endure®
diversifying crop protection

Integrated Pest Management in Europe

The ENDURE Network of Excellence shares the fruits of four years' research with the crop protection community

Project achievements
2007 - 2010

www.endure-network.eu

SIXTH FRAMEWORK PROGRAMME

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FOREWORD

The European Union places great emphasis on plant health and plant protection policies in order to ensure food production and competitiveness of the agricultural sector but also the protection of human health and the environment. In this context, Directive 2009/128/EC, adopted on 21 October 2009, established a new framework to "*achieve a sustainable use of pesticides by promoting the use of integrated pest management and of alternative approaches or techniques such as non-chemical alternatives*". In fact, Member States will have to ensure that the general principles of integrated pest management as set out in the Directive are implemented by all professional users by 2014. It is clear that research has a major role to play to make this possible.

The Network of Excellence (NoE) ENDURE, the major project launched by the European Commission (DG-Research) to support integrated and outstanding research in durable crop protection strategies, has contributed to this debate through research collaboration, coordination and integration between partners from a large consortium of universities, research institutes, farmers' organisations, biological control companies and other stakeholders in Europe and beyond. As mentioned by the Commission in its terms of reference: "*The project should establish itself as a world leader for the development and implementation of durable pest control strategies, and should become recognised as the first point of reference in Europe not only for scientists but also for legislators and users*".

Through the development of new solutions to farmers, ENDURE is also contributing to innovation, which has been identified by the EU as a key driver for a prosperous future. In fact, ENDURE is already contributing to two of the three priorities included in the recent Europe 2020 Strategy: "*Smart growth: developing an economy based on knowledge and innovation" and "Sustainable growth: promoting a more resource efficient, greener and more competitive economy*".

Now that ENDURE comes to an end, the European Commission welcomes its continuation as a European Research Group (ERG) from July 2010. This group will continue working towards i) the integration of research capacities and resources of the partner organisations and ii) the dissemination of excellence to generate European-level and international synergies. The creation of ENDURE ERG responds to the Commission's expectation regarding durability of the network beyond the formal end of the contract.

I am happy to announce that a new project selected under the topic "*Integrated pest management in farming systems of major importance for Europe*" is currently being negotiated and will probably start at the end of 2010 with the overall aim of providing research on novel approaches, strategies, techniques and technologies for IPM. It is important that ENDURE ERG establishes links with this initiative in order to maximise synergies and better contribute to the implementation of Directive 2009/128/EC and to the innovation policy.

The Commission also welcomes the international conference in November 2010, which is a major milestone for ENDURE, a key opportunity to bring together scientists, advisers, policy makers and other stakeholders, and to share the results of four years of work.

Finally, I would like to thank all people and teams who have directly or indirectly contributed to ENDURE and congratulate them for their achievements.

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DIVERSIFYING CROP PROTECTION

These are times of change for crop protection in Europe. In the past, efforts focused on reducing the detrimental effects of pesticides on human and environmental health, while continuing to mainly rely on chemical control. The regulation adopted by the European Union in 2009 – the 'pesticides package' – means that, in the years to come, farmers will no longer have access to the entire range of pesticides they use today and that they will have to adopt the principles of Integrated Pest Management (IPM), incorporating alternative approaches or techniques to reduce their dependency on pesticide use. However, efficiently managing weeds, diseases and arthropod pests ('pests' in a generic sense) continues to be essential. High and stable yield and quality in plant production contribute to the competitiveness of European agriculture. Now is the time to diversify crop protection.

ENDURE: A TRANSNATIONAL AND MULTIDISCIPLINARY NETWORK

Reconciling human health and environmental goals with production is a considerable challenge for farmers as well as all stakeholders involved in crop protection. Expectations are high that research will provide solutions. Only by sharing resources between member states and by creating synergies at the EU-wide level can research rise to this challenge. While there is a history of collaborative research on specific pests or crops, member states have until now chosen to tackle crop protection as a whole on a national basis. The transnational and multidisciplinary community gathered in ENDURE is unprecedented and in itself represents a significant achievement: around 300 researchers from 16 institutions in 10 European countries, including research organisations, universities, agricultural extension services and the biocontrol industry have been working together over the past four years.

THE ADDED VALUE OF ENDURE'S TRANSNATIONAL STANDPOINT

The transnational stand of ENDURE has already generated considerable added value to the exploitation of pre-existing knowledge. Focussing on a selection of crop-pest combinations of major importance as 'case studies', we compared pest problems and plant protection practices in a number of European countries. Indeed, each country developed its own vision of crop protection issues, rooted in the specificities of its soil and climatic conditions and of its own agriculture, history and sociological makeup. We have shown that significant progress can be achieved by sharing local experiences and by testing their potential for broader European-level implementation. Understanding why practices differ between countries also provided an insight into the complex factors that govern pesticide use and helped identify the major bottlenecks and gaps of knowledge that impede further progress. We have developed tools that help specialists maintain a pan-European vision of the evolution of some pests and related control methods.

IPM IS ENDURE'S CENTRAL CONCEPT

IPM is the central concept around which we organised the activities of ENDURE. It is not a new concept and tribute must be paid to those who conceived it and especially to the IOBC for its continued worldwide action spanning many years of development and support of this concept, notably with the production of integrated production guidelines. The Directive for the Sustainable Use of Pesticides now calls for the rapid mainstreaming of IPM in the agriculture of the 27 member states. We believe that this goal requires significant changes in the priorities established for research and innovation in crop protection. As a working definition of IPM, we have adopted that used in California for the implementation of IPM in practice: "*a sustain-*

able approach to managing pests that combines biological, cultural and chemical tools in a way that minimises economic, environmental and health risks". The major characteristics of this approach are that it relies on a combination of complementary methods, that it has to be locally adapted, and that integrated solutions are comparatively assessed according to the multiple criteria by which we can measure sustainability. It is also seen as a continuously improving process heading towards farming systems that are less conducive and more resilient to pest problems, so as to be less reliant on direct control methods.

ENDURE ADOPTS A HOLISTIC APPROACH

One common limitation faced by researchers when developing IPM solutions is the fragmentation of the crop protection research community. Specialists on different types of pests and crops, agronomists, ecologists, economists and social scientists have little opportunity to work together. ENDURE as a highly multidisciplinary community has had a unique opportunity to adopt a holistic approach. We devised a process ('system case studies') in which all these different disciplines collaborate in both the design of innovative cropping systems and in their assessment of increased overall sustainability. The outputs of these system case studies have confirmed the validity of the concept. The methods and tools developed in this process constitute significant contributions that will be re-used in further research initiatives to provide IPM solutions for the diverse farming systems found across Europe.

ENDURE PROVIDES INSIGHTS INTO MAJOR ASPECTS OF IPM STRATEGIES

Thanks to the collaboration between scientific disciplines and expertise pooled among its member institutions, ENDURE produced a set of research studies that enriches major aspects of IPM strategies: increasing the efficiency of chemical control, developing alternatives to pesticides, considering the potential for a wider contribution of ecological processes to the management of pest populations over large time and space scales. It was our deliberate choice to cover a wide range of topics in order to assess the opportunities for future breakthroughs, so that research can be engaged along the lines that emerge from this first appraisal. In so doing, we were careful to consolidate our results and research tools into a Virtual Laboratory that will support further collaborative initiatives on IPM.

ADVISERS ARE A MAJOR TARGET AUDIENCE FOR ENDURE

Past experiences in IPM already established that incipient innovations will not be taken up by farmers and their implementation will be poor if research stands alone and tries to produce ready-made solutions. Moreover, IPM, which must be adapted to local conditions, calls for a co-innovation process in which end-users are involved all along. Considering the very diverse organisation of farming communities across Europe, ENDURE selected advisers as its main target allowing widespread impact among farmers. Indeed, studies from ENDURE social scientists clearly demonstrated that the contribution of advisers and the organisation of advisory services are key factors in the implementation of IPM. Here, too, we took advantage of our transnational position to provide added value to advisers. We developed a web-based ENDURE Information Centre, tailored to advisers' needs. There, they have access to practical IPM-relevant information from a wide range of European countries and validated by ENDURE scientists. We also produced a training guide and other materials to facilitate training in IPM. An international network of advisers has started to crystallize around these tools and this unique initiative is expected to grow over with time.

ENDURE BRINGS SCIENTIFIC SUPPORT TO POLICY MAKERS

IPM implementation is not only a matter of developing technical innovation and sharing knowledge with advisers and farmers. It involves social, human and economic factors that ENDURE researchers from both the biological and human sciences have jointly tried to identify. By assessing the ingredients for successful implementation of IPM in Europe, ENDURE brings scientific support to policy makers involved in implementing the new pesticide legislation at both the EU and national levels. To this aim, ENDURE is contributing to expert meetings, produces 'policy briefs' and gathers its internal expertise on-demand to produce analyses and studies on specific issues.

ENDURE HAS GAINED WORLDWIDE VISIBILITY

In the last four years, ENDURE has acquired worldwide visibility. We implemented mobility schemes for researchers and summer schools for PhD students to increase the cohesion of the network. They were also opened up to people outside ENDURE and they attracted worldwide interest. We conducted specific actions to establish links with research partners outside Europe, in South America, China and North Africa in particular. Regarding communication, all public deliverables and papers from the project are accessible on our website which reports in real time the major stories and outcomes of ENDURE through vivid articles. Many activities produced leaflets synthesising their essential findings for non-scientific audiences in a practical format. Through our website which has had 36,000 individual visitors from 189 different countries and territories, and our bi-monthly electronic newsletter which has a circulation of 2,000, ENDURE has come to be known in nearly all the countries in the world.

ENDURE WILL REMAIN AS A REFERENCE POINT IN CROP PROTECTION BEYOND 2010

Contributing to the sustainable growth of European agriculture through innovative approaches to crop health is a long-ranging goal that requires the maintenance of the collaborative efforts engaged between our institutions in the years ahead. The decision of the members of our consortium to provide in-kind contributions so that ENDURE will continue beyond 2010 in the form of a European Research Group is both a recognition of what has already been achieved and the promise for more success. We planted a tree; the most valuable harvest has yet to come.

1

CASE STUDIES

Improving the sustainability of crop protection strategies and reducing dependency on pesticides

Nine case studies were carried out comparing pest problems and plant protection practices for selected crop/crop pest combinations in European countries. Besides describing the situation in different countries, another objective was to analyse why practices are different and whether optimum practices developed in one country could be adopted by other countries. As a follow-up to the case studies that focused on changes at the crop level, ENDURE initiated three system case studies. The objective of the "system case studies" was to study the effects of redesigning the cropping systems, as well as long-term innovations, on the overall sustainability of the systems.

CASE STUDIES

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 end-users that tends to lead to a higher-than-necessary use of pesticides. Nevertheless, experiences from some countries have shown that end-users are willing to reduce pesticide use when information on optimised pesticide use is available and when they are provided with easy-to-use decision support tools.
To promote the collection and exchange of information on optimised pesticide use, nine case studies were initiated. Another objective of the case studies was to analyse why practices are different and whether optimum practices developed in one country could be adopted in other countries. Eight of the nine case studies addressed specific crops and pest problems while one was more generic, addressing integrated weed control in row crops, using maize as a model crop. Both major and minor crops and annual and perennial crops were included in the case studies (Table 1).

CROP	TARGET PESTS
Wheat	Foliar diseases
Potato	Late blight
Tomato	Whiteflies
Pome fruit	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 Study.

The results are available on the ENDURE website as guides written for end-users (Figure 1). The main outcomes of the case studies are presented in detail in the following articles of this chapter. Here we will just present a few of the conclusions that came out of the case studies, highlighting the value of the case study approach.

the ENDURE network of excellence shares the fruit of 4 years research with the Crop protection community

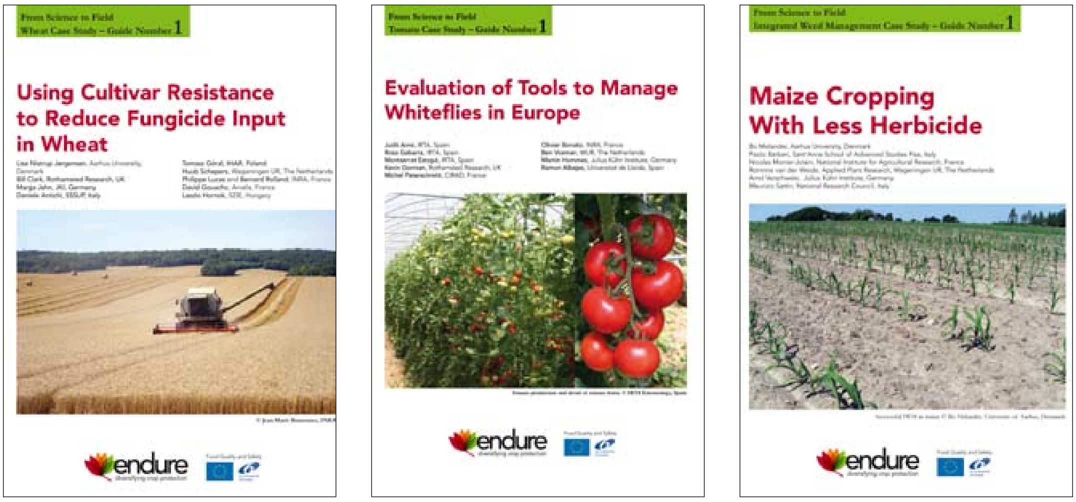

Figure 1 - Examples of guides written for end-users

Example 1: Comparing and explaining differences in pesticide use.

A recent survey by some of the participants of the wheat case study revealed that the treatment intensity (number of standard pesticide doses applied per hectare per growth season) varies significantly between the UK, France, Germany and Denmark. The UK tops the list with a treatment intensity of 7.7 while Danish farmers on average used only 2.3 standard doses of pesticides. Germany and France were intermediate with treatment intensities of 5.8 and 4.0. Similar differences were found for winter oilseed rape. The survey gave rise to a very intense exchange of views on the causes of the observed differences in pesticide use. The intensity of pest problems caused, e.g. by higher disease and arthropod pest pressure or more widespread occurrence of pesticide resistant biotypes, can only partialy explain the observed differences. A wider implementation of IPM tools such as national forecast and warning systems for some of the major foliar diseases, a more widespread use of resistant or partialy resistant varieties and the adoption of reduced pesticide doses also contribute significantly to the lower pesticide use in Denmark. Another important parameter, particularly in relation to use of relatively expensive fungicides, is to encourage farmers to focus on net rather than gross margins (see also Chapter 5).

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 joined forces with other scientists both inside and outside ENDURE and developed a web-based platform, EuroWheat (www.eurowheat.org), containing information on pathogen biology, cultivar resistance, fungicide performance and decision support tools. For more information see Chapter 4.

Example 2: Regional differences need to be considered in IPM implementation

In contrast to most of the other case studies, the Integrated Weed Management case study conducted a joint experiment in three locations in Italy, France and Denmark.. 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 in maize.

The study revealed that the efficacy of the standard chemical treatment and the integrated approach were comparable in all locations. The performance of the advanced integrated strategy was satisfactory in France, partly satisfactory in Denmark but unsatisfactory in the Italian location. Only minor differences were observed in the costs of treatments but the environmental impact, assessed by using the French indicator I-pest, revealed a significant reduction with the advanced integrated approach. The experiment demonstrated that herbicide use can be reduced but that local conditions will determine by how much.

Example 3: Adoption of IPM can be influenced by the market

Scab, brown spot and codling moth are major pest problems in pome fruit. The pome fruit case study examined the state-of-the-art of prevention and adoption of IPM strategies in six pome fruit producing regions: Germany/Switzerland, Spain, Italy, Belgium, The Netherlands and Sweden.

The study revealed that information about 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 all six regions. Although IPM in pome fruit is more widely adopted than in most other crops, bottlenecks do exist such as the lack of acceptance of resistant varieties by the market, highlighting the need to involve the entire food supply chain in IPM implementation.

SYSTEM CASE STUDIES

While the case studies focused on short-term changes at the crop level, the system case studies were dedicated to examining how re-designing the cropping systems and envisaging future innovations could further reduce the dependence on pesticides and improve the sustainability of major European cropping systems. Three case studies were launched: two on arable cropping systems and one on a perennial crop. One focused on winter crop based cropping systems dominated by crops such as winter cereals and winter oilseed rape and typically practiced in north-western Europe. The other arable system case study focused on maize-based cropping systems. Maize is an important crop throughout Europe but is primarily grown for grain production in southern Europe and for silage in northern Europe. The perennial system case study dealt with pome fruit, a crop grown for direct consumption, i.e. food chain considerations and the actors in the food chain, including consumers, play a more important role when it comes to crop protection procedures and IPM implementation than is the case for arable crops.

The two arable system case studies started out by describing existing cropping systems then moved on to designing 'advanced cropping systems' making use of available technologies including the ones not yet widely implemented. The last step was to design 'innovative cropping systems' for the future, i.e. systems implementing emerging technologies that are expected to become available in the foreseeable future. The advanced and innovative cropping systems were developed using a scenario building approach. The results of the arable system case studies are presented in more detail in two articles of this chapter.

The overall sustainability (economic, environmental and social) of the three systems was assessed using DEXiPM, a model developed within ENDURE for an expert-based ex-ante sustainability assessment of innovative crop protection strategies. Using DEXiPM allows for an iterative process re-designing the cropping systems until sustainability has been maximised. For more information see Chapter 4

The ENDURE system case studies represent one of the first attempts to design and assess future European cropping systems. Although it is a rather theoretical exercise we believe that systems case studies have provided valuable input and ideas for future field experimentation on IPM strategies.

CONCLUSIONS

The case studies have shown that focusing on short-term changes at the crop level can result in significant reductions in pesticide use but rarely reduce the dependence on pesticides. Nevertheless, picking these 'low hanging fruits' is the first step towards implementing IPM and sharing experiences across borders can promote this. The second step towards IPM, developing more sustainable cropping systems with reduced reliance on pesticides, is much more complicated but the outcomes of the system case studies clearly indicate that this is possible. Future experimentation and assessment will reveal whether we can realise the 'innovative cropping systems' outlined by ENDURE's system case studies.

WHAT ARE THE ALTERNATIVES TO THE INTENSIVE USE OF PESTICIDES IN VITICULTURE?
Bottlenecks and conditions of adoption in Europe

The sensivity of grapevine to major pests and diseases justifies a high level of protection. To this end, there are alternatives to pesticides based on ecologically sound methods, but they are unequally adopted in the European wine growing regions. The ENDURE grapevine case study evaluated five technical alternatives presently available, and identified the factors affecting their efficacy, factors influencing the decision of farmers to adopt them, the bottlenecks, and the ways to promote them.

Grapevine requires a high level of protection…

In the European Union, the total amount of plant protection products used in viticulture is high: 21.4kg active substance/ha (of which 14.9kg/ha is sulphur), compared to 6.9 and 1.1kg active substance/ha in fruit trees and arable crops, respectively. These products may diffuse to various compartments in the environment (soil, surface and ground water, air), contaminate them and can be potentially harmful to human health and various living organisms. Furthermore, traces of contaminants may be found in wine, which can reduce consumer interest in the product. Given this context, public regulations tend to be increasingly severe, including measures such as a reduction of the number of authorised active substances, controls on the quality of water and of food products, and agri-environmental incentives.

… yet alternatives to pesticides are available

The ENDURE grapevine case study identified five techniques that can contribute to reduce pesticide use:

- Changing the plant material by planting grapevine cultivars resistant to fungal diseases
- Using alternatives to herbicides such as cover cropping and tillage
- Using alternatives to insecticides such as mating disruption and biocontrol agents
- Using alternatives to fungicides such as biocontrol agents
- Reducing the number and dose of pesticide applications using Decision Support Systems.

Yet none of these techniques is currently widely used in European vineyards.

The wine industry must familiarise itself with new fungus-resistant grape varieties

The dissemination of resistant varieties is strongly influenced by the marketing strategies of winegrowers and by the expectations of the wine market.

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Products with a perfect wine quality should be used to promote the new varieties, towards both consumers and winegrowers. To this end, the process of vinification should be optimised for each new variety.

Target consumer groups should be identified for the wines made from new varieties (for example, young people with high environmental consciousness). These wines should create a certain image that the target groups are looking for.
In the regions producing geographically protected wines, the legal framework needs to be adapted.

To give up herbicide use, new equipment and techniques must be introduced

Specific equipment is needed for tilling and/or maintaining cover crops. For cover cropping, few species with low growth rate and low resource demand are available, and Decision Support Systems are missing.

The wine industry should improve the way it integrates environmental practices in its marketing strategy(at present, this is only true for organic viticulture).
The extra-cost of mechanical soil surface management could be covered by subsidies, conditional on compliance with environmental targets.

Decision Support Systems (DSS), a matter of data and networks

In several places, bottlenecks for decision support are the availability of weather data and easy communication tools, and the lack of validation and follow up of DSS at the local scale.
Extension services, advisers and farmers should be trained in using DSS and integration of the information in the farm management.
Trust from farmers depends on the local validation of DSS, and on their engagement with information shared within farmers' networks.

Biological control is still poorly supported and spread

Biological control still needs R&D studies aimed at solving its gaps and weaknesses, and communication on its application protocols and its efficacy towards advisers and growers.
Regulations should be improved to facilitate the registration of products in all countries. Public support for the adoption of biological control and certification to acknowledge it would encourage growers.

Mating disruption needs resources and cooperation

Mating disruption is expensive; yet in the European countries or regions that provide government aid for its application, its diffusion is high. Furthermore pheromone application may be used as a marketing instrument.
The technique must be applied on large areas so vine growers should organise themselves into collaborative networks.

The bottlenecks and conditions of adoption for alternatives to pesticide use

There are often pre-requisites for the development of an alternative to pesticide use, for example, the availability of weather data for DSS or a minimum surface area of treated vineyard for mating disruption. The efficacy of the technique may depend on biotic or abiotic factors, for example climatic extremes limit the efficacy of microbial biocontrol agents; if a variety is only resistant against one fungal disease but planted in an area with high pressure from another fungus, there might be disease outbreaks if the number of fungicide sprays is reduced. Several factors may affect the decision to adopt, for example the availability of labour resources for tillage, costs for mating disruption, the fit between wine produced from new cultivars with market requirements or local regulations. Finally, several types of bottleneck can limit the adoption of innovations: registration of the product (biocontrol agents, sexual attractants for mating disruption, resistant cultivars etc), public support, cost and growers' skills.

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IPM IN THE PRODUCTION OF FIELD VEGETABLES: how to meet the requirements for high quality, food safety and environmentally friendly production?

With regard to pesticide use, vegetable production has to focus on meeting challenging demands: healthy diet (consumers), cosmetic quality (retailers) and higher availability of crop protection methods (growers). There is thus a need for combining sound agro-ecological methods that reduce the vulnerability of vegetable cropping systems to weeds, pests and diseases, through a redesign taking into account crop succession and the land-scape dimension, in order to minimise pesticide use.

Field vegetables: high value crops with strong quality requirements

Field vegetables represent an important part of European agriculture, with an 8.9% share of the overall output value of the European agricultural industry. Vegetables are recognised for their nutritional value and for their impact on human health. Consumers are encouraged to eat at least five portions of a variety of fruits or vegetables a day. To meet the expectations of consumers and the wider society, it is important that the production of vegetables meets high standards with respect to sustainability and safety. The well-directed use of plant protection products (PPPs) is a key factor with respect to both environmentally sound production and to the avoidance of unwanted chemical residues on harvested produce.

Growing vegetables in different countries means relying on different crop protection methods

In a project conducted within the ENDURE field vegetable case study, the different PPPs options that were available to growers in seven European countries (Denmark, France, Germany, Italy, Spain, Switzerland and The Netherlands) for five major vegetable crops (cabbage, onion, carrot, leek, lettuce) were reported for 2008 and the differences between countries analysed. For a given crop, the numbers of active ingredients (AI) registered greatly varies among the countries. For example, methods to control weeds, insects and diseases on cabbage rely on 60 active ingredients in Switzerland compared to 43, 42, 29, 28 and 9 for Spain, France, Italy, The Netherlands, Germany, and Denmark, respectively. Denmark is the country with the lowest number of pesticide options. Switzerland is the country with the greatest numbers of proposed biocontrol options.

Diversification in vegetable cropping systems. ©INRA.

Although economically important, field vegetables are minor crops and crop protection options fall under the "minor use" category

Most vegetable crops are minor crops grown on a comparatively small production area and thus of low economic interest for the pesticide industry when applying for approval of new PPPs. This means that, even through derogation systems or possible extension of authorisation that may apply in new regulations, it will be difficult to match the availability of PPPs to the need for controlling every pest, weed, or disease that may develop in current cropping systems. Therefore, public research must be mobilised to provide for alternative methods to the use of pesticides and/or more environmentally friendly methods. Nevertheless, it also appears necessary to consider the conception and construction of innovative cropping systems less dependent on the use of pesticides.

Making field vegetable cropping systems less vulnerable to weeds, pests and diseases

Every step that can reduce the vulnerability of cropping systems to weeds, pests and diseases must be taken prior to considering the use of pesticides, even where these are available. In the particular case of vegetables, the minor use issue and consumer demand mean there is a strong requirement for doing so. With consideration to the facts that some dynamics take place mainly in the soil, at the field scale and depend on previous crops and/or on the management of inter-crops, and that others will develop through aerial dispersal within and between fields, at the landscape scale, we propose the following options.

Controlling weeds and soil-borne pests and diseases

Before crop establishment, soil steaming can be an efficient alternative in terms of control but may be slow to perform and costly in energy use. Applying the technique only on the row, with soil cultivation between rows during the crop, can be a good alternative as far as weeds are concerned and possibly for most soil-borne diseases, especially for transplanted crops. Biofumigation, although resulting in incomplete and sometimes inconsistent control, must still be regarded as a promising option to control soil-borne pests and diseases, and probably weeds. Most of the work done so far on biofumigation has been applied research with expectations to quickly yield ready-to-use technology. The variability observed in the results is probably partly due to the brassicas that were used and the specific glucosinolates they contain (and isothiocynates they can release) in relation to the sensitivity of the pests and diseases targeted. Indirect control through changes in the soil microflora should also be more widely documented from an epidemiological perspective.

Controlling air-borne insects

A number of methods are proposed at the field or field margin scale, from improving conservation biological control (for example augmentation or insectary plants) or targeted use of pesticides (for example push-pull and attract-and-kill methods, parapheromones and male annihilation techniques). Landscape management based on landscape and functional ecology should also be considered, though it is less easy to implement. One important point is that there is no unique recipe and that efficient solutions will come from local analysis of the problem that needs to be controlled as well as the potential offered by the production situation. There is a need for research on landscape and functional ecology to propose a framework in which such local studies will be considered and developed. There is also a need for more research on chemical ecology, as it offers the opportunity to develop molecules with new modes of action allowing regulation of plant/pest/pest enemy interactions.

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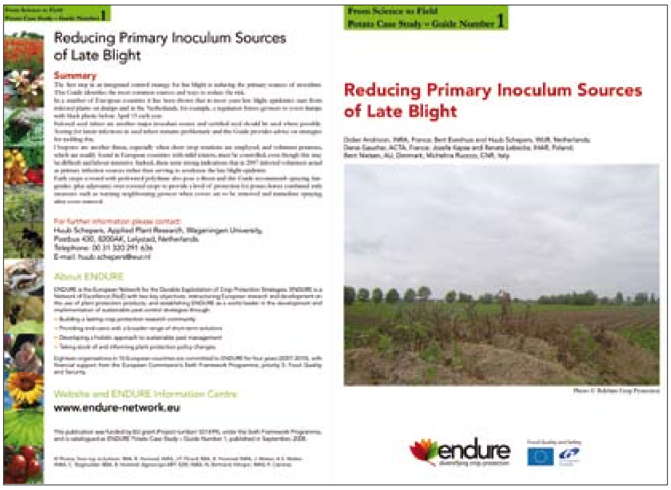
RESULTS OF THE POTATO CASE STUDY

Late blight can completely destroy a crop in two weeks and is therefore considered the most serious potato disease. The fungicide input used to control late blight is very high. An inventory of the best practices to control late blight was made, the conclusions of which are presented in four ENDURE "From Science to Field" guides aimed at agricultural advisers and extension services. The best practices to be combined in an IPM strategy include measures to reduce primary inoculum sources, the use of resistant cultivars, chemical control strategies and Decision Support Systems (DSS) to acurately pin-point the timing of spray applications.

Late blight (caused by *Phytophthora infestans*) is the most serious potato disease and, when first introduced into Europe in the 1840s, was responsible for the Irish potato famine. A conservative minimum estimate of combined losses and costs of control of blight worldwide is 4 billion (4 x 10^9) euros per year; half of this loss occurs in Europe. Higher amounts of fungicide are applied to control blight than in any other crop. Integrated management therefore requires a combination of management techniques to keep disease levels low and at the same time maintain the quality of the environment. In ENDURE the potato case study team made an inventory of the best practices to control late blight in a number of European countries. Four guides dealing with these best practices were published on both www.endure-network.eu and www.euroblight.net.



Guide 1: The ENDURE Guide ‘Reducing Primary Inoculum Sources of Late Blight’.

Best practices

Control measures can be divided into strategic measures and tactical measures. Strategic measures designed to reduce disease pressure include rotation, cultivar choice and measures to prevent primary inoculum sources. These strategic measures are mainly influenced by economic and social factors. Tactical measures include fungicide choice, number of sprays and use of DSS. By restricting fungicide choice, residues or environmental input, consumers, buyers and governments can influence the strategic and tactical decisions made by farmers. Best practices are effective measures still under development and being tested by applied research institutes in agricultural practice. For widespread implementation in practice a number of barriers (economic, costs, risk, risk perception) have to be solved.

Primary inoculum sources

The first step in an integrated control strategy against potato late blight is to reduce the primary sources of inoculum. In a number of European countries it has been shown that most late blight epidemics start from infected plants on dumps. In the Netherlands, for example, regulations force growers to cover dumps with black plastic before April 15 every year to remove this inoculum source. Infested seed tubers are another major inoculum source, and certified seed should be used whenever possible. Testing for latent infections in seed tubers remains problematic; Guide 1 provides advice on strategies for tackling this.

Oospores have been indicated as another inoculum source in several European countries. Oospores are a threat, especially when short crop rotations are employed. Volunteer potatoes, which facilitate oospore formation, must be controlled, even though this may be difficult and labour-intensive. Indeed, there were strong indications that in 2007 infected volunteers acted as primary infection sources rather than serving to accelerate the late blight epidemic.

Cultivar resistance

Late blight resistance of a cultivar offers significant potential in reducing fungicide input as part of an integrated control strategy. Both partial resistance and fungicides can slow the development of late blight. Many reports show that partial resistance in the foliage can be used to complement fungicide sprays, cutting fungicide use through reduced dose rates or extended intervals between sprays.

The use of resistant cultivars varies across Europe. In Western Europe, resistant cultivars are not grown on a large scale because commercially important characteristics such as quality (taste, colour, suitability for frying), yield and earliness are usually not combined with late blight resistance. However, in countries where fungicides are not available or relatively expensive, of resistant cultivars is one of the most important ways to reduce blight damage.

