authorization procedure; and data protection was substantially revised via a three-year process.

The different positions of the Council and the European Parliament led to intense negotiations. In particular, the shift of authorization criteria from risk-based assessment of substances to hazard-based criteria resulting in the ban of substances posing severe risks to human health and the environment caused strong concerns and criticism among users and the industry. This approach entails the ban of plant protection products containing substances that are genotoxic, carcinogenic or toxic for reproduction, and that have neurotoxic, immunotoxic and endocrine-disrupting properties, the so-called 'cut-off' criteria. The absence of an agreed-to scientific definition of endocrine-disrupting properties caused additional uncertainty amongst the farming community. The Commission will consequently provide a draft of specific scientific criteria for this definition only by the end of 2013. Different institutions in the UK (Pesticides Safety Directorate 2008 and ADAS, 2008), in Sweden (KEMI, 2008) and the Netherlands (Wageningen University and Research, 2008) commissioned impact assessments on the potential impact of the 'cut-off' criteria in agricultural production. However, for substances that have passed the revision process, the 'cut-off' criteria will be applicable at the renewal of the authorization. By derogation, a new active substance may be approved for up to five years if proven essential for the control of certain pests and diseases which cannot be contained by other means.
The comparative assessment weighing up the risks and benefits of active substances, based on their inherent properties, will identify products as candidates for substitution, which show significantly lower risk to health or the environment. It comprises detailed provisions sustaining the availability of products, until adequate alternatives are available. The alternatives are subject to a benefit-risk assessment and must be applicable without significant economic and practical disadvantages to the user.

Incentives are created for placing low risk products on the market, including a simplified and faster authorisation procedure and granted authorisation for 15 years compared to 10 years for other plant protection products. The authorization procedure of products for minor uses is simplified, including the extension of data protection by 3 months for each authorisation, to ensure the availability of products.

At present the provisions of the regulation will not affect existing authorisations of plant protection products in the Member States. However decisions on the approval of active substances in the Review programme (European Commission, 2009b) of existing pesticides might affect the authorisation.

Framework Directive to achieve the sustainable use of pesticides

The *Framework Directive to achieve the sustainable use of pesticides* (European Commission, 2009c) addresses for the first time in European legislation risks to human health and the environment posed by pesticides in their use phase. Until now the use phase, except for worker protection, was scarcely considered in legal provisions at the European level. Now, the new legislation aims at minimising risks to human health and the environment resulting from the use of pesticides. Member States are required to adopt National Action Plans setting the framework for the implementation of the provisions to reduce risks and impacts of pesticide use at the national level and must set up quantitative objectives, targets, measures and timetables. The National Action Plans will include provisions on the initial and additional training of distributors, advisors and professional users; regular inspections of equipment and machinery in use; raising users' awareness for the appropriate handling of pesticides; pesticide use in sensitive areas and the protection of aquatic environment. The requirements for pesticide application equipment and machinery are listed in Annex II, in order to achieve a high level of protection for human health and the environment. The requirements for new plant protection equipment and machinery are considered by the *Directive on machinery* (European Commission, 2009d).

The cornerstone of the Framework Directive is to achieve a reduction of risks to human health and the environment with emphasis on the promotion of non-chemical alternatives and the implementation of integrated pest management (IPM). The general principles for IPM, mandatory from 2014, as laid down in Annex III provide the minimum provisions.

The development and implementation of crop or sector specific guidelines is voluntary and is the responsibility of Member States. Training is identified as one of the key elements to advance European agriculture, especially IPM, to achieve a more targeted use of pesticides and reduced impacts on human health and the environment. The minimum requirements for training content are provided in Annex I.

The *Directive establishing a framework for Community action to achieve the sustainable use of pesticides* was adopted in September 2009 and will apply from December 2011. European Member States will now initiate the development of their National Actions Plans. The Directive allows Member States to set up and adapt their goals and measures to their specific national conditions. The implementation of the Framework Directive shall contribute to reduction of risks for human health and the environment and to promotion of IPM and other alternatives in plant protection although the economic situation will greatly influence the uptake of and the shift to different approaches such as IPM.

Regulation concerning statistics on pesticides

The Regulation concerning statistics on pesticides (European Commission, 2009e) was adopted in November 2009. The Regulation enables the collection of the annual amounts of pesticides placed on the market (collected annually) and the annual amounts of pesticides used (collected in five-year intervals) in each Member State. The use figures are to represent selected representative crops of the Member State. The Statistics regulation provides another component assessing the evolvement of pesticide use additionally to the provisions on risk indicators in the Framework Directive. The new national obligation to collect pesticide use figures, uncommon at present in many Member States, will provide a clearer reference frame for goal setting, training and adapting plant protection measures.

Conclusion

The recently adopted pesticides package reflects a new approach to pesticide use and the mitigation of adverse impacts of pesticides to human health and the environment. However, agricultural production is facing competing priorities, most notably, ensuring high yields and acceptable margins on the one hand, and responding to European legislation, with the shift to IPM and sustainable production systems less reliant on pesticides, on the other hand. Uncertainties remain with regard to the future availability of active substances. Facing increasing pesticide resistances can lead either to less leeway in reducing approved pesticides dosages or create an increased awareness and use of non-chemical alternatives. A growing world demand for food, feed and renewable resources anticipated by many organisations (FAO, 2009) could either favour higher intensities of production and associated reliance on pesticides or a major change in the general approach to crop protection..

1.2 | IMPROVING SUSTAINABILITY OF CROP PROTECTION STRATEGIES AND REDUCING DEPENDENCY ON PESTICIDES – SHORT TERM SOLUTIONS EMERGING FROM THE ENDURE CASE STUDIES

Per Kudsk

A core activity of ENDURE has been to collect and exploit the existing knowledge on reducing and optimising pesticide use. The current use of pesticides is characterised by a 'no risk' attitude by the end-users that tend to lead to a higher than necessary use of pesticides. Nevertheless, experiences from some EU Member States have shown that end-users are willing to reduce pesticide use when information on optimised pesticide use is available and when end-users are provided with easy-to-use decision support tools.

To promote the collection and exchange of information on optimised pesticide use, 9 case studies were initiated. Eight of the 9 case studies addressed specific crops and pest problems while one was more generic addressing integrated weed control in row crops adopting maize as a model crop. Both major and minor crops as well as annual and perennial crops were included in the case studies (Table 1).

CROP	TARGET PESTS
Wheat	Foliar diseases
Potato	Late blight
Tomato	Whiteflies
Pomefruit	Apple scab, brown spot and codling moth
Integrated Weed Management	Weeds
Maize	All major pest problems
Banana	Mycosphaerella foliar diseases, black weevil and nematodes
Field vegetables	Weeds and soil borne diseases
Grapevine	All major pest problems

Table 1. Target crops and pests considered in ENDURE Case Studies

Below are the key outcomes of some of the completed case studies presented. Some of the results are available as guides (Figure 1) written for end-users on the ENDURE web page and in the following sections references are given to relevant guides. In the future more guides will be published following the termination of the most recent case studies (maize, banana, field vegetables and grapevine).

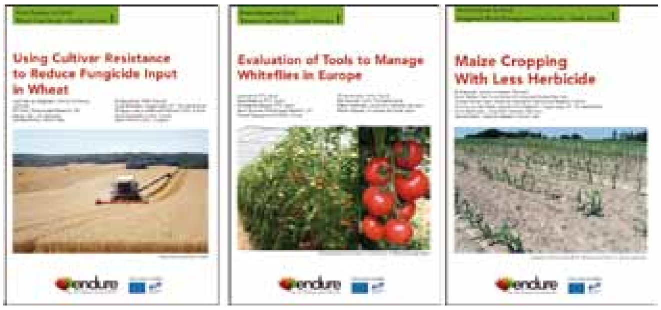


Figure 1. Some examples of ENDURE Case Study Guides
(source: ENDURE website, http://www.endure-network.eu/)

Case studies

Wheat

A recent survey has shown that the treatment intensity (number of standard pesticide doses applied per hectare per growth season) varies significantly between the UK, France, Germany and Denmark.UK is topping the list with a treatment intensity of 7.7 while Danish farmers on average only used 2,3 standard doses of pesticides. Germany and France were intermediate with treatment intensities of 5.8 and 4.0. The observed differences can partly be explained by differences in the scale of pest problems caused by, e.g. higher disease and arthropod pest pressure or more widespread occurrence of pesticide resistant biotypes. Nonetheless, the significantly lower pesticide use in Denmark is also the result of a widespread use of reduced pesticide doses, the existence of a national forecast and warning system for some of the major foliar diseases and farmers being prepared to replace susceptible cultivars by cultivars resistant or partly resistant to major foliar diseases.

The potential impact of growing disease resistant varieties was highlighted by the wheat case study. Results from French trials revealed that the average potential yield increase from fungicide use in resistant cultivars was 7.4 dt/ha compared to 12.0 and 19.4 dt/ha in susceptible and very susceptible varieties. Thus, cultivating resistant varieties reduces the cost-benefit of fungicide use and will eventually lead to a reduced fungicide use (see *From Science to Field: Wheat Case Study - Guide Number 1).*

Certain diseases, such as *Fusarium*, cannot be controlled effectively by fungicides; nevertheless fungicides are widely used for that purpose. *Fusarium* can be prevented through crop rotation and soil tillage. Hence, *Fusarium* represents an example of a pest where non chemical approaches are the only effective measure. The wheat case study collected has made the existing information on non chemical methods available to end-users (see *From Science to Field: Wheat Case Study - Guide Number 2).*

Wheat is considered to be a crop where sharing available information could make a major contribution to reducing pesticide use and dependency. To further promote this development the participants of the wheat case study have joined forces with other scientists inside and outside ENDURE and have developed a web-based platform EuroWheat[1] containing information on pathogen biology, cultivar resistance, fungicide performance, decision support tools etc.

Potato

The potato case study focussed solely on potato late blight as this pathogen is the major pest problem in potato cultivation in Europe. Effective control of potato late blight can require up to 15 to 20 fungicide applications and potato is the arable crop receiving the highest input of pesticides.

In the potato case study the participants focussed on the key steps in integrated control of late blight. First step is to eliminate or reduce the sources of primary inoculum to postpone the time of the first infection in the field. Long crop rotation, avoiding the use of infested seed potatoes, controlling volunteer potatoes and protecting neighbouring potatoes under plastic are measures that can delay the time of the first infection (see *From Science to Field: Potato Case Study - Guide Number 1).*

No cultivars are fully resistant to late blight but some cultivars are partial resistant. Partial resistant varieties can slow down the development of late blight significantly and reduce fungicide input either by reducing the number of applications required or allowing the use of reduced fungicide doses. Decision support systems and proper use of fungicide are other important components of an IPM strategy against potato late blight (see *From Science to Field: Wheat Case Study - Guide Number 2, 3 & 4).*

Tomato

Whiteflies and whitefly-transmitted viruses are major constraints in European tomato production. The tomato case study set out to identify why whiteflies are a major limitation, collect information on whiteflies and associated viruses and list available management tools.

Two whitefly species are pests of tomato in Europe and high incidences of the virus disease tomato yellow leaf curl disease are associated to high prevalence of whiteflies. The incidence of whiteflies also correlates with the level of insecticide use indicating that problems with whiteflies are a principal driver of the use of insecticides.

Biological control, exclusion by greenhouse netting and virus resistant tomato varieties are tools that can be applied in an IPM strategy. IPM strategies based on biological control agents have proven to be effective in certain regions but wider implementation in other regions is limited by a lack of effective biological control solutions and the costs of beneficials (see *From Science to Field: Tomato Case Study - Guide Number 1).*

Pomefruit

Scab, brown spot and codling moth are major pest problems in pomefruit. This case study examined the state-of-art of prevention and IPM strategies in 6 pomefruit producing regions in Germany/Switzerland, Spain, Italy, Belgium, the Netherlands and Sweden.

The study revealed that information on IPM was available in all regions and widely adopted by producers, that modern communication tools are routinely used and that the same IPM tools are applied in the 6 regions. Although IPM in pomefruit is more widely adopted than in most other crops, bottlenecks do exist such as lack of acceptance of resistant varieties by the market. It is envisaged that the experiences gained in the 6 regions can be applied to other regions e.g. in the new EU Member States.

Integrated Weed Management

In contrast to most of the other case studies the Integrated Weed Management case study decided to conduct a joint experiment in maize. The experiment compared the efficacy, cost effectiveness and environmental impact of a standard chemical treatment, an integrated approach combining herbicide use with inter-row cultivation and an advanced integrated approach further minimising herbicide use. The experiment was conducted in one location in Italy, France and Denmark.

The study revealed that the efficacy of the standard chemical treatment and the integrated approach were comparable at all locations. The performance of the advanced integrated strategy was satisfactory in France and Denmark but not in the Italian location. Only minor differences were observed in the costs of treatments but the environmental impact, assessed by using the French indicator Ipest, revealed a significant reduction with the advanced integrated approach. The experiment demonstrated that herbicide use can be reduced but that the degree up to which this is possible depends on the local conditions.

The case study produced a guide highlighting the tools available to farmers to reduce herbicide use in maize and other row crops such as crop rotation, mechanical weed control, stale seed bed and cover crops (see *From Science to Field: Integrated Weed Management Case Study - Guide Number 1).*

[1] See EuroWheat platform: www.eurowheat.org

Maize

This case study examined the key pests and options to reduce pesticide use in 11 maize producing regions in Europe including the adoption of IPM. Very detailed information was collated on the occurrence, importance and population development (increasing or decreasing pest problem) of the key pests in the 11 regions. The results were recently published in an international journal (Meissle et al., 2010).

Besides the above-mentioned study the case study also produced information on non-chemical control of corn borers (see *From Science to Field: Maize Case Study - Guide Number 1)* and more guides on specific pests will be published in the future.

Banana

Pesticide use in banana is high because several pests threaten the production. Effective pest control without pesticides in banana is hampered by the fact that the genetic diversity is poor as the majority of bananas are produced using just one variety.

The banana case study examined the opportunities of reducing pesticide use in banana in general as well as integrated approaches to control *Mycosphaerella* foliar diseases, black weevil and nematodes. A number of guides will be published in the near future.

Conclusion

The case studies produced a wealth of useful information that is ready to be disseminated and for most parts also to be implemented in European farming. It is envisaged that pesticide use and dependency can be reduced significantly merely by sharing experiences and adopting the best practices from one country in other countries. The outputs of the case studies, which also include input to the ENDURE Information Centre besides the guides and the EuroWheat platform, will support and promote this process by providing relevant and up-to-date information to advisors, farmers, teachers and other end-users.

1.3 REDUCING DEPENDENCY ON PESTICIDES: TRANSITIONS TOWARD SUSTAINABLE SOLUTIONS OVER THE LONG TERM

Claire Lamine, Pierre Ricci

ENDURE case studies explored the available knowledge that can be rapidly translated into practical changes, especially considering the extent to which experience gained in local contexts could be more broadly implemented at the European level. They also identified shortcomings and bottlenecks to be overcome over the longer term to make farming systems significantly less reliant on pesticides. It has been a major goal of the ENDURE network to identify the changes required and the transitions that enable these changes, as well as to engage in the appropriate supporting research.

Three general conclusions emerge from this analysis:
- it will require more than optimising today's farming practices or substituting today's technologies and inputs by new ones to sufficiently improve farming systems made vulnerable by years of reliance on pesticides;
- some reconception of farming systems is therefore needed. It calls for a type of innovation that goes beyond the framework of reference currently adopted for the improvement of crop protection methods;
- transitions toward sustainable crop protection strategies cannot be driven by farmers alone. They require a coordinated involvement of the entire agri-food system.

From optimisation of practices to system redesign

Methods and approaches to improve crop protection may be classified according to the ESR categories proposed by Hill and MacRae (1995): E for efficiency, S for substitution, R for redesign.

Improving pesticide use efficiency can be achieved in several ways. They often include monitoring pests and forecasting epidemics to better position and occasionally reduce pesticide applications with the help of decision support systems or precision spraying to reduce pesticide volume and limit diffuse pollution. These approaches improve the use of current pesticides but do not address the issue of the coming reduction of available substances.

A number of methods can be substituted to pesticides to reduce environmental impact. They include biopesticides, augmentative biocontrol, mechanical weeding, resistant cultivars, and prophylactic methods. At present, farmers can seldom rely on them as genuine alternatives to chemical control. For instance, mechanical weeding or biofumigation of soil pathogens will not be sufficient, especially if farmers continue with monoculture. Some methods that are very effective, such as highly resistant varieties, are rapidly overcome by pest evolution when they come to be used on a large scale (McDonald and Linde, 2002). Other methods that exhibit partial efficacy will have a lesser impact on pest evolution but need to be appropriately combined to benefit from additive or synergistic effects and avoid antagonistic effects. Substitution methods do contribute to a reduction of pesticide use, but alone, they do not sufficiently reduce the overall pest pressure and the reliance on control methods.

One should therefore consider how the in-built properties of current farming systems affect the incidence of pest damage. Cropping systems in arable crops, for instance, are often characterised by short crop rotations, high-yielding susceptible cultivars, and high levels of fertilisers. These features are known to increase the prevalence of weeds and diseases and are maintained at the expense of high frequency pesticide treatments. These sorts of observations lead one to adopt a broader perspective in which innovative crop protection strategies actually encompass the redesign of farming systems for lower vulnerability to pests.

This systems approach was reflected mid-way through the ENDURE project with a shift from Case studies to "System case studies" in which the network's pool of specialists in pest biology, agronomy, ecology, genetics, alongside with economists and sociologists came together to develop new strategies, focusing on arable and orchard crops.

Changes in the framework of reference for the design of innovative strategies

Inherent to the IPM concept is the idea of addressing the set of pest problems within a system via a combination of multiple tools. The currently available toolbox fits the purposes of the current farming systems but it may not be the most suitable for new ones. New tools for IPM will have to be designed to operate in combination and fulfil new requirements. Here are some examples from ENDURE's contributions showing how a change in perspective may help address the innovation needed to design more sustainable crop protection strategies.

Assessing yield losses caused by multiple pests

It is a well established IPM rule that treatment should be decided not on the amount of pest population or symptoms, but as a function of an economic threshold that links these amounts to potential yield loss. However, in practice, one given crop is seldom attacked by a single pest and yield loss (or damage) will result from the combined effects of multiple injuries occurring at different stages of development. ENDURE has shown, based on the example of winter wheat, how by combining a simple plant physiology model with knowledge on the damage mechanisms caused by individual pests or types of pests (including diseases, insects and weeds), it is possible to model yield losses as a function of "injury profiles" (Willocquet et al., 2008). In turn, injury profiles are linked with "production situations", a concept that encapsulates both the contextual factors and the way farmers manage their production to adapt to this context.

The benefit of shifting from the usual single pest species point-of-view to this "multi-pest" approach is that, provided one has sufficient field data to link crop management decisions to pest prevalence, it makes it possible to anticipate consequences in terms of yield loss and then to accordingly decide on pest management priorities.

Setting new directions for plant breeding

The genetic features of available varieties are strong constraints in redesigning cropping systems. For instance, species useful for intercropping or for diversifying crop rotations have not yet received much attention from breeders. In major crops, high yield and quality have been the main targets, with lesser attention to resistance to pests; these were assumed to be controlled by pesticides. When this is no longer the case, the ranking of varieties may be significantly altered. Varieties which can sustain some level of pest incidence without being significantly affected in terms of yield are desirable for the design of less vulnerable systems. The French experience with hardy wheat showed how growing these varieties under low input management can provide benefits in terms of both economics and the environment (Bouchard et al., 2008). Reducing fungicides, fertilisers and plant density in parallel is important, as the latter factors indirectly affect disease tolerance. This clearly illustrates the concept of designing at the same time new cropping systems and the varietal types that would ideally suit them.

While considerable progress in our knowledge on crop-pest interactions offers new avenues to improve resistance or decrease susceptibility in crops, breeders should also be aware that their varieties are likely to be used in the future within more diversified cropping systems and will be expected to contribute more to pest management and input reduction than today.

Enlarging time and space scales

To optimise chemical control, farmers tend to focus on the field and the growing season levels. In contrast, the relevant scales for redesigning pest management encompass that of the biological cycle of pests (as well as that of the beneficial organisms that may control these pests) which are much broader, although quite variable.

The need to adopt a large time scale is perfectly illustrated in the case of weeds (Munier-Jolain et al., 2008). The effectiveness of weed control cannot be judged on results within a single season as it is the resulting seed bank left in the soil that will determine subsequent infestation levels. Weed management can also rely on a multi-year strategy: changing the sowing date in successive cycles by diversifying crops within the rotation. The situation is similar with soil-borne pathogens, such as fungi and nematodes. In this case, the succession of host and non-host crops modulates the inocula levels and the antagonistic potential of the soil microflora.

For other pests, spatial dispersion is more important than local persistence and the relevant scale extends beyond fields to encompass the non-cultivated surroundings or even a small region. Considering the role of landscape in pest management, emphasis is commonly placed on conservation of functional biodiversity and the role of beneficials in regulating pest populations, but new results also indicate that the arrangement of vegetation in the landscape affects pest levels (Valantin-Morison et al., 2007, Ricci et al., 2009). As a specific case, the spatial distribution of resistant varieties can be used to increase their durability by slowing down virulent races (Hossard et al., 2010).

Designing and assessing innovative strategies

The principle of acting on multiple levers to manage all major pests in a cropping system is very ambitious and poses serious methodological questions. With classical experimentation, only minor variations of already established systems can be tested. How can we design innovative combinations and compare their outputs in terms of economic and environmental performances? ENDURE invested in the development of a modelling tool, DEXiPM, tested in the System case studies (ENDURE, 2009d).

DEXiPM is designed to make it possible to assess strategies according to sustainable development criteria without requiring an initial set of sophisticated quantitative data. Pre-existing experimental data and expert knowledge can be combined to scan an array of potential solutions among which the most promising ones are selected by comparative assessment. Efforts can then be directed at testing and refining those promising candidates by in-station or in-field experiments.

DEXiPM can also be used as a co-innovation tool. Farmers and other stakeholders can collaboratively define the relative weights given to assessment criteria and identify the contextual elements which could facilitate the implementation of innovative solutions.

Involvement of the entire agri-food system

It is useful to look back at how the current mainstream agricultural systems have emerged in Western Europe in the second half of the last century. It helps to understand that non-technical barriers impede the move toward the reduction of pesticide dependency. It can also help identify appropriate levers.
A study of the case of winter wheat in France at the turn of the eighties (Lamine et al., 2010a) illustrates the path-dependency theory in which an innovation pathway becomes dominant due to a positive feedback loop associated with its implementation (Dosi, 1982, Cowan and Gunby, 1996). The introduction of herbicides and fungicides for field application allowed and led to large-scale adoption of high-yielding cultivars that were more susceptible to diseases.

These cultivars could better take advantage of higher fertilisation rates and sowing density with the use of growth regulators. But these techniques increased the need for chemical control. It is not simply that techniques were combined into a coherent production system increasingly dependent on pesticides, but also that farmers, input producers, advisors and other involved stakeholders responded to the dominant paradigm. They adjusted to each other creating a “lock-in” situation in which no single stakeholder can easily reconsider the initial options alone. The entire food chain and associated institutions – including research – also became gradually engaged in this lock-in process. Although several scientific productions and networks bringing together researchers, advisors and farmers have assessed the technical and economic feasibility of more extensive farming practices since the mid-1980s (Meynard and Girardin, 1991; Bouchard et al., 2008), these remained marginalised and mainstream research efforts were not directed towards such alternatives (Vanloqueren and Baret, 2009).