Breeders are constantly trying to produce cultivars that combine commercially important characteristics with late blight resistance, either by conventional breeding or using GMO techniques. Using cisgenesis - genetic modification using a natural gene from a crossable plant - may prove more acceptable to the public. However, a major barrier remains the durability of resistance, testing for which should be conducted according to EUCABLIGHT harmonised protocols. Guide 4 examines the current situation in Europe, the prospects for further progress and sources of information for advisers and growers.

Guide 4: The ENDURE Guide 'Using Cultivar Resistance to Reduce Inputs Against Late Blight'.

Fungicides

Fungicides play a crucial role in the integrated control of late blight. IPM strategies to control late blight balance a number of factors concerning fungicides, including efficacy and side-effects, but also economic and social factors in addition to the legislation in place.

Control strategies are primarily preventive, but when blight enters the crop the strategy must focus on stopping or reducing the epidemic. A control strategy can be based on a schedule with more or less fixed intervals or based on recommendations derived from a DSS. In a strategy, the first spray, product choice, dose rates, timing and last spray are important elements that can differ from country to country depending on growing conditions, varieties, registered fungicides and weather conditions. It is therefore important that information on all these elements is available to the adviser and/or farmer so he can base his decisions on this information and control blight efficiently. Guide 3 identifies sources for this information and presents a table of fungicides registered for late blight control in five European countries.

Decision Support Systems (DSS)

DSS integrate all relevant information to generate spray advice, in terms of both timing and fungicide choice. Much can be gained by their wider adoption. DSS increase the efficacy of control strategies without increasing risk. DSS can also be used in situations where the number of sprays or product choice is limited by legislation.

All potato growing regions in Europe have one or more DSS available. These DSS can improve the efficacy of control strategies and optimal timing of sprays can, on average, produce a saving of one or two sprays per season. Applying an effective preventive strategy can also avoid dramatic disease outbreaks that have to be stopped by using intensive spraying regimes. Guide 2 examines the DSS currently used in Denmark, France, Italy, The Netherlands and Poland.

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IMPLEMENTATION OF IPM PROGRAMMES IN EUROPEAN GREENHOUSE TOMATO PRODUCTION AREAS. TOOLS AND CONSTRAINTS IDENTIFIED IN THE TOMATO CASE STUDY.

Whiteflies (*Bemisia tabaci* and *Trialeurodes vaporariorum*) and whitefly-transmitted viruses present some of the most intractable constraints to European tomato production. The main objectives of the tomato case study were (1) to identify where and why whiteflies were a major limitation, (2) to collect information related to whiteflies and associated viruses, (3) to establish which management tools are available and (4) to identify key knowledge gaps that limit the uptake of Integrated Pest Management (IPM) programmes and research priorities that would promote their successful application.

Evaluation of applied pest control strategies

Two studies were conducted in 2007 and 2008. The first questionnaire (TCS-Q1) surveyed 10 countries on whitefly species, B. tabaci biotypes, insecticide resistance, whitefly-vectored virus species, whitefly natural enemies and their use in biological control, other control tools and sampling techniques for decision making in greenhouse tomato crops. The second questionnaire (TCS-Q2) was restricted to four areas selected due to their different levels of B. tabaci pressure and virus incidence: Germany, southern France, northern Spain and southern Spain. TCS-Q2 data were grouped according to growing cycles and four different pest control strategies were defined: Chemical (based only on the use of insecticides), IPM-Insecticide (IPM based on the rational use of insecticides), IPM-BC (IPM based on biological control) and organic production (insecticide-free approaches).

Figure 1: The whitefly *Bemisia tabaci*.
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Figure 2: Symptoms of TYLCD in tomato.
© IRTA / J. Arnó.

Distribution of whitefly and whitefly-transmitted viruses

Tomato crops were found to be affected by several insect pests and diseases, some being widely distributed and others restricted to specific areas or crop cycles. Two whitefly species affect European tomato production, Bemisia tabaci (Figure 1), which may cause severe losses due to the plant viruses it can transmit, and T. vaporariorum. B. tabaci is widely distributed in Europe and single infestations are reported from Israel, and some regions of Spain, Greece, Morocco and Turkey. Single populations of T. vaporariorum are usually found in northern Europe, and mixed infestations of the two whitefly species are common in most of the tomato growing areas. Bemisia-transmitted viruses include some of the most damaging viruses, such as the group of species responsible for Tomato yellow leaf curl disease (TYLCD) (Figure 2). TCS-Q2 revealed that wherever the pressure of B. tabaci was high, TYLCD was classified as important or very important.

Pest control strategies

Data from TCS-Q2 revealed that in greenhouses, IPM-insecticide was used in 70% of the surveyed area, IPM-BC in 25%, chemical control in 5% while organic production was rare. Decisions on a calendar basis were generally restricted to chemical strategies. Sampling techniques for decision making were generally based upon whitefly densities and were not related to control strategies or growing cycles but to the country or region. Whitefly populations were usually sampled weekly or fortnightly and whitefly species were identified. As expected, the number of insecticide treatments per month for whitefly control was generally higher in IPM-Insecticide than in IPM-BC. IPM-Insecticide uses 18% less active ingredients (a.i.) per application than the chemical strategy but 17% more a.i. per application than IPM-BC.

Unlike other pest species on tomatoes, the ranking of the importance of B. tabaci within each of the four surveyed regions closely correlated with insecticide use, showing that B. tabaci was one of the principal pests determining insecticide use. This is due to the threat of TYLCD and the low tolerance thresholds. Confirmed cases of resistance have been reported for both T. vaporariorum and B. tabaci to most of the active ingredients used for whitefly control.

TCS-Q2 revealed that IPM-BC was applied in all four regions, the largest acreage (>2000 ha) being in southern Spain. Biological control of whiteflies was mainly based on inoculative releases of the parasitoids Eretmocerus mundus and Encarsia formosa and/or the polyphagous predators Macrolophus pygmaeus (commercially labelled as M. caliginosus) and Nesidiocoris tenuis. Biological control was applied mainly within the framework of IPM and selective pesticides were applied for pests lacking biological solutions or when biological control failed to control the target pest. Natural enemies were also used in organic production but the acreage of tomatoes under this production system is limited.

Other important components of IPM strategies were greenhouse screening and double-door entry systems to reduce B. tabaci movement into greenhouses and the use of TYLCD tolerant tomato varieties. Most tolerant commercial cultivars show a reduced susceptibility to the virus rather than resistance, and they need additional protection from viruliferous insects during the first months after planting. No tomato varieties fully resistant to whiteflies were available.

Pest control recommendations

Based on the obtained results it was concluded that IPM-BC is the recommended control strategy for sustainable tomato production. The most important limitations for uptake of IPM programmes identified in the tomato case study were the lack of a biological solution for some pests and the cost of natural enemies. Other limitations were the low acceptance of the method among farmers, especially around the Mediterranean basin, the costs associated with technical advice and low pest injury thresholds, mainly in areas with high incidence

Figure 3: *Tuta absoluta* damage in tomato fruit.

of TYLCD. To overcome these limitations, research on the following domains are proposed: (1) emergence and invasion of new whitefly-transmitted viruses; (2) the relevance of B. tabaci biotypes regarding insecticide resistance; (3) biochemistry and genetics of plant resistance; (4) economic thresholds and sampling techniques of whiteflies for decision making, and (5) knowledge on native whitefly natural enemies and on other natural biological agents for tomato pest control.

New invasive pests

From the time the tomato case study surveys were made until now a new invasive pest, Tuta absoluta that can cause severe damage reaching up to 100% (Figures 3 and 4), has quickly spread in the most important tomato production areas in the Mediterranean basin. This pest has slowed the expansion of IPM-BC in tomato although predators used for whitefly control, M. pygmaeus and N. tenuis, consume a high number of eggs of T. absoluta and when they are very well established in the crop act as very effective control agents. Today, finding additional biological control agents for this pest is the cornerstone for improving the acreage under tomato IPM-BC.

Further reading: Arnó, J.; Gabarra, R.; Estopà, M.; Gorman, K.; Peterschmitt, M.; Bonato, O.; Vosam, B.; Hommes, M.; Albajes, R. 2009. *Implementation of IPM programs on European greenhouse tomato production areas. Tools and constraints.* Edicions de la Universitat de Lleida (Lleida, Spain), 44pp.

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Figure 4: *Tuta absoluta* damage in leaf.

TRACKING THE WAYS TO REDUCE PESTICIDE USE IN BANANA PRODUCTION

The banana case study provided a challenging opportunity for participants to unite their efforts in taking stock of alternative approaches and innovations to reduce pesticide use in banana production, and to disseminate scientific or technical information to encourage changes in practices. Integrated crop protection is a key target point to promote sustainable production in bananas.

Banana is one of the most traded fruit crops in the world. On the European market, more than 4.5 million tonnes of bananas are traded annually. Even so, intensive banana crops have long been disparaged because of their high inputs of chemical pesticides, and the potential hazardous effects the pesticides could have on the environment and human health. Accordingly, partners of the banana case study agreed to: (1) produce and disseminate scientific knowledge on short- or mid-term innovations designed to reduce pesticide use in banana production and address knowledge gaps, (2) develop and launch projects dealing with some of these gaps and (3) design a set of guides for farmers, field officers, policy makers and other stakeholders that showcase key alternative or innovative strategies to reduce pesticide use in banana production in the major European banana-producing countries as well as other banana-producing countries in the world.

Producing and disseminating scientific knowledge, addressing gaps of knowledge to reduce pesticide use

To address this issue we delivered seven scientific papers depicting or exploring short- and mid-term innovations to reduce pesticides in banana cropping systems. These papers:

- Make an inventory of current alternative and innovative practical strategies to achieve pesticide reduction in banana production systems through IPM approaches
- Review specific strategies implemented to control plant parasitic nematodes in bananas without chemical nematicides.
- Describe a predictive model to analyse the dispersal of the black weevil Cosmopolites sordidus in banana fields. Such a simulation tool should allow for the optimisation of the organisation of vegetation in banana fields in order to delay colonisation and alleviate damage from black weevil without a permanent recourse to insecticides.
- Depict some laboratory tools we designed to monitor fungicide resistance in the foliar pathogen Mycosphaerella musicola, causing the well-known Yellow Sigatoka Disease, or that of the fruit pathogen Colletotrichum musae, responsible for post-harvest damage, and to tackle the assessment of diversity in Mycosphaerella fijiensis populations with VNTR markers (Variable Number Tandem Repeats). These fungal pathogens are amongst the most damaging - and fungicide consuming - in banana agrosystems.

The legume Stylosanthes guianensis: a promising cover crop for banana agrosystems.

Developing and launching projects dealing with identified gaps of knowledge to reduce pesticide use in banana production

We developed two research proposals addressing gaps of knowledge for pesticide reduction in bananas. The first is a project submitted to the French National Agency for Research. The objective of the project is to analyse and model the spatial effects of crop organisation on the spread of pests in the framework of integrated crop management. It targets the design of generic tools for reducing pesticide use in cropping systems. The second project, an ATF project (French National Cooperation) addresses the management of fungicide resistance of M. fijiensis, causal agent of Black Leaf Streak Disease of bananas. It was accepted and the project has been launched.

Producing five guides summing up key alternative strategies and cropping practices to reduce pesticide use in banana production

Designed for farmers, field officers, policy makers and other stakeholders, our guides emphasise innovative strategies that are compatible with integrated crop protection (http://www.endure-network.eu./endure_publications/endure_publications2). The first guide examines the lessons learned from an overall analysis of pesticide use in banana-producing countries, including representative European countries. It then goes through the main alternative or innovative solutions to reduce, in the short and mid-term, pesticide use in banana production. The following four guides give specific examples of the solutions recommended in the first guide. They provide information on the sustainable control of Mycosphaerella foliar diseases, new integrated pest management strategies for black weevil Cosmopolites sordidus, plant-parasitic nematodes and practical ways to grow bananas under the standards of integrated or ecological production as exemplified by growers in the Canary Islands.

Conclusion

Our work shows that the scientific and technical background to change practices, and encourage banana production in sustainable cropping systems less reliant on pesticides, is already partly available. Most of the alternative or innovative strategies we highlighted are currently being further implemented at a larger scale in the framework of two development projects involving three European banana-producing countries. The first project, BIOMUSA, is led by ICIA (Canary Islands, Spain) with the participation of the University of Azores (Portugal), the University of La Laguna (Spain), the Regional Directorate of Agriculture and Rural Development of Madeira (Portugal), and of the Association of Banana Producers in the Canary Islands. The second project, called Plan Banane Durable, is led by CIRAD and the banana growers' association of the French West Indies (France).

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STATE OF THE ART OF INTEGRATED CONTROL OF MAJOR POME FRUIT PESTS AND DISEASES

We collected information on the integrated control methods which are used in 10 major pome fruit production regions of Europe. Integrated control of codling moth (*Cydia pomonella*), brown spot of pear (*Stemphylium vesicarium*) and apple scab (*Venturia inaequalis*) was studied. Analyses showed that, although the spread of new integrated methods is rapid and well dispersed in the major pome fruit production areas, there are social, technical and economic bottlenecks for the further implementation of integrated fruit production.

Integrated control of pome fruit pests and diseases is well established in Europe. Cornerstones of integrated pome fruit production are the biological control of spider mites, such as Panonychus ulmi with the predatory mite Typhlodromus pyri, and the use of Decision Support Systems (DSS) for the control of apple scab caused by Venturia inaequalis. Practical growers choose their chemical pesticide products based on the criterion that they will not affect predatory mite populations. However, due to continuous developments, integrated control is not a steady state of affairs.

Continuous developments of pest control methods

Society continuously changes. Pesticide residues on fruit are a recent societal change that influences integrated production of fruits, and new pesticides are released and older ones banned. Furthermore, many research groups continuously work on new elements of integrated control in pome fruit. They deliver, for example, advanced warning systems, or new environmentally friendly control strategies. New scientific methods of integrated control in pome fruit have to find their way into practice. Often new developments are first introduced into practice locally by researchers themselves and sometimes directly for a whole country. Secondly, advisers have to be convinced of the advantages of the new method before they start promoting it. Further introduction is much dependent on integrating the new method within the total management of the orchard system in practice. That is why there are differences in orchard management systems across Europe. New developments in integrated control measures can be found in scientific literature and congress proceedings. However, it is not clear which integrated control measures are really used in practice.

Therefore, an inventory of integrated control measures used in a number of European pome fruit production regions was conducted by ENDURE.

Focusing on key pests to reduce pesticide use

In this study, the integrated control methods were collected for apple scab (Venturia inaequalis), brown spot on pear (Stemphylium vesicarium) and for codling moth (Cydia pomonella) because these are the pests responsible for a substantial share of the pesticides used to reduce the risk of severe losses in pome fruit production in Europe. This was completed for the following regions: Lake Constance (Germany and Switzerland), Catalonia (Spain), Emilia Romagna, South Tirol and

Apples with lesions of the major disease apple scab caused by *Venturia inaequalis*. Warning systems against apple scab are the oldest among decision support systems. They are very advanced and help to reduce fungicide use.

Scorpionfly (*Panorpa communis*) is a generalist predator in orchards, eating all sorts of soft insects such as aphids. Males have enlarged genitals that look similar to the stinger of a scorpion.

Pear fruits affected with brown spot of pear caused by *Stemphilium vesicarium*. This disease caused a substantial increase in fungicide use in pear ochards.

Apple with penetration of codling moth (*Cydia pomonella*). Several methods, such as the use of mating disruption and the use of granulosis virus are available for sustainable IPM.

Trentino (Italy), Rhone Valley (France), Belgium, Netherlands and Sweden. Further implementation of integrated control measures for these pests will reduce substantially pesticide use in pome fruit production. A questionnaire was created for codling moth and adapted for apple scab and brown spot of pear. The questionnaires in English were e-mailed to scientific colleagues and to plant protection officers across Europe. Personal interviews were carried out in some cases.

Highlights of findings

The inventory showed that control is highly dependent on the use of pesticides, especially in the case of pathogens. A summary of the conclusions is presented below.

Spreading knowledge of new integrated control methods

• New knowledge of integrated control methods is, in general, quickly and broadly spread in the European countries involved in this study.
• Spreading of knowledge is done by governmental or private organisations, including those comprised of growers and retailers, and often by advisory services.
• Information on the timing of pesticide applications based on Decision Support Systems often relies on modern communication technologies such as SMS and e-mail.

Comparing the regions

• Toolboxes in the various regions contain the same tools, such as mating disruption for codling moth and sanitation practices for apple scab, for integrated control of pests in all the regions covered in this study. Hence, there are no differences between northern or southern regions of Europe on this aspect.
• Even the importance of the different tools is very similar in northern and southern regions in Europe.
• There are only small differences in the percentage of growers using the different tools for integrated control between European fruit producing regions.
• It is unknown if newer European member states have access to updated information on tools for integrated control. Newer European member states could profit from existing knowledge through ENDURE's channels of communication.

Major bottlenecks to the adoption of integrated control methods

• There are clear bottlenecks in adopting newer tools for integrated control. For example, the major bottleneck for growing less susceptible or resistant cultivars is that these cultivars tend to be less economically profitable, because marketing strategies fail to achieve good prices for these cultivars.
• A major bottleneck, in general, for integrated control is the lack of selective pesticides. For codling moth this is not the case. For many other pests and diseases, the non-selective pesticides available harm natural enemies and antagonists.
• A bottleneck is that the registration of products, including products which are generally regarded as safe, is slow and costly. Bottlenecks for the implementation of new integrated control measures concern multiple technical and economic factors which need to be tackled in parallel.

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ORCHARD SYSTEM DESCRIPTIONS: guide to future durable apple production.

Four "orchard system" types were defined for sustainable apple production in five European regions: a baseline system, two advanced systems and an innovative system. The base-line system was defined as a reference system in which only synthetic and commonly advised pesticides are used. The advanced systems were composed of locally used IPM methods together with a limited use of pesticides. The innovative system consisted of alternative measures to reduce the application of chemical plant protection products to a minimum.

Blossom of a just planted, modern apple orchard.

Modern apple orchard with nearly ripe crop.

Apple production in Europe is continuously working towards more integrated crop protection. However, in practice a substantial amount of pesticides is still being used. A range of bottlenecks, both social, economic and technical prevent large-scale implementation of IPM methods. The development of an assessment tool, which evaluates the effect of newly introduced IPM methods, can help to identify possible bottlenecks for introduction into practice. To develop such an assessment tool, both qualitative and quantitative descriptions are necessary. In close cooperation with assessment tool developers, such descriptions were made for five European regions. They were Lake Constance (Swiss side), Lake Constance (German side), the Lleida (Catalonia) region in Spain, the Rhone Valley region in France and the whole of The Netherlands.

Studied systems

Four orchard system descriptions were defined for sustainable apple production. These were a baseline system (BS), two advanced systems (AS-1 and AS-2) and an innovative system (IS). The base line system (BS) was defined as a referent system in which only synthetic and commonly advised pesticides are used. The advanced systems (AS) were composed of realistically possible IPM methods together with a limited use of pesticides with good ecotoxicological profiles. And in the innovative system (IS) alternative measures currently being tested in the field were implemented and combined in order to reduce the application of chemical plant protection products to a minimum. The use of resistant cultivars is an important element in these systems. The time horizon for the innovative systems is about 10 years.

Highlights from different regions

The Netherlands

In the base line system (BS), priority is given to optimal control and reducing the risks of crop losses. This results in the use of broad spectrum pesticides, with impacts on non-target beneficial organisms and substantial drift of pesticides. In the advanced system (AS) priority is given to using alternative methods whenever possible to control pests or diseases. This system often comprises the use of selective pesticides and non-chemical methods. Drift reduction of 90% is achieved in orchards adjacent to water bodies. The innovative system (IS) consists of a combination of resistant or tolerant cultivars, high precision pest control and natural pest control. It brings together the best properties of high technology methods with ecological principles. Selective and environmentally friendly pesticides are used for corrections, using only high-precision applications.

Switzerland

The BS follows national guidelines for integrated pome fruit production in which the application of direct control measures for the major pests is based on the use of tolerance levels and forecasting services. The main innovations in AS-1 are scab-resistant cultivars and mating disruption for codling moth. In AS-2, even more alternative strategies are used. In AS-2, protection and enhancement of beneficial organisms are strengthened compared to AS-1, allowing further reductions in the number of insecticide applications. In addition, exclosure netting prevents pests from invading the orchard and supports fire blight control. In IS the cultivars have resistance/tolerance genes against a variety of diseases and aphids, based on pyramidised genes which makes fungicide treatments to conserve genetic resistances obsolete. Alternative pest control strategies include attract-and-kill, sanitation and entomopathogenic nematodes.

Spain

As is the case for the other regions studied, BS pest control relies only on the use of officially permitted chemical pesticides. Resistance management is taken into account, as pesticides with different modes of action are applied. All the pests are kept below economic thresholds. Herbicides are used to maintain a weed-free strip. In the AS-1, arthropod pest control includes the use of mating disruption for codling moth and other pests (leopard moth), mass trapping and attract and sterilise (or kill) for medfly, and biological control against European red mite. In AS-2, landscape elements are planned from a crop protection point of view to increase natural control. Consequently, the number of applications is drastically reduced, and more selective chemicals are used. In the IS, the amount of water applied is further reduced to 5,000m3/ha. The percentage of surface with hail nets increases to 50%. Drift reduction sprayers are used in 100% of the acreage. The use of all innovative control techniques is considered. Among the new ones, push and pull strategies for some arthropod pests, such as aphids, might be available in the future. The control of diseases relies on the use of sanitation measures, varieties resistant to apple scab and powdery mildew and rootstock resistant to phytophthora (monogenic and multigenic resistance), antagonistic microorganisms, resistance inducers and chemicals.

Germany

In the BS the production goal is achieved with conventional pesticide management and sensitive cultivars. The plant protection products have a moderate impact on specific beneficial organisms. Alternative pest management methods are not applied. AS-1 is representative for the region as growers follow guidelines for integrated pome fruit production. In the AS-2, the ecological and environmental sustainability of the production system is further improved. Although the collection of pesticides used is comparable to AS-1, the application frequency is lower. This is achieved with an increased use of alternative pest management methods, especially for arthropod control. The IS is the most sustainable production system in terms of environmental impact. Arthropod control is achieved without chemical pesticides thanks to the use of resistant varieties, pheromones and bio-pesticides. For disease control, technical measures such as rain shelters are installed. The cultivars have resistance/tolerance genes against multiple diseases.

France

In the BS system only synthetic pesticides are used, all registered and commonly advised in 2008. They include broad spectrum pesticides with high efficacy and low cost but poor ecotoxicity profiles. With the exception of herbicide applications, no drift-reducing equipment is used. In AS-1 the use of chemicals is reduced as much as possible through the introduction of sanitation practices to reduce the pressure from major pests and diseases. In AS-2 mating disruption is not only targeted at codling moth, but also controls oriental moth. Moreover the variety planted presents a higher tolerance to aphids. In the IS, the orchard is completely packed in an exclosure net, suppressing all treatments to control codling and oriental moth as well as other Lepidoptera. This net is combined with the use of sanitation practices as well as all the previously mentioned methods to decrease aphid pressure.

Assessment results

The assessment tool SustainOS was developed by Swiss researchers within the ENDURE project. The development of this assessment tool and the descriptions of the orchard systems were produced simultaneously. As expected, the final run with the SustainOS assessment tool showed that sustainability generally increased going from BS, via AS towards IS for all European regions. The attributes for 'environmental sustainability' are rated better for AS-1, AS-2 and IS compared to BS and the attributes 'economic sustainability' are rated worse for AS-2, AS-1 and BS when compared to IS.

Conclusion

The use of the SustainOS qualitative multi-criteria assessment tool can help European apple production to identify more sustainable apple production systems for the future.

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Modern young pear orchard with nearly ripe fruit.

WHEAT DISEASE MANAGEMENT – POSSIBILITIES FOR IPM – PRESENTING GOOD EXAMPLES AND LIMITATIONS

Information was collected on disease control strategies in winter wheat in eight European countries. The main focus of the work was to share existing knowledge on sustainable disease control systems. As an element of European Union (EU) legislation, the importance of IPM including the use of resistant cultivars will have to increase. Few fungicide groups and a high risk of fungicide resistance also call for broader use of IPM in order to safely manage diseases in winter wheat. Specific information collected from the case study can be found on *www.eurowheat.org*.

Yield and yield losses due to diseases

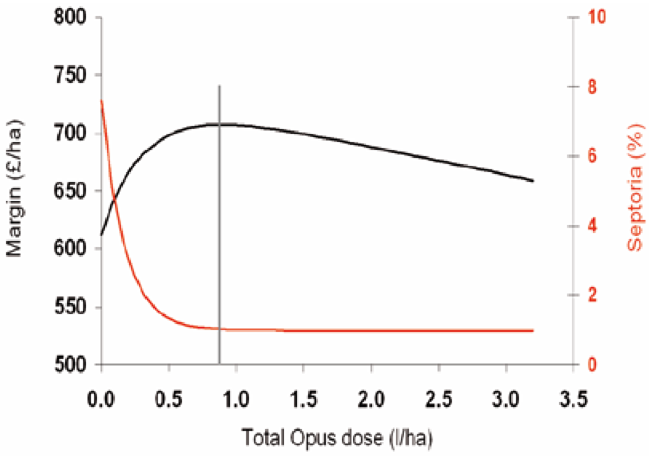
Wheat is the most important cereal crop grown in the EU. The yield levels and cropping conditions vary considerably between the different EU countries. In the countries most suitable for wheat production (Germany, UK, France, Belgium, The Netherlands, Ireland, Denmark) average yields vary between 7 and 8 tonnes/ha, whereas in countries with sub-optimal cropping conditions (Hungary, Italy, Spain, Poland, Greece) yields vary between 2 and 4 tonnes/ha.

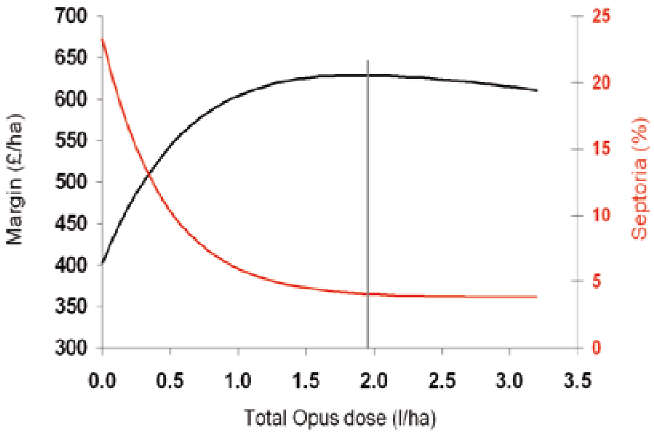
Based on national estimates, septoria tritici blotch, brown rust, take-all and fusarium head blight are considered the most important diseases in the main wheat growing countries with respect to yield loss and quality of grain. Yield losses between 0.5 and 2.0 tonnes/ha are common in many regions. Yellow rust, powdery mildew, tan spot and eyespot are also regarded as important diseases; however, their distribution is much more regional.

IPM elements

The use of resistant cultivars with effective resistance genes is an important measure to reduce the risk of disease development and yield loss. The genetic resources used across Europe vary greatly as few cultivars are grown in more than one country. All countries conduct extensive testing of new cultivars but resistance characteristics rank differently across countries. The exploitation of resistance genes in different countries was also found to vary. Data from cultivar testing has commonly shown profitable yield responses from fungicide treatment in even the most resistant cultivars, indicating that the resistance genes rarely cover all potential diseases. Levels of resistance in cultivars are also known to be changeable due to shifting going on in the pathogens' virulence.

Several **cultural measures** are known to reduce disease pressure. They include factors such as delayed sowing, ploughing rather than non-inversion tillage, crop rotations avoiding wheat and maize as previous crops, reduced nitrogen input and reduced seed rates. However, several of these factors have a significant negative impact on yield and are therefore only utilised to a limited extent. Good risk-assessment systems have been developed for control of *Fusarium* head blight in many countries. Avoidance of minimal tillage in combination with maize in particular as a previous crop is of major importance in order to reduce the risk of *Fusarium* head blight.





Fungicide requirement at economic optima for disease resistant (left) and disease susceptible (right) varieties indicating that the required optimum is very dependent on cultivar resistance (UK).

Safe and sustainable control of Fusarium head blight requires use of cultural factors like crop rotation and tillage methods.

Delayed sowing can reduce the risk from several diseases (take all, eyespot, septoria tritici blotch), but may also increase the severity of others (powdery mildew and yellow rust). In particular, sowing of second year wheat should be delayed in order to minimise the risk of take all. A major delay in sowing will have a negative impact on the yield. The **seed rating** should be adjusted to the sowing time in order to avoid very dense crops, which increase the risk for diseases such as powdery mildew, but also the risk of lodging.

Septoria tritici blotch is the most economically important disease in Europe.

The **nitrogen levels** which are recommended for wheat varies significantly between countries (150-250kg N /ha). Very high nitrogen levels increase the severity of diseases such as powdery mildew. However, in the ranges which are recommended in most countries (150-200kg N/ha) the impact on diseases is regarded as small.

Monitoring and use of DSS: the use of control thresholds in combination with field scouting can be a great help when deciding on the need for treatment. As seen in many countries, specific field scouting can be supported by regional monitoring data updated at weekly intervals. Decision Support Systems (DSS) are available in many countries but are rarely used by farmers as they are often considered not to be user-friendly, too time consuming and may 'fail' by being too risky or too risk-averse. However the potential for reduction in fungicide use, if applied at the right time, is considered to be significant. Results from analysis of historical trials data at a national or regional basis can be used to make general risk assessments and evaluation of expectations for achieving profit from fungicide applications.

Chemical control measures

The strategy for chemical disease control varies significantly between countries. In Poland, Hungary and Italy fungicides are used to a lesser extent than in France, UK, Germany, The Netherlands and Denmark. The number of fungicide applications in winter wheat varies from zero to five treatments per season, depending on the region and disease problems.

The actual input of fungicides can in many situations be reduced by optimising the choice of product and timing. Good experiences from using reduced and appropriate doses have been generated in many countries. The focus in these strategies has been to optimise economic benefit rather than maximising yield.
Only relatively few groups of fungicides are available for the control of the main diseases (triazoles, strobilurins, morpholines, carboxamides and chloronitriles). This makes it difficult to implement anti-resistance strategies that could prolong the life of the fungicides and help to avoid the erosion of their efficacy.

Perspectives and dilemmas

There are several dilemmas when trying to implement lower inputs of fungicides in winter wheat. Some of these are related to the following points:

1/ The risk factors associated with not spraying are high, particularly with the high price of wheat. Most farmers and advisers are very risk-averse, aiming to protect potentially very valuable crops. This can often lead to supra-optimal doses being used.

2/ Success stories cannot be directly transferred from one region to another. Many tools and principles can easily be transferred but the actual optimal combination of control measures and the optimal input use is expected to vary considerably across the wheat growing countries.

3/ It has to be recognised that for several specific diseases the exact risk of disease development cannot be forecast or estimated because their development is very weather dependent.