In ENDURE, social scientists explored such lock-in effects in seven European countries at the levels of producers, advisory systems, and retailer strategies. They looked for clues to the factors impeding or facilitating change toward more sustainable crop protection strategies (Lamine et al, 2010b).
At the production level, a study on the diffusion of innovation among wheat growers in Northern France showed that robust and extensive transitions toward a systemic vision of IPM were greatly facilitated when farmers were engaged in farmer-to-farmer and farmer-advisor social networks. Belonging to farmer groups helped them adapt new practices to their own situation. But it also allowed them to create a collective identity in which the group agreed to move away from the dominant criteria of professional excellence (maximum yield and highly regular “clean” fields) and to turn to more adapted criteria such as economic margin or environmental benefits. These farmers also expressed a renewed interest in agronomic techniques and knowledge.

Looking back at the mid 1960s in Switzerland, IPM development by fruit growers was also led by pioneer groups, but they were strongly supported by researchers and advisors and thereafter IPM was taught as the reference method in agricultural schools (Lamine et al, 2010b). This highlights the importance of the learning processes and the role of the organisation of the knowledge chain.

Engaging along the concept of system redesign also implies significant changes in professional practice for advisors. Furthermore, in a context where public-sector involvement in extension tends to decrease in most countries at the benefit of private advice, advisors increasingly depend on loyalty of their farmer-clients and on the criteria upon which their work is assessed (i.e., usually yields). This situation tends to make advisors risk-averse and reluctant to promote innovative strategies, unless a common agreement is reached on the objectives, as was the case for pesticide dose reduction in Denmark.

Lock-in effects are also apparent at the food chain level. A common example is that of farmers who would like to diversify their crop rotations with a new crop in areas where arable crops are dominant. They often do not find a local outlet for the production of the new crop. Upstream along the food chain, input producers (the agrochemical, seed and biocontrol industries) will obviously adapt to the new context created by the adoption of the EU pesticide package. But stakeholders, downstream along the chain also, will have to adjust to new crop protection schemes that may affect product quality. For instance, actors in the food processing industry may reconsider the quality criteria they impose on farmers which frequently constitute bottlenecks in the shift toward more sustainable practices. In the fruit supply chain, criteria of size and visual aspects are generally considered a non-negotiable consumer demand, and we know that part of the pesticide use is linked to meeting these criteria. However, small scale experiences with short food supply chains supported by local communities

show that direct links between producers and consumers can support gradual change towards organic farming or pesticide use reduction – an indication that consumer demands can indeed change under certain circumstances (Lamine, 2005).

ENDURE social scientists have also examined how private standards, such as GlobalGap, set up by retailers since the mid-nineties could impact farming practices. Although these standards are mostly directed at providing companies with food insurance and primarily require producers to trace their practices, some guidelines emphasise environmental impact and include requirements on crop protection schemes. Not really supportive of IPM as such, they nevertheless might encourage farmers to turn to more environmentally-friendly practices and encourage producer groups to invest in professional advice.

Conclusion

While the optimisation of current farming systems will allow some reduction on pesticide use impacts on the short term, establishing truly sustainable systems that fit the new environmental objectives that the EU is placing on its agriculture is an ambitious and longer term goal. It implies a change of paradigm in the design of farming systems and coordinated changes from a wide range of interdependent stakeholders within the socio-technical system. Research has a significant role to play in supporting this transition process. Sharing the effort within a transnational network like ENDURE will help meet this considerable challenge.

2

ENDURE FORESIGHT STUDY: OBJECTIVES AND METHODOLOGY

Emilie Labussière

2.1 | FORESIGHT AS A TOOL FOR EXPLORATION

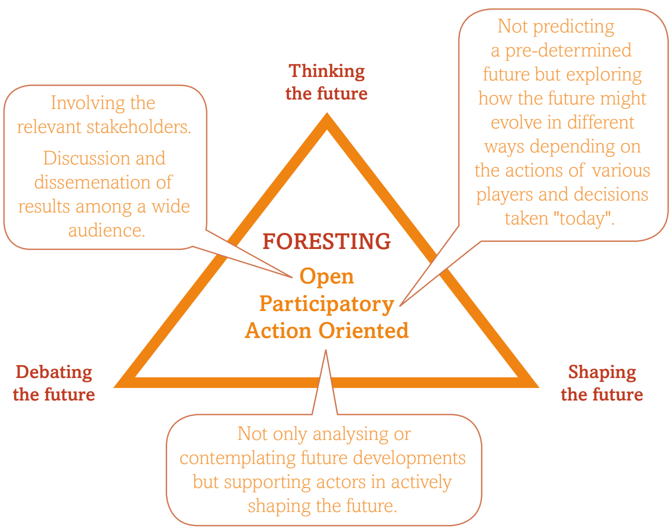
This foresight study was carried out within ENDURE, a European Network of Excellence which aims to create a coherent and sustainable group on crop protection. It brings together a research community committed to the scientific basis and the implementation of sustainable crop protection. ENDURE is building key components that can be jointly exploited by the scientific community such as a common research agenda, identifying gaps in current knowledge and harmonising research programmes to cover unaddressed issues.

It was therefore important for ENDURE to explore what opportunities science and technologies could offer in the next twenty years to move in this direction, and what research agenda should be set in the short term to exploit these opportunities. Because ENDURE is a European network involving various crop protection stakeholders, it was also important to consider how they could contribute to create the appropriate conditions for farmers to adopt innovative farming systems less dependant on pesticides, and what kind of political decisions would support such changes.

Many foresight studies focus on food and food systems, most of them also addressing agriculture. Theses studies consider either the global scale (e.g. Millennium Ecosystem Assessment) or the European scale (e.g. Forward look on European Food Systems in a Changing World), but very little is said about crop protection. As a consequence, ENDURE made the choice to conduct its own scenario analysis considering the potential evolutions of agriculture and crop protection in the future. This exercise has been carried out between July 2007 and March 2010 and has 3 main goals (Figure 2):

- **Thinking the future.** This study helps ENDURE community organising its thinking about the future and envisaging unexpected perspectives for crop protection.
- **Shaping the future.** The scenarios allow identifying long-term research priorities for crop protection at the national and European levels. It is the basis for elaborating and proposing a joint European research agenda.
- **Debating the future.** Foresight is a tool to launch discussions between all crop protection stakeholders.

Figure 2. Three main goals for foresight
(source: http://europa.eu, © European Union, 1995-2010 JRC – IPTS, European Foresight website)



Thinking the future

The overall approach of a foresight study is never predictive but rather explorative. Our analysis does not intend to predict or forecast what crop protection will look like in the future. It does not extrapolate quantitative trends or model future configurations. On the contrary, it aims at building qualitative scenarios as transparent descriptions of possible futures for crop protection in Europe. In practice, the scenarios are a set of narratives with diverse alternatives on how crop protection might evolve in the future.

Naturally, these scenarios are based on current facts and figures, trends in major drivers, as well as potential breakthroughs. Crop protection is not an isolated sector of activity, thus the scenarios have been described within different general and agricultural contexts to inform on how crop protection will be affected by these contexts and by seemingly distantly related policy decisions. They include various elements influencing crop protection in Europe, ranging from external factors such as world demand for agricultural products and climate change to more internal factors such as EU policies and their consequences on European agriculture and stakeholder strategies.

Shaping the future

The five scenarios we developed help consider how different global contexts and different options on the role of agriculture in Europe would impact the solutions adopted to control pests, weeds and diseases. They all address the sustainability of crop protection, exploring contrasted ways in which the goals of agricultural production and environmental risk reduction can be reconciled as regards crop protection.
However, these scenarios were developed mainly to study a number of questions specific to the European research community: which scientific field is a priority in each scenario, what are the key research questions, what would be a major scientific breakthroughs required, etc. This study makes it possible to explore what would be, under a variety of circumstances, the technical and scientific challenges to be met. By identifying long-term research priorities on crop protection at the national and European levels, it is the basis for developing and proposing a joint European research agenda. Because the study considers the entire crop protection system, it also makes it possible to address organisational, societal and policy challenges.

Debating the future

This foresight exercise is an excellent foundation to elicit a debate on crop protection issues at the European level. Putting into discussion the five contrasted scenarios, it gave ENDURE scientists the opportunity to interact within the network, but also with various European crop protection stakeholders such as farmers, extension services, environmentalists, consumer representatives, industry representatives and policy makers. The implications for research were discussed in particular detail.

2.2 | PROCESS

The ENDURE foresight study was one of the integrating activities of the Network of Excellence. Originally planned to last one year, this study proved to be pertinent to more aspects of ENDURE than originally understood and it was finally given more importance and time. It was initiated in July 2007 and was conducted over more than two years and a half.

Scientific knowledge and expertise were brought in by an "expert panel", bringing together ten researchers from four of the ENDURE member institutions and covering a large range of disciplines including agronomy, phytopathology, weed science, economics and social sciences. Management and coordination of the project was provided by a "project team" closely linked with the INRA foresight unit which provided the foresight methodology (see page 3).

The full process encompasses three main phases:
- Delineating the study
- Building contrasted scenarios
- Discussing these scenarios

Delineating the study

As for every foresight study, the first stage was to clearly describe the considered system and its boundaries, especially the spatial scale and time span.

System

In this foresight exercise, we considered the "crop protection" system. We took into account:
- Commercial arable agriculture and horticulture, including non-food productions (feed, fiber, fuel, ornamentals, etc.), but excluding forests and gardens (public or private);
- A range of crop protection approaches going towards Integrated Pest Management, from improving input efficiency to substituting inputs and redesigning the whole agricultural systems;
- A system approach including not only farmers' practices but also industry, food retailers and consumers patterns and practices.

Spatial scale

The study covers Europe. Because agriculture and crop protection are dependant on geographical and climate conditions, we chose not to limit the spatial scale of our study to EU27 but to enlarge it to Europe's geographical boundaries. Interactions between Europe and the rest of world received specific attention when Europe was considered as a single entity. The scenarios do not describe which kind of mosaic will make up Europe in 2030, however European diversity (e.g. the different agricultural models or the different climate conditions between European countries) was taken into account and examples were mentioned when possible.

Time span

A 2030 horizon was chosen. This time span is sufficiently far into the future to allow for significant changes and possible breakthroughs to take place in crop protection practices. It also makes it possible to take into account long-term factors such as policy options and research strategies in terms of scientific organisation and innovation programs.

Building contrasting scenarios

The second phase was to build contrasting scenarios. For that, we followed a French classical methodology (Sébillotte and Sébillotte, 2009):
- We started by building a knowledge base of the system. The panel of experts met several times to set up a **list of variables** that currently influence or will influence crop protection in Europe. Both barriers preventing change and drivers eliciting change were included in this list.
- Then, the panel determined those drivers considered to be most significant to the future of agricultural systems and crop protection. Based on their experience and on literature review, they associated **assumptions** regarding the evolution of these drivers. These drivers were ordered into four components which serve as units for the development of scenarios.
- Several **micro-scenarios** were developed for each component. These micro-scenarios served as scenario building blocks.
- Finally, we combined micro-scenarios to build coherent foresight **scenarios**.

A final scenario development meeting was held in Paris, providing the final expert input needed to wrap-up the study. The main objectives of this meeting were to identify the main challenges and opportunities for future research on crop protection, as well as important messages to send to policy makers.

Discussing the scenarios

Over the three-year process of the foresight exercise, building and discussing the scenarios gave ENDURE scientists the opportunity to interact within and outside the network. In fact, because ENDURE is a European network involving various stakeholders, it was important to consider how each of them could contribute to crop protection changes in the future. Thus, the scenarios were subject to both early interviews in the course of their development and to debates once they were set. This participatory process helped identify research challenges and opportunities and involved:

- Nearly all the ENDURE member institutions.
- "External" researchers whose expertise was relevant to the study. In particular, as our initial expert panel was mainly representative of Northern Europe, we held an additional meeting with experts from Eastern and Central Europe and Mediterranean basin. This regional expertise brought interesting contrasts to the scenarios and specific research questions.
- Various crop protection stakeholders such as farmers, extension services, environmentalists, consumer representatives and industry, most of whom are represented in ENDURE's Advisory Board.

In addition to describing possible futures for European Crop Protection in 2030, this foresight exercise has been an excellent foundation to elicit debate at the European level.

For example, the outputs of the foresight study were delivered during a lunch presentation in Brussels (Figure 3). This presentation, upon the invitation of Mrs Erna Hennicot, Member of the European Parliament, targeted a European-level audience including representatives of farmer unions, agrochemical and biocontrol industries, environmental NGOs, government representatives from Member States and research institutions.

Figure 3. Presentation of the foresight study in Brussels in April 2009

It provided the opportunity for five Directorates General from the European Commission (Environment, Research, Enterprise and Industry, Agriculture and Rural Development, Health and Consumers) to meet and exchange views on crop protection and the pesticide issue.

Several presentations of the foresight study were also given to broad audiences involving national stakeholders, at least in France (GéDuPIC project) and in the Netherlands (Ministry of Agriculture).

This foresight study has been considered as an excellent tool to think about the future. During the debates, it was frequently observed that reality would probably end up as combination of the five narratives we presented. The audience often acknowledged that the scenarios are helpful in freeing oneself from short-term perspectives and clarify the possible options for crop protection over the long-term. They highlight the coherences and inconsistencies in existing systems and serve as a tool to imagine future systems. In particular, many stakeholders underlined the usefulness of this exercise because it helps to picture the broad options that might be taken and their consequences.

Box 1. Schedule of the project

Step 1: Delineating the study
from July 2007 to September 2007
(2 Expert Panel Meetings)
- Implementation of the working group
- Definition of the system
- Collection of input material

Step 2: Building the scenarios
from September 2007 to June 2008
(4 Expert Panel Meetings)
- Identification of key drivers
- Compilation of components, elaboration of assumptions and micro-scenarios
- Combination into coherent scenarios

Step 3: Discussing the scenarios
from June 2008 to October 2009
(Consultation phase)
- Interviews with ENDURE partners
- Interviews with crop protection stakeholders
- Scenario deepening within the expert group

Step 4: Finalising and delivering the study
from October 2009 to April 2010
- Focus on research questions
- Integration of regional heterogeneity *(1 specific meeting)*
- Scenario wrap-up, final report design and delivery *(1 Expert Panel Meeting)*

3
DRIVERS, TRENDS AND ASSUMPTIONS OF THE STUDY

Emilie Labussière, Marco Barzman, Pierre Ricci

In 1997, Rabbinge and Oijen published a paper on foresight methodology in which they emphasise the usefulness of foresight methodology in gaining insights into changes in pest control. Citing three different examples, they predicted an increased range of application for these scenario studies in the future. Following their advice, ENDURE initated in 2007 a foresight study specifically dedicated to crop protection.

To consider the future of crop protection in Europe, we used several contextual drivers and trends common to recently conducted foresight studies on food and food systems. The studies consider either the global scale (Millennium Ecosystem Assessment, 2006; IAASTD, 2009) or the European scale (SCENAR 2020, European Commission 2006c and 2020-II, 2009f; Standing Committee on Agricultural Research, 2007; European Science Foundation, 2009) at different time horizons. Although they all address agriculture, they generally say very little about crop protection.

All of these studies consider a current situation where global demand for food is expected to rise while the further extension of available agricultural surface area will probably be limited. Overall, agricultural systems are predicted to further intensify and gain in productivity (IAASTD, SCAR). Crop protection and pesticides are considered as one tool to increase productivity, and the benefits of managing pests properly are underlined in all of these studies (SCENAR 2020, ESF/COST).

Nevertheless, there are increasing concerns associated with pesticide use. Health concerns over plant protection products are mentioned in all studies. Demonstrated effects on consumers, workers and public health are feeding preoccupations, making food safety the main crop protection topic in many studies (IAASTD, SCENAR 2020). Except in the MEA, the range of environmental externalities associated with pesticide use is secondary. Still, health and environmental impacts of plant protection products have been demonstrated and the trend is to encourage farmers to use them in a safer and sustainable way (ESF/COST).

New technologies such as micro-doses of pesticides, robots and biocontrol are expected to be further developed as developments reducing pesticide use (MEA, ESF/COST). Future cultivars will be more resistant to pests and diseases. There are that biotechnologies can lead to efficient, clean and resistant plants (SCENAR 2020). To save inputs and limit the use of pesticides, such technologies may be accepted even though they raise new additional environmental and health concerns (SCENAR 2020, SCAR).

Climate change is considered as a given. Its effect on pests and diseases is underlined in many foresight studies (SCENAR 2020, SCAR, FFRAF), always linked with concerns about biosecurity and invasive species. Bioenergy crops also raise concerns about emerging species, as well as concerns with a potential increase in the use of pesticide and nitrogen (SCENAR 2020). Most of the studies mention that important research gaps need to be addressed to tackle both of these challenges.

Drawing from the above-mentioned studies, from a literature review as well as from its own collective expertise, the ENDURE foresight study working group selected thirty drivers that currently influence or will influence agriculture and crop protection evolution in Europe. This chapter presents an overview of the past trends, currents facts and future perspectives on these drivers.

The drivers selected were assigned to one of the following components:

- **Global context:** global trends affecting world agricultural demand and supply
- **Agriculture in Europe:** an overview of European agricultural production, trade and Common Agricultural Policy
- **European policies on health and the environment:** an insight into EU policies on health, climate change, water, biodiversity, etc.
- **Organisation and strategies of crop protection stakeholders,** e.g. farmers, civil society and consumers, retailers, agrochemical industry, etc.

For each component, the working group developed short narratives combining some of the assumptions on the future. These micro-scenarios, which are described at the end of each section of this chapter, were then merged into larger coherent scenarios on the evolution of crop protection in Europe up to 2030.

3.1 | GLOBAL CONTEXT

Global food supply

In 2009, the total number of undernourished people in the world reached nearly 15% of the world's population and worldwide, food security and access to food remain major challenges: what is the relationship between hunger in localised areas and global food production? The answer is not as straightforward as it appears, as it now appears that access to food is more critical than the global capacity to produce food. Nevertheless, the question of the world's capacity to grow enough food and other commodities to ensure the needs of future populations, even if it is not what determines the occurrence of hunger, can still be posed.

It is certain that the global demand for agricultural products will continue to grow. World population is projected to jump from 6.7 in 2007 to 8.2 billions in 2030 (UN, 2007). This population growth will be most pronounced in developing nations, while the EU population is expected to stagnate or decline.

Another major reason for such continued rapid growth in food demand is the overall high economic growth and high growth in per capita income. This trend is associated with increase in per capita food consumption and changes in food preferences in favour of dairy, meat and processed foods. In the future, the rising consumption of animal products will probably imply a significant increase in the demand for feed grains and protein feed (OECD-FAO, 2009).

What is difficult is to estimate the pace of this growing demand for agricultural products. On the one hand, some – e.g., the authors of World Agriculture: Towards 2015/2030, or the Institute for Food and Development Policy – are predicting only a modest growth, arguing that world population growth rates have been declining since the late 1960s and that high levels of food consumption per person already reached a plateau in many countries. On the other hand, FAO estimated in 2008 that world food production will have to increase by 50 percent by 2030 to meet the demand, in particular for cereals (Figure 4).

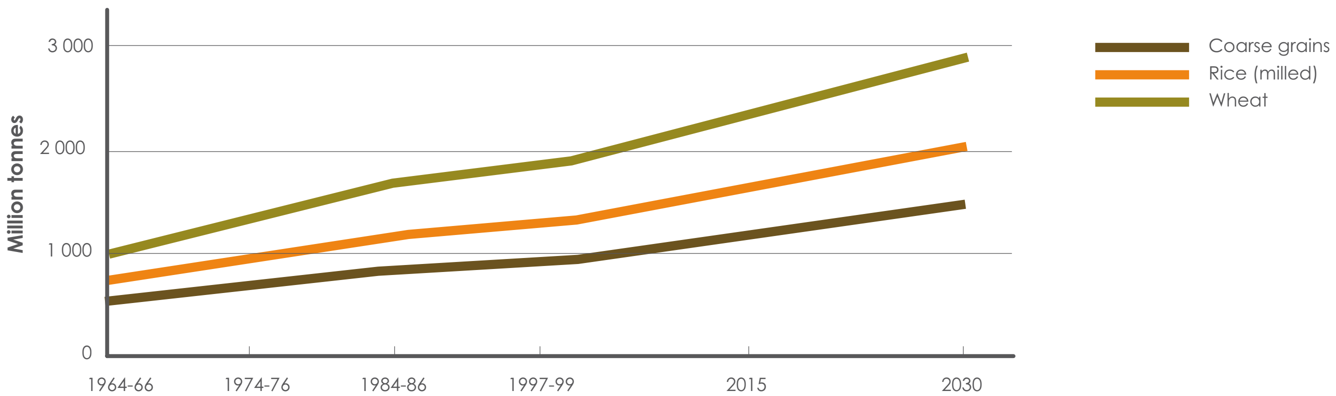


Figure 4. World demand for cereals, 1965 to 2030

(source: © Food and Agriculture Organisation of the United Nations from World Agriculture: Towards 2015/2030 - Summary report, 2002)s

One way to increase global food production is to expand the extent of cultivated land. It is estimated that about 2.8 additional billion ha are suitable in varying degrees for production of arable and permanent crops (FAO, 2002). Regions of the world where agricultural area could increase are mainly Latin America and sub-Saharan Africa. In other regions, such as in new EU Member States, extensive fallow or under-utilised land can be converted to cultivated land. Yet, only a fraction of this extra land is realistically available for agricultural expansion, mainly because of preservation of natural resources and accessibility issues.

In regions where the expansion of land area is not possible, intensification can be a source of production growth. Even if the 1990s saw a slowdown in this trend, yield growth will continue to be the dominant factor underlying increases in crop production in the future. Overall, it is estimated that some 80% of future increases in crop production in developing countries will have to come from intensification: higher yields based on inputs use, increased multiple cropping and shorter fallow periods (FAO, 2002). Improved management and technologies may also push towards higher yields. One of the consequences of this intensification is that transition countries are expected to shift from being net grain importers to being net grain exporters (Von Witzke et al, 2008).

In the long-term, productivity increases must be combined with environmental protection. Organic inputs can contribute significantly to intensification in resource-poor areas. In the wake of the 60s-90s green revolution, some argue in favour of increasing production via a “doubly” green revolution that makes uses of organic inputs as wells as GMOs (Conway, 1997). Others champion agro-ecology with the application of principles from traditional indigenous agriculture and a better exploitation of complexity in agroecosystems. Some also see organic agriculture as part of the solution. An FAO report, for example, estimated in 2007 that sustainable intensification in developing countries through organic practices would increase production by 56% (FAO, 2007). In any event, the solution sought must allow agriculture to be both more productive and more environmentally-friendly, relying more heavily on the intrinsic qualities of the environments concerned and including synthetic inputs only when absolutely necessary.

Apart from intensification, another way to ensure global food security might be structuring food chains, increasing access to food at local or regional scales, in some cases by limiting imports. Indeed, there are voices calling for a decrease in food import dependency, especially in developing countries with a high agricultural production potential. In such situations, it would help re-localize food systems and establish a degree of local food self-sufficiency.

Food prices and international trade regulations

Adding to the challenge of meeting the rising demand for agricultural products, the first decade of the 21st century saw dramatic increases in food prices (e.g. 85% between April 2007 and April 2008, according to the UN, 2008). In the wake of global financial volatility, such fluctuations in world agricultural markets reinforced the global crisis and worsened political and economical instability and social unrest in both poor and developed nations. Spring 2008 was particularly difficult with hunger riots in Haiti, protests in Egypt, shortages and rationing in Thailand, Pakistan, Mexico and many other developing countries.

Short-term emergency measures were adopted to relieve this crisis. Food programmes and food-related development aid were widely implemented, along with concerted international interventions attempting to minimise speculation on food trade.

In coming years, the reduction of trade barriers via multilateral and regional trade agreements will probably increase international competition. Free trade proponents see this trend as playing an important role in improving food security and boosting overall agricultural production. Proponents of food sovereignty, on the other hand, see local food production as the key to ensuring access to food.