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REDUCING PESTICIDE USE INTENSITY IN EUROPEAN CROP ROTATIONS

The ENDURE project provided a unique opportunity to bring together scientists, advisers and farmers across Europe to assess the potential for reducing dependence on pesticides in winter cereal based cropping systems. We conclude that changes in cropping systems and new management technologies offer remarkable potential to achieve reductions in pesticide use.

Why focus on crop rotations?

Crop rotation has long been a fundamental tool for farmers to maintain crop health and soil fertility. A changing sequence of crop types in a field brings nutritional demands on the soil into balance and interrupts cycles of pest build-up. Crop rotations, together with the technologies used to manage the crops within them, can therefore have a very significant impact on the need for pesticides. The ENDURE project brought together a group of scientists, advisers and farmers with a range of expertise to explore and evaluate options for reducing dependence on pesticides in winter cereal based cropping systems in Denmark, France and the UK. Using this exciting opportunity to combine their knowledge of agronomy, of weed, pathogen and insect pest ecology and of management technologies, the group found considerable potential for pesticide reduction.

What do crop rotations in Europe look like today?

• Crop rotations in wheat growing areas of the UK and Denmark are very variable (Table 1). Even the most common crop sequence occurred in less than 10% of fields.
• In France, crop sequences are even more diverse, depending on the region analysed.

***Apera spica venti*, an annual grass weed**
© Aarhus University, Bo Melander.

COUNTRY	CROPPING SEQUENCE				
England (2006)	R,C, W,W	W,W, W,W	R,W, P,W	R,C, W,R	W,R, W,W
% of crop sequences	6.40	4.40	4.40	4.40	3.80
DK	W,W, W,W	B,R, W,W	W,W, W,R	M,M, M,M	G,G, G,G
% of crop sequences	3.6	2.8	2.8	1.6	1.5

W: winter wheat, B: winter barley, SB: spring barley, C: other cereals, R: oilseed rape, P: pulses/legumes, G: grass, M: maize, SGB: sugar beet, H: hemp, BE: spring beans

Table 1: Most common crop sequences in England (after wheat) and Denmark.

How much pesticide do we use in Europe today?

ENDURE calculated the pesticide usage for some typical current crop sequences in the main wheat growing areas of each country. Examples are given in Table 2, columns 1-3.

Pesticide use varies remarkably between countries and is especially low in Denmark. This implies that the potential for reducing pesticide use also varies from country to country.
• The ENDURE case study on winter wheat suggests that the main reasons for this variation include differences in :
• Climatic conditions and associated pest and disease pressure
• The prevalence of pesticide resistance (particularly against herbicides)
• Government policy action plans for pesticide use reduction
• Sources of advice used by farmers
• The scale and organisation of farming operations.

COUNTRY	Typical current rotation	TFI	Rotation with off-the-shelf technologies	TFI reduction	Rotation with developing technologies	TFI reduction
DK	B-R-W-W	2.5	B-R-W-W-SB-SB	-6%	B-R-W-W-SB-SB	-37%
England	W-W-R	6.2	W-BE-W-SB-R	-39%	W-BE-SB-R	-56%
France	SGB-W-R-W	7.2			SGB-W-H-W-R-W	-74%

Table 2: Pesticide usage measured as the annualised Treatment Frequency Index (TFI) for typical current rotations.
See Table 1 for key to crops.

How much pesticide reduction could be achieved with off-the-shelf or developing techniques?

• The group calculated that with currently available techniques and technologies pesticide usage could be reduced to a remarkable extent (Table 2, columns 4 and 5) and they could be reduced still further using technologies likely to be available in the next five to 10 years (Table 2, columns 6 and 7). The maximum potential for reduction was calculated to be 75% or more in France, more than 50% in England and more than a third in Denmark, despite the relatively low current level of usage in that country.

Inter-row cultivation in winter oil seed rape © The Knowledge Centre for agriculture, Peter Bro and Torkild Søndergaard Birkmose

• Some of the most important ways this was achieved were:
• Changes to crop sequence and increased crop diversity, use of spring crops
• Use of new resistant cultivars and weed-competitive cultivars/crops
• Precision agriculture, pesticide targeting
• Forecasting and decision support – improved systems and increased uptake
• Tailoring tillage regimes to specific pest pressures, mechanical weeding
• Habitat management at various scales for conservation biological control
• Trap crops and catch crops.

Would such changes in crop rotation and management be sustainable?

An expert assessment of the proposed new rotations examined the potential effects of the changes on environmental, economic and social sustainability at the farm scale:
• The overall environmental sustainability of the proposed rotations was judged to be significantly improved in France and England and even in Denmark, where the current level of pesticide usage is markedly lower, environmental quality was improved.
• Economic sustainability was judged to be reduced in some or all of the proposed rotations in each country. It was judged that the new rotations may be associated with more risk and reduced investment capacity.
• Social benefits (for example, ease of farm operations, employment, landscape amenity value) associated with the new rotations were usually improved in France but little changed in England and Denmark where current social acceptability was considered strong.

Beyond the farm scale, the proposed rotations have clear strategic implications for policy makers. For example, crop rotations that achieve large-scale reductions in pesticide use almost always have a smaller proportion of wheat, a major staple and traded commodity.

Where do we go from here?

Achieving this strong potential for reducing pesticide use in European crop rotations will depend upon the strategic involvement of policy makers in the development and implementation of regulatory and advisory frameworks. If the complex balance between pesticide use, environmental and economic sustainability and food production security is to be appropriately struck, pesticide reduction strategy must be underpinned by a multi-disciplinary, multi-site platform for research on crop rotations that includes the incorporation of new and emerging technologies.

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DEXIPM, a model for ex-ante sustainability assessment of innovative crop protection strategies.

DEXiPM model is a tool developed to assess the multiple aspects of the sustainability of innovative crop protection strategies. It is meant to be used during the design phase of cropping systems, making it possible to select the most promising strategies before testing them in the field. A wide range of criteria, covering economic, ecological and social dimensions is considered. In addition, the model helps identify which conditions (market, policies, pedo-climatic conditions) could increase the sustainability of a specific strategy. The overall structure of DEXiPM was developed to support the design of innovative arable cropping systems but its generic structure could easily be adapted to other cropping systems such as vineyards and vegetable-based systems.

Designing cropping systems with reduced pesticide inputs usually implies the analysis of several alternatives. Assessing them before the in-field test (ex-ante) is a prerequisite for making it easier to explore truly innovative solutions and to increase the efficiency of the innovation process by reducing the number of solutions to be tested in field experiments (Figure 1). In the evaluation step, it is important to take into account that candidate cropping systems can have different and conflicting impacts on agricultural sustainability, meant in its three classical dimensions: economic, environmental and social. Moreover, taking into account pedo-climatic as well as socio-economic contexts is a way to explore a large range of scenarios accounting for the innovative cropping systems in a given context. In this case, the ex ante evaluation makes it possible to consider innovative systems that may not be feasible or sustainable today, but which might be "tomorrow" in a different context. DEXiPM is a hierarchical and qualitative multi-attribute model allowing the evaluation of cropping systems sustainability according to this complexity. It has been developed for ex ante assessment of the sustainability of arable cropping systems, particularly Integrated Crop Management Systems with a limited use of pesticides.

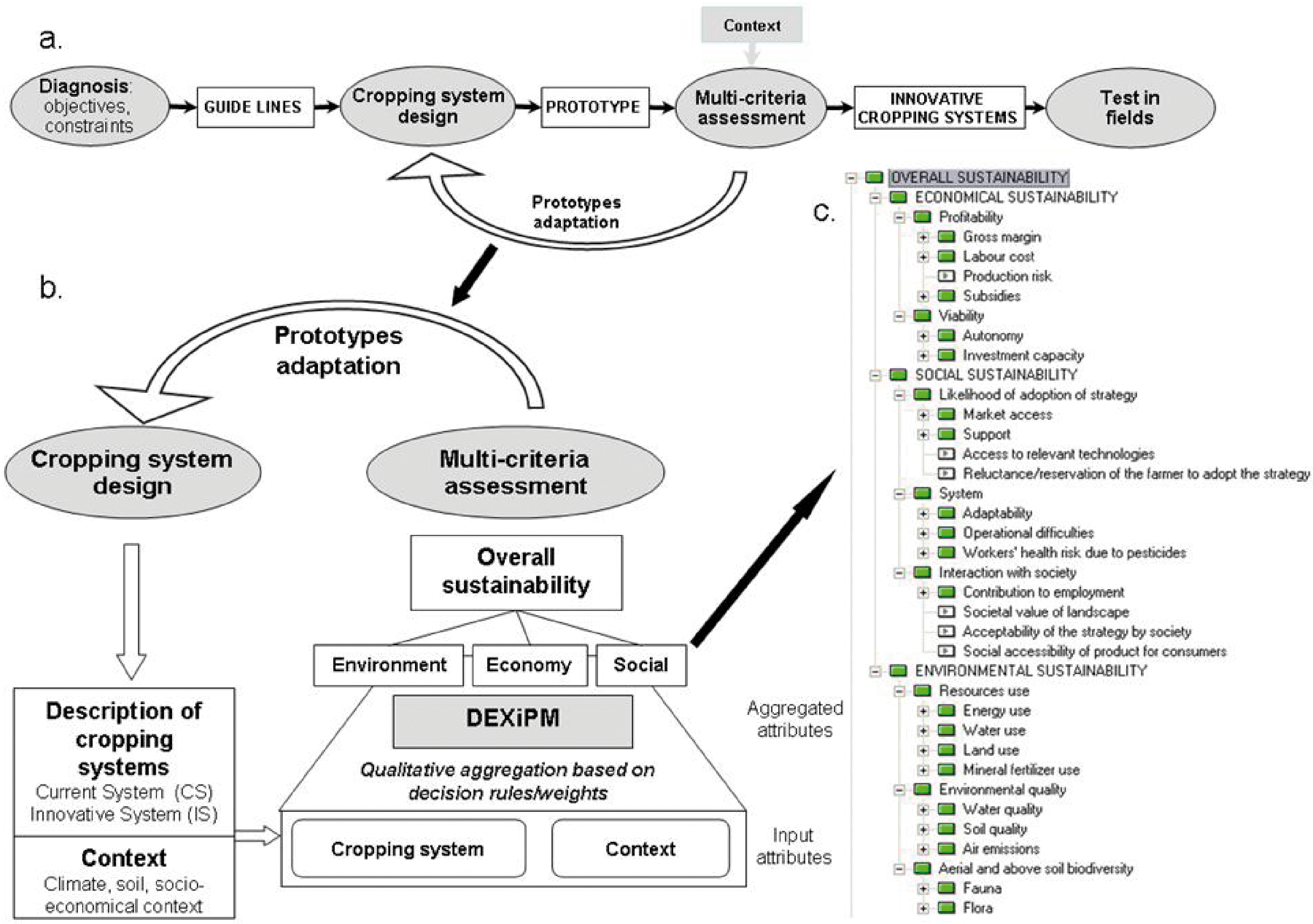

Figure 1 - General description of DEXiPM (b.), detail of the upper part of the decision tree (c.) and how DEXiPM is included in a looping process for the design of innovative cropping systems (a.).

Model description

DEXiPM was implemented within the DEXi decision support system, which allows breaking a problem into smaller thematic attributes, organised hierarchically in a decision tree. In DEXiPM the overall sustainability is divided up into three components, economic, social and environmental sustainability, and each of them is detailed in smaller and less complex issues. Inputs of the model are either a description of the cropping system (crop sequence and crop management) or a description of the context. Intermediate attributes are qualitative indicators of sustainability. DEXiPM has been developed by three agronomists and one sociologist and then submitted for appreciation by experts from various fields (e.g., weed scientists) in order to validate the choice and hierarchy of the attributes. DEXiPM is based on the MASC model and several attributes derived from other models and studies have been added. In comparison to other assessment tools, special attention has been paid to the social and biodiversity aspects.

Model use and conclusions

The model has been used to assess existing or innovative cropping systems described within the ENDURE arable rotations system case study.

• Assessment of cropping systems showed that innovative cropping systems with a limited use of pesticides can have a better overall sustainability, despite the fact that some of the attributes can be negatively impacted.
• Because most of the relevant knowledge on agricultural sustainability has been grouped and organised in the decision tree, DEXiPM is a good tool to encourage discussions on proposals for innovative systems and should therefore help in the design of innovative cropping systems that will then be tested in field.
• The design of DEXiPM is also based on a state of the art of agricultural sustainability which led to point out gaps in knowledge.

What's next?

Possible improvements were highlighted and the model will evolve according to feedback from users and from the on-going sensitivity analysis.

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MAIZE CASE STUDY: current status of pests, pesticide use and alternative options in European maize production.

Using maize as a case study, we identified the most serious weeds, arthropod pests and fungal diseases as well as classes and amounts of pesticides applied in eleven European maize growing regions. Several weed and arthropod species cause increasing problems, illustrating that the goal of reducing chemical pesticides is challenging. Potential options to reduce pesticides and their restrictions are discussed.

Overview of maize cultivation practices

Our survey, based on data from publications, databases and expert knowledge, revealed that maize production systems differ across Europe (Figure 1). While mainly silage maize is produced in the north, grain production dominates in central and southern Europe. Crop rotations range from 80% continuous maize in southwest France to more than 80% well-planned rotation systems in the Ebro Valley (Spain), southwest Poland and Békés county (Hungary). While wheat was the most common crop rotated with maize, rotations with up to five crops have been practiced in Europe. Despite differences in maize cropping, a common set of weeds, arthropod pests and fungal diseases are responsible for the main problems across Europe.

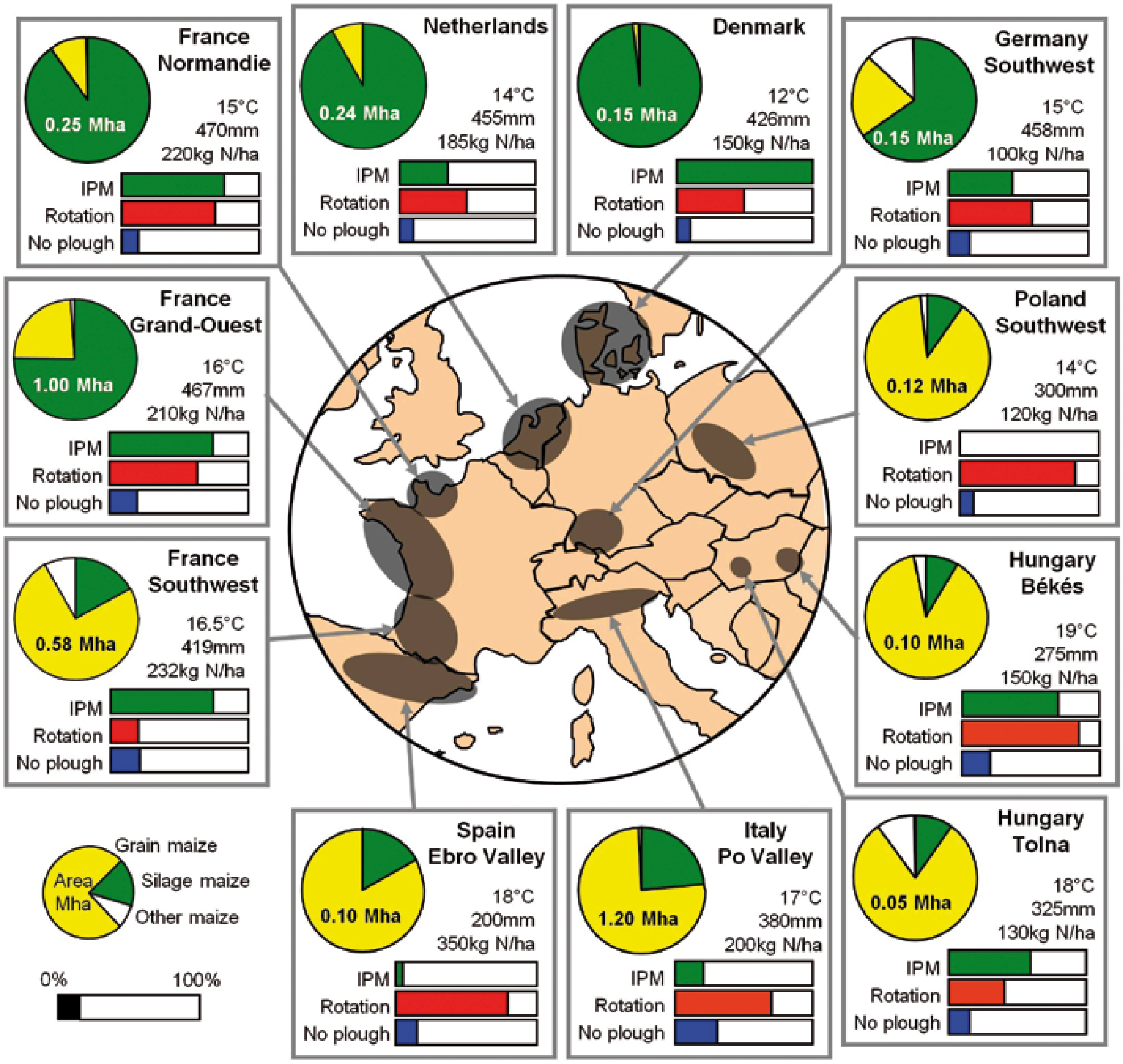

Figure 1: Maize production characteristics.
Pie diagrams: Maize production type. Numbers in diagrams: Total maize area in the region (in million hectares), numbers outside diagrams: average temperature and precipitation from April to October and fertilisers (synthetic and organic) applied per year. Bar diagrams: percentage of maize under IPM (including organic), crop rotation (no maize after maize), and ploughing versus low tillage (including no tillage).
Adapted from Meissle et al. (2010), J. Appl. Entomol. 134: 357-375 (Blackwell Verlag GmbH).

Weeds

More than 50 weed taxa cause problems in European maize production. The most important monocotyledonous weeds in Europe are Poaceae, such as *Echinochloa crus-galli* and *Setaria viridis*. *Sorghum halepense* is a major weed in central and southern regions, while *Elymus repens* and *Poa annua* are important in northern regions. The dicotyledonous weed *Chenopodium album* is perceived as very important by the experts from all countries. Furthermore, *Amaranthus* spp., different Polygonaceae and *Solanum nigrum* are significant. Some regions report increasing problems, mainly with late germinating and perennial weeds. Weeds were controlled with herbicides, mainly post-emergence, in all European regions on more than 90% of the maize production area.

Arthropod pests

The most important arthropod pest is the European corn borer (*Ostrinia nubilalis*), which is present in infested areas in a large proportion of fields (from 20% in Hungary to 60% in Spain) and causes yield losses of between 5 and 30% without control measures. In France and Spain, the Mediterranean corn borer (*Sesamia nonagrioides*) causes additional economic damage.

Between two and four million hectares of maize in Europe suffers from economic damage due to corn boring pests. Within the past five years, populations of corn borers and other lepidopteran pests have been observed to spread. The western corn rootworm (*Diabrotica virgifera virgifera*), introduced in Europe in the 1980s, is currently invading the continent. his beetle, which is the most destructive maize pest in the USA, causes economic damage in Hungary and other central European countries. Seed treatments and soil insecticides are applied mainly against wireworms and corn rootworm larvae, while foliar insecticides are used to fight corn borers and corn rootworm adults.

The European corn borer (*Ostrinia nubilalis*) is the most important arthropod pest in Europe.
© Agroscope ART. / Gabriela Brändle.

Fungal diseases

More than 95% of the maize seeds planted in the surveyed regions were treated with fungicides. *Fusarium* spp. causing ear, stalk and root rot are rated as the economically most significant diseases in Europe. Major problems are the mycotoxins due to *Fusarium* spp., such as fumonisins, trichothecenes and zearelenone, which cause severe health problems for animal livestock and humans. While *Fusarium* problems have increased slightly in southwest Germany and southwest Poland, they decreased in Spain. This can be linked to the growing of genetically modified (GM) maize in Spain, which suffers less damage by corn borers thus providing fewer opportunities for *Fusarium* spp. to enter and infect the plants.

Options to reduce pesticides

Reducing pesticide applications is challenging, especially in southern and central Europe, where the pressure from highly competitive weeds and arthropod pests is higher than in northern countries. Options to reduce the input of pesticides include choice of variety, cultural control measures, biological control, optimisation of pesticide application techniques and the development of more specific and less toxic treatments.

Against weeds, mechanical weed control has already proven to work under commercial conditions in several European countries: in The Netherlands, Italy, France, Spain and Hungary. Pre-emergence control using a stale seedbed, as well as post-emergence cultivation between and within rows, is possible.

Against the European corn borer, biological control with parasitic *Trichogramma* spp. wasps is practiced on about 150,000 ha in Europe with the largest area in France. Efficacy and price can be comparable to insecticides unless pest pressure is very high. One person can apply egg cards to between three and five hectares per hour against first generation corn borer control. Forecast systems to determine the timing for application and efficient logistics are needed for successful application. Another strategy to control corn borers including the Mediterranean corn borer is the use of GM maize expressing an insecticidal protein derived from the bacterium *Bacillus thuringiensis* (Bt). In the EU, Bt maize was cultivated on 107,000 ha in 2008, mainly in Spain.

Major restrictions on alternative pest control methods

Pesticides are relatively cheap and efficient, supply chains exist and growers are equipped to apply them. Several restrictions need to be overcome to enable alternative pest control methods to replace pesticides in an economically competitive way:

1/ Availability. Technology and machinery need to be available and new methods, new application techniques or schemes for reduced pesticide doses need to be adapted to regional environmental conditions and pest problems. In the case of GM crops, the denial of authorisation by regulatory agencies limits their availability to growers.

2/ Organization. Alternatives to chemical pesticides often require a reorganisation of cultivation steps. Exact timing demands flexibility and in some cases additional workers within a window of a few days. Sharing of machinery and services from specialised contractors may solve this problem.

3/ Grower knowledge and training. Growers often perceive alternative pest management strategies and IPM concepts as complex, which limits their willingness to change farming practices. Grower-advisor-researcher partnerships, participation in commercial field trials, grower schools with field training days, and education of consultants may lead to success that motivates other growers to follow.

4/ Economics. New strategies can only be sustainable if they provide longer term benefits and are economically competitive with current strategies. Subsidies or authorisation rules can help to initially establish environmentally friendly methods. The new production system needs to result in an average income for the grower comparable to the previous system. Production costs, yield, market prices and costs for new equipment need to be considered.

5/ Interactions of different strategies. For new pest management strategies applied to solve one particular problem, potential consequences for other pest complexes need to be considered. While interactions are generally limited for rather specific methods, such as mechanical weed control, biological control or Bt maize, cultural methods, such as the change of planting date, crop rotation, or tillage regimes, often have complex consequences on the cropping system.

Further reading

Meissle et al. (2010) Pests, pesticide use and alternative options in European maize production: current status and future prospects. *Journal of Applied Entomology 134: 357-375. http://onlinelibrary.wiley.com/doi/10.1111/j.1439-0418.2009.01491.x/pdf*

Three Maize Case Study Guides are available on *http://www.endure-network.eu/endure_publications/endure_publications2:*

Guide 1: Non-chemical control of corn borers using *Trichogramma* or Bt maize

Guide 2: Western corn rootworm in Europe: Integrated Pest Management is the only sustainable solution

Guide 3: Prevention of ear rots due to *Fusarium* spp. on maize and mycotoxin accumulation

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EVALUATING STRATEGIES FOR INTEGRATED WEED MANAGEMENT IN ARABLE CROPS

Integrated Weed Management is a key issue for European arable crops. An experiment conducted on maize crops in three European locations showed that there is a potential for reducing the reliance on herbicides. However, IWM should be designed and evaluated over the long term and preferably on diversified crop rotations to monitor weed community dynamics and identify possible trade-offs between agronomic, environmental and economic issues.

This article is based on the activities completed within the Integrated Weed Management case study conducted by the ENDURE network. The group included weed scientists from Denmark, The Netherlands, Germany, France and Italy.

Why is weed management a key issue for European agriculture?

Weed management is a key issue for European agriculture, particularly in arable crops, because (a) it is currently based on frequent herbicide treatments (typically a Treatment Frequency Index ranging from 1.5 to 2.5 in most crops throughout Europe, except of course in organic farming), (b) herbicides are the most frequently found pesticide residues when analysing the quality of surface and ground-waters, and (c) the development of weed populations resistant to the most frequently used herbicides is a real threat for the sustainability of current chemical weed control strategies. Weed management is also a key issue because farmers involved in participative research for reducing pesticide use have often been unsuccessful in reducing herbicide inputs.

What is Integrated Weed Management (IWM)?

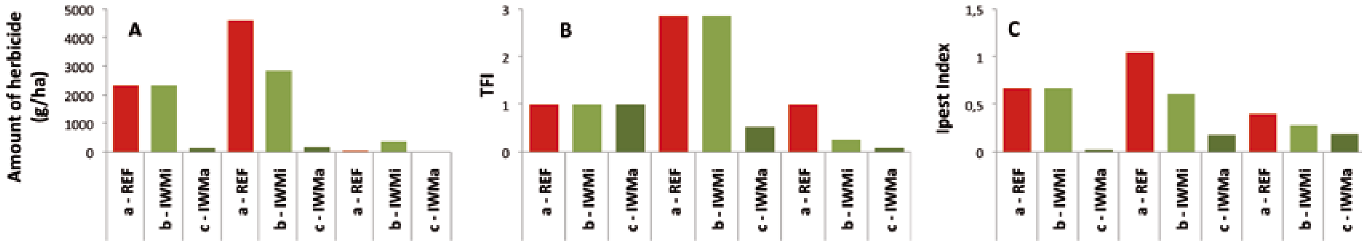
The concept of IWM is to maintain balanced weed floras and to reduce the reliance of cropping systems on herbicides by adopting all available tools for decreasing weed pressure and competition. Because the available techniques typically have lower individual efficacy than herbicides, IWM requires the combining of different measures, hence deeply modifying cropping systems.

IWM in maize: a joint multi-local experiment

A joint multi-site experiment was performed in 2007 within the IWM ENDURE case study. The experiment compared three weed management systems in maize, namely a) a standard reference following the local common weed control measures, b) an intermediate IWM system, and c) an advanced IWM system. The experiment was repeated in three locations, Pisa (Italy), Dijon (France) and Flakkebjerg (Denmark), and both the standard reference and the IWM measures were adapted to local constraints. Similar levels of IWM were achieved through different combinations of pre-emergence cultivations, pre-emergence harrowing, increased crop density, N banded fertilisation, reduced post-emergence herbicide doses, band-spraying of herbicides, mechanical weeding using weed harrow and/or inter-row hoeing.

Is IWM efficient for controlling weeds with low levels of herbicide inputs?

In all three locations, herbicide use was reduced in IWM plots, either expressed as the amount of active ingredient per hectare or as Treatment Frequency Index (TFI). The environmental impact evaluated with the I-pest indicator was also lower in IWM. Weed control efficacy was high and satisfactory in the intermediate IWM system in all three locations as well as in the advanced IWM in Dijon. However, the quality of weed control was lower in advanced IWM both in Pisa and in Flakkebjerg.



Herbicide use and associated estimated environmental impact in the three weed control strategies and the three locations.
A: amount of active ingredient per hectare; B: Treatment Frequency Index (TFI); C: I-pest index, an indicator of environmental impact developed by INRA-Colmar

Is IWM easily adopted by farmers?

There are many factors hampering the adoption of IWM by farmers, among which the most important are related to the very high efficacy of chemical control and to the increase in the complexity of the system associated with the implementation of IWM. Hoeing with currently available tools is more time consuming than spraying herbicides. Crop yield might be lower in IWM, either because of increased competition from weeds (as probably happened in the Pisa experiment) or because of the direct effects of the weed management option (as happened in Dijon, as a consequence of post-emergence weed harrowing). However, lower yields might be compensated by lower input costs. Another limit for IWM adoption is the rational fear of an increase in the seed bank that might occur, even with a small decrease in weed control efficacy. Any increase in weed seed production should be countered by measures taken at the cropping system level, such as diversifying crop rotations, a measure that is likely to affect the system's economic profitability and requires deep changes in the organisation of the agricultural market.

What are the future prospects for IWM research and development?

The development of IWM both at research level and field implementation will depend on four major factors:

- A network of long-term experiments for testing various IWM strategies, including strategies based on diversified crop rotations, and assessing their agronomic, environmental and economic sustainability
- The development of novel technologies for improving weed control with lower herbicide use, such as precision mechanical weeding
- The availability of user-friendly, locally adapted and reliable Decision Support Systems for the major European arable crops
- The testing of novel IWM strategies has thus far been poorly investigated in Europe, particularly strategies based on direct seeding in mulches and cover crop residues. Such strategies are radically different from previously tested ones, which were based on soil tillage and mechanical weeding, and might be a way of solving the trade-offs between pesticide use, economic profitability and other environmental issues.

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A SYSTEMS APPROACH TO IMPROVE THE SUSTAINABILITY OF CROP PROTECTION IN EUROPEAN MAIZE PRODUCTION

Maize-based cropping systems differ significantly across Europe, so a specific activity within ENDURE produced a description of the current situation, and listed and analysed advanced and future innovative tools for IPM. The results of two expert-based surveys were evaluated using a SWOT analysis and a qualitative and multi-attribute model developed within ENDURE. They showed that although maize is cropped differently across Europe, some recommendations regarding the use of five innovative tools are common to all countries.

From a 'crop x pest' approach to a system approach

In order to properly address crop protection in European maize production and achieve more sustainable production with less pesticide use or dependence, a regionally or even locally adapted maize based cropping system (MBCS) approach is essential, i.e. crop protection should consider not only single 'crop x pest' binomials but all variables, constraints and opportunities within the cropping systems where maize plays a major role.

Current, advanced and innovative MBCS evaluated in four EU regions

MBCS differ significantly across Europe, so a specific project within ENDURE began by producing a description of the current situation, followed by a list and an analysis of possible advanced and innovative tools in IPM. MBCS were classified on the basis of three important parameters that strongly determine the characteristics of the system and its crop protection practices: the type of maize production (grain or silage), the cropping sequence (crop rotation or continuous maize) and irrigation (irrigated or not). Four important and diverse European maize producing regions were considered as case studies: the northern region consisting of Denmark and The Netherlands, the central-eastern region represented by Hungary, the south-western region represented by the Ebro Valley in Spain and the southern region with the Po Valley, Italy.

Expert-based surveys to acquire and exploit diffused knowledge

Two expert-based surveys were conducted; in the first, experts were asked to identify main MBCS across the four European regions, their current crop protection status, plus advanced practices (i.e. already available but not implemented) against major pest, weed and disease problems in these systems; while in the second they were asked to evaluate the potential negative, neutral or positive agronomic, environmental, economic and social impacts that innovative IPM tools (those that could be developed and implemented within the next five to 10 years) could have on MBCS in the future. An analysis was performed on MBCS of the four European regions to determine the strengths, weaknesses, opportunities and threats (SWOT) of the systems identified. Using the data collected from the expert-based surveys, partners of the MBCS group described current systems (CS) and proposed the equivalent advanced (AS) and innovative (IS) systems by providing the general information/context (site, soil, climate, regional context) and the main crop protection and management practices for each system/region. The DEXiPM® model for arable crops, a qualitative and multi-attribute model developed within ENDURE, was used to evaluate and compare the environmental and economic sustainability of the current, advanced and innovative systems of each region. The social evaluation was done through an adaptation of the social parameters of DEXiPM.

Maize crops in Hungary.
© Szent István University / Peter Hoffmann.

Maize crops in Denmark.
© Aarhus University / Per Kudsk.

Maize plants damaged by European corn borer (*Ostrinia nubilalis Hübner*). © CNR / Maurizio Sattin.

Different cropping systems across Europe but some common recommendations

In the northern region, maize is mostly cultivated as non-irrigated continuous silage maize or rotated with grasses, while in the central-eastern region the major systems are non-irrigated continuous grain maize or in rotation mainly with winter wheat, or oilseed rape and sunflower. In the south-western region, irrigated grain and silage maize/winter wheat rotations are prevalent, as well as irrigated continuous grain maize. In the southern region, irrigated grain maize rotated mainly with winter wheat or soybean is the main system identified, while other important systems include rotated and irrigated silage maize, as well as continuous and irrigated grain maize.

The SWOT analysis highlighted agronomic, environmental and economic strengths as well as more economic weaknesses for MBCS in rotation; whereas economic strengths, and more agronomic and environmental weaknesses, were identified for continuous MBCS. The same opportunities were identified for both types of systems, while more threats were highlighted for continuous MBCSs. In most of the studied regions, crop rotation is considered a key factor for crop protection sustainability.

The results of the expert based surveys gave advisers and farmers indications on the options available for crop protection in MBCS for immediate implementation of IPM. The experts' proposals and consideration of advanced practices stressed the diverse crop protection situations in Europe, as practices already implemented against a specific pest in one region were proposed as advanced or even innovative in another. However, experts from all regions recommend using five innovative tools for IPM implementation in MBCS. This significant outcome shows that in the future IPM could be unified at the European level. These recommendations included:

- Tolerant/resistant maize cultivars
- Early detection methods
- Pest and disease forecasting models
- Precision/patch spraying using GPS spray maps,
- Community-based decisions through information sharing.

Environmental, economic and social sustainability were evaluated

The DEXiPM evaluation of continuous and rotated CS/AS for each region showed an improved environmental sustainability in northern and central-eastern regions, and overall higher environmental quality in the AS proposed for all countries/regions. It also indicated improved (southern region) or stable economic sustainability in the AS proposed for all countries/regions. The evaluation showed that proposed AS are environmentally and economically acceptable for testing under 'real' field conditions. In contrast, CS/AS of all countries/regions were not sustainable from a social point of view, although the northern region had a higher level of sustainability in all systems due to higher on-farm knowledge and skills, and better external support network (poor in Spain, Italy and Hungary). An evaluation of innovative systems and comparison with the equivalent (continuous or rotated) current and advanced ones is underway.

Regional policies that promote applied multi-disciplinary research and incentives to encourage the adoption of advanced and innovative IPM strategies in MBCS are essential. This research should evaluate systems that are economically competitive with current ones but have longer term benefits.

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Rotated maize in the Ebro Valley, Spain.
© UdL / Belén Lumbierres and Xavier Pons.

2 EXTENSION

Interfacing with European farm advisers and IPM trainers

To meet the EU-policy on crop protection, new scientific operational IPM-tools have to be developed, integrated, validated and disseminated to farmers and, most importantly, used by them in their daily practice of farming.

This chapter is dealing with the last links of this chain which are probably the most difficult parts. Farming is very complex and crop protection is only one part of the day-by-day management. Chemical crop protection has for a long time been a reliable insurance for harvesting a productive crop. Although during the last decades IPM methods have been developed for practical use, with focus on prevention, warning systems, control methods without pesticides, and precision technologies, not much has been implemented yet by the farmer. It is not unwillingness but IPM is a much more complex practice for crop protection than the present pesticide-use. The farmer must have much more knowledge on prevention methods as intercropping, seed quality, monitoring devices to follow-up epidemiology of the pest, know how of damage thresholds and of Decision Support Systems which include bio-control as well. Integrating all this, he/she must be able to take an appropriate measure at any time during the growing season, and trust that the risk of crop loss will be acceptably low at harvest time. And this complex system has to fit in the already complex day-by-day decisions the farmer has to take to run his farm. Therefore it is understandable that it is very difficult for a farmer to replace the current practices of pesticide-use by IPM.

This poses the challenge of how to create a breakthrough in the current way of working by farmers and how to get them use IPM as a reliable crop protection method. A common approach is that scientists show farmers that IPM is working in demonstration fields. A criticism by farmers is that a demonstration field is not a farm, interesting but not applicable in a real farm. And even if IPM is successfully demonstrated at a real farm a common argument is that this farm is completely different from his own a few kilometers away. And the farmer is probably right!

So if bringing science to practice is already a big challenge regionally, how can we expect that ENDURE-knowledge from all over Europe can be useful for the individual farmers in the various countries? Is it not an unrealistic Sisyphus job?

Maybe, but there is one advantage: farmers rely heavily nowadays on the advise of highly skilled and specialized crop protection advisers. Innovative approaches from advisers are trusted by the farmers as long as the outcome turns out well. Therefore we decided that for extension ENDURE should focus on advisers rather than on farmers directly. Another advantage is that most advisers in the EU have a grasp of English the lingua franca of all ENDURE output. We also tried to avoid the pitfall of the one-way knowledge route from science to advisers. In many countries we had already experienced that supply driven knowledge transfer does not work. Most scientific information is not applied enough to

the ENDURE network of excellence shares the fruit of 4 years research with the Crop protection community

be translated by an adviser for practical use. And a psychological burden is that one does not happily embrace information you have not asked for. What we needed was a demand driven chain, but how do you create a demand from advisers?

We tried to tackle this problem in two ways. First we informed advisers about ENDURE and tried to form a network of advisers. Secondly we set up the ENDURE Information Centre (ENDURE IC), a web-based data system on IPM, with science based, (but not scientific papers) very applied information on IPM from the various EU-countries. We anticipated that most advisdrs have no good international network and do not have good access to applied information from abroad. We also anticipated that advisers are interested in new knowledge as they also live in a competitive world, with a need to continuously innovate their advices. So we made a prototype of ENDURE IC specially designed for advisers, we invited advisers from different countries during some field demonstration events where we had a booth with our protoptype, and asked them to give serious feed back after trying-out. We also presented some card games and other new training material where the player should choose the correct IPM-measure for a pest diagnosis, as the adviser comes across every day. In this way we hoped to accomplish both assets, a network where advisers learn from each other and learn from science by adopting the ENDURE IC as their own knowledge platform. In this way we tried to accomplish a more demand driven knowledge platform for advisers.

The two following articles give more details. The first one informs on how the ENDURE IC has been build, what information has been and will be uploaded, and how information can be retrieved by advisers in an interactive way. The second article is about the testing of the prototype, the criteria of selection of sources, the important feed back of the advisers testing groups and the way to enlarge the content and the network of advisers.

The ENDURE scientists form just the interface of the ENDURE IC. We realize that the success depends on an enlarging enthusiastic user group of advisers, which will depend on the quality and the increasing amount of new and valuable knowledge that can be retrieved. Therefore we decided that after the end of EU funding of ENDURE, the ENDURE IC will be continued, updated and enlarged to benefit the advisers network.

But there is only one way to convince you…try ENDURE IC yourself at the congress in Paris during the workshops (and after that whenever you like).

ENDURE INFORMATION CENTRE LINKING EUROPEAN RESEARCHERS AND ADVISERS

The ENDURE Information Centre is an online web-application which aims at disseminating knowledge on IPM and non-chemical alternatives towards advisers. Developed by scientists with the support of advisers, it enables interactive searches of crop protection measures by crop, pest and region. The system is available at http://www.endureinformationcentre.eu.

Search in ENDURE IC

ENDURE IC database contains up to 1000 national documents, reviews and links about IPM and non chemical alternatives of several European Countries. The application provides an interactive tool which enables multilingual searches in a database. The search can be done by combinations of crop, pests, diseases, measure and region or by a free text search system.

After the search, the title of an English abstract and a one line summary are displayed in an overview result list whereupon the user can select the detailed view. The detailed view contains the English summary based on the national documents and the original documents or sources if available.

Development of the system

The development of ENDURE Information Centre (ENDURE IC) followed a prototyping approach, based on the joint collaboration of advisers with researchers. First, to identify the needs a quick scan was conducted among the target end users, i.e. advisory organisations. Researchers and representatives of advisers involved in ENDURE used the results of the questionnaire to build a first version of the application. Special attention was paid to the layout, to make the interface intuitive and easy-to-use. Information needs and functionalities were then discussed with advisers during test sessions organised in Germany, United Kingdom, France, Denmark, Spain and The Netherlands and during 2 international agricultural events (Euro Potato, 2008 in France and Cereals 2009 in United Kingdom). Discussions provided feedback to improve the application.

Quality selection

The aim of the ENDURE IC is to present a European quality selection of sources and documents about integrated and non-chemical control measures in plant protection. All presented measures are aimed to result in less reliance on pesticides. The majority is ready to use in practice. This means that the information is scientifically sound, but also that the measures were tested in the field, and cost-effective. Other results (experimental) inform users about measures which can provide a solution for a given problem but cannot be recommended as best practice: they have been tested in experimental fields, but adoption is only possible under specific conditions.

Knowledge for this quality selection is generated from various national sources as well as inside the ENDURE Network. Sources can be research reports, journal and magazine articles, “grey literature” such as trial reports, websites, leaflets, reports, videos, articles, newsletters etc. The selected sources have the potential to be shared across Europe and provide information and has been judged by members of the ENDURE network.

Even if only ENDURE members have uploaded documents until now; external experts are invited to contribute to the ENDURE IC. A manual is developed to explain the selection criteria for the content, to guide the upload and a harmonised presentation of content.

Endure Network of Advisers

To stimulate a successful dissemination of IPM with ENDURE IC the involvement and commitment of advisers is a key factor. The ENDURE Network of Advisers gathers advisers from different European countries, linked by their interests in different areas of crop protection. It is a unique space for communication and knowledge exchange among advisers from Europe, which is challenging considering that there is no such tradition and that advisory systems differ greatly among countries. The members of the ENDURE Network of Advisers get informed by electronic newsletters about the application and new content and are encouraged to provide feedback, share information and contacts.

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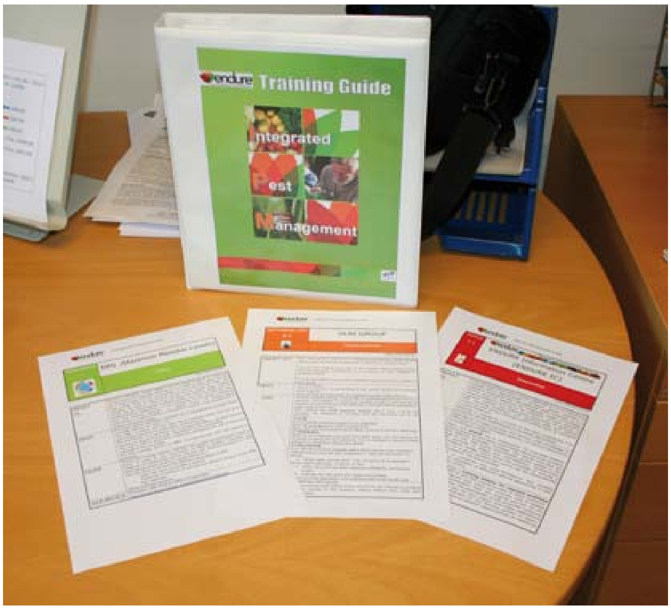
THE IPM TRAINING GUIDE, AN ENDURE TOOL TO FACILITATE TRAINING ON IPM.

This guide is a collection of IPM information in the format of leaflets, data sheets and training modules to be adopted by farm advisers and trainers involved in the implementation of IPM in Europe.
The information is based on the general European IPM principles and participative form of trainings. Thanks to the information in the Training Guide, each trainer has an efficient starting point for building locally adapted training courses in IPM. More particularly, the Training Guide helps finding information or documents on the ENDURE website.



The Training Guide consists of the following four sections:
- Convincing arguments
- Training methods/methodology
- Tools
- Content and modules

Lying as a backbone in all sections, is the principles of IPM, meaning that all materials are collected and described in accordance with the IPM principles, as mentioned in annex III of the EC directive.

The Training Guide is designed as a tool for teachers and trainers. It should provide them with enough information and materials for them to build their own local training sessions. The Training Guide is not meant to be the only source of information about IPM, but should rather function as a solid starting point for teachers and trainers.

Besides an introduction to each of the 4 sections, the TG consists primarily of sheets describing the arguments, methods and tools. The content and modules section consists mainly of ready-to-use presentations from which the trainers and teachers can take relevant passages and include in their own training materials.

The sheets are one-page descriptions of the principle in focus.

The sheets are all build over the same frame, with WHAT IS, WHY, HOW and SOURCES as the headlines.
- WHAT IS gives an introduction to the argument, method or tool.
- WHY justifies why it is relevant in an IPM training context.
- HOW gives information about how to apply the argument, method or tool in a training session (e.g. for which type of audience a special methodology is especially relevant).
- SOURCES tells the trainer or teacher where to find further information about the subject described

A number of Training Leaflets are also linked to the Training Guide. These leaflets provide a more thorough description of a subject of relevance to the trainers.

The ENDURE IPM Training Guide is available through the ENDURE Homepage (www.endure-network.eu) and the ENDURE Information Centre (http://www.endureinformationcentre.eu/).

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ENDURE INFORMATION CENTRE
a tool for knowledge integration and dissemination

The ENDURE Information Centre (ENDURE IC) is a dynamic web-application which disseminates scientific knowledge and practical information on integrated pest management (IPM) outside the network, thus supporting the adoption of IPM across Europe. It is available online via: http://www.endureinformationcentre.eu. Inside the ENDURE network it provides knowledge management services

The ENDURE IC has made an important contribution to the integration and dissemination of crop protection knowledge across Europe. A central point of reference in integrated crop protection was created. Expert knowledge, recommendations and advice about measures and strategies in integrated pest management, including non-chemical alternatives, are made accessible for extension services, advisers, farmers and researchers. For working with the ENDURE IC a user interface was created that allows public users to sift through the content and enables registered users to include new content.

In addition, the back office facilities of the application serve as a tool for the integration and management of internal knowledge and research results inside the ENDURE network. It is limited to authorised users based on a log in. The search and upload mechanisms are identical to the mechanisms of the ENDURE IC.

Technical implementation

The multipurpose roles of use of the ENDURE IC, for public online use and for internal knowledge management, require a suitable data model containing the meta-data and the content. The ENDURE IC is not a database from a technical point of view but it does use a database to save the content in a structured manner. Working with such structured data requires processing it before presenting it to the user. The model distinguishes between information-based data (crop, pests and diseases, topic) and knowledge-based data (report, project, internal backoffice, abstract, source).

To enable collaboration between the different applications developed by the ENDURE network, the members of the Technical Task Force agreed on introducing the concept of 'knowledge types'. This concept uses an abstract entity (data unit) called 'knowledge' to determine which meta-data are commonly shared by all ENDURE applications. Among other information these meta-data include categories crop, pest and topic. Therefore the content is represented by the abstract entity 'knowledge' which is extended for each single application by the application-specific information. Thus the approach presents two advantages. It allows cross-application searches among these meta-data and the data need to be created only once and are shared across the different applications.

In the ENDURE IC the data structure is extended by several types of 'knowledge'. These knowledge types (blue in figure 1) reflect different kinds of information which is offered for different target groups, i.e. for public online use or internal use by scientists. The reports of specific IPM methods, e.g. 'expert reviews' or 'document summaries', projects are directly accessible for public use. In contrast, the Internal Backoffice is designed to distribute ENDURE work documents, intended for internal use only or even comprising confidential information.

Within the database the described knowledge is associated with the true data (in green colour). Each knowledge type contains the abstract as the content part covering multilingual textual information as well as its sources (files, links, and literature).

Dissemination and Integration into the future

The successful development of the ENDURE Information Centre contributes with its multiple functions to the integration and dissemination of practical and scientific knowledge on integrated pest management to and for different stakeholder groups. In the future also external experts, after registration, can integrate their knowledge via the online interface into ENDURE IC. The application will be sustained beyond the EC funding period in the ENDURE European research group and provide a valuable tool for practitioners and research in the future.

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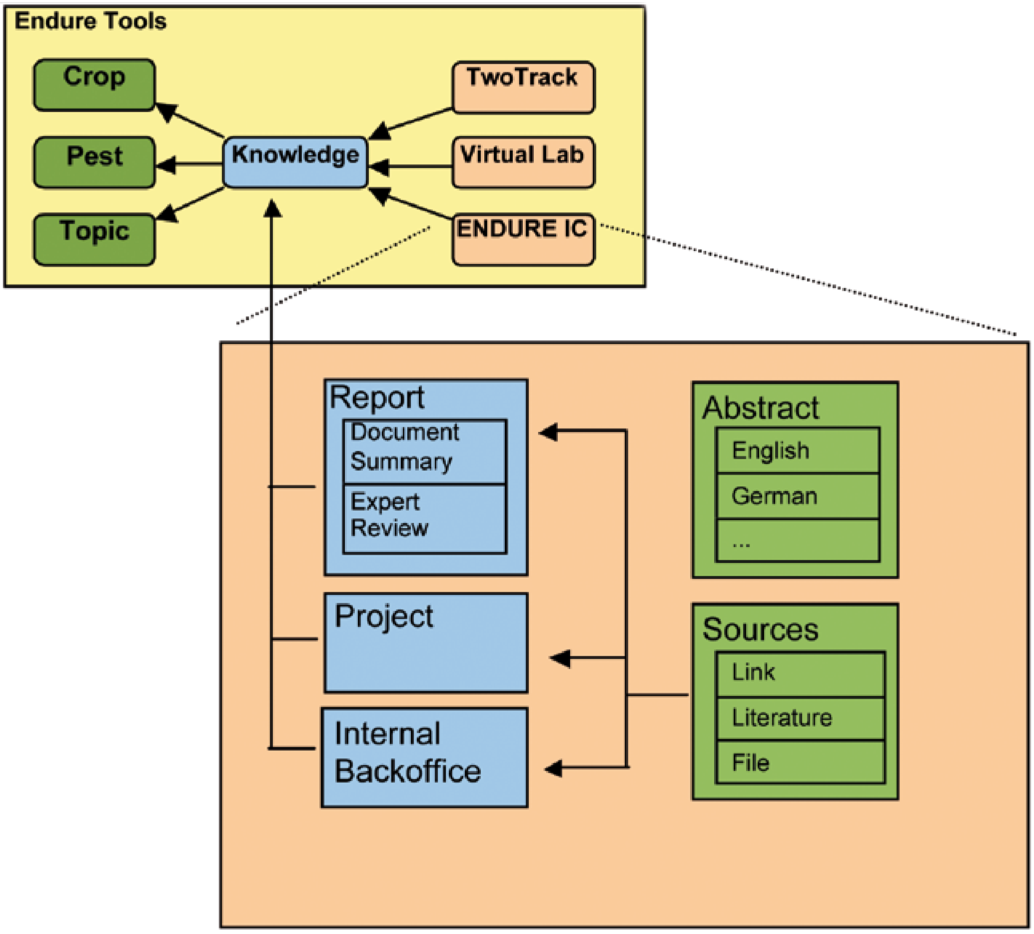

Figure 1 – Implementation concept.

3

MULTI-CRITERIA ASSESSMENT OF SUSTAINABILITY

Demonstration in the case of apple orchards

In a case study we investigated the elements that need to be considered in an overall sustainability assessment. Experts from five regions suggested crop protection strategies that were analysed by life cycle assessment, environmental risk assessment and full cost calculations in order to aggregate these results to an overall sustainability rating. As a result we present a new tool for rating sustainability and highlight the potential of new crop-protection strategies to improve the environmental and economic sustainability.

A NETWORK TO COPE WITH THE COMPLEXITY OF IPM IN ORCHARDS

European agricultural policy requires the implementation of integrated pest management (IPM) by 2014 and all members of the EU have to propose a national action plan adapted to regional conditions. Therefore methods and tools to evaluate the overall sustainability of region-based IPM strategies are needed. Methods that include environmental and socio-economic aspect do exist (e.g. RISE) however, these tools do not attempt to aggregate the various aspects of sustainability to a rating of the overall sustainability of a system. Multi-attributive decision making offers a methodological framework suitable to define hierarchical trees of attributes that build up a rating for an overall sustainability. Such multi-attribute studies have in common that they allow reflecting the complexity of agricultural systems adequately. The number of attributes used in such models is very high, usually more than 80 attributes. Although such large attribute trees can easily be handled by computer programs, much effort is required to understand and communicate the cause-effect relations in these complex models. The goal of the research activity on multi-criteria assessment was to investigate a suitable methodology to evaluate sustainability of current and novel crop protection systems. Examples of apple production in five European regions demonstrate the utility of the proposed methods. We experienced that the so called 'SustainOS' methodology highly supports defining and optimizing region-specific crop protection strategies for orchard systems. A network as we established during the orchard system case study is a very effective way to cope with the complexity of crop protection optimization in order to discover the relevant points for improving the sustainability of orchard systems.

DEFINING NEW CROP PROTECTION STRATEGIES IN APPLE ORCHARDS

The crop protection strategies address major* and minor problems. For disease control these are: apple scab* (Fig. 1), powdery mildew, fire blight, storage diseases, others e.g. calyx rot. For arthropod control: coddling moth* (Fig. 2), other lepidopterans, aphids, spider mites and other pests. For weed control: dicots, monocots and root sucker.

the ENDURE network of excellence shares the fruit of 4 years research with the Crop protection community

Experts in five countries defined crop protection strategies for apple orchards with quantitative data from their respective region. For each country a baseline, two advanced and one innovative system had been defined as follows:

Figure 1 - Apple scab on leaf and fruit. © Agroscope ACW.

BS = Baseline System

It is used as the reference system for comparison of the Advanced and Innovative Systems. It is not necessarily representative of what is carried out in each region. It is defined as a crop protection system where only synthetic chemical pesticides are used. The pesticides are selected and used within the legal framework referring to the year 2009. The criteria to select the pesticides are mainly efficacy and price and, secondarily, selectivity to the main natural enemies. Pesticide resistance management and decision support systems for the main pests are taken into account and used.

AS1 and AS2 = Advanced Systems

Both of them are defined as crop protection systems where non-conventional chemical control techniques are preferred to pesticides. AS2 is a more advanced system than AS1, in terms of crop protection techniques used and ecotoxicity. The techniques used in AS1 are available in the market, and might be used by the average grower in about five years. The techniques used in AS2 are in their final steps of implementation, and, consequently, they may be used by pioneer growers. Pesticide resistance management and decision support systems for most of (AS1) or all the pests (AS2) are taken into account and used. The criterion to select the pesticides is mainly ecotoxicity, paying special attention to selectivity to the main natural enemies.

IS = Innovative System

It is defined as a crop protection system where the ecotoxicity is further reduced to the minimum. The crop protection techniques used are not yet commercially available, but already under research, such as multi-gene resistance.

Figure 2 - Coddling moth: adult and damage. © Agroscope ACW.

Countries/regions under study: CH = Switzerland - Lake Constance region, GER = Germany - Lake Constance region, NEL = The Netherlands, FR = France - Rhône valley, ES = Spain – Lleida.

ORCHARDS IN DIFFERENT COUNTRIES NEED DIFFERENT IPM STRATEGIES

Over all, AS1 and AS2 demonstrate that in all five countries the "ecological sustainability" can be improved using alternative measures that are available on the present markets. The optimization was mainly achieved by using the 'SustainOS' tool in an iterative process including experts from each country. The information concerning the environmental quality and human toxicity was provided by Life Cycle Assessment and the risk indicator model SYNOPS for each active ingredient. Most of the time, the toxicity of the crop protection systems was mainly caused by only one or few active ingredients. Thus, the optimisation process was based on the following three optimization approaches:

- Replace active ingredients (A.I.) with the highest environmental impact with A.I. with a lower impact, if possible
- Replace or reduce the number of applications of A.I. by alternative crop protection measures (e.g. exclosure netting, resistant cultivar, pheromones)
- Enhance drift reduction to more than 75% (e.g. special sprayers, hedges).

The current situation for apple production is that farmers apply crop protection strategies which are combinations of our defined Baseline System (BS) and the Advanced Systems (AS1 or AS2). The portion of these three strategies might be different from country to country and from region to region. It is very likely that an increase of AS2 strategies in all countries would improve the ecological sustainability.

Since the Innovative Strategy (IS) has the most promising potential for improving the overall sustainability of crop protection in apple orchards, we recommend furthering all measures that would speed-up the time for alternative methods that are today only working in trials or laboratories to be available in the market.

IPM strategies have to be developed and implemented on region-specific characteristics since the design of advanced strategies differ in many details among the regions. A tool like "SustainOS" could be very helpful for defining and optimising advanced and innovative systems.

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METHODOLOGY FOR EVALUATING ENVIRONMENTAL AND ECONOMIC SUSTAINABILITY OF CROP PROTECTION SYSTEMS

We developed and applied quantitative and qualitative methodology to evaluate the sustainability of four crop protection systems in apple orchards. Quantitative methods were used for economic analyses, for Life Cycle Assessments (LCA) and for assessing the potential terrestrial and aquatic risks of pesticides. The values calculated were then entered as qualitative output variables in a multi-criteria approach rating the overall sustainability of crop protection systems. The methodology and its tool was developed in our study and is called "SustainOS".

"SustainOS" – A new methodology for assessing sustainability

We developed and applied a multi-criteria procedure for sustainability assessment of orchard systems that includes five elements. The starting point is to choose parameters that describe the farming systems (Figure 1, a). These parameters are then used to conduct quantitative assessments referring to the main pillars of sustainability. In our case we focused on ecology and economy (b). Results of the quantitative assessments (e.g. the terrestrial ecotoxicity of pesticide use calculated with Life Cycle Assessment) are then entered at the bottom of a hierarchical attribute tree as basic attributes (c). These are marked in green on Figure 2, at the bottom of each branch. Here the quantitative results are rated relatively to a reference system called the Baseline System (e.g. "better than Baseline", "worse than Baseline"). We then apply the multi-criteria method in order to aggregate them into attributes of higher levels (d). The aggregation process results in the rating of the overall sustainability of the described crop protection system (e). However, optimising crop protection systems requires knowing which parameters have the highest influence on the overall sustainability. Such cause-effect relations can be easily obtained by investigating the results top-down (white arrows) in the following scheme:

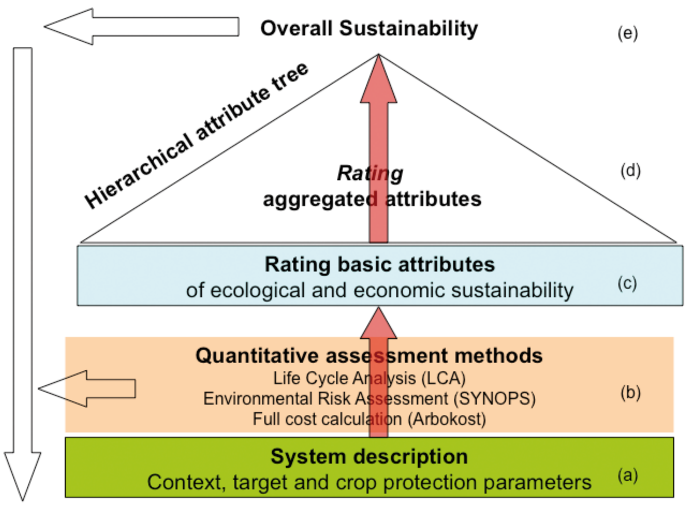

Figure 1 - The 'SustainOS' methodology for optimising the overall sustainability of orchard systems. Red arrows mark the direction of the assessment process. White arrows show the direction of the reflection process in order to optimise the system description.

Quantitative assessment methods

The economic assessment highlights the average profitability, the financial autonomy and the income risk. Crop profitability evaluates the economic efficiency of the orchard systems by calculating the family income per labour hour, the total production cost per kilogramme of first-class apples as well as the net profit per hectare. Farm autonomy is represented by the amount of invested capital per hectare and the return on investment. Production risk is represented by calculation of the income variability due to the standard deviation of yield and fruit quality over the life span of the orchard. Furthermore, the income risk is considered by estimating the portion of years with a dramatic yield loss, i.e. years with less than half of the average harvest.

The eco-inventories were calculated using the information provided by the expert group and the inventories from the ecoinvent and ART databases (ART = Agroscope Reckenholz-Tänikon, Switzerland). The analysis includes the infrastructure, inputs and processes used in the apple orchards. Assessment models developed by ART are used to estimate the various direct field emissions (i.e. NH_3, N_2O, Phosphorus, NO_3-, heavy metals and pesticides). Referring to the basic attributes related to LCA the following impacts are calculated: demand for non-renewable and renewable energy resources, global warming potential over 100 years, terrestrial and aquatic eco-toxicity potential, human toxicity potential, eutrophication potential.

The indicator model SYNOPS assesses the potential risk for terrestrial (i.e. soil and field margin biotopes) and aquatic (i.e. surface water) organisms caused by the application of pesticides. SYNOPS estimates for each application the loads of active ingredient in the soil, edge-biotopes and surface water considering the exposure pathways drift, run-off, and drainage. Based on the estimated loads of active ingredients a time-dependent curve of the predicted environmental concentration (PEC) is derived. From the time-dependent concentration curves, the acute and chronic risk potentials are derived by relating the maximum PEC values to the lethal concentration (LC50) and to the no-effect concentration (NOEC).

Economic and environmental sustainability rating

A hierarchical attribute tree was built both from top-down as well as from bottom-up. The resulting tree is given in Figure 2.: From top-down the ecological attributes 'Resource use', 'Environmental quality' and 'Human toxicity' as well as the economic attributes 'Profitability', 'Production risk' and 'Autonomy' were selected referring to literature. From bottom-up the basic attributes were given by the results of the economic analyses, the Life Cycle Assessment and the SYNOPS results. Since the rating of ecotoxicity is the focus of our study, this attribute is represented with the most sub-attributes providing detailed information on how the ecotoxicity is influenced.

The numeric values derived from the quantitative assessment methods need to be rated indicating if the results of Advanced (AS1 and AS2) and Innovative (IS) crop protection systems differ substantially from the Baseline System (BS). The definition of the four systems is given in introduction of chapter 3. The following five rating classes were applied: 1 = much worse than BS; 2 = worse than BS, 3 similar to BS; 4 = better than BS; 5 = much better than BS. After the 21 basic attributes were rated the ratings of the 13 aggregated attributes were calculated by applying the weights given in Figure 2. With this approach we can easily investigate the reasons for the outcomes and determine the most important parameters of ecological and economic sustainability of apple orchards. The "SustainOS" methodology developed in ENDURE for creating and rating new crop protection strategies for apple orchards can now be adapted to other perennial crops.