In any case, free trade has been a growing trend since 1947, although agriculture has been a major stumbling block. Since that time, eight cycles of multinational negotiations have been held under the governance of the World Trade Organisation (formerly General Agreement on Tariffs and Trade). These negotiations intend to set the rules for trade between nations at a global or near-global level. The current negotiation round, launched in 2001 and known as the Doha Development Agenda, is broader than past global trade negotiations. The Doha round focuses on reforming agricultural subsidies and specifically addresses the needs of developing countries. It aims at lowering barriers to agricultural trade around the world, improving access to global markets.

The progress made in the current round of negotiations is limited. Negotiations were slowed down by a proposal for a WTO “agricultural exception” based on the idea that, unlike other economic activities, agricultural production should not be solely influenced by global market forces. Significant differences emerged between developed nations (the EU, the USA and Japan) and major developing countries (India, Brazil, China and South Africa). There is also considerable contention against and between the EU and the USA over their maintenance of agricultural subsidies, seen to operate effectively as trade barriers (Bouët and Laborde, 2009).

Global energy situation

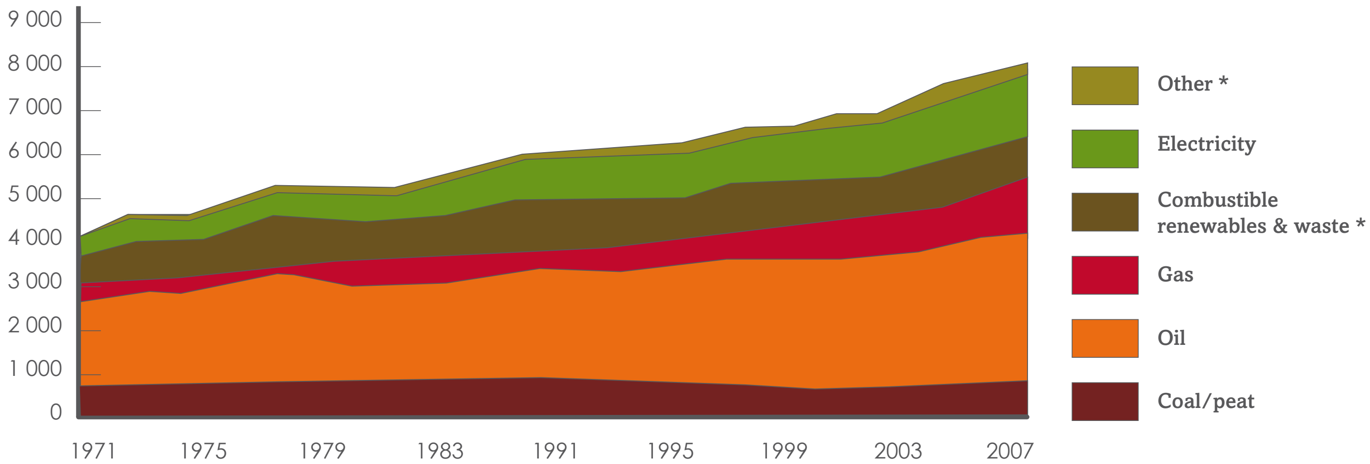


Figure 5. World total final consumption of energy
Mtoe - * Other includes geothermal, solar, wind, heat, etc.
(source: International Energy Agency. Key world energy statistics, 2009)

The overall situation is quite similar for food and energy. A major issue today is supplying the large amounts of energy needed by the growing economies of the world. There is a very high demand coming from both developed and developing countries. In fact, global energy use has risen by 70% since 1971 and continues to increase (Figure 5). Between 2007 and 2030, the International Energy Agency (2009) projects a world primary energy demand increase of 1.5% per year.

Fossil fuels (coal, natural gas, uranium and oil) remain the dominant sources of primary energy worldwide (World Energy Council, 2007). Although proven recoverable reserves vary from one estimate to another, it is certain that these resources are finite. Their future scarcity translates nowadays into ever-growing prices. In August 2006, for example, oil prices jumped and reached new record levels just below USD 80 per barrel. Because of the continuing tight balance between supply and demand, prices are expected to remain relatively high (OECD-FAO, 2009).

Renewable sources of energy (geothermal, hydraulic, solar, wind, tidal and bioenergy) are essential alternatives to fossil fuels. According to the International Energy Agency (2005), the share of renewables in total primary energy supply in IEA member countries increased from 4.6% to 5.5% between 1970 and 2001, but in 2001 renewables accounted only for 15.1% of electricity production in IEA member countries, (e.g. compared with coal: 38%). To meet future demand, innovative energy mixes relying on these energies will be needed.

Bioenergy, primarily from agricultural residues and energy crops, has become one of the most dynamic and rapidly changing sectors of the global energy economy. First-generation bioenergy crops will be replaced by second-generation crops which have the potential to provide benefits such as consuming waste residues and making use of abandoned land (UN, 2007). However, the substantial rise in the use of biomass from agriculture, forestry and waste for producing energy might places additional pressure on farmland and forest biodiversity as well as on soil and water resources. It may counteract other current and potential future environmental objectives such as waste minimisation or environmentally-friendly farming. Bioenergy crops also raise concerns about new crop species, new emerging pests and the potential increase in the use of pesticides and nitrogen (OECD-IEA, 2010).

Along with shifting from fossil to renewable sources of energy, reducing energy consumption and eliminating energy waste is also necessary. There is significant potential for reducing consumption, especially in energy-intensive sectors such as construction, manufacturing, energy conversion and transport. Energy saving has become a priority for the next decades, pushing many countries to implement ambitious policies addressing both energy and climate change issues.

Climate change

Warming of the climate system is widely accepted. By 2030, the average temperature is expected to increase by 1°C whatever the emission scenario may be (IPCC, 2007). Climate change will be different according to geographical patterns. It is expected that warming will be greatest over land and at the most northerly latitudes, and least over the southern oceans and the northern-most parts of the North Atlantic.

In Europe, climate change will probably magnify regional differences (Figure 6). According to international experts, the worst consequences of climate change may not be felt until 2050. However, significant adverse impacts are expected even in the short term due to more frequent extreme events. Direct impacts such as decreasing average annual and seasonal rainfall, more sudden heatwaves, drought, storms and floods will be a serious problem in many regions. In several regions of the world such as South Asia and Southern Africa, food security might be threatened by climate change (Lobell et al., 2008). Warmer and fewer cold days and nights, warmer and more frequent hot days and nights are likely to lead to changes in yields. Heavy precipitation events might also increase damage to crops. Global warming, associated with rising sea levels, increased droughts and meteorological disasters is expected to push climate refugees to flee certain regions of the world.

The relationship between climate change and agriculture is a two-way street. On the one hand, climate change affects agriculture. On the other hand, agriculture contributes to climate change in several major ways. Concerning the impact of climate change on agriculture, modifications in yields are expected. The geographical distribution of plant pests and diseases might also be extended; risk of invasions might be higher. Plants are likely to be more vulnerable because of additional stress caused by heavy drought and precipitation.

However, in Europe, agriculture can adapt via adjustment of planting dates and crop variety, crop relocation and improved land management. Europe will probably still enjoy favourable pedo-climatic conditions for agriculture (with the exception of the Mediterranean region, according to Olesen, 2007). In 2005, agriculture accounted for an estimated emission of 10-12% of total global anthropogenic emissions of greenhouse gases. This can be mitigated by options such as improved agronomic practices, improved livestock and manure management, nutrient use, tillage, and residue management. Many mitigation opportunities are based on available technologies and can be implemented immediately, but technological development will be a key driver ensuring the efficacy of additional mitigation measures in the future (Smith et al., 2007).

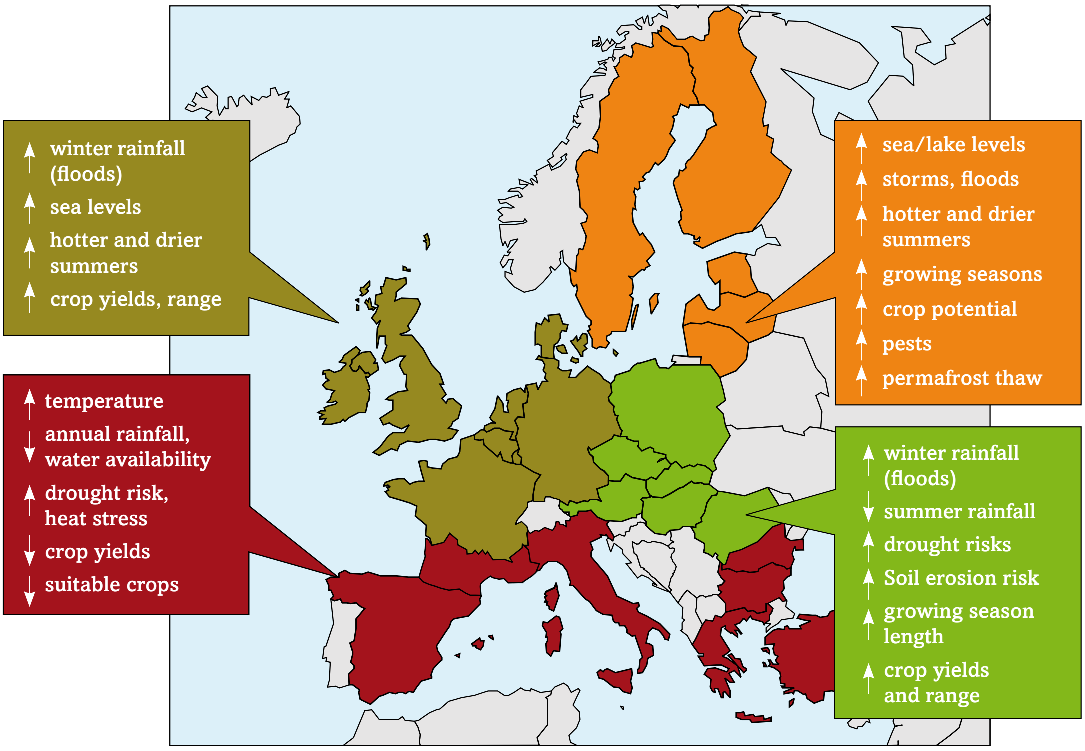


Figure 6. Projected impacts from climate change in different EU regions *(source: http://europa.eu, © European Union, 1995-2010 DG Agriculture and Rural Development webpages)*

Countries around the world are considering actions to mitigate climate change and its impacts. Over a decade ago, most countries joined an international treaty, the United Nations Framework Convention on Climate Change, to begin to consider what can be done to reduce global warming and to cope with whatever temperature increases are inevitable. In 1997, 37 industrialized countries and the European community approved the Kyoto Protocol. International negotiations are now under way to draw up an agreement to govern global action on climate change after 2012, when the first commitment period of the Kyoto Protocol expires. The a minima agreement concluded in Copenhagen in December 2009, seeks to limit a rise in temperatures to 2°C above pre-industrial levels and sets a goal of a $100 billion/year aid to help developing nations confront climate change from 2020 onwards. The 2020 goals include a European Union goal of a 20% cut from 1990 levels. This 20-20-20 target has been adopted in 2007 (see chapter 3.3). The USA plan a 17% cut in their emissions from 2005 levels, or 4% cut from 1990 levels. These international efforts to tackle the challenge posed by climate change will probably be reinforced in the next decades.

Demographic trends and population distribution

As mentioned earlier, world population is projected to be about 8.2 billions in 2030 (6.7 in 2007). This population growth will be most pronounced in developing nations, while the EU population is expected to stagnate or decline. In very broad terms, global demographic distribution patterns and trends may be summed up in terms of two processes, urbanisation and counter-urbanisation.

The pace of urbanisation is increasing with economic development. In 2008, world population reached a landmark when more people lived in urban than rural areas. Most of the world's population now lives in urban areas. Over the next decades, cities and peri-urban areas are expected to absorb all of the expected population growth, while at the same time drawing in some of the rural population. By 2030, virtually all population growth may be urban. It is largely recognised that this phenomenon will occur mainly in the developing world. Asia, in particular, is projected to see its urban population increase by 1.8 billion, Africa by 0.9 billion, and Latin America and the Caribbean by 0.2 billion (Figure 7).

The trend is opposite in developed countries, where people tend to move out of cities to the surrounding areas (Champion, 1989; Gkartzios and Scott, 2005). Many factors explain this counter-urbanisation, which is mainly considered as a reaction to overcrowding and housing costs in inner-cities. People choose to move away from urban areas mainly to improve their quality of life. Progress in individual mobility and public transport infrastructure favour long-distance commuting. Living close to work is no longer a necessity. The development of information technology also makes it possible to work from home. Counter-urbanisation also concerns businesses which also find in the countryside benefits such as lower land values, available sites for all types of development, lower local taxes and high-quality amenities.

Started in the US in the mid 1970s, this "back to the countryside" phenomenon is not new. Counter-urbanisation is a common trend in the "well developed" parts of the world, and has contributed to rising rural populations in many parts of Europe. It is expected to continue, even though urban spread also implies more limited areas for agriculture and nature.
The facts, trends and future perspectives mentioned in this section were combined into micro-scenarios. For each component, the working group built short stories compiling some of the assumptions on the future. The micro-scenarios for the component "Global context" are described in Table 2.

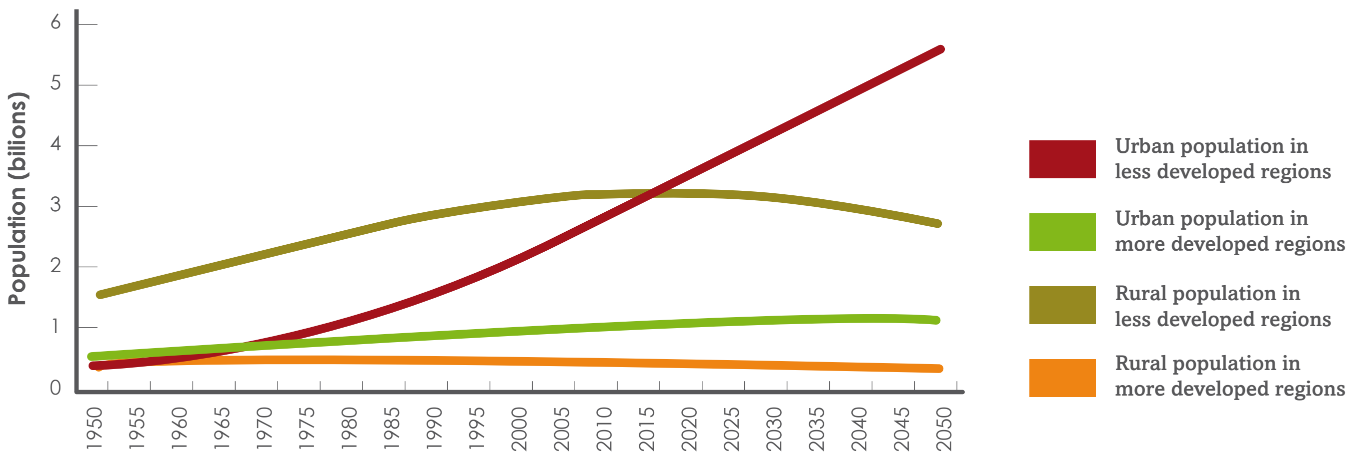


Figure 7. Urban and rural population growth
(source: United Nations, Department of Economic and Social Affairs, 2007)

Micro-scenarios on "Global context"

The facts, trends and future perspectives mentioned in this section were combined into micro-scenarios. For each component, the working group built short stories compiling some of the assumptions on the future. The micro-scenarios for the component "Global context" are described in Table 2.

GLOBALISED AND FREE MARKET	PROTECTION BARRIERS STRENGTHENED	ACTIONS TAKEN TO PREVENT A GLOBAL ENERGY CRISIS	PRIORITY TO LOCAL DEVELOPMENT
Food shortages and associated social unrest favour successful WTO negotiations on agriculture. Barriers and subsidies on agriculture goods are suppressed	Global food supply is ensured by redistributing production and balancing prices. WTO schemes are abandoned to the advantage of trade protection and subsidies	Concerned by the global energy situation and the threat of climate change, nations are taking concrete decisions to reduce energy use and limit greenhouse gas emissions	Global food-related tensions had been alleviated thanks to second green revolution. In industrialised countries, the counter-urbanisation tend is reinforced

Table 2. Micro-scenarios on "Global context"

3.2 | AGRICULTURE IN EUROPE

European agricultural production

EU agriculture produces large quantities of diverse and high-quality products (Figure 8). European agricultural production reflects the different climatic and topographic conditions present in each country that influence growing conditions for crops and pasture.

In the EU-27, the main crops grown on arable land are cereals: overall production was about 270 million tonnes in 2006, with three countries (France, Germany and Poland) accounting for about 50% of production. This soaring production translates into a high European self-sufficiency ratio with respect to cereals, in spite of a slight recent decrease in this area. Field pea, sugar beet, oilseed rape and sunflower remain important arable crops. They are followed by forage crops, the volumes of which considerably vary within each country due to different natural conditions, production, consumption behaviour and history (European Commission, 2008b).

Vegetable and fruit crops are fundamental crops for food consumption and value. The most important vegetables in terms of production are tomato (14 million tonnes), carrot (5 million tonnes) and onion (5 million tonnes). The main fruits are apple (12 million tonnes), orange (7 million tonnes) and peach (3 million tonnes). While apples are produced by almost all Member States, other fruit and vegetable production tends to be highly concentrated in just a few Member States: tomato, orange and pear in Italy and Spain; onion in Spain, the Nether-

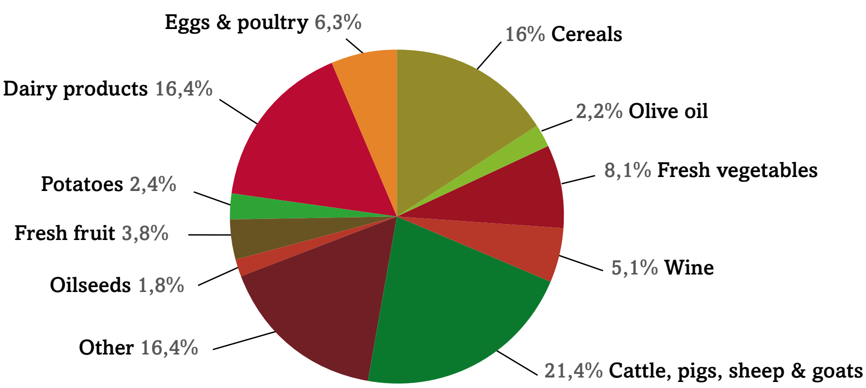


Figure 8. Main EU agricultural products (% share of production by value) *(source: http://europa.eu, © European Union, 1995-2010 DG Agriculture and Rural Development webpages)*

lands and Poland. Most crops are relatively concentrated in the EU Mediterranean countries, as in general, the climate conditions in the south of Europe are more favourable to such productions (Eurostat, 2008a).

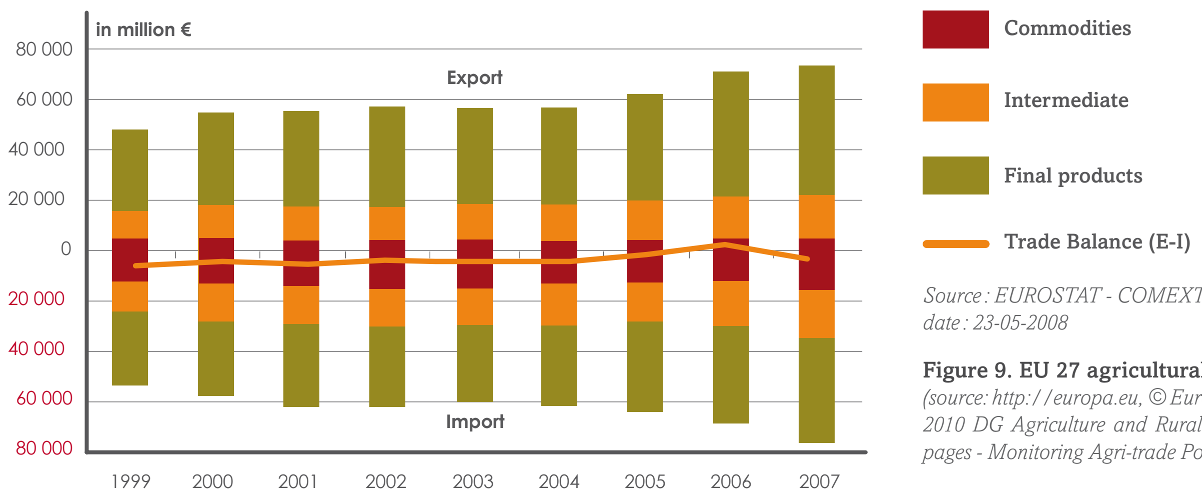
Winegrape and olive are two other key EU Mediterranean crops. The European Union is the largest wine production region in the world, with 3.67 million hectares of vineyard cultivated in 2008. Traditionally, Spain, Italy, France and Greece are the main wine producing countries, but new Member States such as Bulgaria and Romania are also joining the group. The European Union also dominates the international olive oil market. The EU's top four producing countries (Spain, Italy, Greece and Portugal) grow more than 70% of the world's olives, and the EU accounts for a similar share of global olive oil production. Olive farming is an important agricultural activity in the EU's southern Member States, with 5 million hectares harvested in 2007 (European Commission, 2010a).

Animal production needs to be mentioned, as, together, the four main meat types (beef and veal, pigmeat, poultrymeat and sheepmeat/goatmeat) account for 1/4 of the total value of European agricultural production. Livestock farming is distributed across the EU, but many regions are specialised in one or more types of meat production. For example, Ireland produces 7% of the EU's beef. Pig production is concentrated in regions of Belgium, France, Germany and the Netherlands, while 54% of sheep husbandry takes place in Spain and the United Kingdom. With about 150 million tonnes of milk produced per year, the dairy sector makes a substantial contribution to the agricultural turn-over. Milk is produced in every single Member State without exception, with Germany, France and the United Kingdom as the main producers (Eurostat, 2009).

Most of the EU production of agricultural raw materials (about 70%) is processed, generating both products for final consumption (many of which are essential daily products) and intermediate products (such as oils, fats and sugars) for other manufacturing activities. The European food and beverage manufacturing sector is the largest manufacturing industry in Europe (188 billion €of added value generated in 2005). Quality is part of the added value of the products. Thus, EU law lays down stringent requirements guaranteeing the standards of all European products for food safety and hygiene, labelling and nutritional information, food additives, animal and plant health and welfare regulations. In Europe, quality is also associated with traceability: since 2005, traceability systems have been compulsory for all enterprises involved in food and animal feed. Food quality is also covered by a comprehensive system of food labelling, which covers geographical and other designations. Protected geographical indications (PGI) and protected designations of origin (PDO) were created in 1992 with the aim of protecting specific product names from misuse and imitation and to help consumers by giving them information concerning the specific characteristics of products. The EU now has over 700 geographical indications and designations of origin (not including those for wines and spirits).

European agricultural trade

Europe is a major player in the world's agricultural markets. Not only does it export basic agricultural commodities, but it also exports processed products worldwide. But it is not all one-way traffic. The EU is also the biggest importer of agricultural products in the world. To balance supply and demand, the EU often imports cereals (22.4 million tonnes in 2007), which are mainly coming from Brazil and Argentina. These heavyweight exporters are also providers of animal feed stuffs such as soya cake. More perishable agricultural products such as meat, dairy products and eggs tend to be imported in much smaller quantities (Eurostat, 2008b). Although the net trade of the EU has been almost in balance in the recent past, relatively small fluctuations cause a switch in the net position of the EU over the years (Figure 9). 2006 was an exceptional year, with the value of EU exports of agricultural products (estimated about 72 billion euros) overpassing the value of import products (valued at 68 billion euros).