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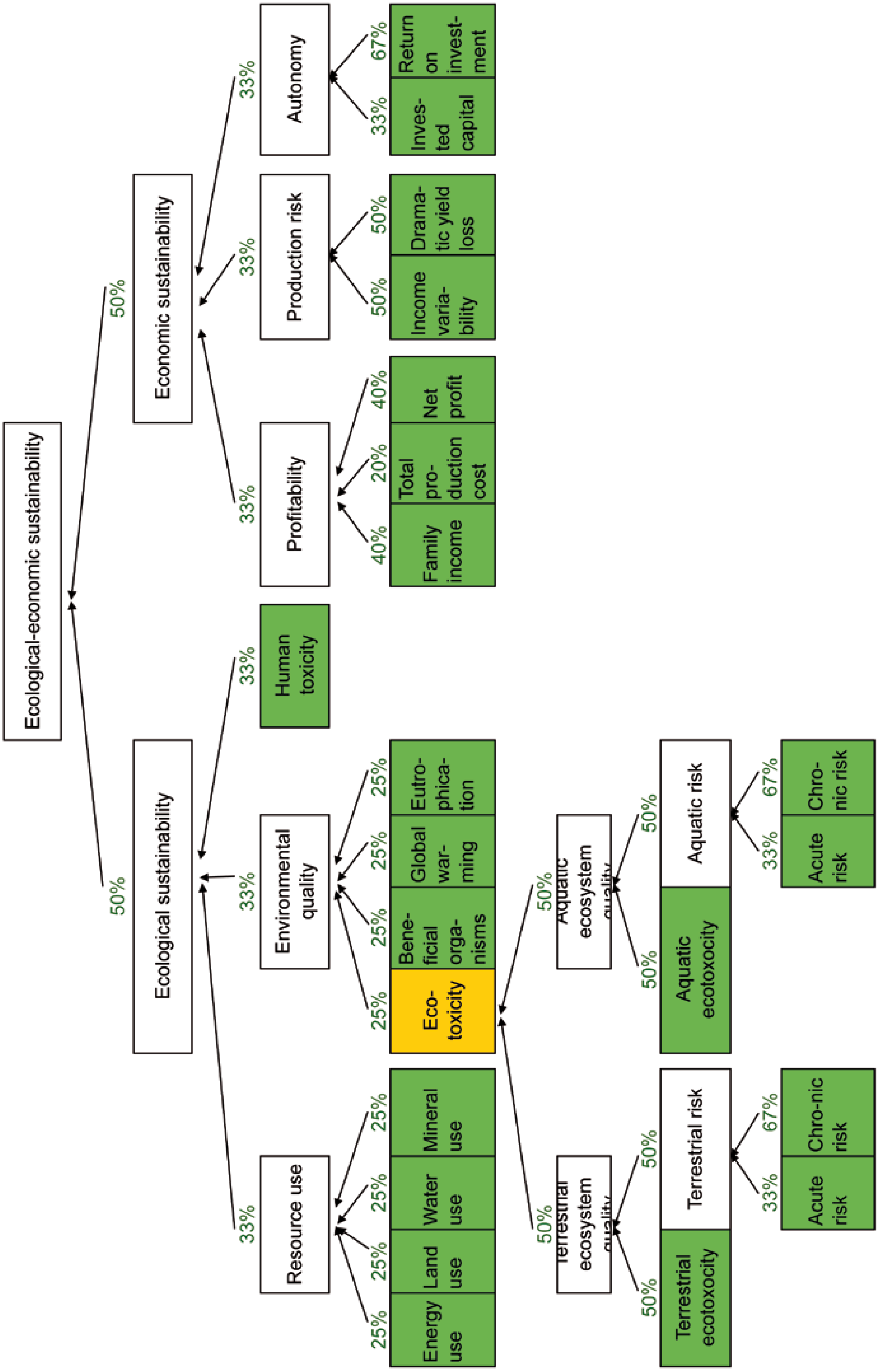

Figure 2 - Hierarchical attribute tree for assessing the ecological and economic sustainability of orchard systems. Basic attributes are in green print; the attribute being optimised primarily is in yellow print.

ECONOMIC ASSESSMENT OF CROP PROTECTION STRATEGIES

The economic sustainability of apple orchards may be improved with advanced or innovative systems. To achieve this, it is necessary to secure yields and fruit quality. Furthermore, costs of non-chemical strategies and innovative products should be comparable to expenditures in pesticides, and the increased demand for labour should not outstrip the reduction of machinery use.

Crop protection strategies

The four crop protection strategies in five European countries/regions as described in the introduction of chapter 3 are taken into consideration for calculating economic indicators.

Economic indicators

Crop profitability, farm autonomy and productivity risk of the orchard production were evaluated. Crop profitability is meant to evaluate the economic efficiency of the orchard system in securing grower's incomes. Farm autonomy is centred in analysing the grower's capacity to invest, and the economic viability of the production. Production risk is intended to making estimations of the potential costs that could be caused, or the potential benefits that could be attained due to the variability of crop yield and fruit quality. The economic indicators were calculated with the Arbokost model, which was created by Agroscope Changins-Wädenswil and has been tested with data collected in Swiss orchards.

Production costs and family income

The economic indicators for each orchard system in each region are presented in terms of relative values where the baseline system (BS) represents 100%.

Production costs

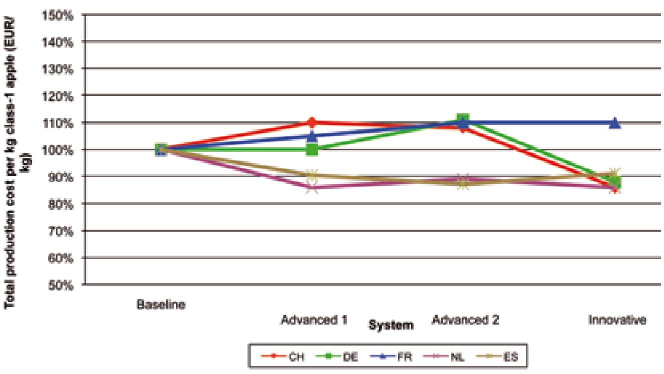

Figure 1 -Production costs per kg apple class-1.

The installation of a hail net acts to increase this indicator (CH: AS1, DE: AS2). This higher investment is compensated with savings in irrigation costs (ES: IS) and reduction in functioning costs (FR: AS2). Full IP implementation does not always reduce crop protection costs (NL: AS2). Increments in yield and fruit quality matter (CH and DE: IS).

Return on investment

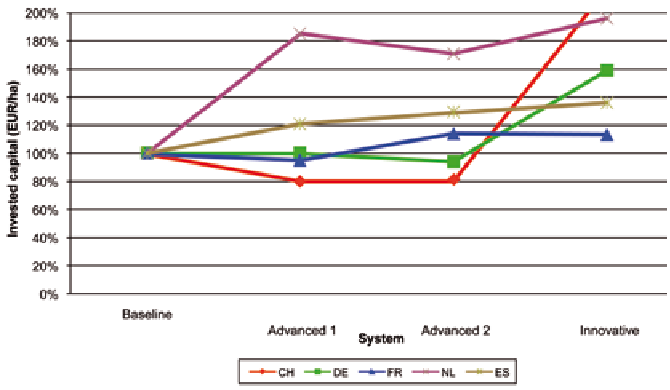

Figure 2- Return on investment.

The explanatory reasons following Figure 1 are confirmed. Furthermore, reduction in productivity (yield) are worthy, always when the quality is increased (class-1 share) and the direct costs are reduced. This means that labour costs do not exceed savings on machinery use, and the value of non-chemical strategies and innovative products do not exceed costs of conventional pesticides (FR: AS2).

Risk related to family income variability

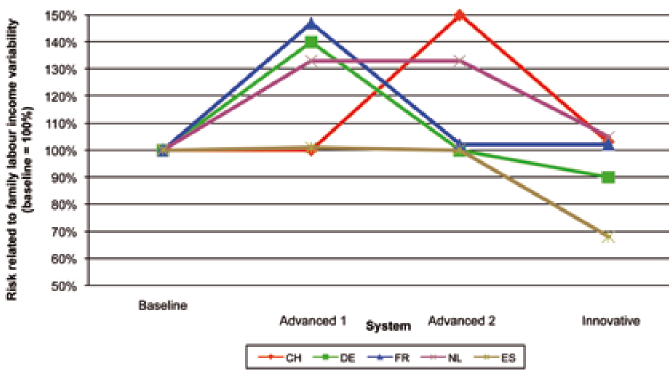

Figure 3 - Risk related to family income variability.

The values for this indicator were determined by a group of experts in crop protection. For them the uncertainty associated to production under BS and IS is the same (except in Spain where yield variability is expected to be reduced). More uncertainty in the production in terms of yield and fruit quality are either linked to AS1 (FR and DE), or AS2 (CH). In the Netherlands, the uncertainty is lower, even when the price is the highest because only the yield variability is pointed out as a risky factor. In Germany and Spain the low risk observed in the IS is boosted by extremely high shares of class-1 fruits.

Regional differences

Securing high yields and improving fruit quality contributes to enhance the economic productivity and to acquire higher autonomy in terms of return on investment.

The design and implementation of crop protection strategies would be successful only when these strategies are adjusted to the regional conditions (irrigation requirements, necessity to install a hail net, potential occurrence of pest and diseases).

Crop protection techniques which are under development (innovative systems) are promising in guaranteeing stability of the production in a comparable (or even better) level than the chemical control does. With the crop protection techniques which are currently available in the market (AS1 and AS2), the stability of the production can be fulfilled when very high levels of fruit quality (share of class-1) are obtained, since the income variability can be reduced.

The transition from BS to IS is worthy, because profitability is increased, rates of return are enhanced and risks related to income variability are maintained or even decreased. Intermediate stages (AS1 and AS2) are competitive only in the case of increased crop yields and fruit quality. Furthermore, expenditures in pesticides or their equivalents should be reduced while expenditures in labour costs for crop protection (training in integrated crop protection and time invested in decision-making on fields including monitoring and visual control) should not increase. In a contrary case, a bottleneck can occur in the implementation of IP.

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WHAT IS THE ENVIRONMENTAL IMPACT OF PESTICIDES IN APPLE ORCHARDS?

To quantify the impact of surveyed and new IPM strategies on the environment, the potential aquatic and terrestrial risk was assessed at the landscape level. For this purpose the GIS-based risk-assessment tool SYNOPS was applied to four European orchard regions which differ in respect to their environmental conditions, pest pressure, intensity of pesticides use and possibilities for innovation.

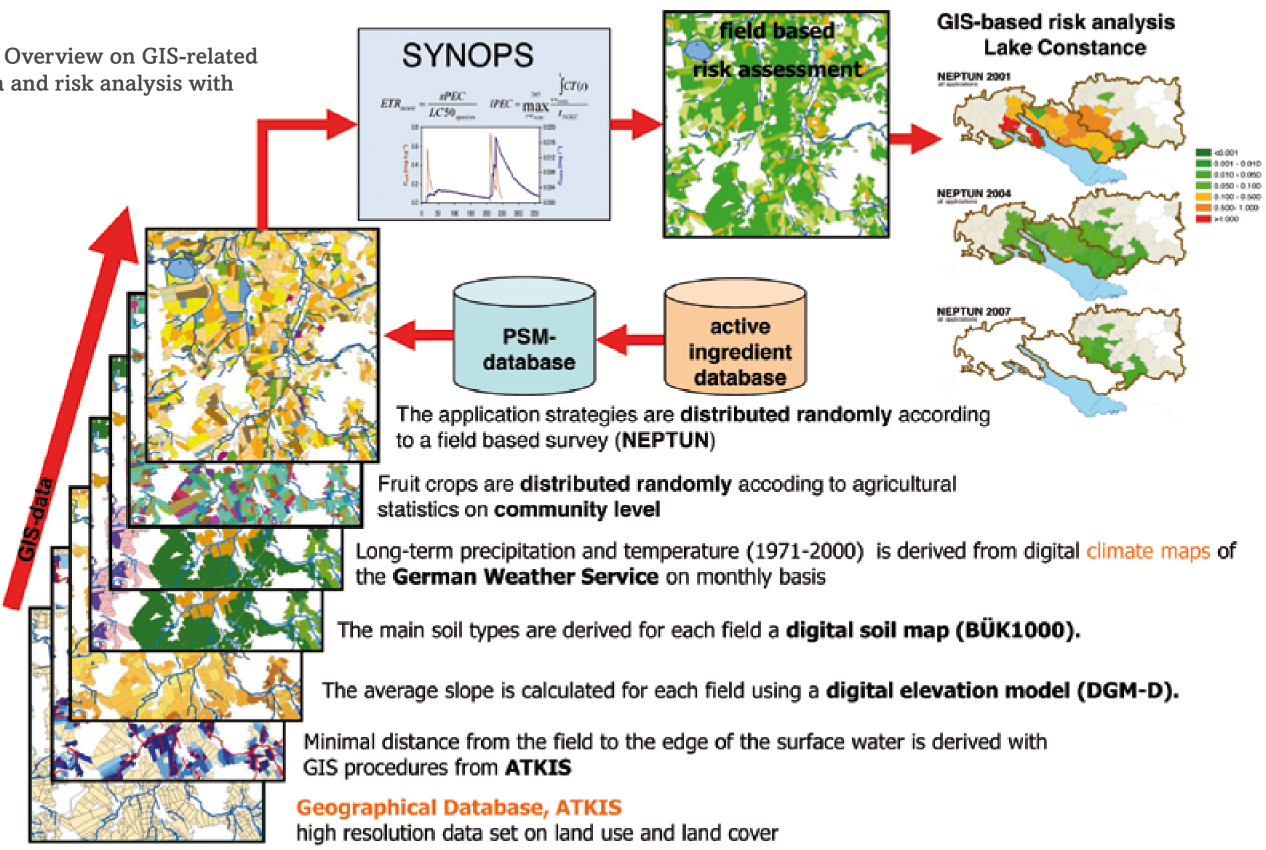
Environmental risks related to pesticides at the landscape level

The application of advanced and innovative cropping strategies in orchards may contribute strongly to an overall reduction of the environmental risk related to pesticides. To quantify the impact of new IPM strategies on the environmental risk and to analyse information of the farmers' willingness to adopt these strategies, it is mandatory to assess the potential risk in the context of the landscape. For this purpose the GIS-based risk-assessment method SYNOPS was applied to four orchard regions in Europe: Lake Constance in Germany, Lake Constance in Switzerland, Rhone Valley in France and Emilia-Romagna (part Ferrara) in Italy.

SYNOPS, a tool for regional risk assessment

SYNOPS-GIS was developed to assess the environmental risk potential of plant protection strategies on a landscape level using GIS functionalities by linking it to geo-referenced databases for land use, soil conditions and climate data and to a dataset of regionalised surveys of pesticide application. The GIS databases were established by integrating all environmental information on a field level which is necessary to estimate the environmental exposure by drift, run-off and drainage (Figure 1).

Figure 1 - Overview on GIS-related input data and risk analysis with SYNOPS.



In a first step all necessary field-related and environmental data were collected for the four regions. The data sources depended on the different regions. For Germany and Switzerland national GIS data on land cover, soil and climate were available. For the Italian region a combination of CORINE land cover data and region-specific data for soil, slope and climate were provided. For the French region specific digitalized field data was used. The data of all regions was collected in a unified spatial database, which was linked to information of currently used pesticide strategies either from field-based surveys (France, Switzerland and Germany) or from advisors' surveys (Italy). The application calendars were randomly distributed to the orchards.

Aquatic risk potentials

Using this database, the regional risk potential was assessed with SYNOPS for all orchards within each region. The assessments were conducted on the one side with drift reducing measures assuming a realistic distribution of hail nets, hedges and usage of drift reducing equipment, and on the other side without these measures. The results for the Rhone Valley in 2008 are shown as an example in figure 2.

The field based risk potentials are then aggregated to represent the regional risk by calculating the 90th percentile or the orchard area above a certain risk level (e.g. ETR>1). The aggregated acute and chronic aquatic risk potentials with and without considering the drift reduction measures are summarised for the years in which survey data was available for each region. The results calculated with drift reduction measures show a reduction of the 90th percentile of risk potential in the region by 77%. The orchard area above the tolerable risk level (ETR>1) was reduced by 23% (Tab.1).

drift reduction measures	number of orchards	area [ha]	area with ETR>1 [ha]	%	90th percentile
no	3157	1871	703	37.6%	89.64
yes	3157	1871	535	28.6%	19.99

In the French region no significant differences could be observed between different years (2006-2008). In the German orchard region a significant reduction of the aquatic risk could be observed from 2001-2007. The final results of each region will be demonstrated in the presentation at the final ENDURE conference.

Potential for reducing environmental risks

Besides environmental risk assessment based on surveys of pesticide use, the impact of the baseline, advanced and innovative systems were assessed by distributing the defined application calendars of each system to the geo-referenced orchards in the different regions. We showed that the regional aquatic risk potential of the baseline system (BS) is in the same category as the risk potential calculated with the actual pesticide use surveys when no drift mitigation measures are considered. The advanced systems AS1 and AS2 and the innovative system (IS) showed a significant improvement of the regional risk potential.

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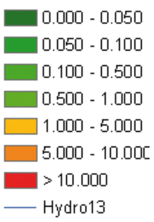
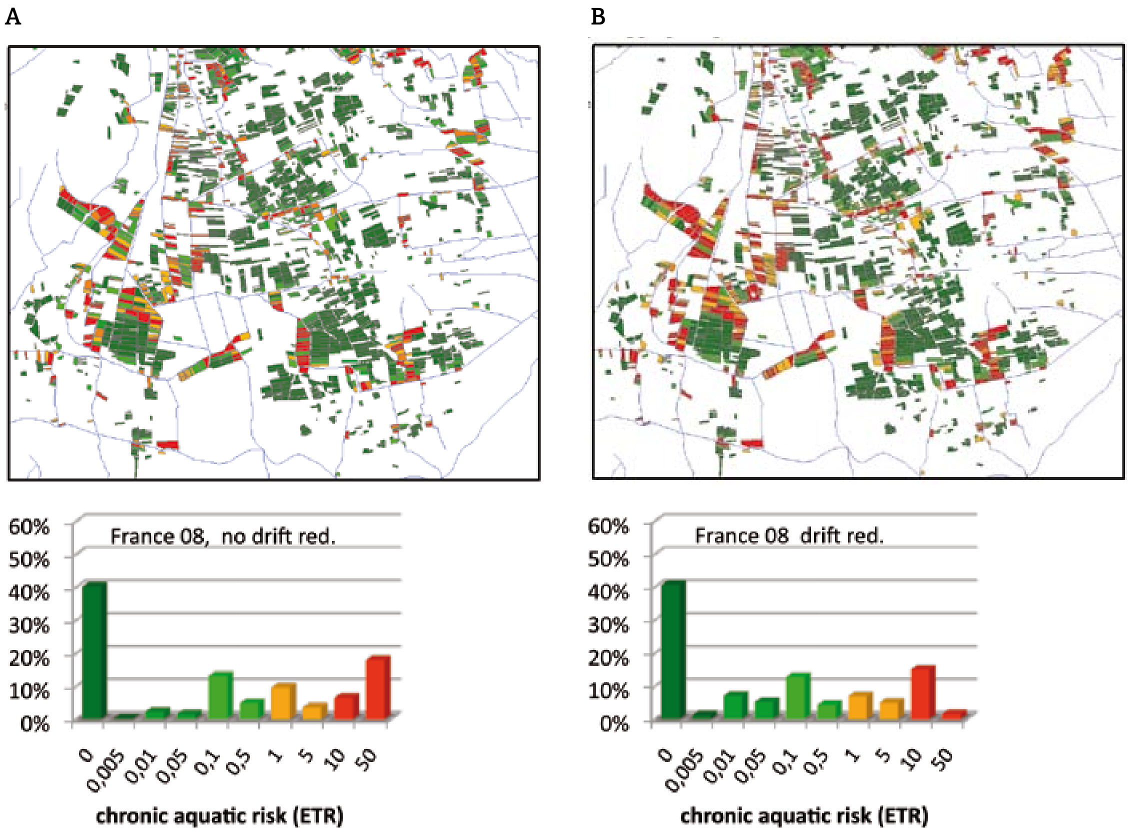
Figure 2 - Maps and frequency distribution of chronic aquatic risk potentials in the French orchard region Rhone Valley calculated with SYNOPS for 2008.

A) without considering drift reduction measures and B) with drift reduction measures.





LIFE CYCLE ASSESSMENT OF APPLE CROP PROTECTION STRATEGIES

The goal of the Life Cycle Assessment was to calculate the environmental impact of four plant protection systems in five regions across Europe. Our calculations show that the non-renewable energy demand and the eco- and human toxicity can generally be decreased by applying advanced and innovative systems. The nutrient enrichment is very low for all regions and there are only small differences within a region, because the fertilisation is the same in all systems.

Crop protection strategies

The crop protection strategies taken into account for this Life Cycle Assessments (LCA) are the systems described in the introduction of chapter 3 (page 10). The analysis encompasses the production of all inputs and all activities in the orchards within a year of its full productivity period. Quantitative data were collected by partners from the respective countries and regions. The task of the LCA was to calculate and analyse the crop protection systems according to LCA standards. The Swiss Agricultural Life Cycle Assessment tool (SALCA) was used for calculating the impact assessment (including environmental inventories of agricultural inputs). The estimation of direct field emissions was performed according to methods developed by Agroscope ART (http://www.agroscope.admin.ch/oekobilanzen/index.html?lang=de). For the impact assessment, the following methods were used:

- Demand for non-renewable and renewable energy resources (Hischier et al., 2009)
- Global warming potential over 100 years (IPCC, 2006)
- Terrestrial and aquatic eco-toxicity potential (USES-LCA, Guinée et al., 2001)
- Human toxicity potential (USES-LCA, Guinée et al., 2001)
- Eutrophication potential (Hauschild & Wenzel, 1998)

Comparison of environmental impacts

Agriculture has to fulfil multiple functions, which cannot be covered by a single functional unit. We used the following functional units: 1) Area occupation (ha*year), representing the function of land cultivation (sustainable land use, landscape protection, limited use of basic life resources) and showing the level of production intensity; 2) yield (kg), representing the productive function. The results could be used to compare the environmental impacts of several plant protection strategies within a region. A comparison across regions is not feasible, because a regional assessment would have needed a larger data source and a different approach.

Non-renewable energy and eco-toxicity

Figure 1 shows the impacts linked with the management of resources (energy demand, global warming potential and ozone formation potential). The results generally strongly depend on the field operation intensity, the amount of mineral fertilisers applied and the hail net construction. For these impact categories, the systems AS1, AS2 and IS show lower values than the BS. This is caused by a decreased number of the pesticide applications and a reduced quantity of pesticides used.

The environmental and human toxicity values strongly depend on the active ingredients applied exemplarily shown for the aquatic ecosystem here (Fig. 2). The results differ considerably between the systems (Fig. 2). In all regions AS 1, AS 2 and IS show lower impacts than the BS system.

Conclusion

This study shows the potential to decrease the environmental impacts for all impact categories in all regions when shifting from the baseline systems to more advanced and innovative systems. However, especially the impacts of the innovative systems were underestimated, because several alternative methods (resistant varieties, confusion techniques) could not be assessed in the LCA, due to a lack of corresponding LCA data.

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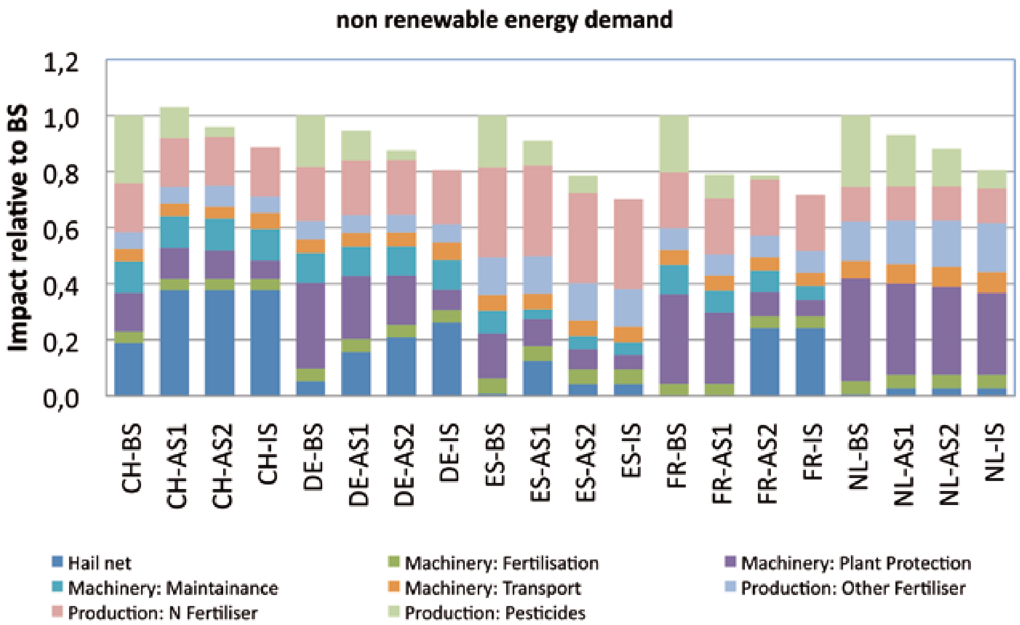

Figure 1: Non renewable energy demand . Impacts are presented relatively to the BS strategy. CH = Switzerland, DE = Germany, ES = Spain, FR = France, NL = Netherlands, BS = Baseline system, AS = Advanced System, IS = Innovative System

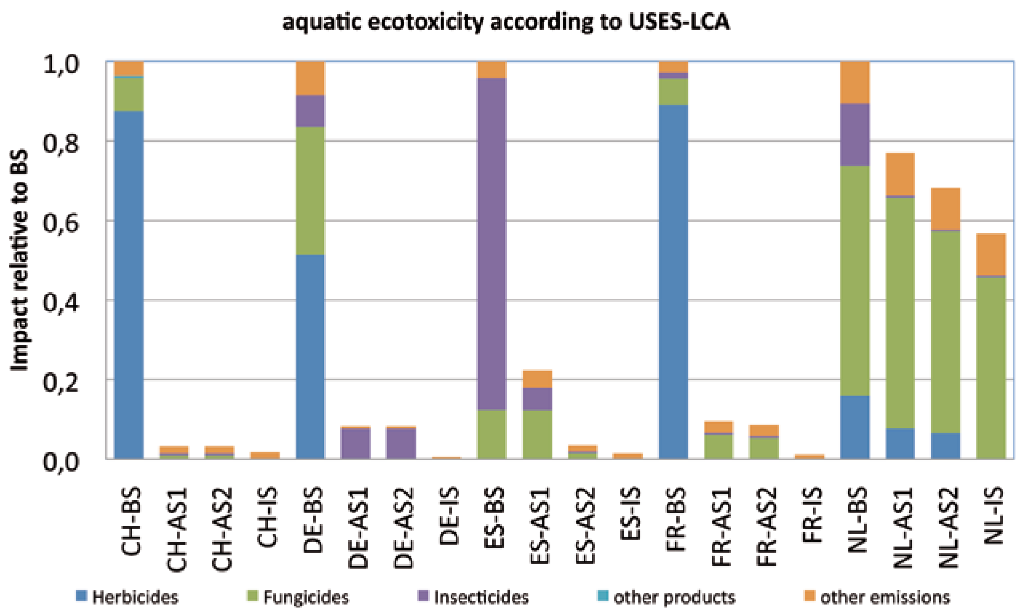

Figure 2: Aquatic ecotoxicity according to USES-LCA. Impacts are presented relatively to the BS strategy. CH = Switzerland, DE = Germany, ES = Spain, FR = France, NL = Netherlands, BS = Baseline system, AS = Advanced System, IS = Innovative System

SUSTAINABILITY RATING OF CROP PROTECTION STRATEGIES FOR APPLE ORCHARDS

We present the methodology "SustainOS" for defining, assessing and rating region-specific crop protection strategies. It will be demonstrated how an orchard system can be optimised regarding ecotoxicity while other sustainability attributes are also regarded. Results show that in all five European regions under study optimisation potential can be identified by integrating alternative crop protection measures such as using resistant cultivars, exclosure netting, pheromones and drift reducing equipment.

The place of ecotoxicity among other sustainability attributes

The goal of our study is to propose crop protection strategies with an optimized ecotoxicity. Figure 1 shows where 'ecotoxicity' is situated among other sustainability attributes relative to the ecological and economic sustainability.

Figure 1 shows the three top attributes of the ecological sustainability and of the economic sustainability. Further details are given in the article "Methods for evaluating sustainability of crop protection systems" at the beginning of chapter 3.

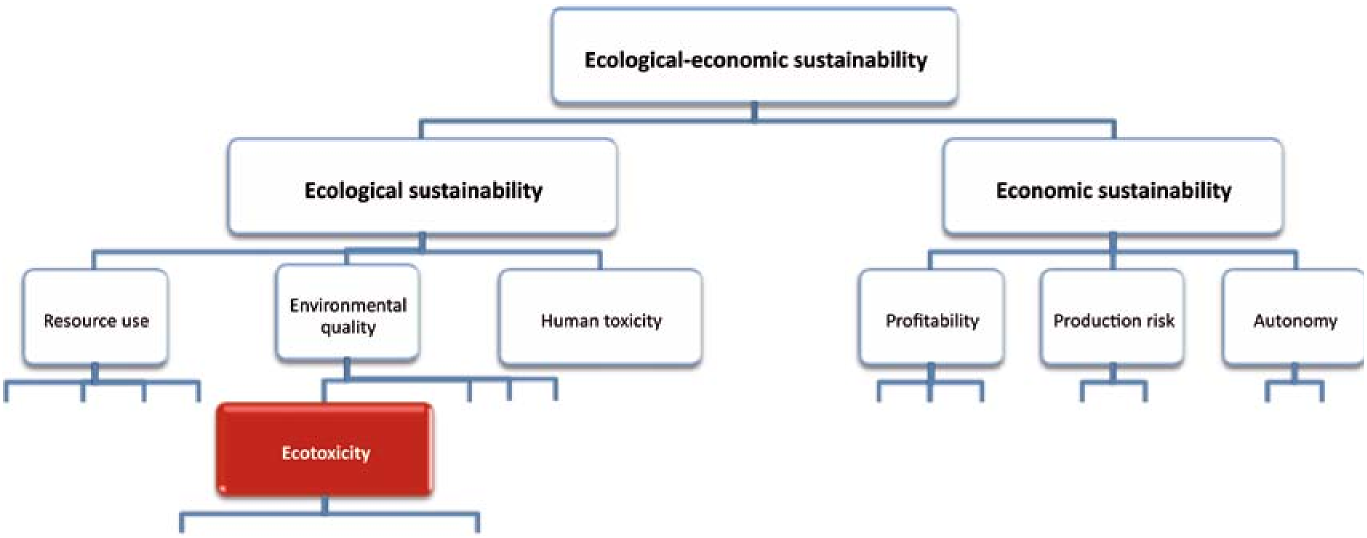

Figure 1 - Ecotoxicity is a sub-attribute of the ecological sustainability.