Source : EUROSTAT - COMEXT/ Extraction date : 23-05-2008

Figure 9. EU 27 agricultural trade balance *(source: http://europa.eu, © European Union, 1995-2010 DG Agriculture and Rural Development webpages - Monitoring Agri-trade Policy)*

The EU's agriculture and food industry is strongly affected by international trade negotiations, particularly those of the WTO. The EU's trade in Processed Agricultural Products is governed by a series of bilateral agreements, which also includes specific preferential regimes (e.g. with Euro-Mediterranean and Mercosur). The EU is the largest market for agricultural exports from developing countries, and led the way among the wealthier nations in granting duty and quota free access to products originating in less developed countries. Over the last few years agricultural prices were very volatile in the EU and world markets. 30 years of steady decline in commodity prices were broken by a large increase in 2007(+85% between April 2007 and April 2008). This price rise was broad-based, led by cereals, fol¬lowed by vegetable, oilseed and meat and dairy products. Agricultural prices reached exceptional levels by early 2008, and since then, most of them sharply decreased. The structural causes of the price hike (growth in global food demand, development of the biofuel sector, long-term decline in food crop productivity growth, associated with financial crisis and speculation) remain in place. They are expected to sustain higher prices over the next decade (European Commission, 2009g).

Evolutions in the Common Agricultural Policy

Adopted in 1960, the initial European Common Agricultural Policy focused on encouraging higher productivity to ensure a stable supply of affordable food. It offered subsidies and guaranteed prices to farmers, providing incentives for them to produce. It was so successful in moving agriculture towards self-sufficiency that the EU had to contend with almost permanent surpluses of the major farm commodities.

The EU had to bring in policy measures to try to limit production of surpluses. Following a path of successive reforms started in 1992, surpluses were reduced and the CAP was re-centred around three main policy axes: support product prices, producer income, and structural adjustment. The common organisation of agricultural markets (first pillar of CAP) specifies and supports prices for certain agricultural goods such as cereals, sugar, meat and dairy products. In addition, intervention stocks ensure market stability, equal access to goods and equal treatment of buyers. CAP reforms in the 1990s, partly resulting from the WTO agreement of 1995, reduced the capacity of the EU to use export subsidies. Measures such as direct payments or Less Favoured Areas payments were also implemented to support producer income.

Trade globalisation, consumer demands and EU enlargement bring new challenges to EU agriculture. It is still expected to ensure sufficient and secure food supply, but also to respond to the public demand, preserve the environment and the countryside while providing a fair standard of living for the agricultural community. Thus, CAP evolved from a model to promote self-sufficiency and ensure the security of food supply to one that is increasingly concerned with quality and the environment (second pillar of CAP). The reform of 2003 changed the way the EU supports its farm sector. Under the new system farmers still receive direct income payments to maintain income stability, but the link to production has been severed. Farmers have to satisfy environmental, food safety and animal welfare standards (see chapter 3.3). Farmers who fail to do this will face reductions in their direct payments (a condition known as “cross-compliance”). CAP also encourages farmers to pro-

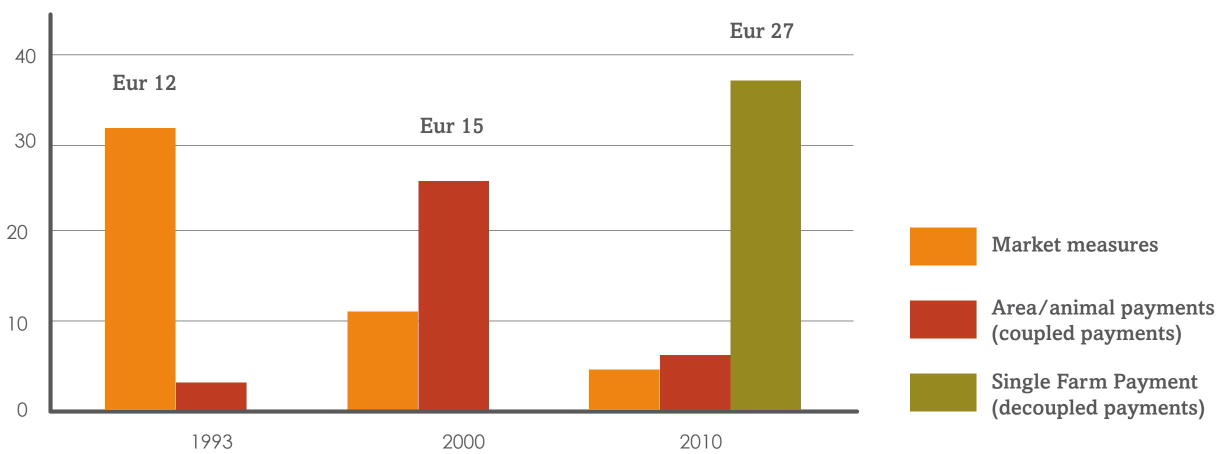


Figure 10. The path of CAP expenditure (billion euros)
(source: http://europa.eu, © European Union, 1995-2010 DG Agriculture and Rural Development webpages)

duce high quality products demanded by the market. Globally, decoupling subsidies and production made them more competitive and market-oriented (European Commission, 2004a).
This significant shift in the manner of support, from market measures to decoupled payment, is illustrated in Figure 10.
In November 2008, EU agriculture ministers reached an agreement on the "Health Check", which aimed to modernise and simplify the CAP, thereby removing production restrictions to farmers. The debate on the CAP post 2013 is expected to focus on four main points: address concerns about food security while the world's population is rapidly increasing, ensure good land management of EU territory, tackle the problem of climate change and support balanced development in rural areas (European Commission, 2009h).

Contribution of agriculture to the Lisbon Strategy

The Lisbon strategy for growth and jobs was launched in 2000 as a response to globalisation. The idea is for the EU and its member countries to cooperate on reforms aimed at generating growth and more and better jobs by investing in people's skills, the greening of the economy and innovation. One of the objectives of the strategy is to reduce the environmental impact of economic growth in Europe by saving energy and promoting new environment-friendly technologies. Strong economic performance goes hand in hand with the sustainable use of natural resources, and this is the guiding principle for the contribution of CAP to the Lisbon Strategy. CAP will continue to make a concrete contribution to more growth and jobs in the future. In particular, many rural areas of Europe would face major economic, social and environmental problems without CAP. Thus, rural development measures can play a significant role in fostering and maintaining prosperity in rural areas.

Adopted in 2005, a European Agricultural Fund for Rural Development complements the strategy in favour of rural areas. It has three major objectives: improving the competitiveness of the agricultural and forestry sector, improving the environment and the countryside and improving the quality of life in rural areas and the diversification of the rural economy. This fund promotes rural development activities by financing measures such as encouraging development of micro-businesses, encouraging the take-up and use of ICT and making use of opportunities from improved local infrastructure (European Commission, 2006d). Local initiatives such as Leader contribute to the creation of new jobs, the improvement of incomes and to the promotion of equal opportunities in rural areas and support diversification (on-farm and off-farm).

One of the consequences is that the diversification of the economy of rural areas to other sectors than agriculture is progressing. For example, 35% of European farmers had another income-generating activity beside agriculture in 2007, this percentage being even higher than 50% in many countries and regions, particularly in Slovenia, Sweden and Cyprus (European Commission, 2009i). This trend is expected to continue.
The facts, trends and future perspectives mentioned in this section were combined into micro-scenarios. For each component, the working group built short stories combining some of the assumptions on the future. The micro-scenarios for the component "Agriculture in Europe" are described in Table 3.

Micro-scenarios on "Agriculture in Europe"

The facts, trends and future perspectives mentioned in this section were combined into micro-scenarios. For each component, the working group built short stories combining some of the assumptions on the future. The micro-scenarios for the component "Agriculture in Europe" are described in Table 3.

COMPETES ON THE COMMODITY MARKETS FOR BASIC CROPS	COMPETES ON SPECIALISED MARKETS	FULFILS THE OBJECTIVE OF SELF-SUFFICIENCY	FEEDS PEOPLE AT LOW ENERGY COST	CONTRIBUTES TO THE *TERRITOIRES*[2] ATTRACTIVENESS
Agriculture is positively stimulated by competition. Farmers compete on commodity markets. They tend to reduce manpower and production costs.	Agriculture is contributing to the knowledge based bioeconomy. Farmers compete on specialty markets, with innovation as a priority.	Confronted to the decline of the global food market, the EU has to ensure a diverse food production for its population. Agriculture is providing the EU domestic market	Facing the global energy crisis, the EU commits to limit transportation and reduce imports. Domestic agricultural production is favoured and reorganised in foodsheds.	The EU is no longer a major exporter of basic agricultural products. It invests in non-agricultural sectors. Multiple services rendered by agriculture remain essential to rural development

Table 3. Micro-scenarios on "Agriculture in Europe"

[2] From the french territoire / the italian territori. Territoire here is seen as a combination of a physical area, its community and its economic activities.

3.3 | EUROPEAN POLICIES ON HEALTH AND THE ENVIRONMENT

Advances in plant protection significantly contributed to increasing yields and ensuring regular production. Today, however, the systematic use of pesticides is questioned due to increasing awareness of their negative impacts and the demonstration of undesirable adverse effects on ecosystems, non-target useful or domestic species and on human health. These observations argue in favour of increasingly restrictive regulations at both the European and national levels. In this section, we will focus only on policies on health and the environment that are linked with crop protection.

Health and nutrition policy

The use of plant protection products can generate direct or indirect risks for users (operators, workers) and the general population (bystanders, consumers and residents) exposed via air, water or food. Acute exposure to pesticides can lead to death or serious illness. Chronic pesticide exposure is known as a problem most often in occupational settings, particularly among rural populations where men, women, and children all work and live in close proximity to fields and orchards where chemicals are applied and stored (WHO, 1990). Long-term exposure to pesticides can increase the risk of developmental and reproductive disorders, immune-system disruption, endocrine disruption, impaired nervous-system function, and development of certain cancers. Children are at higher risk from exposure than are adults.

Current policies aim to minimise the risks posed by pesticides on human health. On the one hand, the products considered as the most problematic (carcinogens, mutagens, endocrine disruptors, substances toxic for reproduction or which are very persistent) will not be approved unless exposure to humans is negligible. EU regulation on the placing on the market establishes a mechanism for the substitution of more toxic pesticides by safer (including non-chemical) alternatives. On the other hand, the use of plant protection products is now under policies aiming to limit human exposure. Sensitive areas (public parks and gardens, sports and recreation grounds, school grounds and children's playgrounds and in the close vicinity of healthcare facilities) are defined. In these areas, the use of pesticides should be minimised or prohibited and low-risk pesticides as well as biological control measures should be considered in the first place. Good practices and personal protection equipment are the basis of worker protection. Education, training and certification programs are also implemented, improving the quality and efficacy of pesticide application, and limiting the risks. By 2014, integrated pest management will be the baseline of agricultural practices.

It is necessary to ensure that pesticide residues should not be found in food or feed at levels presenting an unacceptable risk to humans. Maximum residue levels are therefore set by the European Commission to protect consumers from exposure to unacceptable levels of pesticides residues in food and feed. A new regulation, adopted in 2008, completes the harmonisation and simplification of pesticide MRLs, whilst ensuring better consumer protection throughout the EU. With the new rules, MRLs undergo a common EU assessment to make sure that all classes of consumers, including the vulnerable ones, like babies and children, are sufficiently protected. A labelling is possible for residue-free food, especially organic products.

Apart from the direct relationship between health and pesticides, there are other public policies that link health and agriculture. It is obviously the case with policies on nutrition, which encourage the consumption of certain food products, considered as "healthier". In 2007, the EU adopted a Strategy on nutrition, overweight and obesity-related health issues, which promotes greater fruit and vegetable consumption as one of a number of tools to improve public health, particularly regarding the prevention of chronic diseases such as heart disease, cancer, type 2 diabetes and obesity. This strategy also encourages food labelling (labelling of foodstuffs to enable European consumers to get comprehensive information on the contents and the composition of food products), health and nutrition claims (e.g. "low fat", "high fibre" or "reducing blood cholesterol") and school milk / fruit scheme (provide milk / fruit to school children).

Regulations on plant protection products and GMOs

In 2006, along with the adoption of the REACH regulation, a proposal has been made to improve the procedure for placing plant protection products on the market. In addition and with a view to decreasing the overall risk from pesticides use in the EU, the Commission adopted both a Thematic Strategy on the Sustainable Use of Pesticides and a proposal for a Framework Directive, which will impose appropriate training for professional users, restrict the use of pesticides in certain areas and start the development of relevant indicators. The priority list of substances for further evaluation of their role in endocrine disruption recently established will be taken into account by regulators when drafting legislation as the list ranks the

substances according to possible effects to wildlife, human health and to exposure concerns. Recent advances in the regulation on plant protection products are exposed in detail in chapter 1.1.

Biocontrol may be a good alternative to pesticide use. Like all other products used to control pests and diseases, they need to undergo a comprehensive risk assessment. Although the procedure has been adapted to better meet the characteristics of micro-organisms, the registration is based on rules originally developed for synthetic pesticides. These strict rules are often considered as an economic barrier to the use of alternative pest and disease control solutions (IBMA, 2005).

Biotechnology holds the potential to breed plants that are more drought resistant and stress tolerant, and to increase agricultural productivity while reducing such inputs as fertilisers, pesticides and water to ensure long-term sustainability, but they raise many concerns. In order to ensure that their development takes place in complete safety, the European Union established a legal framework regulating genetically modified food and feed in the EU. This framework pursues the global objective of ensuring a high level of protection of human life and health and welfare, environment and consumer interests, whilst ensuring that the internal market works effectively. The use of GMOs needs to be in tune with the precautionary principle. Therefore the authorisation of GMOs for deliberate release into the environment is made through an environmental and health risk assessment, which is mainly based on the scientific assessment of the European Food Safety Authority. Authorised GMOs are subject to systematic post-marketing monitoring, labelling and traceability requirements.

Some countries, including Spain and Romania, currently permit the use of certain GM crops. In spite of significant concerns over the use of genetically modified organisms, this trend may become more widespread in the future. The major question in biotechnology is perception and acceptance by the consumers and in agriculture in general. Trying to satisfy the demand for transparency, the EU responded with new labelling regulations for GMO presence in food and feed and ingredients, above a threshold allowing for adventitious contamination. In the future, it is likely that biotechnology and GMO products will only prosper in an environment where risk/benefit assessments are fully transparent, where traceability and monitoring are organised and where the consumer is given a free choice (Byrne, 2003).

Agri-environmental policy

Making the CAP compatible with market requirements goes hand in hand with environmental integration. For ensuring sustainable agricultural activities, farmers have to respect common rules and standards preserving the environment and the landscape. These rules are the reference level up to which the costs for complying with these obligations have to be borne by the farmer, according to the "Polluter-Pays-Principle".

Within CAP, voluntarily actions can also be encouraged. Beyond their obligations, farmers can employ their own private resources and factors of production to deliver environmental public goods and services which are of interest to the wider public and society. Committing to more than the application of usual good farming practice, they can be remunerated through agri-environment measures. Farmers enter into a contract for a minimum period of five years and are paid for the additional cost of implementing such commitments and for any loss of income which the commitments entail.

Agri-environment measures may be designed at the national, regional, or local level so that they can be adapted to particular farming systems and specific environmental conditions. They can relate to productive (objectives of input reduction, organic farming, extensification, preventing erosion, maintenance of biodiversity) or non-productive land management (set aside, maintenance of the countryside and landscape features, public access (European Commission, 2005).

Water policies

Agriculture is a key source of diffuse pollution. Modern-day agricultural practices often require high levels of fertiliser and manure that can lead to high nutrient (e.g. nitrogen and phosphorus) surpluses that are transferred to water bodies and can promote eutrophication. The situation is the same for plant protection products that may contaminate both surface and groundwaters (EEA, 2005). The monitoring of pesticides is a challenging task due to the high number of registered pesticide substances. There is limited information available and a lack of reliable data on pesticides in ground and surface water. However, pesticide pollution is reported in a number of national reports.

Protection of water resources is one of the cornerstones of environmental protection in Europe. The stakes are high. The issue transcends national boundaries and concerted action at the European level is necessary to ensure effective protection. The EU Water Framework Directive was adopted in 2000. For the first time, this regulation implements river basins as action units, beyond any administrative or political boundary.

The Water Framework Directive expands the scope of water protection to all water bodies (surface and ground water) and sets as clear objectives that a good status (good ecological and good chemical status) must be achieved for all European water bodies by 2015 and that water use be sustainable throughout Europe.

The Nitrates Directive is an integral part of the Water Framework Directive and is another one of the key instruments in the protection of waters against agricultural pressures. It aims to protect water quality by preventing nitrates from agricultural sources polluting ground and surface waters and by promoting the use of good farming practices.

Biodiversity Action Plan

The European Community and its Member States are contracting parties to the UN Convention on Biological Diversity and EU Heads of State and Government undertook in 2001 to halt the decline of biodiversity in the EU and to restore habitats and natural systems. In May 2006, the European Commission adopted a communication on Halting Biodiversity Loss by 2010 – and Beyond: Sustaining ecosystem services for human well-being. The Communication underlined the importance of biodiversity protection as a pre-requisite for sustainable development, as well as setting out a Plan to achieve this. The EU Biodiversity Action Plan contains measures such as the Birds and Habitats Directives, which set the same high standards for nature conservation across 27 countries and create a Europe-wide ecological network of protected sites (Natura 2000 network) which is destined to conserve over a thousand of rare, threatened and endemic species and some 20 natural habitats. Agri-environmental measures encouraging biodiversity conservation in the farmed countryside are also part of the Action Plan (European Commission, 2006e).

Climate change and energy policy

Concerns about climate change finally led to an ambitious common policy on energy. In 2007, the EU adopted an integrated energy and climate change policy, promoting a low-carbon, energy-efficient economy and including ambitious targets for 2020 (European Commission, 2008c).

The first objective is to reduce greenhouse gas emissions to prevent critical global warming. The EU is committed to reducing its emissions by at least 20% from 1990 levels. It will mainly play on the emission trading scheme, granting fewer emission allowances. This scheme currently covers 10,500 installations in the energy and industrial sectors, collectively responsible for 40% of the EU's total greenhouse gas emissions. Safe use of carbon sequestration and geological storage technologies may also be promoted, which could eventually remove most carbon emissions from fossil fuels used in power generation and industry.

Providing a secure supply of energy, the EU will increase the share of renewables to 20% by 2020. It is estimated that consumption of fossil fuels could be cut by 200m-300m tonnes a year, by switching to renewables. National targets will be strengthened for all member countries, and each country will be required to increase production and use of renewable energy in electricity generation, heating, air conditioning and transport. A fixed 10% of transport fuel needs should be covered by biofuels, provided they are sustainably produced.

The last objective is to achieve a 20% energy consumption reduction. This could cut greenhouse gas emissions by almost 800 M tonnes a year. Energy-efficient technology, products and services need to be developed in areas with the greatest energy-saving potential. Top priorities are placed over buildings (efficient lighting, heating, cooling and hot-water systems), transport (with teleworking as an alternative) and manufacturing (towards eco-products).

Micro-scenarios on "European policies on health and the environment"

The facts, trends and future perspectives mentioned in this section have been combined into micro-scenarios. For each component, the working group built short stories compiling some of the assumptions on the future. The micro-scenarios for the component "European policies on health and the environment" are described in Table 4.

"POLLUTER PAYS" PRINCIPLE	PLANT PROTECTION PRODUCTS ONLY USED IN A TARGETED WAY	PRESERVE THE RESOURCES ESSENTIAL FOR FUTURE PRODUCTION	REDUCE ENERGY CONSUMPTION AND LIMIT EXPOSURE TO PESTICIDES	SEARCH FOR A BETTER QUALITY OF LIFE
Pesticides are largely used, but stakeholders are held legally accountable for any damage. Agricultural areas are disconnected from natural zones	The EU adopts more cautious regulations on pesticides than other regions of the world. Farmers take advantage of precision agriculture not to use pesticide	Concerns emerge regarding the risk of harming future production. Conserving the natural resources that are essential for production is the priority	Modern low-energy agriculture is implemented. Because of health concerns, pesticides are banned from cities and used with caution in the countryside	Quality of life is given priority. Healthy food, preserved biodiversity and landscape are the demanded. Pesticide legislation is strengthened

Table 4. Micro-scenarios on "European policies on health and the environment"

3.4 | ORGANISATION AND STRATEGIES OF CROP PROTECTION STAKEHOLDERS

Farmers

Today, a majority of farmers in Europe largely relies on the use of plant protection products, which have proven to be cheap, easy to use and represent quick solutions to control pests. In 2007, European farmer expenditures on crop protection products came to 9.2 billion €, with an intensity of plant protection product consumption varying from one Member State to another (in 2003, highest in Portugal and the Benelux, lowest in the Baltic Member States, according to Eurostat, 2008b). It remains difficult to have acurate and updated data on pesticide consumption at the European and national level. Overall, the data supplied by ECPA show that the total amount of plant protection products used in the EU in tonnes is declining, but only slightly. However, this declining trend in volume might just be linked with the appearance of more potent, low-dose new chemicals.

The demonstration of undesirable adverse effects of pesticides on ecosystems, on non-targeted useful or domestic species and on human health, associated to technical problems such as resistance led to question their intensive use. Farmers' primary occupation is food production, but in recent years they increasingly face the demand to add the environment and land management in their repertoire, together with food safety and quality, animal health and welfare skills. Adapting to these new requirements is a slow process influenced by many factors.

Of course, economics play an important role, as farmers' first rationale to reduce the use of pesticides is usually to save costs. Farm structure (family / non-family labour[3], part-time / full-time farmer, income and capital) is an important factor and change in production practices is affected by farm size. In Europe, the general trend for farming is the concentration of agricultural holdings. The renewal of farms and technological progress is causing the smallest holdings to disappear replaced by larger ones. It is especially the case in the new Member States. Additional external factors can explain farmers' decisions to change: their interest in the environmental effects of their practices, their worries about the efficient use of natural resources and the growing limits and restrictions on the use of certain inputs (ENDURE, 2009a).

Organic agriculture is often upheld as the solution to the agriculture-versus-environment debate. Defined as "a production system that sustains the health of soils, ecosystems and people", organic agriculture relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects (IFOAM, 2008). Globally, organic farmers restrict the use of artificial fertilisers and chemical synthetic pesticides, preferring to use on-farm inputs and to exploit natural processes. They tend to prioritise indigenous breeds of plants and animals and adopt longer and more diverse crop rotations to break weed and pest cycles. They prevent soil erosion by sowing green manure crops after harvesting and planting and retaining hedges, meadows and

[3] Agriculture remains very much a family-oriented activity in Europe: of the 17.9 million people working regularly on commercial agricultural holdings across the EU-27 in 2005, around 90 % were farm holders or members of their families.

natural vegetation. Although it does indeed contribute to reducing pollution from synthetic inputs, organic agriculture is not environmentally-neutral. There are many forms of organic agriculture, some of which are major contributors to copper and sulfur pollution. In addition, some object that organic farming induces higher prices and lower average yields in comparison with conventional agriculture.

Civil society

Overall risk perception on the use of pesticides varies from one population to another. The main general concerns about crop protection regard health and the environment. Civil society is concerned by the exposure to pesticides in general (especially for vulnerable groups), but also, as consumers, by residues of pesticides and GM foods. Concerns for water contamination and loss of biodiversity, emerged recently, accompanied by awareness-rising campaigns.

Thus, a more significant part of the European population (sometimes with a limited perception of the real agricultural practices) is requesting to use pesticides at levels "as low as reasonably achievable", to implement Good Agricultural Practices and to fully integrate crop protection into farming systems.

Consumers

The food chain is also shaped by changes in consumer demand and preferences. Consumer preferences find expression in various ways, foremost in changing purchasing behaviours but also through political influence on national and regional governments, retailers, food processors and farmers themselves.

The most direct consumer influence is exercised via the shopping basket. Quality and economic realities shape in priority the choices of consumers. While quality continues to matter to consumers they appear to be making more trade-offs among product attributes as they reduce total spending. Health issues concerning food additives, preservatives, or salt/sugar content remain important choice criteria.

Other consumers are starting to consider environmental issues when making consumption choices. It was shown that animal welfare and environmental issues, such as food miles, food energy use, soil and water degradation or types of farming practice tend to be included in the consumer choices (European Commission, 2010b). These issues are becoming important driving forces in the EU food sector. The recent increase in the total area under organic farming illustrates the continuing positive trend in the organic sector in the EU, and the continuing expansion of consumer demand for organic produce may reinforce this trend. The share of EU farming land that is organically managed is about 4%, and it may rise up to 25% by 2030 (FAO, 2002).

Retailers

Retailers are perceived as major drivers of European agri-food systems. Relying on certification schemes, not only are they determining price and food quality attributes, but they started, in recent years, to implement private agri-food standards that are also related to the environment or animal welfare (Henson and Reardon, 2005). A reduced use of plant protection products meets consumer demand, but some of these standards go beyond the scope of existing regulations by forbidding the use of some authorised molecules and requiring the use of biocontrol tools (ENDURE, 2009b). This can be challenging for farmers, which are often requested to have zero-residues in their products, as well as no damages at all.

Retailers seek a consistent supply of good quality product. Their preference is often given to reliable suppliers working in integrated supply chains. Such forces, in combination with consumer demand, can influence farm enlargement and specialisation, the use of inputs and patterns of land use, as well as basic husbandry decisions, such as the selection of crop types and varieties and the timing and frequency of management operations.

Crop protection industry

The European plant protection industry is a significant economic player on the world market. Over the past decades, it has been continually consolidating and restructuring, a process that is ongoing. Strategic alliances between agrochemical, biotechnology and seed companies are reinforcing their access to basic technology and their competitiveness. In 2007, the market for crop protection products in Europe (EU-27 and nations from the European Free Trade Association) increased by 5.2% to reach 17,080 million €at the ex manufacturer level (ECPA, 2008).

Fast adoption of synthetic pesticides contributed significantly to the development of agriculture, but social, political and ecological factors drove recent changes. In addition to biological properties and profitability, the selection criteria for plant protection products now include ecological and safety profiles. This is making R&D for new pesticides more expensive, and reinforces the trend towards consolidation in the agrochemical industry as companies need a larger scale of operation to recoup the cost of registration and testing. However, the number of new chemical entries reported seems to maintain, with only a slight downward trend (Bijman and Joly, 2001).

Searching for new active ingredients remains a strong focus in the agrochemical industry, but suppliers are tackling the recent challenges concerning health and the environment. Having major role in crop protection, the industry often adopts a pro-active stance toward promoting change to reduce health and environmental risks. Ensuring the long-term use of their products is a vital part of their strategy, mainly because of the tremendous R&D investments made. Designing products and services that fit IPM is necessary for maintaining their competitiveness on the global market. They have developed new products with fewer undesirable effects (target specific, less disruptive to the farm ecosystem) and are providing services to minimize intervention (threshold versus program sprays, better application, scouting and decision support services). Some companies are investing in biocontrol as a complementary solution, but this is expected to remain a small part of the market. Agrochemical companies often play the role of local advisors, playing a real role in prevention and promoting a safe use of their products.

The private sector can sometimes promote change in crop protection. The British “Voluntary Initiative” is one notable example. It is a research, training and awareness-raising program initiated by the pesticide industry. It enjoys the support of government and major farming organisations and represents a significant effort in reducing pesticide impacts on water and biodiversity (Kidd, 2005). The threat of a pesticide tax was a sufficient driver to create the Voluntary Initiative back in 2001, but the programme is still going strong.

Agricultural advisers and extension services

Advisors have an important role to play in promoting new agricultural practices. They remain an essential component of the agricultural knowledge system and are considered to be a cornerstone of the decision making at the farm level.

Across Europe, advisory services are differently organised and have different capacities. Plant protection products sellers remains important advisors for farmers. The competition is fierce between advisors particularly because pesticide makers or distributors have started to develop an advisory service that is provided for free to the farmers on condition, of course, of being a customer. However, independant advice can be charged for by new companies, and free advice is developping in several countries in Europe (e.g. via the Chambers of Agriculture) (Filippi and Vargas, 2009).

A side effect of this fierce competition is the decrease in the number of advisors independent from the pesticide industry, although this figure should also be related to the decrease of the number of farmers. The privatization of the extension services is said to delay further implementation of advanced forms of IPM that used to be promoted by independent advisors.

Micro-scenarios on “Organisation and strategies of crop protection stakeholders”

The facts, trends and future perspectives mentioned in this section were combined into micro-scenarios. For each component, the working group developed short narratives combining some of the assumptions on the future. The micro-scenarios for the component “Organisation and strategies of crop protection stakeholders” are described in Table 5.

DEVELOPMENT OF “GREENER” PLANT PROTECTION PRODUCTS	INNOVATION CLUSTERS INVOLVING FARMERS	FARMER EFFORTS ARE SOCIALLY RECOGNIZED	MAJOR CHANGES IN MOBILITY, WORK HABITS AND CONSUMPTION	RESIDENTS, VISITORS AND BUSINESSES INTERACT FOR THE BENEFIT OF EACH TERRITOIRE
Agrochemical industries develop new molecules with safer modes of action. Farmers use them in a responsible way. Civil society still question the use of pesticides	Authorities implement a cross-cutting innovation policy. All economic actors are involved in innovative clusters. Farmers are a central piece in the economy.	Consumers are aware of the global food situation. They change their diets and turn to local food. Citizens recognize and value the efforts of farmers.	High energy prices imply major changes. Citizens gather in cities where collective transportation is favoured. They change their eating habits according to theirs foodsheds	Decisions results from trade-offs between the territoire stakeholders. Farmers determine their crop protection strategies according to the local demands.

Table 5. Micro-scenarios on “Organisation and strategies of crop protection stakeholders”

4

FIVE SCENARIOS FOR CROP PROTECTION IN 2030

Marco Barzman, Emilie Labussière, Pierre Ricci

These scenarios are intended to show how changes in agriculture in Europe in the next 20 years could impact crop protection and what it means in terms of research needs. They should be judged based on the soundness of their internal logic rather than on their predictive power. The ultimate goal is to help policy makers decide program priorities in their current agenda, in order to cope with future changes and challenges.

We purposefully developed simplified scenarios assuming a uniform situation throughout Europe so as to depict extreme situation types.

The scenarios are built around three different contexts defined according to the type of governance shaping European agriculture:

- in the first context, the rules are set by a globalised and free market (scenarios 1 & 2)
- in the second, Europe organises its agriculture with the goal of answering global challenges: food self-sufficiency or energy-saving (scenarios 3 & 4)
- in the third, governance of agriculture is handed over to local communities (scenario 5)

Table 6. Main components of the scenarios

COMPONENTS	MICRO-SCENARIOS				
Global context	Globalised and free market	Globalised and free market	Protection barriers strengthened	Actions taken to prevent a global energy crisis	Priority to local development
Agriculture in Europe	Competes on the commodity markets for basic crops	Competes on specialised markets	Fulfills the objective of self sufficiency	Feeds people at low energy cost	Contributes to the territoires attractiveness
European policies on health and environment	"Polluter pays" principle	Plant protection products only used in a targeted way	Preserve the resources essential for future production	Reduce energy consumption and limit exposure to pesticides	Search for a better quality of life
Organisation and strategies of crop protection stakeholders	Development of "greener" plant protection products	Innovation clusters involving farmers	Farmer efforts are socially recognized	Major changes in mobility, work habits and consumption	Residents, visitors and businesses interact for the benefit of each *territoire*
	→ Scenario 1 **The Commodity Market Player**	→ Scenario 2 **The Specialised High-tech Grower**	→ Scenario 3 **The Sustainable Food Provider**	→ Scenario 4 **The Energy-saving Producer**	→ Scenario 5 **The Community-conscious Farmer**

4.1 | SCENARIO 1
THE COMMODITY MARKET PLAYER

High food demand in 2010 coupled with a free-market agenda caused trade barriers and subsidies to agriculture to disappear. In 2030, agriculture and farmers are back in the limelight as important actors of the European economy. The EU competes with other agricultural production heavyweights on commodity markets. Land is partitioned between regions dedicated to intensive agriculture and protected non-agricultural areas. Farmers increase their competitiveness on basic crops by reducing manpower and production costs. Pesticides are used as best cost/benefit crop protection solutions. However, the application of the "polluter pays" principle favours the development of lower-impact crop protection strategies.

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The world faces the challenge of feeding itself

In 2030, although global food production increased by nearly 40% thanks to the agricultural intensification of regions like Eastern Europe, Latin America and Africa, the overall world demand for basic agricultural commodities remains high.

Back in 2010, food shortages and associated social unrest in Asia and Africa tipped the scale in favour of successful WTO negotiations on agriculture resulting in free-trade of agricultural goods coupled with long-term international development aid programmes and short-term emergency food aid programmes. Over the years, the consensus emerged that the best response to ensure food availability is a truly globalised and free market.

Today, nations around the world have done away with trade barriers and subsidies on agricultural goods. A large share of the demand in developing countries is met by food imports. Relative to the rest of the world, Europe is less negatively affected by climate change. Overall, climatic and geographic conditions here are among the most stable for agricultural production. Thus, the EU embraces the responsibility to provide food to the rest of the world, along with other agricultural production heavyweights such as the USA, Canada, Argentina, Brazil and Australia.

The EU meets world demand through intensification and competitiveness

Feeding the world is a moral responsibility but it is also a good market opportunity which Europe successfully continues to take advantage of. Back in 2015, the EU adopted the free trade agenda and, taking advantage of high farmgate prices, completely did away with CAP subsidies. Direct payments to farmers were eliminated as they were no longer justified in a context where agricultural prices were high. After an initial adjustment period, European export agriculture was positively stimulated by competition and agriculture was further intensified. In particular, total arable land area increased thanks to the conversion of extensive fallow or under-utilised land in new EU Member States such as the Ukraine and Belarus.

Free trade and absence of subsidies have favoured farm concentration. Farmers increase their competitiveness by reducing manpower and production costs. They tend to specialise on increasingly homogeneous crops grown in increasingly larger fields. Basic crops such as wheat, maize, rape, soybean and sunflower cover most of Europe's arable land. There are, however, regional differences: maize, olive and sunflower are typical of Southern European countries while grain, beet and potatoes dominate Northern and Eastern Europe.

Production and processing are not connected to local markets. Most farmers are under contract with large transnational food companies who settle in the most productive regions in the EU selected according to pedo-climatic conditions and labour availability. These companies implement set practices and technological packages via the farmers they have contracted with, thus reinforcing the homogenisation of agriculture in Europe.

Agricultural stakeholders are encouraged to face up to their responsibilities

Maintaining competitiveness on the global market is an over-riding priority affecting all European agriculture-related policies. Back in 2010, several economic studies[4] argued that overly stringent laws could lead to significantly lower yields thereby reducing competitiveness. The Commission considered the issue seriously and regulations on plant protection products remained at the same level as in 2009.

Yet, the green agenda was not relaxed as European civil society continued to express a demand for nature conservation, less uniform landscapes, and for the protection of natural resources.

The conflict was partially resolved by partitioning land use. On the one hand, large areas are devoted to intensive agriculture with ecological compensation zones nevertheless mandatory on large farms. On the other hand, protected non-agricultural areas such as forests, regions unsuitable for agriculture, and water harnessing and ecologically sensitive zones are established for natural resource conservation and recreation.

In addition, the implementation of the Framework Directive on the Sustainable Use of Pesticides led to a reduction of the "unnecessary" use of pesticides in Europe. More significantly, the EU has shifted to a regime where all stakeholders are held legally accountable for any damage caused by pesticides, rather than relying on upstream regulatory constraints. The "polluter pays" principle is applied: farmers, agro-industry, advisory services are now obligated to face their responsibilities regarding health and the environment. There is an a *posteriori* follow-up of the use of pesticides based on impact assessments, post-production controls and measurement of ecological and sanitary impacts.

[4] Nomisma Institute - European Agriculture of the Future, the role of plant protection products, January 2008: "Proposed EU measures could lead to a dramatic reduction in yields. One scenario predicts that the yields of wheat, potatoes, cereals and wine grapes could be reduced by respectively 29%, 33 %, 20 % and 10% by 2020."

Crop protection is by-and-large reliant on pesticides

Yield is the main goal. To protect their crops, farmers look for solutions with the best cost/benefit ratio and which are easy to implement on large farms. Their view is generally accepted, and chemical control still remains the standard option.

European agriculture remains reliant on pesticides and the agrochemical industry continues to find European agriculture a highly rewarding market. It is not business as usual however. Application of the "polluter pays" principle encourages the development of new molecules with safer modes of action and the cautious and parsimonious use of products. Industry invests in R&D on new plant protection products and focuses on new screening methods to find new modes of action.

In 2030, new generation plant protection products do not have biocidal effects. An entire new range of products are designed to reduce pathogen virulence or to increase host tolerance. The development of impregnated biodegradable polymer carriers, novel structured fluids such as reversible gels and new technologies to remove or inactivate residues from the end products generate "greener" pesticides. Most of them function via temperature, humidity or time-triggered release. The ultimate option contemplated is the use of plants as delivery systems.

Although major progress is made, in 2030 the use of plant protection products is still questioned in Europe. Many challenges remain as this strategy is confronted to the evolution of pest resistance to pesticides and overcoming of plant resistance, health concerns (residues, workers and general exposure of citizens) and environmental contamination.

Box 2. The Commodity Market Player

I'm the largest farmer in the region. I'm proud of my 3,500-hectare farm and of my grain which is shipped worldwide. And I'm proud to be a farmer. You know, most of the other farms around don't have real farmers on them, they're owned by insurance companies.

Most of the time, I'm keeping an eye on the market, I don't really have time to deal with crop protection. My pest control advisor takes care of that. But you know, on such a big farm, bottom line is that the simplest and cheapest way to control weeds and diseases is chemicals.

Still, we have to be extra careful with our pesticides: we are held legally accountable for any impact we may cause. My advisor is very competent and regularly keeps in touch with the companies. They regularly provide us new and greener products. Of course, we could still make a mistake. That would be terrible! But I'm not worried, my advisor is very conscientious. He always makes sure everything is done cleanly. He spends hours in the field, scouting and checking for run-off, drift or any mishap.

4.2 | SCENARIO 2
THE SPECIALISED HIGH-TECH GROWER

Here, high food demand coupled with the free trade agenda caused trade barriers and subsidies to agriculture to disappear. Europe made the choice to adopt precautionary rules stricter than in the rest of the world, encouraging farmers to become entrepreneurs in the knowledge-based bioeconomy advocated in the Lisbon strategy. Producers turned to high added-value specialty crops which allow investing in low-impact innovative crop protection solutions. In 2030, crop protection is treated as an integral part of the production process, and new technologies such as robotics, information technologies and nanotechnologies are mobilised. Precision agriculture is associated with prevention.

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Today, nations around the world have done away with trade barriers and subsidies on agricultural goods. A large share of the demand in developing countries is met by food imports. Relative to the rest of the world, Europe is less negatively affected by climate change. Overall, climatic and geographic conditions here are among the most stable for agricultural production. Thus, the EU embraces the responsibility to provide food to the rest of the world, along with other agricultural production heavyweights such as the USA, Canada, Argentina, Brazil and Australia.

Legislation based on the precautionary principle shapes EU competitiveness

The last 20 years have seen a shift in the regulation of chemicals. Following European civil society requirements, the European Commission chose to adopt rules actually stricter than in the rest of the world. Back in 2007, the Commission implemented the REACH regulation, aiming to improve the protection of human health and the environment from the risks that can be posed by chemicals. For plant protection products, a new revision of the 91/414/EEC Directive, promoting stricter hazards cut-off, pushed towards an even more restrictive registration. In addition, in 2015, after five years of implementation, the Framework Directive on the Sustainable Use of Pesticides was further strengthened to mainstream high-level IPM.

Europe's decision to adopt more cautious regulations on pesticides than other regions of the world incited European farmers to shift away from basic commodities. The sudden withdrawal of a large number of pesticides from the market was unfavourable to low-cost production of agricultural goods which lost their competitiveness on the global market. Commodity crops gradually decreased in significance in Europe. They are now grown in less constrained regions such as Russia and Kazakhstan.

Nevertheless, in 2030, agriculture continues to be a major source of income for Europe. Since 2000, standards of living in developing countries have significantly risen, increasing global demand for specialty products. In the meantime, the EU turned to domestic production of specialised, high-quality and high-value products for export. This agricultural orientation makes it possible to invest in low-impact innovative crop protection systems that satisfy the new EU standards.

Agriculture contributes to the EU knowledge-based bio-economy

Innovation is recognised as key to maintaining European competitive advantage. It is fully supported. The Lisbon strategy was successfully implemented and, back in 2015, the Commission adopted a cross-cutting innovation policy to strengthen innovation capabilities in business clusters across all economic sectors, including agriculture. The European Common Agricultural Policy is now integrated into a broader policy named "Towards an innovative and competitive knowledge-based bio-economy"[5].

In 2030, European agriculture is highly diversified and produces a large range of high added-value goods for specific export markets: unique food products associated with a recognised trademark or image (e.g. wine brands, Protected Geographical Indications), top grade products (e.g. ornamentals, plants and seedlings, organic products), and new crop varieties specifically engineered for green chemistry[6] (fatty acids, essential oils and aroma molecules, oilseed rape with glucosinolate serving as a biopesticide).

Intensive agriculture predominates. Regions tend to be specialized. Overall, there is an industrialisation of European agriculture with quality as the priority. Traceability confers added-value, so the origin of feed and food ingredients and sources is clearly identified for all European agricultural products. Food industries specialise in processing specialty products. The EU therefore needs to import basic goods, which are at times associated with lower quality or higher environmental or health impact.

The overall agricultural intensification is seen as a necessary trade-off against the successful contribution of agriculture to the European Knowledge-Based Economy. It is well accepted by civil society as long as the landscape remains diverse and preserved. In addition, civil society appreciates the fact that sustainable crop protection technologies based on a limited use of pesticides are developed.

[5] "The life sciences and biotechnology are the main scientific drivers of the bio-economy which is worth an estimated €1.6 trillion a year in Europe. [...] The EU's overarching ambition to build the world's most competitive knowledge-based economy implies the existence of an efficient and effective bio-based economic infrastructure to support it in a sustainable fashion. Such a bio-economy would also assist rural development and sustainability, ensure the long-term competitiveness of the European agriculture, food and chemical industries, and reduce climate-changing greenhouse gas emissions". European Commission, Laying the ground for a prosperous bio-economy. http://ec.europa.eu/research/conferences/2005/kbb

[6] Green chemistry is the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances. Anastas PT, Heine LG, Williamson TC. Green chemical syntheses and processes: introduction. In: Anastas PT, Heine LG,Williamson TC, editors. Green chemical syntheses and processes. American Chemical Society; 2000.

Innovative crop protection technologies are developed

Crop protection has a special role to play in this knowledge-based bio-economy. Obviously, protecting crops within this restrictive European legislative framework is challenging and complex. Nevertheless, because farmers grow high added-value specialty products, they can afford to rely on sophisticated crop protection. They rely on robotics, biotechnology, nanotechnology, and information technologies. Some of their strategies are fully integrated in the production process or even throughout the entire innovation chain, from the design of specific crop genotypes, to processing via patented technologies and marketing along well identified distribution channels. Opportunities for innovation and diversification are created to the extent that crop protection has become a significant sector of economic activity. In addition, the use of crop protection technologies not based on pesticides confers a higher value to many of the agricultural products relative to non-EU products.

Quality production relies on sanitised and resistant plant material. In such systems, planting healthy material is really a basis, along with using appropriate genetic material. Biotechnologies are largely used to enhance plant resistance, add value to some agricultural products (e.g. synthesising new molecules), and facilitating the production process (e.g. sentinel plants to signal when/where there is a pest or disease). The benefits of healthy planting material need to be maintained during crop growth. Most of European specialty crops are produced under controlled conditions that minimise pest occurrence. In addition, protected agriculture eases the use of efficient biocontrol methods.

Farmers fully exploit the options offered by precision agriculture and information technologies. They adopt high-precision methods, spraying pesticides as a last resort and only in a targeted way. Detection of pests and diseases is improved, especially thanks to nano-sensors, real-time molecular and infrared detection. Decision-making software is largely adopted. Automated systems are predominant, in particular for mechanical control (laser-assisted removal of weeds, GPS-assisted steering systems) and targeted spraying. Besides, green chemistry is developed and becomes by itself a source for new environment-friendly plant protection products, such as biopesticides.

While managing these high-tech agricultural systems, farmers acquire specific know-how which is also considered as a high-value asset and is exported worldwide.

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Box 3. The Specialised High-tech Grower

I do think I can be proud of my top grade ornamentals and aromatics! You know, I'm a central piece in our economy. Breeders, engineers, input suppliers, investors, the food industry, factories, distributors, brokers and international exporters all depend on the well-being of my production!

Innovation is our driver, even if it is quite an investment. That's why, I've been working in a technological cluster with other engineers. We meet regularly to improve or revamp production processes for our crops. Keeps me busy, but I try to make my daily tour of my high-tech greenhouses, just to make sure everything is running tip-top.

Of course, I have to pay attention to crop protection; That's one of the in-built parameters of my system. But you know, along with prevention, continuous adjustment of the greenhouses environment prevents any pest problems. This year, for example, we succeeded in increasing the temperature of our basil greenhouses with zero *Fusarium* wilt, just thanks to a super accurate level of humidity control!

4.3 | SCENARIO 3
THE SUSTAINABLE FOOD PROVIDER

In this scenario, international authorities reduced food tension by redistributing agricultural production. Protection barriers were strengthened around developing countries, causing the global food market to decline. Consequently, in 2030, the EU ensures a diverse food production for its population while conserving the resources that are essential for production. Farmers are expected to manage robust cropping systems designed to deliver reliable and stable production even under unfavourable conditions. Cropping systems are made inherently less vulnerable to pests, and farmers address pest problems by drawing from a diverse array of approaches, including biocontrol, plant genetics, cultural and mechanical methods.

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COMPONENTS	MICRO-SCENARIOS				
Global context	Globalised and free market	Globalised and free market	Protection barriers strengthened	Actions taken to prevent a global energy crisis	Priority to local development
Agriculture in Europe	Competes on the commodity markets for basic crops	Competes on specialised markets	Fulfills the objective of self sufficiency	Feeds people at low energy cost	Contributes to the territoires attractiveness
European policies on health and environment	"Polluter pays" principle Land partition	Plant protection products only used in a targeted way	Preserve the resources essential for future production	Reduce energy consumption and limit exposure to pesticides	Search for a better quality of life
Organisation and strategies of crop protection stakeholders	Development of "greener" plant protection products	Innovation clusters involving farmers	Farmer efforts are socially recognized	Major changes in mobility, work habits and consumption	Residents, visitors and businesses interact for the benefit of each *territoire*

Fear of food crises deeply modified the global food market

Since 2010, food availability has been a worldwide issue. High food prices, unequal access to resources and geopolitical tensions created a difficult situation. Many regions suffered from the effects of climate change such as extreme weather events, disturbed climatic conditions, and emergence of new pests, which caused important yield losses. In developing countries, there were hunger riots.