Defining new crop protection strategies

We studied the four crop protection strategies (BS, AS1, AS2 and IS) in five European countries/ regions as described in the introduction of chapter 3. The proposed advanced and innovative strategies comply with the guidelines for integrated pest management (IPM) of the respective country.

Rating new crop protection strategies

Twenty-one single results, called basic attributes, from life cycle, risk and economic assessments were qualitatively rated using the following classes:

1 = much worse than BS; 2 = worse than BS; 3 = similar to BS; 4 = better than BS; 5 = much better than BS.

We defined rating scales that produce robust results. Thus, one rating class above or below means that the crop protection strategy increases or reduces the sustainability to a relevant extent. The rating class 5 or 1 means that the system differs very strongly from the Baseline System.

The assessment results of the 21 basic attributes were aggregated hierarchically. The following results are derived from the SustainOS tool we developed for defining, assessing and rating apple orchard systems.

General potential to improve the ecological sustainability

The AS1 strategy in all countries improves the 'ecological sustainability' compared to the BS strategy. This progress is relatively stronger in Germany, France and Switzerland than in Spain and The Netherlands. The AS2 strategy shows strong improvement compared to the AS1 in the case of The Netherlands, France and Spain, but the progress is relatively low in Germany and nil in Switzerland. In contrast, for Switzerland the improvement of the IS strategy is strong compared to the AS2, while in Germany and The Netherlands this progress is only moderate and nil for France and Spain. Over all, AS1 and AS2 demonstrate that in all five countries the ecological sustainability can be improved using alternative measures that are available on the present market.

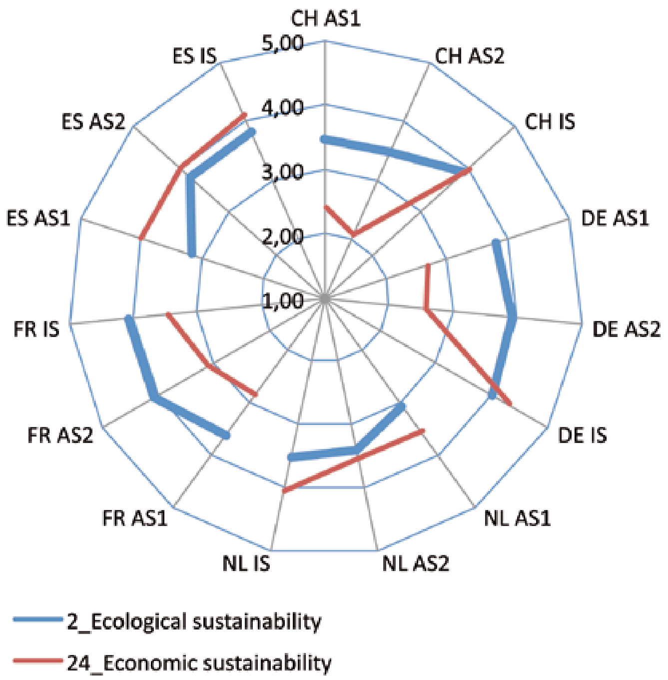

Figure 2 - Ecological-economic sustainability rating for five countries and three crop protection strategies in apple orchard systems; rating classes: 1 = much worse than BS, 2 = worse than BS, 3 = similar to BS, 4 = better than BS, 5 = much better than BS; BSis the Baseline System of the respective country.

Among the three sub-attributes of the ecological sustainability it is 'Human toxicity' that has the highest potential for improvements in all countries (Fig. 3). The 'Environmental quality' also has a serious potential to be optimised in all countries. In contrast, 'Resource use' is not much affected by the optimisation of the plant protection strategies. Further improvements concerning the 'Resource use' could be possible as well. For example Spain demonstrates that an improved irrigation system has a strong positive effect on lowering the water use. But the optimisation of 'Resource use' was not the focus of our study.

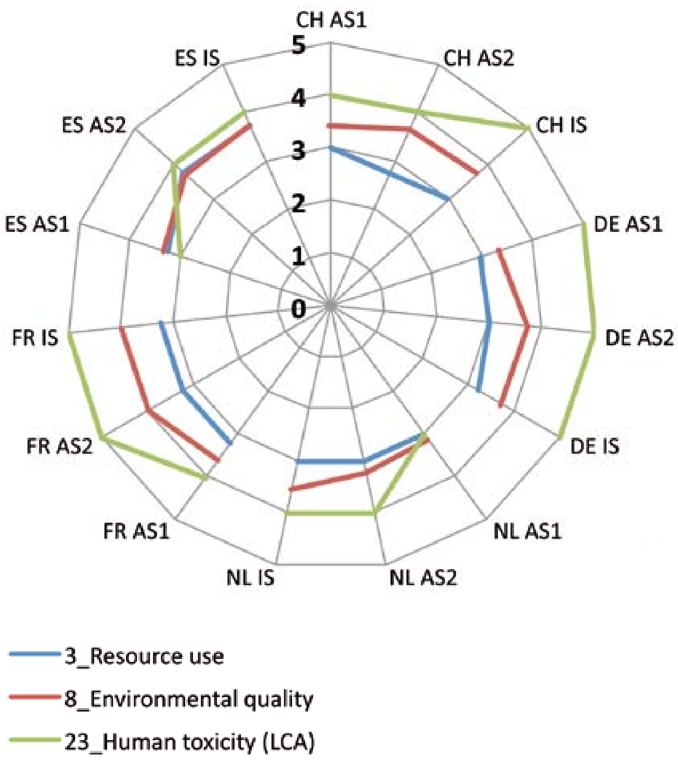

Figure 3 - Ecological sustainability rating for five countries and three crop protection strategies in apple orchard systems; rating classes: 1 = much worse than BS, 2 = worse than BS, 3 = similar to BS, 4 = better than BS, 5 = much better than BS; BS: Is the Baseline System of the respective country.

Rating results for 'Ecotoxicity'

'Ecotoxicity' is a sub-attribute of the 'Environmental quality' and the central attribute of our study. Figure 4 demonstrates that for all regions the AS1 strategy got a rating above 4, indicating that they are better than the BS strategy of a specific region and that for each region AS2 and IS strategies result in better ratings than AS1.

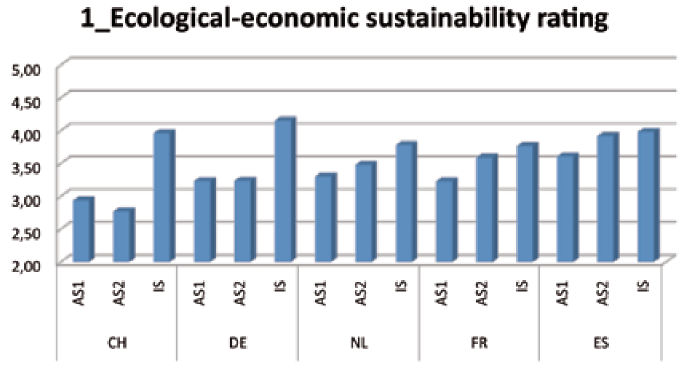

Figure 4 - Ratings for the ecotoxicity of three different systems in five countries compared to a respective Baseline System.

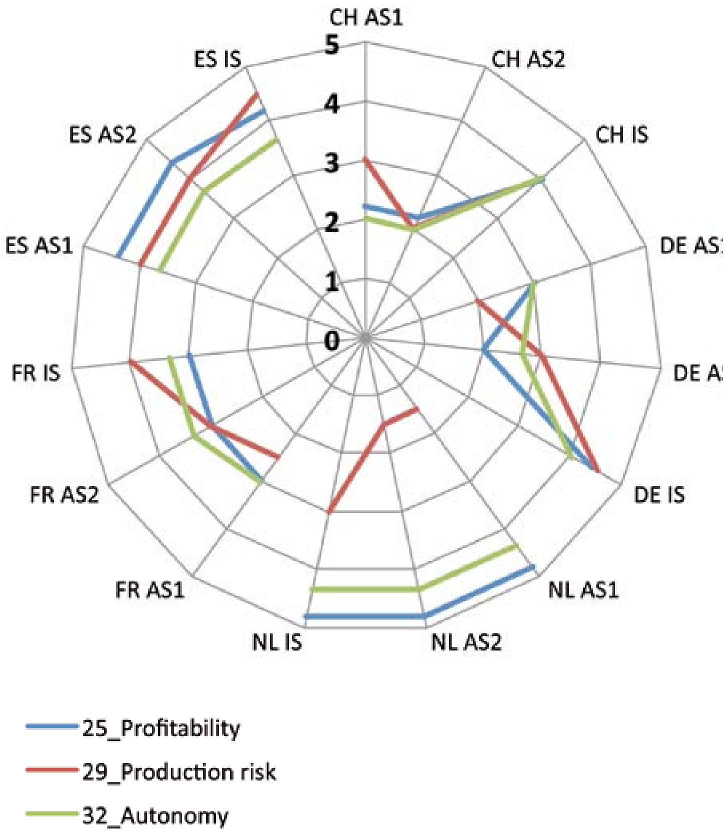

Figure 5 - Economic sustainability rating for five countries and three crop protection strategies in apple orchard systems; rating classes: 1 = much worse than BS, 2 = worse than BS, 3 = similar to BS, 4 = better than BS, 5 = much better than BS; BS: Is the Baseline System of the respective country.

Achieving such progress is possible if:

a) scab tolerant/resistant cultivars are planted;
b) the environmentally worst active ingredients are replaced;
c) drift reduction is enhanced up to 90% through spray techniques and drift-reducing elements such as hedges;
d) alternative methods such as mating disruption, attract and kill, exclosure netting or introduction of predators and parasitoids are applied.

General potential to improve the economic sustainability

Economic disadvantages are the price for the ecological progress for AS1 and AS2 strategies in the case of Switzerland, Germany and France (only for AS1) as Fig. 2 shows. In contrast, for The Netherlands and Spain a win-win situation is indicated between ecology and economy not only for the AS1 strategy but also for AS2 and IS (Fig. 2). However, the IS strategy shows for all countries an improved economic situation compared to the BS strategy (Fig. 2), based on higher or more stable yield and portions of 1st class fruit. While the economic sub-attributes 'Profitability' and 'Autonomy' for all countries show a parallel improvement among the strategies, the 'Production risk' might be over proportionally increased like in the case of The Netherlands or decreased like in the case of Germany (Fig. 5).

Conclusion

Further improvements of the ecological-economic sustainability can be expected if the innovations presumed for the IS strategy become commercially available. One example is the breading of new cultivars with multigene resistance against several major pests. Experts estimate a time horizon of 30 years for a genetic solution for apple scab, fire blight, powdery mildew and aphids integrated in the same cultivar. In addition, it takes at least ten years for a new cultivar to be established in the apple market to a relevant portion. The assumed higher yield per hectare and the higher portion of 1st class fruit for the IS strategy are the prerequisites for the economic success.

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4 RESEARCH

Priorities and prospects in IPM research and technology

A significant amount of existing knowledge can be exploited to reduce pesticide use and risk, as the ENDURE case-studies have shown (see chapter 1). However, the case-studies have also identified bottlenecks and knowledge gaps that impede further progress. Innovation is also needed to develop more sustainable approaches to crop protection that are less reliant on pesticide use.

Developing these innovations poses a tremendous challenge to researchers, especially since a large range of disciplines needs to be involved. It has been an essential role of ENDURE, as a network of excellence, to construct a pan European and multidisciplinary research community that can rise to this challenge.

But what research is relevant? Our basic understanding of crop-pest systems has considerably improved in recent years, without a great deal of impact on farming practices. So, just investing in more research is not enough. Identifying priorities, exploring edge-cutting areas and advanced technologies to assess their potential contributions to IPM, and developing and sharing tools and resources to assist the crop protection research community have been main areas of focus over the last four years of ENDURE.

IPM does not come as a unique and final recipe. It requires gradual progress through the incorporation of different scientific and technological contributions. Some of the contributions of ENDURE aim at increasing the efficiency of chemical control in order to reduce its impact. Others have considered how alternatives to pesticides can be made more effective and accessible. In the longer term, our vision of IPM extends beyond changing individual inputs to encompass the ecological processes involved over the temporal and spatial scales at which they operate.

IMPROVING CHEMICAL CONTROL EFFICIENCY

At this level, one should exploit as much knowledge as is available on the behaviour, ecology and epidemiology of pests together with the characteristics of control methods in order to carefully optimise the number, type and timing of chemical treatments. Decision Support Systems (DSS) are needed to support this complex process. Many such systems, based on different approaches, are already available. ENDURE has surveyed 70 European DSS with the aim of identifying the “best parts” of each ones, that could be combined in a new generation of improved systems that would be better adapted to the goals of the Directive for the sustainable use of pesticides.

Decisions (if, when and how to treat) should be based

the ENDURE network of excellence shares the fruit of 4 years research with the Crop protection community

not only on modelling and forecasting but also on 'real-time' monitoring of pests and environmental conditions before, during and after the growing season. Inclusion of these data into decision engines promotes more carefully-tailored control actions and can also guide precision spraying devices, leading to substantial reductions in the amount of pesticide applied. Although the innovative systems sketched by ENDURE scientists can look quite futuristic, some of the components and technologies are becoming available. Indeed, it has already been possible to test the concept of a task controller for precision spraying at the field level.

OVERCOMING LIMITATIONS ON DEVELOPING BIOLOGICAL ALTERNATIVES TO PESTICIDES

Biocontrol agents have proved very effective in controlling arthropod pests, diseases and weeds in certain situations. However, considering the amount of research invested for decades in these methods, the restricted availability of biocontrol agents on the European market and the extent of application of biocontrol in practice are rather disappointing. Furthermore, most use of biocontrol is in protected crops and it has hardly impacted on the much larger acreages of arable and horticultural crops. In the context of new pesticide policy, there are opportunities for further development and ENDURE is making recommendations on how to improve the prospect of biocontrol, from a technical point of view but also including economic and social issues. Our studies also reviewed the concept of conservation biocontrol of invertebrate pests and identified priorities for research on landscape ecology that would support habitat management for beneficial organisms.

Increasing the role of plant resistance is the foremost way of reducing reliance on pesticides, for plant diseases at least. A major limitation is the speed at which pathogen populations can evolve to overcome the resistance traits bred into crop cultivars. From the perspective of sustainable development, resistance genes must be treated as rare natural resources and must be deployed with care. Within ENDURE, a large group of scientists (geneticists, plant pathologists and modellers) have collaborated to explore ways of exploiting plant genetic resistance to ensure its durability. The results, from theoretical and empirical studies, provide guidance on how to choose and combine resistance genes in breeding strategies and on how to deploy resistance varieties in space and time.

Managing ecological processes over time and space Because of the persistence of seed banks in soil, weed management cannot be considered over a single cropping season. Experiments in different countries suggest that manipulating crop rotations is a potent lever for obtaining a balanced weed flora, thus reducing the reliance on chemical weed management. ENDURE has undertaken an analysis of field data from five European countries. A methodology has been developed to compare weed amounts in these different sets of data. Preliminary results suggest that rotations can indeed be used to change weed infestations to a large extent and that this effect can be related to a combination of sowing dates and of crop and herbicide choice over a three year crop sequence. The effects of crop management on weed communities can also be investigated using functional traits that define the life-history, physiology and competitiveness of individual weed species. ENDURE has created a Weed Traits Database for 21 common European weed species to assist with the modelling of weed population dynamics, and includes all the relevant parameters to simulate the whole weed life-cycle.

Pest migration or dispersion and pest control by natural enemies are processes that develop at spatial scales that exceed the limits of the farmer's field and need to be approached at the landscape level. It is increasingly accepted that landscape management can be used for pest control, yet there are still few examples of actual implementation. Combining expertise in agronomy and pest ecology, ENDURE has reviewed the existing knowledge worldwide. The conclusion is that, within agricultural landscapes, the spatial distribution of resources and their dynamics through time markedly affect the abundance of insect pests, via their natural enemies, and also affect weed diversity. Therefore, the landscape design has the potential to make a strong contribution to IPM.

KEEPING IN LINE WITH IPM PRINCIPLES

The above topics have been selected in the ENDURE research program because of their contribution to the different elements needed for IPM. It is at the core of the concept of IPM that you do not rely on a single method but on the combination of different complementary approaches. Typically, in an IPM perspective, farmers should first implement the prevention principle by taking some strategic decisions before the start of the growing season: choose a rotation that reduces weeds and soil-born pest problems, select varieties having appropriate resistances, and decide on the spatial lay out of the different crops and varieties and on the introduction of non cultivated areas to favour a pest-suppressive landscape. Then, during the growing season, they should give priority to non chemical control methods - the use of biocontrol agents for instance - before deciding to rely on pesticides. They also should manage control methods on the basis of forecasting and monitoring the pest status within their fields to reduce the use of pesticides to the necessary minimum, with the help of a DSS.

Researchers too have to integrate this IPM perspective in their own approach. It means that the innovative methods they may design will not be assessed for their individual efficacy, but rather for their ability to combine with other methods into an overall effective strategy. Indeed, within ENDURE, a group of scientists from several institutions and countries, often combining different disciplines, was in charge of each research topic. These groups worked separately for one part, but they also collaborated to the System Case Studies, providing inputs to the design of advanced or innovative systems (see Chapter 1).

THE VIRTUAL LABORATORY: A RESOURCE FOR SUPPORTING CROP PROTECTION-RELATED RESEARCH

Research results produced by ENDURE are not intended to be final achievements but rather starting points for future research to support the development and the implementation of IPM in Europe. The multidisciplinary scientific community gathered by ENDURE has been careful to consolidate the knowledge, data bases and tools accumulated during the project into a common resource: the Virtual Laboratory (VL). This resource is designed to support collaborative research on IPM by ENDURE and beyond. Indeed, the VL is an invaluable asset that ENDURE is proud to maintain, enrich and share with the crop protection research community.

Some of the key features in the VL, among others, are illustrated in this chapter:

- the Weed Traits Database already mentioned;
- EuroWheat, a comprehensive information platform supporting Integrated disease management in wheat;
- Wheatpest, a model for analysis wheat yield losses from multiple pests;
- Quantipest, a collaborative platform to unify information on pest characterisation;
- UniSim (Universal Simulator), an open-source software package for collaborative ecological modelling.

A RESEARCH COMMUNITY LOOKING AHEAD

Conducting research together and setting up the lasting resource of the Virtual laboratory have been means for creating, for the first time, a transnational and multidisciplinary research community working on crop protection. We were also eager to share our objectives with younger scientists to make them responsive to IPM issues and attract them to this critical area of research. Three summer schools were held on important topics: “Biodiversity supporting IPM”, “Modelling approaches to support IPM” and “New and emerging agricultural pests, diseases and weeds”. This initiative generated a strong interest from nearly 300 applicants, from whom we selected a total of 49 PhD students from 29 countries representing five continents.

Another ENDURE activity was to identify what further priorities should be set up in research to meet the challenge placed by the new pesticides legislation on European agriculture. To support this analysis, ENDURE has looked at the possible futures of crop protection in Europe. The five scenarios build in the ENDURE foresight study ‘European crop protection in 2030’ differ in agricultural context and in the options taken to manage pests. This exercise provides a useful basis for research planning. It will also help policy-makers and other stakeholders in the agri-food system to set their own priorities and thus it also contributes to the objectives presented in Chapter 5.

TOWARDS A GENERIC DECISION-SUPPORT SYSTEM FOR WEED MANAGEMENT

Following a detailed evaluation of nine existing decision-support systems (DSS) related to weed control, three were selected that contained features especially relevant to the construction of a new DSS of generic application to optimizing the choice and application of herbicides based on a series of biological, toxicological and economic criteria. The new system ('IPM-DSS') will also incorporate option for non-chemical weed control.

Background and approaches

A survey of 70 decision-support systems (DSS) for crop protection analysed by ENDURE researchers (see article on potato late blight in this chapter) included nine related specifically to weed control. Based on a number of criteria, we selected three systems that have particular potential for reducing the use of herbicides, and also offer opportunities for integration into a single generic DSS. The three systems were:

• 'DECIDHerb', constructed by INRA in France with features that predict the timing of emergence of different weeds, assess the probability of short- and long-term needs for weed control, and enable the user to rank alternative treatment options according to their preferences.

• 'GestInf', constructed by CNR in Italy, with features that predict relative yield loss as a function of increasing weed densities, and also estimate short-term yield loss and expected economic net return of alternative treatment options.

• 'CPOWeeds', constructed by Aarhus University in Denmark, with features that estimate dose-response functions of single herbicides incorporating differences between weed species, weed growth stages and climatic conditions, and can also recommend tank mixes of herbicides to contend with specific combinations of weed species, weed growth stages and climatic conditions, and optimized for arbitrary constants relating to herbicide dose rates, e.g. cost or indexes.

Towards a new DSS

A basic rationale behind a new DSS incorporating the above features is that weeds are not homogeneously distributed in time and space, and the efficiency of various control measures depends on conditions in time and space, why all treatments should be based on field registrations. This requirement has specific implications for the interactions between the DSS and the end-user. The DSS will also include guidelines specific for combinations of crop and region when different types of weeds should be considered throughout a full growing season. The user will initially enter a field report, and the DSS will then run through three main steps:

1/ Evaluate the need for control

2/ Identify herbicides and doses rates specific for the target by use of dose-response functions and considering the possible use of mixtures

3/ Present and rank alternative treatment options according to a series of attributes including cost, efficacy and other considerations

Sprayer

For a selected crop x region combination, the new system (termed 'IPM-DSS') can be customized to consider only certain of the possible criteria. Work is underway to incorporate non-chemical control measures as well as herbicide applications, according to the requirements in Directive 2009/128/EC. A simple but functional DSS prototype, which may be used to test functional integrity of components with different origin, will be available in the Virtual Lab by the end of September 2010

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EVALUATION OF DECISION SUPPORT SYSTEMS FOR POTATO LATE BLIGHT

We have evaluated several existing decision-support systems (DSS) for control of potato late blight, in order to identify their best features and compare their performance. Seven systems have so been installed on the Euroblight website and can be linked to weather data from different parts of Europe to predict periods of outbreak and compare these predictions against real data on disease incidence. We are developing recommendations for building a new, unified DSS encompassing the best features of existing systems and potentially applicable throughout the EU.

Computer-based decision-support systems (DSS) have established an important role in European agriculture for assisting growers and advisors with aspects of agronomy and crop protection. However, they have so far focused on a limited number of crop-pest combinations and their uptake has been patchy for a variety of reasons. Researchers in ENDURE have done a detailed review of available systems in order to identify some of the attributes underpinning success or failure and features that can be included in DSS in the future.

70 European DSS related to crop protection were surveyed in our study. Of these, 15 concerned pathogens and diseases in potato including the very damaging potato late blight (Phytophthora infestans) that can cause high losses of yield and requires relatively high input of fungicides.

Approaches

Most existing DSS for potato late blight use meteorological data to calculate infection periods and subsequent risks of epidemic progress. These calculations are used as a basis for recommending timing of the first fungicide application and often to predict the need for subsequent applications.

In order to facilitate comparison of the available DSS models for late blight, a testing platform has been installed on the established Euroblight website (http://www.euroblight.net/EuroBlight.asp). This testing platform is targeted primarily at researchers and advisors, who have special interest in development of new tools and new concepts to improve management of potato late blight.

On this platform, the different systems can be uploaded and installed. There is also a facility for uploading and storing different weather datasets to compare the predictions and robustness of the systems. Seven different DSS have been installed on the test platform so far, and weather data originating from many locations in Europe in the period of 2006-2009 have been entered in the weather database.

Selected DSS can be run on selected weather datasets, and responses from the DSS's can be evaluated and related to other information such as data on timing and severity of late blight attacks. One output of particular interest is to define 'blight favourable weather' in which severe outbreaks are most likely to occur. Initial results show good correlations between weather variables and periods with high and low risk for infection during a growing season.

Potato flower

A model capable of describing fungicide degradation has also been installed, in order to predict how long time a fungicide application will maintain satisfactorily levels of efficacy with different time intervals between applications.

The future

Our study has identified several features of existing systems that could potentially be combined in a new, unified European DSS for potato late blight. A new system should include:

- recommendations for timing, selection of fungicide compounds and dose rates, so the total number of applications and the total input of fungicides (cost or TFI) is minimized
- provisions that ensure that environmental risk is minimized
- integration of principles of integrated Pest Management (IPM)

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A MODEL FOR AN INNOVATIVE CROP PROTECTION SYSTEM IN THE FUTURE ILLUSTRATED FOR MAIZE

To show how innovative techniques for monitoring and precision spraying can be used we have developed a generic model for crop protection system for future high tech cropping systems. We have illustrated how to work with it taking maize as a model crop.

Plant diseases, pests and weeds are major problems in crop production where they lead to yield and quality losses. Attention to the pesticides used to control these problems has been increased as they can have detrimental effects on the environment and human health.

A system whereby diseases, pests and weeds can be identified at a much earlier stage than is now the case would make it possible to limit the amount of chemicals to be applied. Earlier identification could also allow the grower to use biological control or take other, localized measures. Moreover, application of pesticides using optimal spraying techniques, or other environmental friendly control measures can add to the savings of pesticide use.

Assuming in the future that use of only minimal amounts of pesticides is allowed, the challenge was to investigate how this could be achieved if not restricted by the costs or the amount of required research needed for operation of the crop protection system to be developed. The result was a model for an innovative crop protection system for the future. Subsequently we have investigated what it will take to implement such a system and what is the potential of the system. Which techniques are already available and which innovations are to be expected? Because of the complexity, the focus was on one crop only. Maize was chosen as a model crop since for this crop knowledge is available regarding existing expertise on mycotoxin producing Fusarium species, application of beneficial organisms, monitoring of pests, diseases and weeds and the application of innovative precision spray technology in one system, illustrating how the model could be used.

A generic model for an innovative crop protection system

It is crucial that one should take actions before, during and after the growing period. Before growing a crop one should collect (environmental) data that characterize the (history of) field and environmental conditions and make sure that starting material (seeds, bulbs or seedlings) and soil are clean with respect to relevant diseases for the crop to be grown. Once the growing period has started one should on a regular basis scan the field for the presence of diseases, pests and weeds. First this should be done on a macro scale level (field level). This will indicate the location where special attention is needed. This identified spot should subsequently be monitored in detail on the micro scale level (on plant level), to specify the nature, stage, development, severeness of the infection(s) and/or infestation(s). Additionally the field should also be monitored for environmental factors using the same approach. Gathered data should be analyzed in a holistic way in a so called “decision engine” resulting in an action plan for measures to be taken on the different levels (see Figure 1 for a schematic representation of this model).

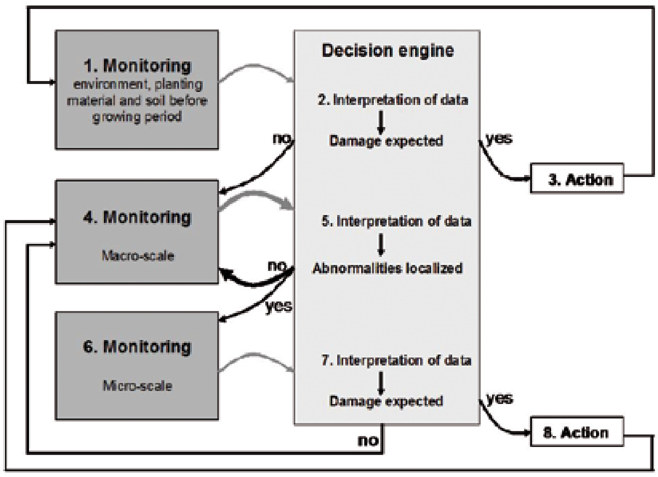

Figure 1 - Generic model of an innovative crop protection system. Steps 1, 2 and 3 are performed before the growing period; the other steps during the growing period.

Innovative techniques for monitoring environmental data, weeds, pests and diseases

Cameras can be used to visualize pests, fungi and weeds. However, it is desirable to be alerted for risks of pests or diseases in a crop before the symptomatic phase. This can be done by getting information about environmental data that promote disease development. Alternatively characteristics of plants can indicate the presence of pests, diseases or weeds.

There is a broad range of innovative vision technologies available that can be used for these monitoring purposes, sometimes combined with micro-sensors or satellites so that localization of measurements can be fixed by GPS coordinates. By measuring changes in reflectance characteristics (using spectral analysis), we can get insight in the kernel maturation stage of a maize crop, the incidence of aflatoxin within silk and cob, diseases in the plant, the level of soil humidity distributed over the field, spatial patterns of clay and humus in the field, presence of residues of crops or weeds, etc. By measuring fluorescence of green parts of plants, plant stress can be detected which can be an indication for the presence of pathogens. The use of IR cameras enables the measurement of crop temperature.

Molecular techniques that detect DNA or RNA that is specific for the harmful pathogens, pest organisms or weeds, can identify these long before disease symptoms or weeds are visible. All types of developmental stages of viruses, bacteria, nematodes, fungi, insects, etc. can be detected in plant material, seed, soil, water, air or any other environment using PCR- or sequencing based methods. Seeds or seedlings of weeds can also be detected this way in soil. The simultaneous detection of multiple organisms is possible, as well as quantification or discrimination between living and dead organisms.

Serological techniques, such as ELISA-based methods, can detect specific proteins of viruses and bacteria. These techniques enable a very fast detection of pathogens in numerous environments.

Pests and diseases can also be detected indirectly by measuring volatiles. These can be produced by a plant upon attack of a pathogen and can subsequently be measured by so called electronic noses. Pheromone traps enable the detection of pests.

A potential monitoring technique for pests is based on acoustic detection, as sounds produced by insects can be species specific

Innovative precision application techniques

It is recommended that plant protection products are applied as targeted as possible. Pesticides can be automatically applied using programmed spray volumes and required doses of pesticides in combination with a GPS system and a spraying robot. Some precision spray techniques are combined with vision technology, for instance for individual weed plant control.

Alternative control measures

Examples are biological control, application of plant extracts, use of pheromones, application of beneficial organisms, culturing measures, use of vacuum cleaners to suck up insects, UV treatment to kill microorganisms, use of pheromones for mating disruption, mass trapping, lure and kill, destruction of weeds by burning, high pressure air or finger hoeing, etc. A potential innovative measure could be laser beam killing of insects.

Conclusions

The individual elements of the system presented are generally available but still have to be improved before they can be linked together in an innovative crop protection system. This also requires knowledge about damage-thresholds, dose-response relations, biology, ecology, population dynamics, etc. It will obviously not be implemented in the near future but is meant as an inspiration to solve upcoming challenges in future farming if the use of pesticides will be even more restricted.

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DOCUMENTATION AND PROOF OF CONCEPT OF A PRECISION AGRICULTURE TASK CONTROLLER

A precision agriculture task controller (PATC) is a user operational and mobile work unit that is able to control the dose rate of e.g. a field sprayer based on imported geo-referenced data.

Field tests of the PATC as the communication link between a farm management and information system (FMIS) and a sprayer controller was successfully completed. Only a few user inputs via the PATC terminal were required before and after the field operation. The PATC system transferred the field operational plan, generated within the FMIS, to real dose rate control, contemporary with data transfer from the sprayer to the FMIS. The data was stored and utilized by the FMIS for accounting the field operation in terms of ha/h, costs/ha, dose rate, area covered, time and date, and applied amount. Additionally, on-line maps of environmental sensitive areas bordering on to e.g. water courses, lakes, marsh (http://kort.arealinfo.dk) was used with the PATC to automatically ensure that the farmer complies with the local regulations.