To solve this global food crisis, international authorities took on redistributing production and balancing agricultural prices. Trade protection and subsidies were substituted for WTO free-trade schemes. Developing countries were urged to turn their export-production to domestic food-production. In an attempt to limit price increases, many of them have followed these recommendations and have chosen to produce food for their domestic markets, even if few are technically able to be self-sufficient. They cut their food exports causing the global food market to decrease tremendously. Technical cooperation programs were launched to help developing countries boost their primary production and become self-sufficient. These programs provide a range of assistance to improve rural and agricultural development in southern countries[7].

Long-term food self-sufficiency is given priority across Europe

The European domestic market was confronted to the decline of the global food market. As importations were limited, agricultural production was encouraged for domestic consumption and became a priority land use. Self-sufficiency in food and feed became the main goal ascribed to European agriculture. It is still the case in 2030.

Back in 2015, the EU adopted a Common Health Policy encouraging people to eat “healthier” diets with more fruits, vegetables and whole grains, and less meat. It changed European food demand. In addition, consciousness-raising campaigns made the European consumers socially aware of the global food situation. Gradually, they turned to local food and started demanding a large diversity in food, at average prices.

In the EU, population is slightly decreasing[8] and producers do not have major difficulties to provide food for everybody. However, concerns emerge regarding the risk of harming future production, which would threaten European food self-sufficiency. As natural resources (soil, water, genetic diversity) are the basis of future agricultural production, they need to be protected. In 2030, conserving those resources that are essential for production is the new priority. European farmers are now expected to manage robust cropping systems designed to deliver reliable and stable production even under unfavourable conditions.

European agriculture and food systems are diverse and robust

This new situation implies major changes in agricultural systems. In particular, rebalancing agricultural production in Europe involves the cultivation of new crops. Protein crops are now grown in large quantities both for human consumption and for cattle rearing. To ensure food self-sufficiency, animal and vegetal productions are also reconnected. Agricultural production in green or glasshouses is also ubiquitous, as it is a way to ensure high productivity for particular crops such as small fruits and vegetables.

To statisfy consumer demand, there is a diversity of crops grown in Europe: grains, fruits and vegetables. Having a diversity of food crops in time and space is partially insuring the robustness of agricultural systems.

To optimise overall production, minimize the risks and insure the robustness of the whole food chain, authorities influence the coordination of agricultural activities from one region to another. Economic incentives and extension services are used to allocate crops according to their most favourable growing conditions (soil, climate, pest pressure). Local advice systems are put in place to help farmers choose the varieties they can grow and how, matching the growth conditions and EU food needs. Producers can be required to grow specific crops according to the needs, the local market or geographical conditions, but they are paid for it. The EU also takes the strategic risk of growing certain crops in certain places in order to ensure the global robustness of its system.

[7] “The European Commission provides a range of assistance to improve rural and agricultural development in developing countries. The aim is to promote broad-based rural economic growth and equitable access to production assets, markets and services. The Commission is also committed to helping these countries develop their own capacities and to the sustainable management of natural resources.” European Commission External cooperation programmes. Supporting rural development http://ec.europa.eu/europeaid/index_en.htm, consulted on 09/07/08.

[8] “The Union’s population is set to grow just slightly up until 2025, thanks to immigration, before starting to drop: 458 million in 2005, 469.5 million in 2025 (+ 2%), then 468.7 million in 2030”. Commission Communication of 16/03/05, Green Paper “Confronting demographic change: a new solidarity between the generations”.

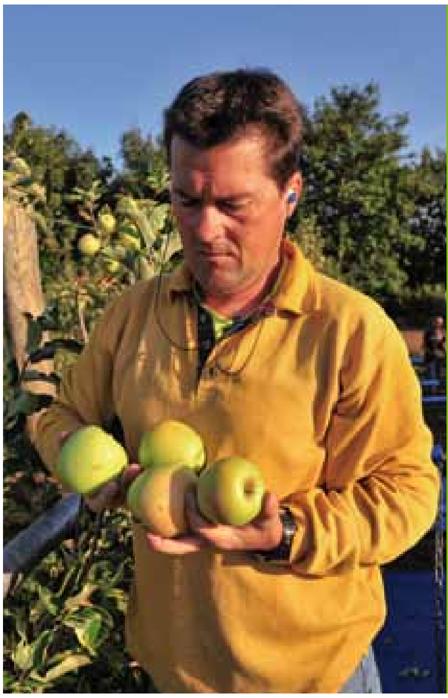
Cropping systems are inherently less vulnerable to pests

To ensure long term reliability and stability, farmers seek to develop cropping systems that are inherently less vulnerable to pests. Rather than managing pest outbreaks, they adopt long-term strategies to tackle the underlying causes of crop loss. Agricultural stakeholders work together to redesign these production systems, drawing on ecological engineering, landscape ecology and varieties adapted to regional conditions.

To stabilise losses due to pests, farmers grow a diversity of crops (mixed cultivar stands, long rotations) in complex and diverse systems. The European breeding sector is boosted by the demand for a diversity of varieties. Resistance to biotic and abiotic factors and adaptation to high-level IPM are taken into account in a harmonized registration system which enables the development of new varieties such as low-input varieties.

Farmers address pest problems by drawing from a diverse array of approaches. They use all possible means and create synergies by integrating complementary methods: biocontrol agents, plant genetics, cultural and mechanical methods, biotechnologies, and information technologies. Chemicals can guarantee food production. They are still used with caution, to address problematic pests in critical situations. Post-harvest and storage pest and disease control is especially important. Heat treatments, controlled atmosphere, fumigations with natural substances preserve food as much as possible.

As European self-sufficiency could be vulnerable to exotic pests or disease emergence, the EU implements a new biovigilance system at the EU level. This system relies on contingency plans and rapid-detection / rapid-reaction forces, which ensure that pest and disease outbreaks are diagnosed and managed quickly.



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Box 4. The Sustainable Food Provider

It's nice to be recognised! Because I've had stable yields for five years straight, my farm was designated as the local pilot farm.

So next week, I'll host a training session on soil buffering capacity. My colleagues will see how much you can produce with these ecosystem-based techniques.

It's true, my farm gets subsidies in exchange for diverse and stable production. But I had to obtain a degree in agronomy, and now I need to justify everything. It means a big investment in time and a lot of paperwork!

This year, despite all of my efforts, apple production will be low. I didn't want to spray because I had high levels of beneficials in the orchard. Hopefully next year will be better! Well, we'll have carrot juice instead of apple juice. 2030 was an outstanding carrot harvest!

4.4 | SCENARIO 4
THE ENERGY SAVING PRODUCER

High energy prices prompted the EU to redesign its economic landscape. In 2030, people and economic activities concentrate in dense urban centers, while the countryside gradually loses its population. Agricultural policy is integrated into a broader policy on energy and carbon: farmers are expected to produce food at low energy costs. In urban and rural areas, farmers face the challenge of managing pests using low-energy methods. In the cities, fruits and vegetables are grown within zero-pesticide micro-farms and industrial food production units relying on composting and recycling. In the countryside, arable crops are grown in large farms integrating livestock, bulk crops and nitrogen-fixing crops.

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COMPONENTS	MICRO-SCENARIOS				
Global context	Globalised and free market	Globalised and free market	Protection barriers strengthened	Actions taken to prevent a global energy crisis	Priority to local development
Agriculture in Europe	Competes on the commodity markets for basic crops	Competes on specialised markets	Fulfills the objective of self sufficiency	Feeds people at low energy cost	Contributes to the territoires attractiveness
European policies on health and environment	"Polluter pays" principle Land partition	Plant protection products only used in a targeted way	Preserve the resources essential for future production	Reduce energy consumption and limit exposure to pesticides	Search for a better quality of life
Organisation and strategies of crop protection stakeholders	Development of "greener" plant protection products	Innovation clusters involving farmers	Farmer efforts are socially recognized	Major changes in mobility, work habits and consumption	Residents, visitors and businesses interact for the benefit of each *territoire*

The World is tackling a global energy crisis

A global energy crisis emerged in the early 21st century. Total energy demand increased significantly, especially in developing countries. Fossil energy was becoming increasingly scarce and costly while global energy consumption continued to rise. In addition, there were increasing concerns over global emissions of greenhouse gases and climate change linked to high energy consumption. Reducing energy use was high on the agenda.

Faced with such a situation, experts recommended that urgent action be taken. In 2010, EU member States agreed on the "20-20-20 targets". They committed to a reduction in greenhouse gas emissions of 20% below 1990 levels, to an increase in the share of renewable energies in the energy consumption of 20% and to a reduction of primary energy use of 20% by 2020. However, few countries worldwide had taken sufficiently strong actions. Today, in 2030, global energy consumption is still increasing. The effects of climate change are now apparent. Severe droughts, heavy rainfall spells and extreme storms occur frequently. Around the World, large numbers of climate refugees leave regions beset by extreme events.

The EU recently strengthened its targets of use of renewable energies to 40%. Solar, wind, tidal, and nuclear energies, and processing waste and biomass are the new priorities. To limit energy consumption and reach a 40% reduction, the EU also made the radical political choice of limiting transportation, reducing imports and favouring domestic production.

The EU goes through major transformations

High energy prices caused a major transformation of the European landscape. Mobility patterns change as individual mobility was limited by ever-increasing energy prices. People could no longer afford to drive and public transportation was enhanced. Since 2015, significant progress was made in implementing collective low-energy transportation. Advances in housing technology led to the development of buildings with net-zero energy balance. People concentrated in cities while the countryside gradually lost its population. As a result, today, in 2030, most European economic activity takes place in and around cities where housing, industry, leisure and farming compete for land. In contrast, rural areas are sparsely populated. People living in rural areas are nevertheless part of a thriving European virtual economy as information networks irrigate all parts of Europe.

Concerned by increasing transportation costs, the EU took the political decision to reduce its international exchanges and relocated its industrial and agricultural productions on its territory. For agricultural goods, production and distribution is now following the foodshed[9] model. Agricultural production is strongly segregated. Fresh produce and poultry are produced inside large cities and in peri-urban food-belts. Commodity crops and large livestock, on the other hand, are produced in an industrialised countryside. Food-industries are located in the countryside and outside cities. Processed goods are brought into cities via special low-energy transportation systems.

Europeans adjust to these new conditions and gradually change their diets according to the goods produced in their foodshed. Community supported agriculture and local distribution networks are well developed and satisfy demands for reduced transportation of agricultural goods.

European agriculture is highly segregated between urban and rural areas

In 2030, European agricultural policy is integrated into a broader policy on energy and carbon. In addition to producing food locally, farmers are required to reduce energy consumption and even to generate energy. They acquire a more holistic approach; each decision is determined by energy and carbon footprint. Modern low-energy agriculture is supported. In both city and countryside, farmers are encouraged to adopt energy-saving practices. They limit the use of non-renewable inputs and rely on nitrogen fixation rather than synthetic fertilisers. They implement renewable energy facilities such as energy-positive glasshouses. They also integrate animal and cropping systems (manure is used to save synthetic nitrogen and produce energy).

Fruits and vegetables are grown within cities. To ensure sufficient food production, industrial food production units complement family-operated micro-farms. Industrial units, such as vertical greenhouses[10] and productive green walls, are operated by full-time farmers and based on highly controlled hydroponics. Micro-farms, such as community or family operated gardens and roof-top gardens allow part-time citizen-farmers to produce food. They rely on intensive organic methods such as “French intensive gardening”[11] and “organoponicos”[12]. Composting and recycling are important features of this urban agriculture. Poultry and small farmyard animals are raised in the cities. Around the city, more professional food production takes place within an intensive peri-urban food-belt where plant and animal production are integrated.

In the countryside, specialized producers grow arable crops (commodity, fibre and bioenergy crops). Their large farms integrate livestock, bulk crops and nitrogen-fixing crops either in rotation or as living mulches. Indeed, producing synthetic nitrogen is energy consuming[13], so farmers switch back to using manure and enhancing nitrogen fixation. Even if renewable energy is used to produce the synthetic nitrogen needed, cattle and nitrogen-fixer play once again an important role in agricultural systems. Machinery use is limited, with preference given to no-till practices which sequester carbon.

[9] “Foodshed is a conceptual definition to describe sustainable food systems, defining the origins and destinations of food within a particular bioregion”, www.foodshedproject.ca/glossary.html

[10] One vertical farm with an architectural footprint of one square city block and rising up to 30 stories (approximately 3 million square feet) could provide enough nutrition (2,000 calories/day/person) to comfortably accommodate the needs of 10,000 people employing technologies currently available. Dickson Despommier, The Vertical Farm: Reducing the impact of agriculture on ecosystem functions and services.

[11] French Intensive gardening involves raised beds which have humus added to promote deep root growth. The beds are typically 5-feet wide and 12-feet long, with narrow paths between beds. Boards are placed along the sides to maintain soil and promote drainage.

[12] Organoponicos consist of low-level concrete walls filled with organic matter and soil, with lines of drip irrigation laid on the surface of the growing media. There are 200 such gardens in Havana, Cuba supplying its citizens with more than 90 percent of their fruit and vegetables. They yield up to 24 kilograms per square meter. http://en.wikipedia.org/wiki/Organop%C3%B3nicos

As for bioenergy crops, massive efforts were made concerning technical aspects of their cultivation and processing. Their productivity is now high. In order to produce energy, and because land is a limited resource, residues from food production and processing are used for fuel or as raw material for the chemicals industry. Aquaculture also contributes. Marine and aquatic organisms such as microalgae[14] are used for bioenergy. Natural areas, urban parks, forests, pastures and soil covers play an important role as carbon reservoirs helping to mitigate climate change by slowing the release of carbon into the atmosphere.

Low-energy methods rule crop protection

Farmers face the challenge of managing pests using low-energy methods.

A zero-pesticides approach is adopted in cities because of the high-population density. Confined high-tech agriculture, associated with healthy planting material and sanitation, is a good way to protect crops while producing energy, but it is not enough. Urban farmers also rely on crop diversity to spread the risks. They use new resistant varieties, adapted to urban agriculture practices and to citizen consumer demands. Because pesticides are not allowed, alternative methods relying on biological control, ecological engineering and mechanical tools are largely implemented.

In the countryside, crop protection is challenging as large homogeneous fields favour the emergence of new pests and diseases particularly in new bioenergy crops. In addition, the use of no-till practices increases weed pressure, although this is alleviated by the use of diversified rotations, relay crops and living mulches.

Crop protection must be very efficient to ensure that investment in precious inputs (land, water, fertilizers) is not wasted, and chemical control is part of the strategy. Because of the high degree of awareness on pesticides in the cities, societal pressure on farm worker health issues is high. Thus, plant protection products are used in a targeted way, exploiting the options offered by precision agriculture and information technologies. The development of green plant protection products also facilitates their large-scale use. In addition, measures are adopted to limit worker exposure to pesticides, including efficient protective equipment, advice on safe crop protection practices and regular health check-ups.

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Box 5. The Energy Saving Producer

My production unit is only 0.5 hectare in surface area. It doesn't sound like much, but with 10 stories, I can actually produce fresh vegetables for 1000 households. It's a real challenge to feed all these people with no pesticides and as little energy and space as possible! We recycle nearly all our water, which is great but it also means sanitation problems. We end up sterilising everything by solarisation.

My job is all about finding compromises between minimising energy inputs and reducing pest risks. My livelihood depends on it. Not like those city gardeners, they do it for fun! Their part-time, family-community work is nice, but if they have a crop failure, it doesn't really matter. They can still buy the food that urban farmers like me produce!

I feel closer to the big producers in the countryside, even though they can use pesticides. They're working hard to provide us with commodity crops and meat.

[13] Agricultural energy consumption is broken down as follows: 31% for the manufacture of inorganic fertilizer, 19% for the operation of field machinery, 16% for transportation, 13% for irrigation, 8% for raising livestock (not including livestock feed), 5% for crop drying, 5% for pesticide production, 8% miscellaneous. Energy costs for packaging, refrigeration, transportation to retail outlets, and household cooking are not considered in these figures. Comparison of energy inputs for inorganic fertilizer and manure based corn production, McLaughlin N.B. et al. Canadian Agricultural Engineering, Vol. 42, No. 1, 2000.

[14] "It is estimated that the biomass productivity of microalgae could be 50 times more than that of switchgrass, which is the fastest growing terrestrial plant […] Microalgal farming could be potentially more cost-effective than conventional farming." Y. Li, M. Horsman, N. Wu, C.Q. Lan, and N. Dubois-Calero – Biofuels from Microalgae, Biotechnol. Prog., 2008.

4.5 | SCENARIO 5
THE COMMUNITY-CONSCIOUS FARMER

The EU moves away from being a major exporter of basic agricultural products. *Territoires* become instruments for economic growth, and agriculture is seen as essential to maintaining their economic attractiveness. The multiple services rendered by agriculture are in tune with the demands of territoire actors. Crop protection is required to satisfy specific demands placed on the factors affecting the attractiveness of territoires. Pesticides are used as a last resort. Advances in ecological engineering allows farmers to manage pests by manipulating ecological processes and by increasing spatial, temporal and varietal diversity at the landscape and cropping systems levels.

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The EU gives priority to local development

The world produces all the food it needs. Food-related tensions are alleviated as regions like Asia and Africa have significantly increased their domestic production, thanks in particular to a second green revolution[15].

Europe produces some of its own food and feed. It no longer competes with other heavyweight food producers and moves away from being a major exporter of basic agricultural products. It imports some specific goods to supplement its own production. European member states massively invest in non-agricultural sectors such as electronics, automotive, chemical, civil aircraft and shipbuilding sectors. Industrial goods are exported and continue to be major sources of foreign income. The service sector, including tourism[16] is also developed and Europe continues to be the region of the world that is most visited by foreign tourists.
In Europe, it has been several decades that people, companies, and economic activity in general have returned to the countryside, driven by the search for a better quality of life. The result of this counter-urbanisation is a blurring of differences between rural and urban areas. Concerns about maintaining rural areas and its social fabric have emerged. In parallel, European civil society demanded a rural development supporting policy targeting the agricultural and forestry sectors, the environment and the quality of life in rural areas.

In 2030 in the EU, government-led decentralization finally led to the rise of the regions. Each policy is now locally negotiated and adapted to local needs in strict application of the subsidiarity principle. The concept of *territoire* is a major building block for European initiatives and policies. It is a combination of a physical area, its community and its economic activities. The EU uses it as an instrument for economic growth and hands over to *territoires* the responsibility for their own development. *Territoires* find themselves competing for residents, visitors, investors and businesses. It is in their interest to gain recognition that they are different and attractive.

Agriculture is interwoven with other *territoire* activities

Agriculture coexists within a dense network of small cities and villages. It is considered essential to the economic development of *territoires* because it is a major determinant of their attractiveness in terms of economics, cachet, aesthetics and environmental quality. In addition to food production, *territoire* stakeholders expect agriculture to render multiple services that contribute to quality of life and economic activities and attract new residents, tourists and entrepreneurs.

Local specificity confers a competitive advantage. It is nurtured and farmers become major contributors of territorial identity. The European landscape is now a highly diversified mosaic where a diversity of farming activities provide a multiplicity of services which are recognised, valued, valuated and paid for.

Agricultural production is a cheap way of managing large areas of land and maintaining landscapes. European farmers create amenities for agro-tourism and recreational activities. They are expected to protect natural resources such as water and soil and to increase wild and cultivated biodiversity.

Food production also contributes to territorial development. Labels based on geographical origin[17], methods of production or quality benefit agricultural products but also benefit *territoires* by strengthening their identity and preserving resources when they are associated with environmentally-friendly methods of productions. A diversity of locally customized standards make their appearance. Food distribution patterns also diversify. Consumers seek tighter links with agriculture. Community supported agriculture, farmers' markets, "you-pick", food fairs and other local distribution schemes develop.

[15] "In the next few decades, a major international effort is needed to feed the world […] The new Green Revolution will be less about introducing new, high-performance varieties of wheat or rice, important as they are, and much more about making wiser and more efficient use of the natural resources available to us." J. Diouf, FAO Director-General, 13 September 2006

[16] "Europe is the world's region most visited by tourists: in fact, six EU countries are in the world's top ten destinations for holiday-makers. Not surprisingly the sector is very important to the European economy. Tourism is a cross-cutting sector, involving a big diversity of services and professions, linked to many other economic activities and policy areas." European Commission – Enterprise and Industry, consulted on 28/07/08. http://ec.europa.eu/enterprise/services/tourism/index_en.htm

[17] Protected Designation of Origin, Protected Geographical Indication and Traditional Speciality Guaranteed are regimes within the Protected Geographical Status framework. This EU legislation which came into force in 1992 ensures that only products genuinely originating in their region of origin are allowed in commerce as such. The law protects the reputation of regional foods and eliminates unfair competition and misleading of consumers by non-genuine products, which may be of inferior quality or of different flavour. These laws protect the names of foods such as Gorgonzola, Parmigiano-Reggiano, Melton Mowbray pork pies, Asiago cheese, Camembert de Normandie and Champagne. from www.en.wikipedia.org/wiki/Protected_Geographical_Status

Local negotiations affect the choice of plant protection strategies

In 2010, when quality of life was given priority, pesticide legislation had been strengthened and lower impact alternatives were developed. Now, in 2030, plant protection products are used "as a last resort when all else fails". When they are needed, bio-pesticides are preferred to synthetic chemicals as they are perceived to have lower interference with multi-functional goals. They function as a security net that allows farmers to take risks with innovative strategies.

In general, the choice of plant protection strategies results from trade-offs between the need to protect crops and other stakeholder demands such as residue-free water, abundant wildlife, or soil conservation. Other demands placed on agriculture regarding landscape, cultivated biodiversity, water availability, the production of local emblematic food, and recreation are less directly affected by crop protection but must nevertheless be taken into account when devising strategies.

In such a context, diversity and the exploitation of natural processes are the main ingredients to develop farming systems that simultaneously provide in-built protection against pests and satisfy the goals ascribed to agriculture by the community. Ecological theory is applied to cultivated ecosystems. Advances in ecological engineering provide insights into how to create the conditions that both enhance biodiversity and agricultural production. It involves increasing spatial diversity at the landscape level by combining perennial and annual elements and by juxtaposing cultivated and non-cultivated areas. Within cropping systems, polycropping, cover cropping and growing a high diversity of crops, as well as increasing temporal diversity with rotations and relay crops reduce pest pressure. Crop genetic diversity is yet another major tool to manage pest communities and spread the risk. In-situ peasant breeding ensures lasting seed genetic diversity and a continued match between the varieties and local requirements.

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Box 6. The Community-conscious Farmer

I'm on my way to City Hall to our quarterly land-use meeting. Right now, it's my grapes that are on my mind. This year, they were hard hit by powdery mildew. You know, I grow them for PDO Tokay, for export.

With our local *territoire* agreement on the safeguard of riparian life and all, I couldn't spray, not even rock sulphur. My grape income will be very low and I'm not sure how to go ahead with my plan to extend my stable. I need it for my agro-tourism activities. So I'm applying for higher compensation on account of my conservation efforts.

I can't complain though. I'm glad we are doing so well in our territoire, all of us, not just farmers. Yes, there's a lot of negotiations at the community level, but it's worth it. The compensations allow me to try out new and more socially acceptable practices. It's very knowledge demanding, but I'm involved in a learning group with other farmers. It's very helpful.

5

LEARNING FROM THE SCENARIOS

5.1 | CROP PROTECTION OPTIONS TO RECONCILE AGRICULTURE AND ENVIRONMENT

Pierre Ricci

Crop protection is not an isolated issue. Accordingly, the scenarios are described within different general and agricultural contexts to examine how crop protection will be affected by these contexts and by apparently distantly-related policy decisions. This chapter, however, focuses on crop protection itself and on the contrasted options taken in the various scenarios.

This study has been conducted at a turning point: the demand for clean environment and food safety has reached a climax and was translated into EU legislation, especially into the so-called "pesticides package" passed in 2009. Other environmental legislation on water, soil conservation and the preservation of biodiversity also impact crop protection. These texts, as they gain full effect in coming years, will challenge the means most farmers throughout Europe currently use to manage pests.

Our background assumption, independent of the scenario, is that the demand from European civil society for safety and a clean environment will not diminish over the next twenty years. Another general driving force is the pressure to double food production within forty years to feed an increasing population. This global issue translates differently at the level of European agriculture according to the different contexts of the scenarios. The five scenarios therefore explore contrasted ways in which the goals of agricultural production and environmental risk reduction can be reconciled with respect to crop protection. The following section highlights their main characteristics and the conditions required for their realisation through a SWOT (Strength-Weakness-Opportunity-Threat) analysis[18].

[18] The Energy Saving Producer scenario has not been included in the SWOT analysis

A SWOT analysis of four crop protection systems

The Commodity Market Player assumes that the agrochemical industry produces a new generation of plant protection products – "green chemicals" – that meet the requirements of reducing risks in a satisfactory manner. In parallel, the development of ecotoxicological knowledge beyond general predictive models makes it possible to monitor the actual impact of these chemicals and to adjust treatments in real time to avoid undesired effects.

The strength of this scenario is that farmers can protect their crops with methods similar to those in use today. They need not introduce radical changes in their cropping systems. Consequently, farmers can easily adapt to the requirements of a competitive global market.

Its weakness is apparent in today's mainstream agriculture: highly efficient chemicals with targeted modes of action exert a strong selective pressure on pest populations, leading to rapid build-up of resistance. As green chemicals will be rare and costly products, greater efforts will have to be made to address "durability" (their sustained use). Some of the solutions explored in *The Sustainable Food Provider* to ensure sustainability may have to be also incorporated in this scenario.

The Commodity Market Player offers a great opportunity for the agrochemical industry, which is at present largely based in Europe, to retain its domestic market and use it to support its innovation effort.

The major threat would arise from a disappointing health and environmental performance of these chemicals if they prove not to be as harmless as expected or if the demands from public health and environmental protection proponents rise to a point where they cannot be met.

This latter situation is precisely that considered in ***The Specialized High-tech Grower***. Few chemicals are left available and can only be used in small amounts or under restrictive conditions. Therefore, pest management relies as little as possible on curative measures and favours prevention: healthy planting material, clean substrates, protected cultivation… The inherent properties of the cultivated plant (genetic resistance, physiology…) and its local treatment (seed coating, antagonists…) are also exploited. The introduction of biocontrol agents finds favourable conditions under controlled confined environments. Precision agriculture is used to minimize the impacts of curative methods whenever growers have no other choice.

The strength of this scenario comes from the fact that pest management is not a separate issue but is embedded in the production process itself and relies on advanced technologies or at least on knowledge-intensive processes.

In contrast to the generic solutions used in *The Commodity Market Player,* solutions here are very specific to each production system and process. The weakness of this scenario results from the diversity of crop pest problems to be addressed and the large amount of specific knowledge and tools required, which could increase production costs and restrict these solutions to high added value crops. However, as high technologies generated in other industrial sectors are increasingly transferred to agriculture, they could become more affordable, even for commodity crops grown on a large scale.

Because it relies on a knowledge-based type of agriculture and on knowledge-based crop protection, this scenario offers an opportunity to develop science and technologies as factors of competitiveness and even as products that can be exported.

This very artificial mode of production is vulnerable to changes. It can be threatened by exotic pest invasions (see for example how invading pests have compromised IPM schemes in protected horticulture), climate change or changes in the market, if adapting solutions to such changes requires overly high and frequent new technological investments.

The Sustainable Food Provider, assumes that a considerable research effort coupling agronomy and the ecology of human-driven ecosystems is engaged. The knowledge acquired establishes rules and principles for the design of farming systems inherently less vulnerable to pests and for agroecosystem management practices that maintain pest populations at low levels. This creates the conditions under which an array of control methods with moderate but synergistic effects can be efficiently used to cope with occasional outbreaks. Parsimonious use of pesticides remains as a last resort option and provides a safety net to avoid unacceptable crop losses and reduce farmers' risk aversion.

The strength of this scenario comes from its long-term vision: sustainability and preservation of natural resources for future production are given priority. Therefore, once established, farming systems remain efficient over years and have the ability to adapt to gradual changes.

Its weakness lies in the difficult trade-off that may occasionally appear between preserving the environment vs. preventing immediate crop losses when severe pest problems that escape ecological regulation emerge and call for heavy use of pesticides to maintain a sufficient level of production. This difficulty can partly be solved by allocating crops away from geographical situations where their vulnerability to pests is excessively high.

Farmers are major actors of the implementation of this scenario which requires local adaptation to the conditions of the agro-ecosystem. It offers them the opportunity to develop new skills, greater qualification and an improved recognition from the rest of the society for their role as both food providers and actors in sustainable development. By overcoming the current challenge on environmental issues, European agriculture restores its image as a model for the world. The opportunity lies also with the development of new products and services appropriate to this type of agriculture.

Major environmental changes such as erratic climatic events or irruption of new major pests can represent a threat in this scenario if they overcome the resilience and plant health buffering capacity of the ecosystem. It can also be compromised in case some other major constraint is imposed on the farming systems. This is explored in *The Energy-saving Producer* in which high-tech intensive systems and more extensive ecological systems co-exist to save energy consumption. But other constraints, like a change in the ratio between labour and food prices, would also affect this scenario in particular.

The Community-conscious Farmer, assumes that the members of the community living in a territoire are willing to pay for non-market services from agriculture. Farmers can then reach agricultural and environmental goals simultaneously by investing into ecological management. The environment is a source of solutions for agriculture, and for crop protection in particular as it provides biotic and abiotic factors of regulation of pest populations. Conversely, agriculture produces ecological services in addition to food production.

One source of strength in this scenario lies in that the local arrangement of cultivated fields, field margins and non-cultivated areas in time and space can be used to better regulate pest populations by acting on crop diversity, landscape, crop succession and other factors at scales larger than the farm level. Frequent negotiations among neighbouring farmers and between farmers and other residents and local planners render agro-ecosystem management at large spatial and temporal scales feasible.

Its weakness lies in that farmers depend on the compromises reached with other *territoire* stakeholders and that local negotiations may become difficult if interests diverge excessively. In *territoires* where crop production plays a subsidiary role, farmers may find themselves with few crop protection solutions beyond what they gain from ecological management. Some serious pest problems could be impossible to tackle in these situations, leaving farmers with no other option than foregoing the production of specific crops particularly vulnerable to pests.

This scenario offers a unique opportunity to deepen our understanding of the functioning of human-driven ecosystems and to develop an ecological engineering approach to pest management. Coordination at the *territoire* level means that observation and experimentation can take place at large spatial and temporal scales. It offers arenas for the study of interactions between cultivated and non-cultivated areas.

The rationale of this scenario is that reduced income from agricultural production – due to crop losses, reduced yield goals or crop choice – is compensated by the community in exchange for the ecological services rendered by agriculture. But this balance could be threatened if the value ascribed by the community to these paid-for positive externalities decreases. For instance, if tourism declines, the value of an aesthetic landscape is reduced.

The scenarios seen from an IPM point of view

All the scenarios comply with the principles of IPM that will be mandatory throughout the EU by 2014 (see chapter 1.1). However, they play differently with the approaches that these principles establish. They illustrate how different weights can be placed on control methods, on monitoring and forecasting methods, and on prevention methods.

In *The Commodity Market Player,* the choice is made to continue to emphasise control methods. As a consequence, efforts are needed to devise new methods and combination of methods in such a way as to reduce unwanted impacts.

In *The Specialized High-tech Grower,* impact reduction results from finely targeting control methods in time, location and intensity according to measured needs. This objective is reached by emphasising monitoring pest populations and forecasting problems. It implies advances in the epidemiological knowledge and in the technologies required to generate and exploit this intelligence.

The *Specialized High-tech Grower* also insists on prevention by implementing a range of prophylactic measures. But both *The Sustainable Food Provider and The Community-conscious Farmer* extend the IPM prevention principle to the design of more diversified systems that are less likely to generate high pest populations and are more resilient to their effects. This approach reduces the need to rely on harsh control methods and makes it possible to adopt methods that would not prove satisfactory under higher pest pressures.

These various options are therefore directly related to the kind of knowledge and technologies that will have been developed and made available.

	SCENARIO 1 THE COMMODITY MARKET PLAYER	SCENARIO 2 THE SPECIALIZED HIGH-TECH GROWER	SCENARIO 3 THE SUSTAINABLE FOOD PROVIDER	SCENARIO 5 THE COMMUNITY-CONSCIOUS FARMER
Crop protection features	Stakeholders' accountability New green chemicals Improved ecotoxicology allows monitoring actual impacts of use	Limited chemical options Priority to prevention and use of plant properties Precision agriculture to limit impacts of curative methods	Systems with low pest vulnerability Ecological management to minimize pest levels Combined synergistic methods to control outbreaks	Environment provides solutions to crop protection Diversity to manage pests communities Natural processes exploited
Strengths	Crop protection quite similar as today's Farmers need not change their farming systems radically	Pest management embedded in knowledge-intensive production processes	Long-term vision preserves natural resources and provides sustainability	Local negotiations enable concerted actions for agro-ecosystem management at the *territoire* scale
Weaknesses	Chemicals exert strong chemical selective pressure on pest population Durability is a major issue	High demand in diverse knowledge and technologies to produce crop and process-specific solutions	Difficult trade-off between long-term goals and threats of immediate crop losses	Range of available control methods is limited in case of serious pest problem
Opportunities	Innovation led by agrochemical industry is made possible by a dynamic market	Science and technology development are factors of competitiveness, and even become export products	Farmers increase skills and enjoy social recognition	Optimal conditions for the development of ecological engineering for pest management
Threats	Ecological performance of green chemicals may not satisfy rising health and environmental demands	Rapid external changes (pest invasion, climate, market) may overpass the pace of technological innovation	Rapid and extreme changes overcome ecosystem resilience Other constraints (e.g. energy crisis)	Remuneration of ecological services needs to balance yield limitations

Table 7. SWOT analysis of each crop protection system

5.2 | CONSIDERING REGIONAL DIVERSITY

Émilie Labussière, Marco Barzman

The five scenarios convey five different views on the future of crop protection in Europe. Each is purposefully homogeneous so as to accentuate contrasts between scenarios and create a relatively uniform situation within a scenario that allows its inner logic to stand out. In addition to this homogeneity, some colleagues and other stakeholders to whom we had presented the scenarios thought that they were biased in favour of northern-Europe. In fact, we do acknowledge that the membership of our initial panel of experts was not representative of all of Europe – they came from Denmark, France, the Netherlands, and the UK.

To enrich and balance our study, we took advantage of the diversity within the ENDURE network to enlarge our panel and involve additional experts in the process. We also held meetings with agricultural experts representing the Mediterranean basin (from Greece, Italy and Spain) and Central and Eastern Europe (from Germany, Poland, Slovenia, Bulgaria and Hungary). We were thus able to point out ways in which European physical and human geography adds depth and subtlety to our study. In some instances, the entire set of five scenarios remains applicable even when taking into account regional specificities. For example, the crop species highlighted in our scenarios can easily be substituted by other species more typical of the Mediterranean. In other ways, particularly regarding land use patterns and national historical and cultural specificities, particular scenarios or variations thereof appear more pertinent.

Olive, a Mediterranean crop

The large regions of Europe are associated with specific crops. Durum wheat, rice, citrus, wine grape and olive are among those more specific to the Mediterranean basin. We looked at the different possible production regimes applicable to olive as a way to evaluate the applicability of the scenarios on crops other than bread wheat, maize or apple and to provide a glimpse at future trends in the production of a commodity that non-experts would associate with low-input production.

Olive is produced across the entire Mediterranean basin. Europe provides 80% of the global olive oil production, 97% of which is from Spain, Italy and Greece. Demand has been steadily increasing for decades.

In Crete, as in many Mediterranean areas, olive is grown as a traditional food crop in extensive production systems. Ancient terraced olive groves are managed to insure a minimum level of production even in rocky and seemingly unproductive land. The use of traditional varieties and management techniques are among the low-investment strategies preventing crop loss and ensuring adaptation to local pedo-climatic conditions.

In other regions of Greece and in Italy, olive is cultivated as a high added-value crop. There, most of the olive production is processed into high quality oil benefiting from worldwide recognition for its health and organoleptic properties. It responds to established standards, guaranteeing the full market value of the product, often associated with Protected Designation of Origin labels. Farmers manage intensive systems with inputs and a tree density twice that of traditional orchards.

Responding to the massive and increasing world demand for olive oil, new large and input-intensive short-term olive plantations are appearing in Andalucia (Spain) and Alentejo (Portugal). In the Alentejo, the recently built Alqueva dam, which created Europe's largest artificial lake, is meant to promote intensified agricultural production. In this new olive production regime, young short-stature trees are planted in densities that are up to five times that of traditional orchards. They are drip irrigated, fertigated, and pruned and harvested by machinery. Turn-over is rapid to take advantage of the production potential of younger trees. Maximising yield is the priority and quality is secondary. Crop protection in these systems tends to require more intervention.

It is easy to see how each of the three contrasted olive production systems depicted above fit in our scenarios: extensive approaches for local food production (the example from Crete) in *The Sustainable Food Provider;* quality production for export (the Greek and Italian example) in *The Specialised High-tech Grower;* and intensive production for bulk exports in *The Commodity Market Player* (the Andalucia and Aletenjo example).

Modifying the scenario to fit local specificities

Different farm sizes and types of tenure dominate different regions. In Central and Eastern European countries, the political changes initiated in the 1990s produced two contrasted types of farms. Many state-owned farms were converted into large private holdings, as is the case for example in former East Germany. In other cases, in Bulgaria and Romania for example, "reprivatisation" resulted in handing over very small fragments of land to a large number of farmers. More recent trends include the concentration of farm holdings (European Commission, 2008b) sometimes with Western European companies buying and exploiting land, for example in Poland and Romania. In the Western parts of Europe, farm size tends to increase in Northern parts, in Denmark for example, while small holdings are stable in countries such as Italy. Land ownership and the economic structure of farms also vary. Family-run small farms are typical in many regions of Italy, Greece, Bulgaria and Slovenia. In these cases, the landowner is also the farm manager and can at times rely on family labour. In contrast, in corporate farms or large farms, the owner may not be the farm manager.

The pertinence of each scenario varies according to these sorts of regional differences. *The Commodity Market Player* easily fits in areas where large-scale corporate farms or cooperatives producing commodity-like crops are becoming dominant. *The Community-conscious Farmer* appears more likely in areas where family-owned small farms with ties to the local economy are prevalent. In the case of *The Energy-saving Producer,* the nearly empty countryside that it pre-supposes in the future is widely perceived as unlikely, perhaps because this situation is not currently represented.

Another source of regional variation concerns differing perceptions of priorities due to cultural or historical differences. For example, the idea conveyed in *The Sustainable Food provider* that food security in Europe might become a priority is perceived as secondary in the wealthier parts of Europe while it still appears as a present-day concern among more recent EU members. One aspect of this scenario however requires some qualification when applied to Central and Eastern European countries. This concerns the European-level coordination of cropping systems depicted which would not be accepted if it came via the enforcement of centrally planned prescriptions – reminiscent of the old soviet-inspired system. That is why the coordination of cropping systems in *The Sustainable Food Provider* is achieved via economic incentives.

Responses to *The Community-conscious Farmer,* whereby the multiple services rendered by agriculture to a local *territoire* are recognised, varied according to national configuration. For Denmark, this scenario was judged as not very pertinent whereas it was felt as describing a current reality in Italy where *territoires* are used as political decision units and the multiple services rendered by agriculture are recognised. In regions such as Tuscany (Italy) or Transylvania (Romania), the strong value attached to landscape, traditional practices and cultural heritage also resonated with this scenario.

Nevertheless, the absence of strong commercial links to international markets implied by both *The Community-conscious Farmer* and *The Sustainable Food Provider* appear not acceptable to many Central and Eastern European farmers. They are said to consider their economic success as dependent on their ability to participate in globalisation. Attraction to local food markets and other local commercial opportunities seems more conceivable among highly educated farmers in Western parts of Europe.

The Specialised High-tech Grower can apply to many situations in Europe. High-added value production of ornamentals based on high levels of investment in technology in the Netherlands is a good illustration of this scenario. But high-value high-investment cropping systems are also conceivable based on an "appropriate" low-tech model where high investments in knowledge substitute for high-tech. Greenhouse tomato production in Almeria (Spain) or sweet pepper (paprika) in Hungary offer present-day illustrations of such systems.

Lastly, it should be noted that climate change will impact Northern and Southern Europe in different ways. In particular, southern experts pointed out that climate change would exacerbate water scarcity in the Mediterranean regions. They see this water problem as a key challenge for the future and consider a *Water-saving Producer scenario* as more pertinent there than *The Energy-saving Producer.*

In any case, it is easy to surmise that in the reality of Europe in 2030, regional specificities will actually produce a mosaic borrowing from the different scenarios as well as from variations on the scenarios.

5.3 | MAJOR ADVANCES IN RESEARCH WITHIN THE SCENARIOS

Pierre Ricci

Whatever the scenario, crop protection will be significantly different in 2030 from what we know today. Among the conditions that make these scenarios possible, advances in multiple fields of science are key factors. In fact, each scenario relies on the assumption that one or several breakthroughs are made in particular areas. In the following narratives, we strove to understand how some specific research developments could have taken place by 2030 in four of the scenarios, supporting the corresponding approach to crop protection.

Here, we make no attempt at a comprehensive description of the scientific basis of crop protection and we focus on the major issues that emerge from this foresight exercise. We adopt the point of view of an observer in 2030 who describes achievements with no consideration on how they have been reached. Some are already in progress in 2010; others will obviously require more investment and longer efforts. Further consideration of these implementation constraints will be needed to derive a precise research agenda from the following analysis.

The Commodity Market Player

The regulation on the placing of plant protection products on the market passed by the EU in 2009, introducing cut-off criteria based on hazards to human health, disqualified large classes of pesticides. This regulation stimulated the agrochemical industry to diversify its search for new agri-chemicals and to look for compounds that would cause little health and environmental concern and would then benefit from fast-track registration.

Chemists took advantage of the major trend of research in the exploration of the biodiversity to screen a large number of natural substances from plant and microbial origin for biological activity. Some of these substances were used as new biopesticides. More importantly, many of them have been exploited to synthesise bio-mimetic molecules serving as "leads" for new families of plant protection products.

Substances active on the basic vital function of pests (i.e. pesticides proper) have been avoided to the benefit of modes of action targeting functions involved in interactions between organisms. The field of Chemical Ecology, which used to provide mostly insect sex pheromones as biopesticides, has enlarged its scope. It has discovered multiple signals that are exchanged between organisms from different realms within communities and regulate their behaviour, development and interactions. For instance, crops are now treated with mixtures of compounds that repel phytophagous insects and attract their enemies. On the other hand, the fast growing understanding of the complex molecular networks at play within organisms during their close interactions has provided a number of interesting targets and endogenous signals, thanks to the developments in System Biology. Substances "priming" defence mechanisms in plants or preventing toxin production by fungi are now commonly used.

Some companies placed emphasis on chemicals active on a wide range of crop-pest systems, such as inhibitors of genes involved in the general susceptibility of plants to pathogens, the draw-back being that they may also affect non target interactions and could produce detrimental perturbations on the rest of the ecosystem. To avoid this, other companies prefer products with very specific targets, such as factors governing parasitic host-specificity, but these are more rapidly overcome by pest evolution.

These new plant protection products result from intensive research efforts both in chemistry and in biology and prove very costly to develop. Preserving their durability is therefore a top priority for the industry which is supporting large programs in Population Ecology to develop models for predicting how pest populations change as a result of using their products. They have found that there are some optimal combinations of products and resistant varieties[19] that considerably decrease the risks of pest overcoming these two factors. Firms now provide farmers with packages combining chemicals together with the appropriate cultivar and advice for an effective and durable use.

Most of the plant protection products now on the market have low acute toxicity. However, spreading them repeatedly at a large scale could have significant undesirable biological effects. Researchers in environmental toxicology benefited from significant support from public research. They now have a much refined appraisal of the persistence and breakdown of these new compounds in the environment and they study how even low amounts of them could affect organisms on the long range. DNA-based technologies allow in-field monitoring of the biodiversity in real time, so that problems are detected early enough to allow efficient corrective measures.

[19] see the Specialised High-tech Grower scenario

The Specialised High-tech Grower

It would be difficult to say where research in crop protection is conducted nowadays! In this space industry design department where they are converting a Mars exploration robot into a scouting device to detect weeds in vineyards and use laser beams to kill them? In this nanotechnology lab were they are fitting an antenna to a chip that will be inserted in the stem of plants, calling the farm manager on its mobile phone when they suffer a pest attack? Among these physicists tuning a hyper-frequency scanner borne by a drone overflying fields and detecting disturbances in chlorophyll activity at a distance for early identification of patches of disease? Or in this artificial intelligence lab where they are teaching insect morphology to a computer that identifies intruders on 3D pictures taken by a survey camera in a greenhouse? Nowadays, as plant production processes are designed just as any industrial process, with researchers working in departments within innovation clusters, exchanges between very different sectors have become the rule. This offers the high-tech grower many opportunities to take advantage at a marginal cost of innovations initially developed for the space, health or communication sectors.

Hydroponic systems in greenhouse containment facilities have gained a large extension in specialist product farming. They protect crops from both potential soil-borne and air-borne pests. If this first line of defence is breached, they offer climate control as an additional means of preventing outbreaks and create optimal conditions for highly effective application of biocontrol agents. When it comes to cultivating farmland in open environment, DNA technologies are used as chips for testing the healthy condition of the soil or for real time detection of epidemics.

Whatever technologies they develop in the cropping process, growers know that even more technological advances are captured within the seed. Of course, seed coating and biofilms protect the developing plantlets and soil pathogens are kept away from their roots by inoculation with selected symbiotic microorganisms. But, more importantly, the plant genome itself results from sophisticated molecular breeding, tilling and transgenic approaches. With specialist product farming now a significant part of the agricultural economy, many plants have been turned into ‘green factories’ producing pharmaceuticals, chemicals, oils, polymers and fibre. This was made possible by establishing efficient genomics and metabolomics platforms which were used to decipher the plant metabolic pathways, but also the cellular and metabolic processes involved in plant immunity[20]. A large inventory of genes involved in host and non-host resistance in a diversity of crops has been used to introduce sets of resistance genes, now increasingly piled into single genotypes to provide lasting multiple resistances. These investments also benefited the more classical food and feed crops.

[20] See Plants for the future strategic research agenda, 2007
www.epsoweb.eu/catalog/tp/index.htm

The Sustainable Food Provider

Once it had decided that self-sufficiency was to become the priority ascribed to its agriculture, the EU launched a large collaborative research program called “Innovative agriculture for sustainable food and feed supply in Europe” to shape the kind of new farming systems that would best meet this objective and to assess how these systems could be distributed throughout Europe. One main feature of this program was that it gathered teams from a large range of disciplines (agronomy, biology, ecology, economy, sociology, modelling, law and public policies) and provided a unique arena where these specialists, ordinarily working in separate institutions, could interact and collaboratively produce guidelines and recommendations. Recommendations included studies on the transition process between the pre-existing production systems and the new ones, how to support farmers along innovation trajectories, and the kind of organisational and economic incentives needed to channel stakeholders towards the desired new systems. The research program also invited these stakeholders from the various European regions to contribute, according to the co-innovation principles. Now, this program has been permanently established as a scientific network for sustainable agriculture in Europe.