Innovative technology for precision agriculture task control

The objective within ENDURE was to demonstrate a proof of concept of an on-line information flow between a sprayer, and a central database (FMIS). Figure 1 shows the principal information flow as regards to PATC relevant entities. A novel web server technology based distributed electronic control system was developed in a Danish innovation project and used as part of the proof of concept PATC (Nørremark et al., 2009). The sprayer control was operated from the systems client, a ruggedized personal computer (PC) based terminal placed in the cabin of the self propelled sprayer, communicating with the SprayMaster 9500 web server (Lykketronic A/S, Løgstør, Denmark). The system provided full leverage of standard PC architecture and web server technology. The PATC user interface required a standard web browser on a terminal (depicted as PC terminal in Fig. 1) where the PATC system was activated by accessing the web services of eDag and aPlan (Agromat Data, Vejle, Denmark) (depicted as users/service providers, expert systems etc. in Fig. 1). Software installed on the PC terminal ensured that the web services provided by the SprayMaster 9500 was passed on to eDag and aPlan. The eDag and aPlan servers acted as relays for the sprayer data, and passed on data further to the FMIS (DBLR Plante IT, Skejby, Denmark) (depicted as field databases etc. in Fig. 1).

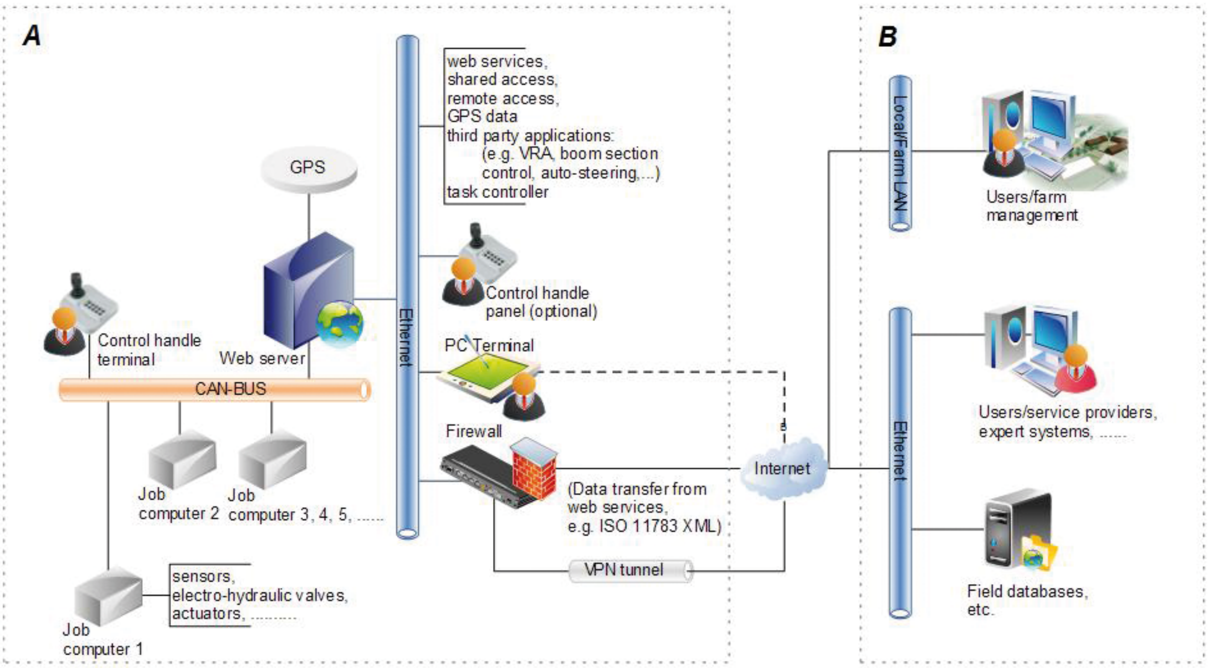

Figure 1 - Generic model of an innovative crop protection system. Steps 1, 2 and 3 are performed before the growing period; the other steps during the growing period.

Conclusions

It was possible to demonstrate a PATC for a spraying operation using novel agricultural machinery technology. The proof of concept PATC used both commercialized and semi-commercialized products. It was shown that it is possible to ease the user operability with the needs of task control in real-time. The open source and standards used for the proof of concept components offered a suitable and inexpensive basis for the realization of a PATC and served as the hardware solution for numerous combined control and information and communication technologies in relation to integrated pest management strategies. As an example, the PATC demonstration showed that the task of avoiding spraying of environmental sensitive areas can be automated based on a few user inputs.

Perspectives

Based on this study, it was realized that there is a large need for a common agreement to multi-purpose and semantic web-service oriented ICT architecture for integrated pest management within the domain of agricultural machinery electronics, task controllers and FMIS. It should take all its important aspects into consideration, including available technologies and protocols, interoperability, information on regulatory and monitoring requirements, standardization, human-machine coordination, and interests of different stakeholders. In addition the degree of automation in data communication, and geo-data handling and representation to the users should be maximized. The latter is of vital importance for the durability of ICT and automation at on-going field operations and farm management for sustainable agriculture.

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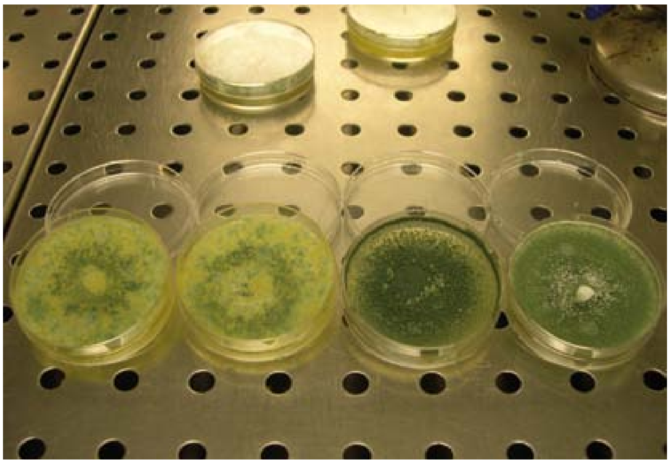
EVALUATING GAPS AND OPPORTUNITIES FOR BIOCONTROL IN EUROPE

A detailed analysis of the successes and failures with biocontrol in Europe, focused on microbial control agents for plant pathogens and conservation biological control of invertebrate pests, has identified some of the key biological and economic constraints to the evaluation and commercial development of biocontrol agents, and ways these may be overcome by research, technical improvements, industry initiatives and policy interventions.



Petri dishes containing different species of the biocontrol agent *Trichoderma* .
© IP-CNR / Michelina Ruocco.

A parasitic wasp that attacks pollen beetle in oilseed rape.
© Rothamsted Research.

In the past 20 years there have been significant developments in the biological control of crop pests and diseases. In addition, several pesticides have been withdrawn because of health and environmental concerns associated with their use. There is therefore increased interest in the development of alternative methods of control, including the use of biological agents. Within ENDURE we have reviewed gaps and opportunities for biocontrol, focusing on the development of microbial biocontrol agents (MCBAs) for plant pathogens and the role of conservation biocontrol (CBC) of invertebrate pests. A brief summary of results and recommendations is provided below.

Factors influencing the success or failure of biocontrol

Despite increasing demand for alternatives to chemical control, the role of biological control in crop protection has remained quite modest despite decades of research. One key step in the registration of a plant protection product in the EU is its inclusion in the list of active substances (Annex I of former Directive 91/414/EEC). Fourteen MBCAs were included in the list in 2010 (with seven more pending). We analysed 90 published reviews of CBC and found good evidence that management of farmland can increase the abundance or activity of naturally-occurring antagonists. However, there is a need for more research on the ecology and behaviour of natural enemies, invertebrate communities and their performance at different spatial scales. Within ENDURE, specialists in biocontrol have worked with landscape ecologists to identify priorities for strengthening CBC and improving its ecological context.

Screening criteria for the development of commercial bio-products

Programs for screening antagonists for disease control of plant pathogens are often focused on testing antagonistic properties in vitro, in bioassays and subsequently in crops. For commercial use, however, antagonists must fulfill many more criteria and we have identified several that should be considered. These include (i) the spectrum of activity and likely market size; (ii) availability of rapid-throughput methods for eliminating candidates with undesirable characteristics; and (iii) ease of mass production and evaluation in field experiments.

Economic considerations: cost and profitability analysis

We have made comparisons between costs for a typical chemical pesticide and for an MCBA in terms of production costs (including raw materials, packaging, energy, manpower, and consumables), as well as costs of registration, sales, research and administration. The development and commercial success of biocontrol agents is constrained by the size of the companies involved and the fact it is a young, relatively undeveloped market. Four areas relating to cost and profitability have been considered:

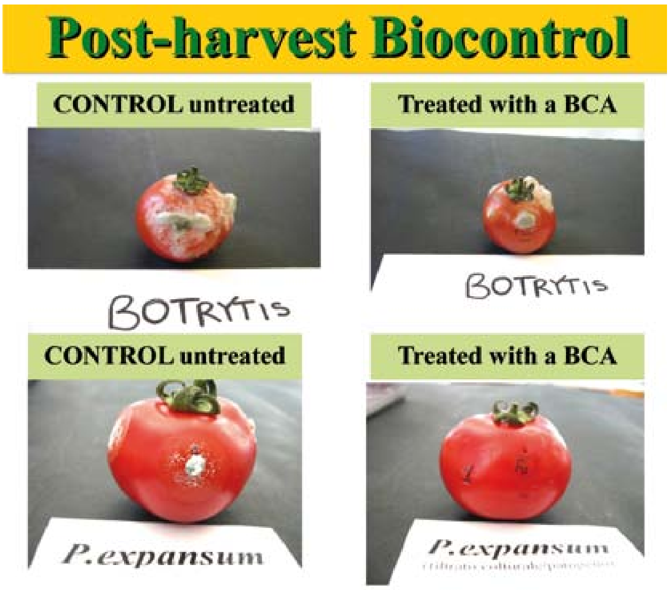
Size of the target market - Most MBCAs are being developed for small, if not niche, markets. In addition, the potential market for MBCAs is fragmented, taking in minor crops of little interest to large chemical companies.

Cost of production – Unlike most chemical synthesis, producing MBCAs requires a complicated and much more expensive four-phase production process starting with fermentation and running through extraction, purification, and formulation and packaging.

Cost of registration - The estimated cost for registering a MBCA is currently lower than that for a chemical pesticide, though the size of the investment is still very high in comparison with the potential market.

Business profitability - Comparing estimated production and other costs relative to the sales value at plateau level, highlights large differences between chemical pesticides and microbial biocontrol agents. The gap between the two in terms of estimated profit is nearly 10-fold in favour of chemical pesticide.

***In vitro* competition assay for testing the mycoparassitic activity of Trichoderma hatzianum against Rhizoctonia solani .**



Post harvest biocontrol: tomato treated witn a BCA product in post harvest to control the pathogens *Botrytis cinerea* and *Penicillium expansum* .

Options for the smaller biocontrol businesses include developing into larger markets such as grapevine and field crops through venture capital backing or entering into agreements with other manufacturers or suppliers to expand a product portfolio. In contrast, CBC is associated with relatively few saleable products except plants or seeds for habitat creation. This, together with the desirability in many cases of coordinating habitat management over a large scale, means that the adoption of CBC is likely to be driven to a large extent by government policy through incentives, regulation and extension services.

Conclusions

The main technical conclusions of the study and perspectives for future R&D projects highlight the need to improve the screening of biocontrol agents, to improve knowledge on efficacy-related issues, to promote multi-disciplinary approaches to integrate biocontrol with IPM, to develop adapted delivery technologies and to safeguard the durability of biocontrol. For CBC the priority is for research on ecological interactions, especially at large scales, and to demonstrate the effect on pest suppression. Other key issues relate to training of advisers and farmers, the development decision-support systems and the establishment of farmers' networks. Future issues for industry include quality control and the improvement of distribution systems.

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EXPLOITATION AND DURABLE MANAGEMENT OF PLANT GENETIC RESISTANCE FOR IPM

Pest and disease resistant cultivars are key elements for pathogen control, pesticide reduction, and food security. However, their resistance is often overcome by pathogen evolution. Combining different resistance factors in varieties, evaluating the selection pressure on pathogen populations, and modelling pathogen evolution are cornerstones of durable and well-designed breeding and deployment strategies for this component of IPM.

All cultivated plant species are susceptible to pests and diseases. However, natural plant genetic resistance is available in almost all plant species, either in cultivated species or in wild relatives. For example, wheat is generally susceptible to yellow rust, but resistance can be found in several wheat varieties and related species. Apple is susceptible to scab, but strong resistance is observed in old cultivars and wild Malus species. Genetically based resistance may thus be a simple and efficient solution to protect plants against pathogens. However, pathogens and pests evolve. Thus, when a resistant variety is planted and exerts selection pressure on a local pathogen population, the result may be pathogen adaptation to the newly introduced resistance. Durable management of plant genetic resistance is therefore a major issue.

Apple scab resistance assessment in a glasshouse (INRA). Foreground: actively growing grafted plants; background: plastic film covering the inoculated plants to maintain a high relative humidity during the first 48 h after inoculation. ©INRA.

Approaches

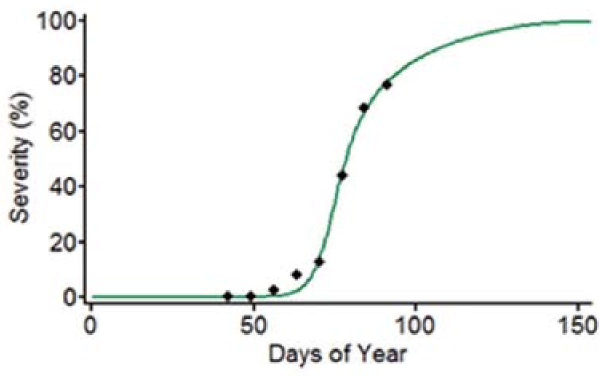
An ENDURE research group is specifically addressing the question of optimal exploitation of plant genetic resistance. It aims to assess and predict the impact of disease resistance genes in crops on pathogen population dynamics to yield decision support for choosing resistance genes (and gene combinations) in breeding strategies and to optimise deployment of resistant varieties in space and time. Two areas of research were developed: one dealing with biological experiments to assess selection pressures exerted by resistance genes on pathogen populations, and one focussing on modelling pathogen population dynamics and evolution to derive effective resistance deployment strategies in time and space.

Biological experiments

Our experiments targeted several pathosystems (wheat rust, wheat septoria blotch, oilseed rape black leg, pepper/tomato nematodes, apple scab, and grape mildew) to examine diversity changes in pathogen populations and the fitness of different pathogen strains subjected to host genotypes differing in resistance factors.

Modelling

Modelling approaches were based on three models constructed previously at INRA, Wageningen and Aarhus University. These were extended or adapted to new situations or pathosystems. The models consider main features of host-pathogen systems such as crop growth, pathogen dispersal capacity, proportion and spatial arrangement of resistant and susceptible varieties, types of resistance (complete or partial, pyramiding several resistances in a single variety versus using them in separate varieties), corresponding pathogen fitness, and rotation of varieties with diverse resistance properties in time. The models describe the dynamics of pathogen density in time and space with corresponding disease severity and genetic composition of the pathogen populations in relation to landscape, agronomic measures and weather conditions.



The goodness-of-fit of the INRA model (solid line) to data (points) of the yellow rust severity on a susceptible variety in pure stand in field plots inoculated by a yellow rust pathotype. (Vallavieille-Pope et Goyeau, 2004).

Experimental design for testing adult wheat plants resistance to *Septoria tritici* under polytunnel conditions
©IHAR

Results

Some of our key results are as follows:

• random spatial patterning of different monogenic (single gene) resistance traits can reduce pathogen density and corresponding disease severity at the same level as multigenic resistance (based on more than one gene); thus pyramiding major resistance genes can be favourably replaced by breeding several monogenic resistance varieties to be grown in mixtures.

• maintaining high proportions of cultivars with non-specific (partial) resistance and/or deploying cultivars with high levels of such resistance are durable option for resistance deployment.

• combining monogenic resistance and quantitative (partial) resistance in a single variety was shown to extend the time span during which monogenic resistance remains effective.

• rotating cultivars with major genes for resistance over time and/or pyramiding several of such genes into single cultivars risks the evolution of pathotypes with multiple virulence traits.

• if pathogen races able to breakdown mono- or multigenic resistance exhibit reduced fitness, spatial heterogeneity of resistant/susceptible varieties can significantly decrease the pathogen density and the rate of spread of new races. However, such reduced fitness is not always observed.

• the use of susceptible varieties in mixtures with moderately resistant varieties decreases mixture efficacy, favouring multi-virulent pathotypes. Varieties with moderate levels of resistance can be effectively exploited in mi xtures including highly resistant varieties.

• at the landscape level, fine-scale mixing of resistance (within field mixtures) is the most effective option.

• pathogen dispersal capability does not influence the relative contribution of landscape level measures to disease suppression.

• combining spatial heterogeneity and rotation in time (for annual crops) of genetic resistances with other non-genetic IPM methods (sanitation, biocontrol, reduced spraying etc) should be the best way to preserve the efficacy of genetic resistance over time.

• the tactic of combining reduced rates of fungicide with partial plant resistance deserves more attention both experimentally and by computer simulation.

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DURABILITY OF RESISTANCE TO ROOT-KNOT NEMATODES IN TOMATO AND PEPPER

Incorporating durable root-knot nematode resistance into Solanaceous crops like tomato and pepper is a major challenge for plant breeders. Our aim in ENDURE was to evaluate the effects of resistance genes used in different genetic contexts on the ability of virulent nematodes to overcome them, in order to promote the durability of these genes in time and space.

Damage on susceptible plant.

Root-knot nematodes (RKN) *(Meloidogyne spp.)* are major plant pathogens of vegetables in most production areas, including the Solanaceous crops tomato and pepper. Due to the banning of chemical nematicides, current control strategies are based mainly on the deployment of resistance *(R)* genes, eg *Mi(s)* in tomato and *Me(s)* in pepper. These genes are effective against a wide range of RKN species, including M. *arenaria,* M. *incognita* and M. *javanica,* the most common species in temperate and tropical areas. However, the recent emergence of virulent populations able to overcome the resistance conferred by some of these R genes may constitute a severe limitation to their use in the field. Our major objectives were to evaluate and promote the durability of these R genes under agricultural conditions. For that purpose, we designed a set of experiments to evaluate the effects on the nematode populations of the selection pressure of R genes used in different genetic contexts: pyramiding versus alternation of R genes, quantitative effects of different genetic backgrounds, and dosage effects of R alleles (homozygous versus heterozygous).

Evaluation of resistant genotypes

Using molecular markers developed for marker-assisted selection, we have constructed and evaluated tomato and pepper resistant genotypes. First, we showed that the tested R genes direct different response patterns in root cells depending on the pepper line and nematode species, and that these different response patterns are linked to the possibility or not for virulent nematodes to overcome the *R-genes*. For this reason, the pyramiding of R genes based on their complementary mode of action may make it possible to prevent the breakdown of RKN resistance.

By comparing the resistance conferred by heterozygous or homozygous R genotypes in susceptible or partially resistant genetic backgrounds, we showed that both the number of R alleles and quantitative non-specific effects may influence the selection pressure exerted by the R-genes on RKN populations. In all these experiments, the life-history traits and reproductive fitness of virulent and avirulent nematodes were compared. Interestingly, a fitness cost was found associated with unnecessary virulence (i.e., when virulent nematodes infested susceptible plants) in laboratory-selected populations.

These results indicate that, although plant resistance can be broken, it might prove durable in some conditions if the virulent nematodes are counterselected in susceptible plants. This could have important consequences for the management of resistant cultivars in the field.

Perspectives

Three-year field experiments are currently in progress to compare i) the alternation of single *R-genes* in rotation, ii) a mixture of lines bearing single *R-genes* sown in the same plot, and iii) the pyramiding of two *R-genes* in one line. Results will allow the identification of conditions lowering the emergence of virulent biotypes of RKN in the field, and to assess the time required for the improvement of soil health (reduction of parasites under their damage threshold) using R-plants as RKN "traps”. This transfer from the laboratory to the field will constitute the ultimate validation of the previous observations.

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THE EFFECTS OF CROP ROTATION ON WEEDS IN ARABLE CROPPING SYSTEMS ACROSS EUROPE

We tested whether crops, grown in sequence ('rotations'), have important effects on the standing weed amount in arable fields across Europe. Data were provided by ENDURE partners on percentage area of ground covered by weeds (weed %cover), count and biomass. Analysis of these data showed that measurements of weed amount could be converted to counts for analysis. We find that rotations can be used to produce predictable changes in weed amount and might be manipulated to achieve EU-wide targets for crop yield.

Weeds are extremely important components of the agricultural ecosystem. They are probably the single most important constraint on crop productivity. However, they also support wider functional biodiversity, such as bio-control, either by providing food or shelter for beneficial organisms. Getting the balance right between these competing beneficial and detrimental properties of weeds is a primary goal of ENDURE and a necessary prerequisite for achieving Food Security-driven goals of increases of at least 50% in food production by 2030 with minimal impact on the environment (OECD-FAO 2008; Royal Society 2009). Within ENDURE we have asked whether: 1) rotations might be used to changes in weed amount, irrespective of the levels of pesticide management; and, 2) the resulting patterns of weed amount might be applied EU-wide?

Weed data

Data were provided on weed %cover, count and biomass, and the cropping sequence, for fields from Denmark, Germany, Hungary, Italy and the UK. As these different measures of weed amount could not be analysed together, we asked whether the measures could be standardized by converting them to weed counts?

We found that both weed %cover and biomass were strongly related to weed count. These relationships were not greatly affected by the country or crop the weeds samples were measured in. We also found that there was little difference in the relationships for grass and broadleaved weed types. Unsurprisingly, there were important effects of the timing of sampling; the weeds were found to grow larger over time. The fits of the full models were good, indicating that %cover and biomass could be converted in counts for our analysis of rotations.

Rotational analysis

The rotational analyses on the EU data are currently ongoing. Preliminary analysis of the UK weed data-set has shown there are historical effects of past crops on weeds for up to 3 years. We also find that the crops may be simplified to crop management classes describing the sowing date, crop and herbicide type; for example winter wheat becomes a winter-sown cereal with similar properties to other winter sown cereals. We have validated the model predictions against an independent dataset. This work shows that rotational analyses could be a powerful tool for estimating and predicting weed abundance in current crop sequences, potentially allowing sequences that better reconcile the competing needs for weed control to maintain crop productivity and the demand for increased farmland biodiversity to be identified.

Conclusions

- Different measures of weed %cover and biomass can be standardized by conversion to weed counts;
- relationships were not greatly affected by country or crop, and there was little difference in the slopes of grass and broad-leaved weed types;
- weeds were found to grow larger over time, changing the relationships;
- preliminary analysis of the effects of rotations shows there are historical effects of past crops on weeds for up to 3 years;
- crops may be simplified to crop management classes describing the sowing date, crop and herbicide type;
- the rotational model predictions have been validated against an independent dataset;
- this suggests that rotations might be used to predict and achieve EU-wide targets for crop productivity and functional biodiversity for IPM.

Where now?

We believe that rotations might be used to achieve EU-wide targets for crop productivity and functional biodiversity, and we can predict weed count values for particular crop sequences. These predictions should be experimentally tested and validated across the EU. To show that we can predict in-field weed counts from crop sequences would be extremely powerful, not just for farmer stakeholders, and emphasise the great value of EU-wide scientific research.

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THE WEED TRAITS DATABASE:
a resource for predicting shifts in weed communities

The weed community present in any given field is largely a product of management history including crop rotation, herbicide choice and type of cultivation. Therefore, any changes in crop husbandry associated with increased uptake of integrated pest management strategies may result in shifts in the weed spectrum regardless of whether those strategies are directly targeted at weeds. We have constructed a Weed Traits Database for 21 common European weeds in order to predict these shifts in weed communities and allow future problems to be anticipated and mitigated.

Recent decades have seen dramatic shifts in the species community composition of arable weeds both on a National and European scale. Increased use of fertilisers and herbicides, together with changes in cropping patterns have selected against certain groups of weeds and left present-day communities of competitive species or ones that have developed herbicide resistance. These changes can be interpreted in the context of plant traits (or characteristics) that have responded to the changes in management. For example, a shift from spring to autumn cropping has selected against obligate spring emerging weeds in the UK. The trait-based approach also has the potential to predict future shifts in weed communities in response to novel crop management strategies, including the uptake of integrated pest management, and the consequences for production and biodiversity.

Why do we need a Weed Traits Database?

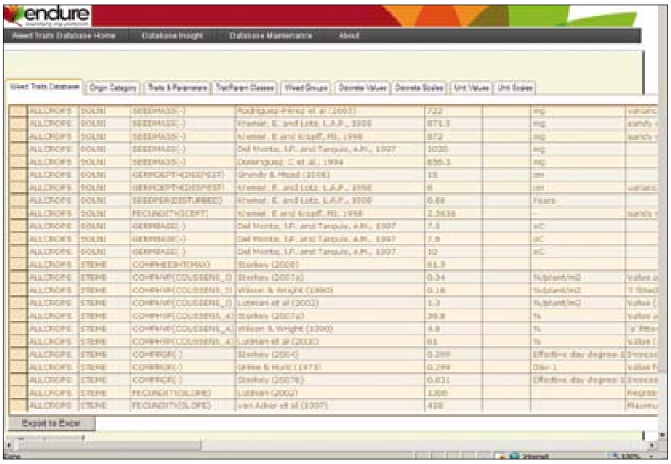

Figure 1 - Screen shot of Weed Traits Database.

Using plant traits to predicting the impact of changes in crop management or climate on weed communities involves a number of steps:

- Define specific drivers such as timing of cultivation associated with changes in crop management
- Identify traits that will respond to these drivers
- Use computer models to generate scenarios and quantify relative importance of drivers.
- Interrogate traits database to identify weed species that will be positively or negatively affected by management change.

The last step in this process relies on a source of data on relevant weed traits. The majority of these data are already present in the literature for the commonest weeds in Europe. However, the data are difficult to find. We have therefore built a web-based Weed Traits Database (WTDB) for 21 common European weeds (Figure 1). The choice of traits to be included was driven by the requirements of a weed population dynamics model developed within the Universal Simulator software (see companion article in this chapter).

Weed population models have been criticised in the past for promising much in terms of predicting of absolute numbers of weeds under different scenarios but delivering little in terms science that is of practical use to a farmer. The development of WTDB addresses this concern. We acknowledge that predicting the dynamics of a single species in a field may never be achieved with sufficient accuracy to inform control decisions without prohibitively detailed measurement of environmental variables. However, we do believe it is possible to use models to identify qualitative shifts in weed floras by identifying the traits that respond to management and comparing the values of those traits within the species pool.

A future for the WTDB

The intention has been to make the WTDB as complete as possible for the traits and species currently included. However, for it to be a useful tool for the future advance of weed science, three things need to be done. Firstly, the usefulness of the trait based approach needs to be demonstrated by validating the functional predictions against published data on weed community shifts under changing management. Secondly, the WTDB needs to be dynamic in that new data should continually be entered and analysed by the international weed science community. Both of these objectives rely on a final criterion: the continued funding of the IT infrastructure and scientists to support the database. The scientific consortium responsible for the development of this valuable tool is committed to meeting these objectives.

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THE POTENTIAL OF LANDSCAPE MANAGEMENT IN IPM

The ENDURE project provided an exciting opportunity to assess the role landscape management might play in suppressing pests and encouraging natural enemies and to identify future research challenges for its implementation in IPM programs. Our conclusions, drawn from literature reviews and data analyses, are that landscapes can markedly affect the abundance of insect pests, via their natural enemies, and also affect weed diversity.

A farmed landscape with semi-natural habitats.
© Rothamsted Research.

The potential for landscape management to reduce pest problems in agriculture fields has been the focus of a major study within the ENDURE project. Traditionally pest control is focused in farmers' fields where the insect, weed and pathogen pests do their damage. However, many pests migrate or disperse at a larger scale and may make use of non-crop elements of the landscape at times when they are not damaging crops. Natural enemies that control pests also move around the landscape and may make use of both crop and non-crop habitats.

Over the last 20 years it has been increasingly recognised that landscape management has a role to play in suppressing pests and encouraging their natural enemies. Yet there are relatively few examples where the principles of landscape management have been implemented. ENDURE has represented an exciting opportunity to bring together scientists with a range of expertise on agronomy and on pest biology and ecology to evaluate knowledge on landscape management for pest control and to explore tools to study and design pest-suppressive landscapes.

What is a landscape?

Ecological landscape is the physical arrangement of different elements, such as land use, vegetation types, resources etc, and can be described in terms of the proportion, spatial structuring and temporal dynamics of the elements. Most important for pests and natural enemies are the landscape elements that provide them with the resources they need such as food, space, favourable microclimatic conditions and refuges from their enemies. Each of these could affect pest abundance directly by affecting their dispersal, mortality or reproduction, or indirectly by affecting pest control by natural enemies. In agricultural landscapes, the spatial distribution of resources as well as their dynamics through time are affected by farming practices and by the regulatory framework within which farmers operate.

The questions addressed by the ENDURE study:

1/ What is expert opinion of the potential for landscape management to suppress insect pests by encouraging natural enemies?
2/ What landscape characteristics lead to suppression of insect pests and weeds?
3/ What future approaches are needed to achieve pest-suppressive landscapes?

Expert opinion of landscape management for insect pest suppression

• In a study of expert review papers, almost all of 154 reports on managing resources in the landscape for pest suppression cited a benefit to natural enemies. Half cited a strong benefit.
• 82% of the 77 reports that cited effects on pests indicated that landscape resource provision was also linked to a positive effect on pest control. 17% showed strong effects.
• Evidence for benefit was strongest in arable crops, field vegetables and vineyards.

Landscape characteristics that affect insect pests and weeds

• Semi-natural habitats in the landscape favour in-field attacks against pests by natural enemies.

• Other beneficial measures include diversification of crop and landscape vegetation, provision of habitat corridors to encourage movement and provision of refuges.

• There are significant correlations between the area devoted to a particular crop at the landscape level and the abundance of pests in these crops.

• Landscape structure appears to affect weed diversity in fields

A farmed landscape with semi-natural habitats.

more than landscape composition. Weed diversity increases when the number of landscape elements increases, whatever the vegetation in these elements. This may be because more boundaries between elements, provide more refuges for weeds in complex landscapes.

Recommended future approaches and conclusions

This ENDURE study has highlighted the potential that landscape design has to make a strong contribution to IPM and reduce the need for chemical pesticides. Our results indicate that landscape characteristics affect the abundance of pest insects via their natural enemies, and affect weed diversity in fields. Both composition and configuration of the landscape have a role to play: the presence of resources (e.g. uncultivated or untreated areas) helps to increase biocontrol of pests, whereas landscape structure seems to affect weed diversity.