Pest management is an important issue within this program. The primary concern is that crop protection methods do not affect natural resources and the health of the ecosystem. Therefore, elaborating on the well-established IOBC guidelines for IPM, the program has incited research in several directions to enrich the toolbox of complementary methods that can be used to substitute pesticides. Now, for instance, augmentative biological control has come into common use, even in field crops, because its success rate was considerably increased by combined research in genetics, physiology, ecology and technology on improving production and release of beneficial organisms at an acceptable cost. However, when developing and assessing innovative farming systems, it has also become apparent that arranging crop species and varieties in time and space, selecting crops according to the local pest constraints, taking care of the soil biological activity, and managing semi-natural areas around the cultivated fields are all very efficient levers to reduce the pressure of pests and the need for active control measures.

Substantial progress in the ecology of the agro-ecosystem[21] combined with developments in epidemiology has generated a better understanding of the changes in pest population demography and genetics on a multi-year basis, as well as the biotic and abiotic factors that regulate theses changes. Now, farmers have decision support systems that tell them how to organize their cropping system to reduce the risks, how to cultivate even in the presence of pests below the economic threshold and how to treat only in case of major outbreaks.

[21] see the Community Conscious Farmer scenario

A critical point in developing the new farming systems was the lack of appropriate plant material. Previously, breeders used to design varieties for uniform cropping systems, assuming that inputs would be available to alleviate limiting factors, including chemicals to deal with pests. Preference used to be given to those varieties expressing the highest yield under the largest range of situations, even if their full potential was expressed only under chemical control, and some very successful cultivars were extremely susceptible. Now this kind of situation is no longer accepted. The cultivated plant brings its own contribution to pest management: it tolerates at least some level of attack without a severe yield loss, it is resistant to a range of pests or reduces diseases progress through its architecture or physiology, or it competes with weeds.

Plant geneticists have adapted to this program. They now have methods to fully exploit natural plant diversity, such as association genetics. Based on new knowledge on the physiology of the diseased plant, they use predictive modelling of genotype-phenotype relationships to identify tolerance-related traits. Exploiting upstream research on susceptible plant-pest interactions, they have come across genes providing large-range resistance, in contrast to the highly specific resistance genes previously used. They also know how to exploit the genotype x environment x practice interactions to adapt varieties to a diversity of local cropping systems. Now, when they collaborate in the network with other disciplines in prototyping innovative agricultural systems, they help define the best adapted plant materials, and they turn their breeding efforts towards these "ideotypes". Research in plant breeding has also supported a large change in field testing and in registration systems which now offers a wide range of cultivars for the diverse needs of farmers.

The Community Conscious Farmer

With people now massively living and working in the countryside, the ecology of human-inhabited ecosystems has become an important field of research. Ecologists had to admit that the theories and laws developed in the twentieth century for slowly-evolving natural ecosystems were ill-fitted to deal with this new project. Now, they have adapted their concepts to ecosystems that undergo frequent breaks and which are human-driven to produce services. For *territoires*, managing properly their ecosystem is just as important as building roads or producing energy. So ecologists enjoy high recognition and support. They have established a dense network of permanent ecological observatories where they monitor changes in biodiversity and watch for the possible consequences of climate change. But they are also expected to provide effective rules for appropriate ecological management.

Ecologists have a special interest in agriculture because it mobilises a large share of the *territoires* area and because it is involved in producing multiple services. In fact, ecology and agronomy are now fully integrated and scientists tend to look at farmers as managers of the ecosystem. Of course, farmers do not fully agree and plant production remains their major goal. But they have learned that successful production does not depend only on what happens at the plant and field levels and that their production benefits from services produced by the whole ecosystem, especially as pest management is concerned.

Indeed, ecologists have now gained deep insights into the so-called functional biodiversity and they are able to model the ways it affects the productive functions of the ecosystem. They have for instance identified a set of organisms (flowers, birds, insects and earthworms) as good indicators of ecosystem health and they have told farmers to watch them and warn authorities if they see them become rare or disappear. Similarly, when farmers observe an unusual outbreak of pests, they call on the ecology advisor (who has replaced the plant protection advisor of past times) who tries to diagnose the failure in biological regulation and proposes corrective measures.

Solutions are worked out at the scale of the entire *territoire*. Landscape ecology now understands how the local abundance of pests and of their enemies is influenced by the spatial distribution of their habitats at a large scale. This knowledge allows the ecology advisor to propose an optimal lay out of the various crops in the cultivated areas, of the network of semi-natural areas that surrounds them, as well of the other land uses. These recommendations go beyond pest management objectives: spatial heterogeneity is also used to improve water quality, carbon sequestration and landscape aesthetics, all services that the community expects farmers to contribute to.

Other areas of research have also focused on the kind of knowledge that is useful to local communities. Pest biologists, for instance, have gained a better understanding of the success factors of augmentative biocontrol[22] which is used to complement naturally occurring beneficial organisms when they are not satisfactorily efficient. They work out rearing methods adapted to small scale production in local factories. Similarly, plant breeders have turned away from all-purpose uniform varieties[23] and are now working on schemes adapted to in situ breeding according to the specific needs of the *territoires*. Their focus is on producing population varieties, keeping a level of intraspecific diversity that allows the cultivated plant material to evolve along the years with its environment, and especially to cope with changes in pest populations.

Economists and sociologists have been called on to establish the mechanisms by which agriculture can be better integrated into the economy of the *territoire*. Farm profitability is dependent on the payments for the ecological services it provides to the community. Economists have devised schemes and tools to help valuate these services, for which there was initially no established market, and to maintain these prices at levels that allow farmers to sustain their commitment. Overall, the persistence of an active agricultural sector results from the common appraisal of the benefits it brings to the community. Therefore, communities have sought the help of sociologists to devise permanent conflict-solving and coordination mechanisms between farmers and the other stakeholders in the *territoire*.

[22] see the Sustainable Food Provider scenario
[23] see the Sustainable Food Provider scenario

5.4 | POLICY IMPLICATIONS

Marco Barzman

The scenarios can be used to guide policy initiatives on crop protection, whether they concern legislation on crop protection, research and extension, stakeholders involved in the food system, or the broader economic environment affecting agricultural production.

Legislation directly affecting crop protection

At the time of the writing of this study, the European Union has just completed a comprehensive policy package directly affecting the availability, the use-phase, the statistics on and the disposal of pesticides, as well as a harmonisation of acceptable minimum residue levels (see chapter 1.1). Member States are currently working to translate or apply these EU-wide policies at the national level. Here, we only highlight areas where policies could enable specific developments suggested in the scenarios.

Pesticides

Crop protection in *The Commodity Market Player* is based on the use of chemicals enjoying radically lower health and environmental impact because they are based on completely different modes of action, many of which may not be biocidal at all. It is fair to assume that the initial R&D on such new chemicals may suffer from competition with classical pesticides. If this new class of chemicals is to be given a chance, then some type of fast-track registration process may be considered.

The Commodity Market Player also assumes that pesticide users, producers and distributors are held accountable for the environmental and health impacts they cause. If such legal responsibility for non-point source pollution is desired, then a traceability and detection system needs to be extended to cover the entire lifespan of molecules. Pesticide use records, monitoring of products in the environment, and associated legislation are needed to make that a reality.

Bio-pesticides and biological control agents

Bio-pesticides and biological control agents are important components in nearly all scenarios. It appears that current legislation affecting these alternative products needs to be improved if they are to be more widely used. ENDURE conducted an assessment of the current Europe-wide situation concerning the use of biological control agents in agriculture (ENDURE, 2009c). The study concludes that the current registration process which was originally set up to reduce the risks associated with synthetic molecules is not adapted to these types of products. For example, the time and cost of registering a microbial biocontrol agent, even though it is currently lower than that for a chemical pesticide, makes its introduction on the market four times less attractive in terms of returns on investment than its chemical equivalent when the market potential is taken into account. Regulations that are more favourable to the development of and access to bio-pesticides and biological control agents are therefore needed.

Cultivar registration criteria

All scenarios require new pest resistant cultivars and most scenarios require a wide diversity of cultivars, some of which need to perform well in low-input conditions. In *The Energy-saving Producer* for example, cultivars must provide satisfactory yields in a low-nitrogen regime and at the same time must be resistant to a multiplicity of pests to avoid loss of precious investments in inputs. Since most registration processes rate the value for cultivation and use of candidate cultivars in optimal fertilizer and crop protection regimes, cultivars that may have interesting properties in non-optimal situation may rate poorly. A new process of registration of cultivars is therefore needed to make available a wider diversity of resistant varieties, to increase plant genetic diversity and, in general, to provide plant material better adapted to IPM.

Minor uses

The maintenance of a diversity of crops is important in all scenarios except in *The Commodity Market Player*. It allows for a diversity of highly specialised plant products (*The Specialised High-tech Grower)*, as a risk spreading strategy (*The Sustainable Food Provider*) or to satisfy locally-specific needs (urban agriculture in *The Energy-saving Producer*, *The Community-conscious Farmer*). Future pesticide policies must ensure that access to pesticides is not limited so severely as to preclude resorting to pesticides on those crops when all else fails. In fact, the ability to resort to pesticide use in minor crops acts as a kind of security net allowing farmers to take the extra risk associated with the use of alternative strategies. Policies limiting access to pesticides need to take this into account.

Research & extension policies

The scenarios offer insights into the knowledge areas, tools and services that are key to developing crop protection strategies that better fit sustainability goals. They also provide pointers on how to go about strengthening the innovation process.

Research areas supporting innovation

With regards to the body of knowledge pertinent to crop protection, the scenarios assume advances in a number of specific scientific and technological areas. These represent areas for research that need to be given priority to ensure progress. Since the various crop protection approaches adopted in the scenarios are all based on a sound rationale generating positive consequences, it can be considered that the entire set of priority areas collectively emerging from the scenarios constitute a proposal for a long-term research programme.

Plant genetics is a key sector in all scenarios. Until now, yield and quality have received priority as plant breeding targets, often at the expense of resistance to pests. Support should be given to a reassessment of the desired characteristics of cultivars and to investments in technologies adapted to these goals. Establishing efficient genomics and metabolomics platforms can be used to decipher the plant metabolic pathways, but also the cellular and metabolic processes involved in plant immunity and to better understand the plant-pest interactions. A large inventory of genes involved in host and non-host resistance in a diversity of crops can be used to introduce sets of resistance genes into single genotypes to provide lasting multiple resistances. But this knowledge may also contribute to ecology-based strategies.

Regarding plant protection products, *The Commodity Market Player* assumes the development of green pesticides based on new non-biocidal modes of action. They may for example reduce the virulence of a pathogen, induce plant defences, or impair the ability of pests to find their host. Exploiting such strategies requires a better basic understanding of plant and pest physiology and plant-pest interactions.

The Commodity Market Player also assumes that users are accountable for the environmental impact of their pesticide usage. This calls for significant progress in eco-toxicology regarding monitoring the fate and evaluating the impact of pesticides with efficient indicators. EU national policy makers are interested in using risk and impact indicators to set goals and evaluate the progress of national pesticide action plans. In many cases, however, the state of the art in this area was deemed not satisfactory enough to immediately adopt such indicators. Obviously, research in this area needs to deliver usable knowledge and methods to respond to this demand.
The new and emerging technologies that are invoked in *The Specialised High-tech Grower* require significant R&D efforts if they are to be successfully made use of in crop protection. Futuristic prototypes drawing from robotics, biotechnology, nanotechnology, and information technology designed for crop protection purposes currently exist. However, most are prohibitively expensive, slow, or otherwise impractical. More effort in this area is needed to make these approaches better adapted to farmer needs.

The Sustainable Food Provider assumes that our level of understanding of ecological processes taking place in agroecosystems has reached a high enough level to enable their exploitation in a way that will stabilise pest populations at satisfactorily low levels. Today's reality is that the few ecologists that do study agricultural systems usually look at how agricultural practices affect biodiversity. Very little work is done on the converse, i.e., how biodiversity, and natural processes in general, can be used to benefit agriculture in general, and crop protection in particular. This is a wholly new area of study and competencies that need to be supported.

The Community-conscious Farmer assumes that farmers are paid for the multiple services they render beyond food production. Agriculture, and crop protection in particular, can have positive or negative impacts on natural resources but the precise nature of this relationship is still not well understood. Research drawing from ecology, landscape ecology, zoology, botany, hydrology and applying this expertise to cultivated systems will fill this gap. But the concept of compensation for ecosystem services rendered also poses questions in the social and human sciences. At present, environmental economists are still in the early stages of grappling with the question of how to place a monetary value on ecosystem services and how to compensate farmers. Support in this area is therefore needed.

Social processes affecting crop protection are pertinent in all five scenarios. They may relate to the pressure for health and environmental protection placed on farmers, to multi-disciplinary research approaches, to new and more collaborative ways to innovate, or to the social network farmers are a part of. Research in the social and human sciences can improve our understanding of these processes and propose avenues for purposefully build on them to mainstream crop protection in tune with sustainability goals.

Multi-disciplinary research

All scenarios move away from single-solution silver bullet types of approaches. Even in *The Commodity Market Player* which describes a relatively simpler crop protection picture, a diversity of methods is needed to prevent pest populations from eventually overcoming the continuous use of a particular control method, even if it is initially the most favourable solution. Also, crop protection in all scenarios is no longer uniquely a matter of temporarily suppressing pest population. It must satisfy multiple additional demands. That is why research must create synergies by integrating knowledge and complementary methods drawing from a diverse array of disciplines.

But multi-disciplinary research is challenging. It is not a spontaneous process. Researchers need to learn how to communicate, to share common goals and to work efficiently with colleagues outside their own area. Research policy can support this process via dedicated funding, with institutions created for that purpose, and by training and recruiting specialised facilitators. It can be geographically extended to foster sharing of expertise and experiences across Europe, for example. Such initiatives provide significant added-value relative to purely national outlooks on crop protection strategies.

Co-innovation

Innovation results from interactions between a number of sectors in society. Public and private research, extension, farmers, stakeholders are active participants in this process. When the various sectors are purposefully engaged in a collaborative design and development effort, then we can speak of co-innovation. All five scenarios include multi-sector interactions from which innovation emerges. In *The Commodity Market Player*, the legal accountability of producers, distributors and users for the impact of new green plant protection products encourages co-innovation among them. *The Specialised High-tech Grower* assumes a dynamic R&D process emerging from a collective effort between various sectors such as farming, industry, engineering and research. *The Community-conscious Farmer* must devise crop protection strategy as a result of regular interactions and coordination with other actors of their territory.

The collective and multi-sector character of innovation should be recognised and supported. This will accelerate and improve the R&D process and help to reconcile more quickly the heterogeneous needs of the different stakeholders concerned. Funding for research can require a minimum degree of cross-sectoral collaboration and R&D centres based on the business cluster model should be planned.

There is also a spatial dimension to co-innovation. In crop protection, it is becoming increasingly clear that phenomena occurring at spatial scales larger than the cultivated field are significant and could one day be exploited. *The Sustainable Food Provider* and *The Community-conscious Farmer* suggest such developments. In both these scenarios, there is the possibility to coordinate the actions of multiple local actors over large physical areas. Landscape-level changes in land use, cropping patterns, or non-cultivated vegetation can improve strategies based on conservation biological control or can modify the dynamics of particular pest populations. Coordinated interventions, such as the use of pheromone confusion over large areas, are known to improve efficacy. At present however, there are very few mechanisms available to create such large-scale concerted action. The conditions eliciting coordination among individual farmers and other local residents remain to be established. Policies aiming for this innovative objective could be drawn up.

Extension

Extension is an important element in the co-innovation process. There are several ways that extension services can be strengthened to better address the new demands.

In general, innovation – away from simple single-solution approaches such as use of classical synthetic pesticides – emerges from a collective learning process rather than as a result of a linear transfer of a ready-to-use technological package. Farmers learn and adapt new strategies via their involvement in support groups or innovation networks. Agricultural extension agents can take on a key role in facilitating farmer-to-farmer or farmer-advisor-researcher interactions. But promoting these interactions may require changes in advisory systems. It should be noted that changes in farmer practices and associated mindset is a process that takes place over a period of years. Therefore, policies aiming to provide support should also be planned over the longer term.

The use of biological control agents, which is an important element of crop protection in most of the scenarios, may require particular attention from extension. The ENDURE study on biological control agents found that their mainstreaming requires improving their acceptability among farmers. The study recommends supporting training on maximising the effectiveness of beneficial organisms by satisfying the requirements specific to live organisms. It also calls for the development of Decision Support Systems that can manage the higher level of complexity reached when biological control is integrated in a systems approach to crop protection.

Stakeholder involvement

Innovation requires people. The scenarios clearly show that crop protection is not solely determined by the individual farmer. Social processes involving networks of farmers, farmer-advisor interactions, R&D, the input and food supply chain, societal pressure and policies all contribute to the strategies adopted. When devising policies affecting crop protection, care should be taken to take into consideration the pressures on farmers and the collective dynamics they are a part of. In fact, policies can be designed to support change in the entire IPM food network that is compatible with the new demands placed on it.

As a first step, it is important to include a wide range of stakeholders throughout the policy making process. This will ensure that a wide variety of demands such as economic viability for the farmer, market-related constraints, environmental considerations, and social equity are taken into account. This will help to gain buy-in from the various sectors of society concerned by crop protection. It will also help to add coherence and avoid unwanted contradictions within the overall policy environment.

All stakeholders need to be better informed of and made more sensitive to their various respective needs and points of view. The scenarios show that there are ways to reconcile different goals. Production goals and environmental goals, for example, no longer need to be antagonistic.

Policies indirectly affecting crop protection

Crop protection does not exist in isolation. It is embedded within the production process which is itself dependent on factors beyond the farm. Changes in agricultural contexts create contrasting food systems each with different goals, opportunities and challenges that affect crop protection both directly and indirectly. When thinking of the policy levers to drive crop protection in a particular direction, toward IPM for example, it should be borne in mind that many policies affecting contextual factors such as prices, land tenure, availability of labour or farm size can also limit or open up options in crop protection. Increased stability in farm gate prices of agricultural goods favours long-term strategies, thus giving a better chance to sustainability goals to be taken into account. Similarly, land ownership, in contrast to leasing, will favour long-term investment and longer term strategising. High availability of affordable agricultural labour will favour labour-intensive approaches, some of which may represent desirable alternatives to chemical-intensive solutions. Farm size affects crop protection practices. For example, recent increases in pesticide use in Denmark can be explained by the reduced flexibility in crop protection due to increases in the size of individual farms.

Conclusion

The strong pesticide policy adopted by the EU in 2009 has set the stage for new crop protection systems less reliant on chemical control. Looking ahead with the help of the scenarios at how these systems could establish we see that their development requires support from further enabling policies that reach beyond crop protection proper. Only by encouraging research, innovation, extension and the involvement of all food chain stakeholders and by considering how more global issues will affect pest management solutions will policy makers reach their goal of a safer and yet competitive European agriculture.

CONCLUSION

European agriculture faces multiple challenges in the coming decades. It must meet strengthened health and environmental requirements while satisfying the growing demand for food production fuelled by a booming world population. It is expected to contribute to the production of renewable energy and non-food products and to render ecosystem services. It must remain competitive in a globalised world while ensuring farmer income and the economic viability of the agri-food chain. Such challenges make it necessary to rethink our production systems without continuing with solutions inherited from a past situation moulded by a different set of stakes.

Within these systems, crop protection is a sector in which the contradictions between past solutions and current sustainable development goals are especially prominent. Addressing these contradictions and developing new appropriate pest management solutions will therefore be a significant indicator of the adaptive capacity of agriculture.

In 2009, Europe adopted legislation on pesticide registration and use more stringent than ever before. This legislation set the stage for new crop protection systems less reliant on chemical control. Today, in response to legislative deadlines, actors and decision-makers are incited to mainly pay attention to short-term solutions consisting in limited improvements on current approaches or in the adoption of known solutions such as organic farming. By looking at the longer term with this scenario-building exercise, we identified a set of more diversified solutions likely to better satisfy the need to reconcile economic, social and environmental goals.

The five scenarios developed in this foresight study are representative of the diversity of feasible protection systems. They also show that the likelihood to implement the various options are tied to more global choices regarding the objectives ascribed to agricultural activity (export, food self-sufficiency in Europe, natural resource management) and production types (arable vs. specialised vs diversified crops).

None of these protection systems is based on a single approach. Even in the scenario where chemical control – albeit improved – is central, a combination of chemicals and other tools is assumed to ensure the desired level of sustainability. That is why the various individual tools within the future crop protection toolbox will not be designed merely according to their inherent efficacy but first and foremost as components that work well in combination with other components in an Integrated Pest Management (IPM) solution.

All scenarios assume scientific and technological breakthroughs in several research areas. Efforts are obviously needed in the field of impact evaluation by building on advances in eco-toxicological knowledge and improved indicators. However, the implementation of new crop protection systems will not come about without a significant investment in innovation. This innovation effort concerns private research on the side of input suppliers. It also calls for an increased contribution from public research both in the acquisition of supporting knowledge and in the development of integrated solutions.

Part of the contrast between the protection systems lies in the relative weight placed on three approaches that are part of IPM: control methods proper which need to be diversified and used in combination; surveillance and forecast methods allowing appropriate timing, spatial positioning and intensity of control to ensure a good match with needs; prevention methods which include the design of systems resilient to the action of pests and contributing to limiting their populations. Each approach emphasises particular research avenues.

Regarding control methods, the development of alternatives to conventional pesticides is a priority in all scenarios. Biological control has significant opportunities in most of them if it can be made more successful by improving our knowledge of its physiological, genetic and ecological underpinnings. Use of physical methods of control is also promising, particularly with regards to weeds. Furthermore, there is still a wide open area of understanding to explore that will contribute to renewing the set of chemical tools based on novel modes of action.

To strengthen our capacities of surveillance, detection and forecast, we can count on the development of technologies for collecting, modelling and processing data on pest outbreaks. Steering tools to fine-tune treatments and other interventions making use of these data are also needed. These technologies must be supported by a considerably deeper understanding of the genetics and dynamics of pest populations, their epidemiology, and their evolution under selective pressure from environmental factors, control methods and other agronomical practices.

The design of robust cropping systems relies foremost on the properties of the plant material available to farmers. A major challenge will be to develop a new generation of cultivars that integrate more resistance traits and fit the needs of new cropping systems defined with the contribution of plant breeders. To meet this challenge, progress in plant genetics (plant genomics, molecular breeding, tilling and transgenic approaches) will need to be combined with the discovery of sets of genes governing plant-pest interactions and plant immunity.

Optimising the spatial and temporal arrangement of crops also contributes to the robustness of cropping systems. The diversification of crop species and varieties, the management of their deployment across the landscape and the management of adjacent non-cropped areas constitute pest regulation factors. Two of the scenarios strongly rely on the concept of an ecological management of plant health. However, there is still a considerable gap of knowledge to be filled on the processes at work within anthropogenic ecosystems prior to considering the development of management technologies adapted to this goal. The success of this approach may also depend on whether the societal demands for environmental quality will be sufficiently sustained to promote the development and implementation of economic instruments to compensate for ecosystem services.

Independent of the scenario, crop protection in Europe in 2030 will be very different from what it is today. Needed changes will involve not merely farmers but the entire agri-food chain. In this chain, a diversity of stakeholders finds themselves “locked-in” around protection systems in which chemical control was central. Release from that situation will not occur spontaneously. It requires knowledge sharing, interactions between public and private research, planned links between the supply chain and retail, local coordination and the involvement of government. Understanding the social processes at play in the transitions toward new protection systems and the development of mechanisms enabling coordination among these actors constitute in all cases an essential research area.

No doubt that these transitions need to be considered starting today. This foresight study will have reached its goals if it helps concerned stakeholders in their decision-making process and in reaching shared and coordinated goals.

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IBSN 978-2-7380-1276-0
september 2010
Published by INRA