How can landscape design for IPM be implemented in the real world? Most European landscapes are shaped through human activity, largely at the level of the individual but this activity is modified through government planning and regulation from the local to the European level. The spatial scale at which the landscape functions demands the involvement of government planning if the type and intensity of land-use is to be modified to build pest-suppressive landscapes. There are important challenges that currently limit the development of policy for encouraging landscape management for IPM. We identify the following issues that should be considered by funders and researchers to provide the evidence-base to enable policymakers to implement landscapes for IPM:

Carabid beetles eat both insect pests and weed seeds.

- Further progress in the design of landscapes for IPM is likely to depend on future large-scale studies and combined analysis of data from multiple research groups.
- Agreed, common approaches and methodologies are therefore needed. The current diversity of descriptors, measurements and methodologies limits the ability to compile and compare the results of existing studies.
- Landscape descriptions conventionally used in landscape ecology are often not appropriate to the agricultural environment. In particular, more consideration should be given (i) to measurements of landscape structure and (ii) to recording the impact of farmer practices at a landscape scale.
- Modelling of pest and natural enemy behaviour in virtual landscapes should be used to enable the testing of landscape arrangements that would be difficult or impossible to replicate on the scale of a real landscape.

The larvae of hoverflies feed on aphids.

Where now?

This study predicts that pest-suppressive landscapes could be achieved by the distribution of sufficient non-cultivated habitats within them. If landscape management is to become a practical tool for policymakers to reduce dependence on pesticides, this prediction must be tested at a European scale to demonstrate the generality and robustness of the principle. We propose a comparative study using paired landscapes with different amounts of non-cultivated habitats and/or crop diversity in different European regions, focusing on quantifying the effect of landscape composition and layout on the abundance of natural enemies, their effect on pests and the benefits to crop productivity.

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THE ENDURE VIRTUAL LABORATORY: a resource supporting the development and implementation of IPM in Europe.

The ENDURE Virtual Laboratory is a multidisciplinary resource intended to support all aspects of research on crop protection including basic work on novel interventions as well as the integration, through experimentation and modelling, of control tactics into coherent and sustainable IPM systems. Having evolved during the course of the ENDURE project, it is seen as central to supporting the durability and future expansion of a partnership committed to the validation and wider implementation of IPM for agriculture in the EU.

Since the inception of the ENDURE project, partners in the consortium have been coordinating research efforts, collating existing data and information on IPM, and sharing expertise in most areas of the biosciences that relate to crop protection. This work has generated numerous outputs in terms of new results, protocols and tools that provide a foundation for the improvement and wider implementation of IPM strategies in an EU context.

The ENDURE Virtual Laboratory (VL) was initially conceived as a central repository of experimental material, facilities and methods being contributed by partners to support collaborative research within the consortium. The sharing of these resources was seen as essential to confront new challenges posed by the need for sustainable intensification of agriculture and to address new policy requirements introduced by the EU and by national agencies.

Figure 1 - Front page of the ENDURE Virtual Laboratory (http://vl.endure-network.eu/) showing the two main sections of the VL and in this case (Physical Resources) the different categories of resources available.

Representatives of all partner organisations contributed the data necessary to populate 'core' elements of the VL including information on sites for field experimentation and unique collections of insects, pathogens, seeds etc. As ENDURE as progressed, the VL has assumed a broader support role through the hosting of research platforms and other outputs of the ENDURE project including databases and modelling tools.

Technical specifications and content

The VL is coded in PHP which integrates with a number of central MySQL databases dedicated to specific areas of the VL. Development work is done locally on servers at Rothamsted before the final version of each release is uploaded to the ENDURE Tools Server hosted by JKI in Germany. The entry portal (Figure 1) is designed to provide intuitive links to the major features, which are either embedded within the VL or reached via hyperlinks to resources hosted elsewhere. A schematic showing the key aspects of IPM research supported by the VL is shown in Figure 2.

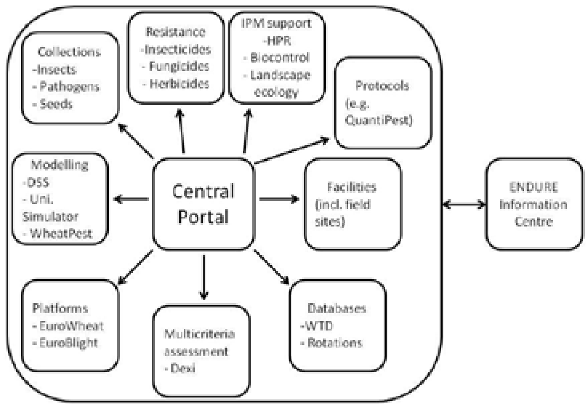

Figure 2 - A schematic showing the key aspects of IPM research supported by the ENDURE Virtual Laboratory.

Many of these are under development, awaiting outputs of research activities reported on elsewhere in this volume. Major features include:

• EuroWheat (see separate article) is a comprehensive synthesis of existing knowledge of wheat pathogens and their control. Information on fungicides is included to assist decisions on optimal choice of compounds and dose-rates aimed at minimising chemical inputs and contending with fungicide resistance problems.

• EUResist aims to collate knowledge and ongoing research activities across Europe relating to the analysis and management of resistance to insecticides, fungicides and herbicides. It complements the outstanding distillation of information and training material provided by the industrially-led international Resistance Action Committees.

• QuantiPest (see separate article) is an initiative to support field-based experimentation to evaluate and validate IPM tactics. It covers pest diagnosis, sampling and other aspects of experimental design.

• Modelling tools (analytical and simulation-based) that have a key role in developing a system-based approach to understanding ecological and evaluating the sustainability of different crop protection scenarios. This includes the mathematical underpinning of computer-based decision-support models developed to aid precision agriculture.

• Databases supporting theoretical investigations of pest population dynamics (eg. the Weeds Traits Database – see separate article) or of trophic relationships between crops and pests under different management practices (eg. contrasting crop rotations)

Future developments

The VL is seen as a critical component of the continuation of the ENDURE partnership to underpin crop protection science and policy, in conjunction with a other organisations with complementary expertise. To reduce the cost and effort of expansion, new features can be added primarily as hyperlinks although there will be a continuing and important commitment to maintaining and updating the existing content. Future development will be linked closely to research projects involving partner organisations to ensure relevance to the changing face of crop protection in Europe.

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EUROWHEAT.ORG
Support for integrated disease management in wheat

Wheat diseases have a major impact on yield, quality of grain and fungicide requirements. EuroWheat collates data and information on wheat disease management from several countries, analysing and displaying this information in a European context. It provides significant added value on a European scale to support local advisers, breeders and other partners dealing with disease management in wheat through supporting IPM in the broadest sense.

Information in EuroWheat

Fungicides

Many countries provide information about fungicide efficacy based on national field trials. EuroWheat has collected this information giving an overview of registered products, their efficacy (Fig. 1) and resistance risk:

• Fungicide efficacy ranking – eight wheat diseases ranked by five different countries

• Review on problems related to fungicide resistance

• List of fungicide trade names and actives in different countries, as a searchable feature

• Survey on pesticide use and yield responses to fungicides in some EU countries

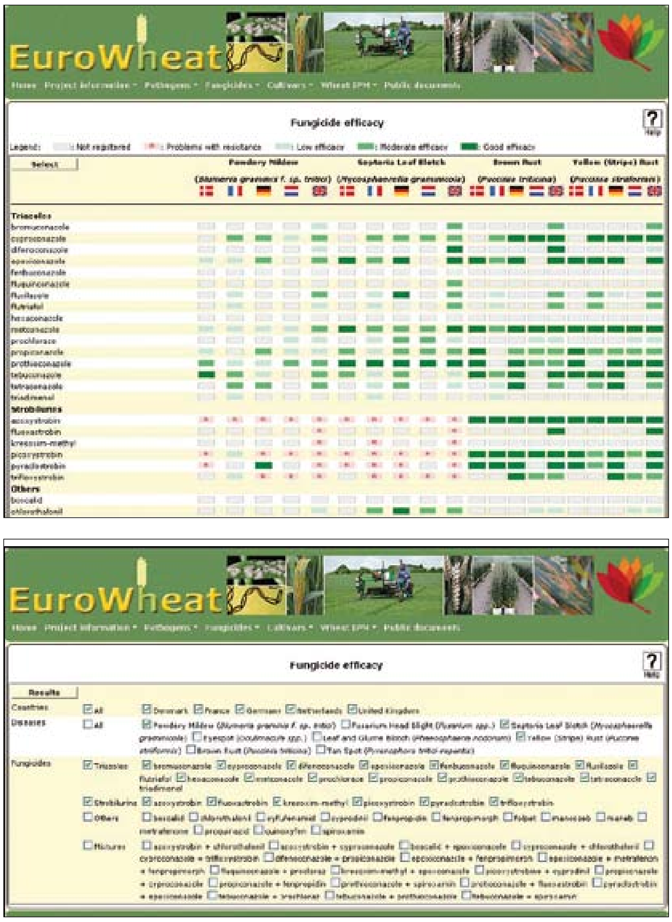

Figure 1 - Five countries ranking of fungicides efficacy for control of different diseases on the EuroWheat.org website.

Wheat IPM

Under this heading information and links to relevant disease management tools are given:

• Overview and links to decision support systems dealing with wheat diseases in Europe

• Wheat disease thresholds recommended in eight countries

• Information and thresholds for seed borne diseases

• Overview and documentation of cultural practices reducing specific diseases

Pathogens

Pathogen characteristics such as virulence and aggressiveness play a significant role in evaluating the risks of disease epidemics in cultivars possessing various sources of disease resistance. Since many of the most damaging pathogens, such as the rusts, may be spread by the wind across national borders, updated information about pathogen features in neighbouring countries serve as an 'early warning' for farmers:

• Overview and analysis tool for wheat yellow rust virulence pathotypes in Europe (six countries)

• Fusarium head blight: how to minimise attack and mycotoxins

• Cultivar resistance to Fusarium head blight, including ranking of cultivars

Cultivars and yields

The cultivars grown vary to a great extent between countries. Grain yield may vary significantly across cultivars and environments due to the genetic yield potential and environmental stresses, including climate and disease pressure:

• Links to national cultivar databases

• Yield levels in different countries

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WHEATPEST: a new tool to analyse yield losses caused by diseases, weeds and insects on wheat.

The primary objective of crop protection is to limit crop losses. To achieve this goal, prevention of various pests (pathogens, weeds and animal pests) has to be taken into account in the design of cropping systems (prophylactic measures). It is therefore essential to be able to rank yield losses in order to help define priorities, not only in terms of tactical and strategic decisions for farmers but also for defining economically-efficient research programs. A model called WHEATPEST was developed within the ENDURE network to help analyse wheat yield losses.

The production system-injury profile relationship

A production system is represented by the set of environmental (physical, chemical, biological) and socio-economic factors underpinning the yield of a given crop. Production systems can be defined on the basis of the combination of crop management practices occurring in a given field. This is because strategies and tactics for crop management are a reflection of the physical (soil and climate), chemical (soil and atmosphere), biological (cultivars and biotic factors), and socio-economic (e.g. markets, farm organisation) environments where a crop is grown.

An injury profile is defined as the combination of injury levels caused by the multiple pests (pathogens, weeds, animal pests) that affect a crop during a growing cycle.

Strong links exist between production systems and injury profiles. These links have been demonstrated for several crops worldwide. The production system-injury profile relationship can therefore be used as a framework to model yield losses caused by multiple pests.

Modelling complex systems does not require complicated models!

Considerable effort has been made to model both crop growth and pest epidemiology. Because of the complexity of such models, and the numerous interactions they address, it did not appear appropriate to increase complexity still further by combining a sophisticated crop model with one of the epidemiological models already available. A different approach was used to develop WHEATPEST. The knowledge available in published papers was captured within a simple generic framework that had been already used for rice and potato. All parameters of WHEATPEST have been derived from published papers.

Input, state and output variables of WHEATPEST

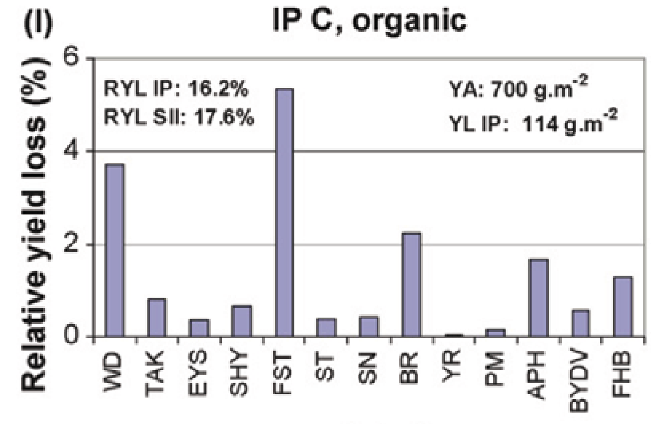
• Three types of output variables are simulated by WHEATPEST: attainable yield, yield losses caused by individual pests, and yield losses caused by the injury profile.

• The state variables of WHEATPEST are: development stage, dry weight of organs (roots, stems, leaves, ears), and Leaf Area Index.

• Several drivers are required to run WHEATPEST. Climatic data describing mean daily temperature and solar radiation must be provided as well as the dynamics of radiation use efficiency. The dynamics of 13 types of pest are also required: weeds, take-all, eyespot, sharp eyespot, fusarium stem rot and head blight, Septoria triciti, Septoria nodorum, brown rust, yellow rust, powdery mildew, aphids, and barley yellow dwarf virus.

Evaluation and sensitive analysis of WHEATPEST

It is always good practice to evaluate the predictive power of a model. Data coming from various trials in France (INRA), Poland (IHAR), and Denmark (Aarhus University) were used to assess the predictive ability of WHEATPEST. A wide range of climates and cropping systems were represented in the datasets. The performance of WHEATPEST appeared to be reasonable (similar to those of other crop models that do not include pests). However, predicted yields were sometimes quite different from the observed values. A thorough sensitivity analysis was done to identify the most influential parameters that will be adjusted to improve the predictive power of the model.



Example of outputs provided by WHEATPEST for an organic production system - RYL IP: relative yield loss caused by the injury profile. RYL SII: relative yield losses cumulated over the individual injuries. YA: attainable grain yield; YL IP: grain yield loss caused by the injury profile. WD: weeds, TAK: take-all, EYS: eyespot, SHY: sharp eyespot, FST: fusarium stem rot, ST: Septoria tritici , SN: Septoria nodorum , BR: brown rust, YR: yellow rust, PM: powdery mildew, APH: aphids, BYDV: barley yellow dwarf virus, FHB: fusarium head blight.

A two year experiment in Central Europe

A two year experiment was done in Poland (IHAR) to characterise four contrasting crop management systems for spring wheat: intensive, integrated with possible use of pesticides, integrated without pesticides, and organic systems. Climate, crop status, injury profiles and yields were monitored. The results constitute a reference in terms of agronomic, economic and environmental performances of various crop managements of spring wheat in Central Europe. These results also contributed to the evaluation of the predictive power of WHEATPEST.

Experimental wheat field in an organic certified farm Gogole Wilekie, Poland.
© IHAR.

What's next?

Beyond the potential integration of new features (e.g. representation of other pests in the model, prediction of qualitative losses), WHEATPEST can be used to perform diagnoses of existing production systems of wheat, to anticipate the risk of yield losses for innovative crop management plans, to help design protocols to characterise injury profiles encountered in various European production systems, and to help define priorities in terms of research programs. WHEATPEST is already used as an educational support for pre- and post-doctoral students. An online version of WHEATPEST is available through the virtual lab of ENDURE. This online tool allows users to run the model with their own set of input variables and parameters. Numerical as well as graphical outputs are downloadable.

Reference

Willocquet L, Aubertot JN, Lebard S, Robert C, Lannou C, Savary S. Simulating multiple pest damage in varying winter wheat production situations. 2008. *Field Crops Research. 107 (1): 12-28.*

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QUANTIPEST:
a collaborative platform for research on pest characterisation.

QuantiPest is one of the research platforms of the ENDURE Virtual Laboratory. It is being developed to support experimental design and the sharing of protocols to characterise pest injuries or pest populations. This will in turn improve the consistency and comparability of work on crop protection.

European agriculture needs to develop and implement new crop protection strategies with reduced dependence on pesticide use. Within ENDURE, the Virtual Laboratory (VL – see separate article in this chapter) aims to ensure the durability of the network by sharing of knowledge, resources and facilities. The VL includes a number of research platforms on specific topics of importance for research on Integrated Pest Management (IPM).QuantiPest is one of these platforms and focuses on pest characterisation by providing information to help design protocols appropriate for characterising pests or pest injuries in small-scale field experiments or in commercial fields.

QuantiPest: aims and objectives

Many references and tools have been produced in order to identify and quantify pest injuries and pest populations, but this information is fragmented. QuantiPest aims to overcome this fragmentation by providing access to the most relevant information sources, methods and protocols. The platform is not intended to be exhaustive in this respect, but rather to provide references, methods and tools to help the development of protocols adapted to specific experimental objectives.

QuantiPest: content

The types and the sources of information available in the platform can be diverse. Documents can be website links, article/book references, pictures, documentation on sampling methods, examples of methodological studies and methodological tools, protocols, scales for pest pressure characterisation, useful software and numeric applications, computer aided programs for training purposes. The content evolves continually and is updated thanks to users' contributions.

QuantiPest: structure

The platform is structured around three main areas:

1/ A knowledge area which consists of educational pages containing information on pest and pest injury identification, pest and pest injury quantification, methods and tools for sampling.

2/ A documentary management area that allows user to search, by keywords, for relevant documents in the documentary database associated with the platform.

3/ A training area that gives access to training programs designed to help users to improve their abilities in pest/pest injury identification or quantification.

QuantiPest: functionalities

As QuantiPest is a collaborative platform, it includes functions that allow users to comment and discuss the information provided by the platform. Users can also suggest other approaches or references using an input mask linked to the documentary database associated to the platform. Another function allows the design of training programs that consist of a set of multiple-choice questions with pictures. "Mosaic of pictures" is a function that assists users with identifying pest or pest injuries: users navigate through successive sets of pictures to find the description of the pest related to the most similar pictures.

Target group

QuantiPest is mainly targeted at researchers, engineers and technicians that perform experiments in fields or in greenhouses, in order to understand a mechanism under a production situation (from plot scale to landscape level) or to assess alternative methods to pesticide use and IPM strategies.

QuantiPest is also targeted at engineers and technicians involved in monitoring or scouting for pests or pest damage in commercial fields.

Benefits for QuantiPest's users

QuantiPest represents a time-saving resource for users, providing rapid and easy access to information on the most relevant and tested protocols.

It can contribute to aspects of experimental design and to the standardisation of methods of data capture and processing. The information sources included in QuantiPest are diverse, and as well as scientific papers include the content of the 'grey' of the grey literature and personal expertise. By facilitating these key components of research on IPM, the platform is intended to be a durable resource supporting the sharing of expertise and collaborative research across Europe. In this respect, it complements the overall objectives of the VL.

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UNIVERSAL SIMULATOR: an open-source tool for collaborative ecological modelling.

Universal Simulator (UniSim) is a software package for collaborative ecological modelling, developed within ENDURE with co-financing from Danish funders. UniSim is extendible and open for re-use. It is open-source software according to the GNU General Public License. UniSim was developed as a tool for better collaboration in ecological modelling – to study the dynamics of pests and to assist with developing and evaluating crop protection strategies.

What are models? According to the philosopher Wittgenstein, language itself is a model of the world. When we think and communicate about the world, we are building upon a model of the world. In the natural sciences, models of the world are formulated in mathematics. The resulting description is precise, which helps when presenting and discussing the model. In addition, the formalism of mathematics makes it possible to infer and hypothesize about the nature of the real world, based on the model description. Thus models can both deepen our understanding of the world and be a tool for practical planning and problem solving.

Models in physics are exact descriptions of the physical world. What the mathematical equations describe, and what we sense, are equally true representations of reality. In ecology, however, the systems under study are alive, ever-changing, complex and incorporate a great deal of uncertainty. Hence ecological models cannot be exact representations of reality. They are reduced versions, representing only the most important components and processes and applicable only under certain defined conditions.

'Black box' approach

Ecological models can easily become very large. The mathematical logic of big models is usually implemented in computer software. Software tools help, both to manage model complexity and to analyse model behaviour.

Due to the many resources going into the development of big models, their software is often proprietary: outsiders are not allowed to look inside the model. It is, as if we now have two objects under study (Fig. 1): one is the original system–open and full of nature's intricacies, the other is the model–a black box polished and unyielding to scrutiny.

For the natural system we can still use the methods of natural science, performing experiments and analyse the outcomes. The black box model, however, will remain an enigma, an artefact with some reported structural and behavioural similarities with the real system.

'White box' approach

Black box models hardly count as scientific products. Even though their makers describe how they function, how can we tell if they have not unknowingly made some error in their programming of the model? The most reliable and versatile models in science must be white boxes (Fig. 1): models that are as well-documented as their black counterparts but in addition are completely open to scrutiny. Whenever possible, scientific models should be implemented as open-source software. This is the approach adopted with the Universal Simulator.

Figure 1 - Natural system, black box model and white box model.

Universal Simulator

Universal Simulator (UniSim) is a software package for collaborative ecological modelling, developed within ENDURE with co-financing from Danish funders. It was originally developed as a tool for weed-modelling only but we soon realised that it had much broader application. Currently it forms the basis of models to simulate plant growth and the population dynamics of weeds and insect pests. Current users are found at several ENDURE institutions and, in addition, a few researchers from the USA.

UniSim is composed of a GUI (graphical user interface) main module which is used to open and execute model specifications read from XML files. The XML files specify the components constituting a model. The functionality of these components is defined in plug-in libraries. This makes UniSim extendable and open for re-use. It is programmed in standard C++ and is open-source according to the GNU General Public License. It is available from www.ecolmod.org. UniSim enables modellers to focus on just the detail they want to model. For instance, it is possible to construct a model for seed germination and then combine this with existing models of weeds, crops and farm management to extend its relevance and scope. The primary aims are to facilitate collaboration, reduce resource expenditure and maximise scientific progress.

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BUILDING SCENARIOS FOR EUROPEAN CROP PROTECTION IN 2030

The legislation on pesticides adopted by the EU in 2009 is setting the frame for a future where crop protection will not be able to rely on chemical control as much as it does today. While we are struggling to adjust practices within the short deadlines set up the new regulations, it is worth considering also to which crop protection systems deeper transformations over the next 20 years could lead.

To build up the five scenarios proposed in this foresight study, we first considered different agriculture futures and their influence on crop protection. In the context of rising global food demand, Europe could become a more active global trader or it could get concerned by food sovereignty and secure a diversified domestic production. European agriculture could ambition to become the world's breadbasket as climates change or it could focus on specialised high-quality products. European populations could become more urban and leave room for large scale agriculture or they could populate rural landscapes and expect ecological services from their farmers.

Of course, the five scenarios incorporate contrasted options in crop protection itself. Control methods could remain at the core of pest management, but would rely on a new generation of 'green chemicals' combined with a renewed set of cultivars with multiple resistances to pests. Or the introduction of multiple advanced technologies could allow efficiently preventing, forecasting and monitoring pest development, reducing the need to apply direct control measures, and finely targeting them so as to minimize their impact. Alternatively, the focus could be on designing diversified cropping systems that are inherently less likely to generate high pest pressure and more resilient to their effect. Managing the whole agro-ecosystem, beyond the mere cultivated area, could recruit functional biodiversity to regulate pest populations while producing other valuable ecological services.

Scenario 1: The Commodity Market Player

High food demand in 2010 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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Scenario 2: The Specialised High-Tech Grower

Here, high food demand caused trade barriers and subsidies to agriculture to disappear. Europe has 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 have 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 strongly mobilised. Precision agriculture is accompanying prevention.

© Aarus University.

Scenario 3: The Sustainable Food Provider

In this scenario, International authorities have reduced food tension by redistributing agricultural production. Protection barriers have been strengthened around developing countries, causing 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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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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Scenario 5: The Community-Conscious Farmer

The EU moves away from being a major exporter of basic agricultural products and invests in non-agricultural and service sectors. Territoires become instruments for economic growth, and agriculture is seen as essential to maintaining 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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Given the long lag period for the development of crop protection systems, we should realise that today's decision will shape the future of crop protection. The scenarios create distinct futures for farmers and other stakeholders and should enlighten their reflection according to their own goals. The study signals to policy makers that the change initiated by the new pesticide legislation requires support from further enabling policies, some of which reach beyond crop protection proper. Above all, providing the knowledge, technologies and innovation on which the scenarios rely is a tremendous challenge for research. In this study, ENDURE lays the groundwork for priority setting in a future pan European research program on crop protection.

A full version of the Foresight study 'European Crop Protection in 2030' is available on the ENDURE web site: www. endure-network.eu

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THE ENDURE SUMMER SCHOOLS: connecting PhD students worldwide.

As part of ENDURE's higher educational activities, three residential one-week Summer Schools for PhD students were organised by SSSUP at Volterra (Italy). The aim of the Summer Schools was to provide high-quality educational fora for discussion between PhD students working on crop protection issues worldwide and internationally renowned experts from ENDURE partners and other institutions.

Subjects

Three cutting-edge relevant interdisciplinary subjects linked to the development of novel strategies for improved IPM were selected for the Summer Schools:

"Biodiversity supporting IPM"
The objective was to provide a theoretical framework and analytical tools enabling the PhD students to critically review projects dealing with biodiversity in agro-ecosystems and to set up innovative research examining the elements and aspects of biodiversity which can positively affect sustainability related to crop protection. Biodiversity was treated at different levels, from gene to habitat and from field to landscape. The relevance of specific genes, species or habitat features for crop protection was explored from the points of view of the cropping system, of non-cropped elements (e.g. hedgerows, landscape configuration) and of the complex of noxious and beneficial organisms interacting in an agro-ecosystem.

"Modelling approaches to support IPM"
The objective was to provide a profound theoretical basis in modelling approaches in general and regarding different IPM applications in specific, to make students aware of the complexity of IPM modelling and to let them work on models created within the ENDURE Network. This has enabled the students to gain awareness on the importance of modelling to support field and lab research in IPM, to critically review existing models for crop protection, and to be more prepared in their own research projects to the difficulties rising from such complex modelling situations.

"New and emerging agricultural pests, diseases and weeds"
The objective was to stimulate students to develop a comprehensive approach of the problems posed by biological invasions in agro-ecosystems and of the possible solutions offered by IPM strategies in the light of the foreseeable evolution of technologies and of international policies on agriculture and trade. The impacts of new and emerging insect pests, diseases and weeds on crop yield, yield quality and the functionalities of agro-ecosystems have been treated in lectures spanning from the biology and ecology of these organisms to their management (including quarantine issues).

Educational approach
The Summer Schools were characterised by a very high level of interaction among lecturers and students, facilitated by team work and discussion sessions. Students prepared a poster presenting their PhD project, which was discussed in a dedicated informal session at the start of the week, also aimed to break the ice in the group. The interdisciplinary programme, the highly diverse composition of students in terms of expertise and geographical provenance, and the beautiful venue made all three Summer Schools very lively, stimulating and enjoyable events.
To sum up, the three Summer Schools involved 49 PhD students from 29 countries of the five continents (Table 1), selected from nearly 300 applicants.

Table 1 - Provenance of students selected for the three ENDURE summer schools.

COUNTRY	# STUDENTS	COUNTRY	# STUDENTS
Argentina	2	Italy	3
Australia	2	Lebanon	1
Austria	1	Madagascar	1
Burundi	1	Malta	1
China	2	Nigeria	2
Colombia	1	Pakistan	1
Croatia	1	Poland	2
Denmark	2	South Africa	1
Ethiopia	1	Spain	5
France	3	Switzerland	1
Germany	3	Turkey	1
Hungary	3	Uganda	1
India	2	UK	1
Iran	1	USA	2
Israel	1	Total	49

Follow-up
Several positive and spontaneous follow-up actions have stemmed from the success of the ENDURE Summer Schools. Students' networks have been created through common mailing lists and potential links between ENDURE and students' home institutions have been established.

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5 IPM IMPLEMENTATION

The ingredients for successful IPM implementation in Europe

ENDURE takes a step back to look at the bigger picture. Researchers from both the biophysical and the social and human sciences jointly look beyond the biophysical realm at social, human and economic factors key to the implementation of IPM. Their relation to policy is addressed. The ENDURE Network of experts offers assessments on specific questions relevant to IPM implementation.

ENDURE defines Integrated Pest Management (IPM) as "*a sustainable approach to managing pests by combining biological, cultural and chemical tools in a way that minimises economic, environmental and health risks.*" It sees IPM as a continuously improving process in which innovative solutions are integrated and locally adapted as they emerge and contribute to reducing reliance on pesticides in agricultural systems.

Historically, IPM is an approach to crop protection that emerged from the biophysical sciences in the 1950s. Since then, researchers and extensionists worked hard identifying technical solutions or approaches to developing solutions for IPM practice to become a reality. The need to widely implement IPM now appears increasingly both more urgent and more feasible. More urgent because of the current societal demands now translated into European, and soon into national legislation. More feasible because significant advance in biological and agronomic knowledge now make it possible to support IPM practice in a number of cropping systems. Now, the crop protection community realises that advances beyond the biophysical sciences and outside research are also required.

It is akin to taking one step back as a way to get the "bigger picture". A more systemic understanding that can help answer questions such as "why haven't farmers adopted IPM yet?" and "what would it take for mainstream farmers to widely adopt IPM?". ENDURE researchers from both the biophysical and the social and human sciences jointly addressed such questions. The research shows that farmers are a part of a larger social and economic environment which currently favours pesticide-based crop protection. The study of this stable mesh of social interactions and economic forces allows us to identify the changes needed for a sustained and profound transformation of crop protection to take place.

The situation can change and ENDURE looked at the ways that change occurs and how it could be fostered. For example, findings show that farmers do not usually transform their crop protection suddenly and in isolation. Rather, they move along gradual transition pathways and their practices evolve in interaction with their social network (see "Reducing dependence on pesticides"). At the ENDURE 2010 Conference, "IPM in Europe", three farmers from Denmark, United Kingdom and France are invited as public speakers to convey their expectations and real-life experience and on these questions.

[1] from Cliff Ohmart, Vice-President SureHarvest, California, USA, speaking at Diversifying Crop Protection, ENDURE's 2008 International Conference held in La Grande Motte, France in October 2008.

the ENDURE network of excellence shares the fruit of 4 years research with the Crop protection community

IPM implementation is certainly a challenge and a priority in the years to come, not only for farmers and advisers, but also for stakeholders in education, research, industry and retail as well as for policy-makers, environmental and consumer protection groups, and regulatory and funding agencies (see “Framework conditions for a successful implementation of NAPs in Europe”). Indeed, many inter-connected stakeholders beyond farmers are involved in making change possible. They are both upstream (i.e., national and European policy, chemical industry, research, extension…) and downstream (buyers, processors, retail…) in the agri-food supply chain. They can even be apparently outside the agri-food system and still contribute to change, as one study showed (see “The Role of NGOs in Reducing Pesticides”) by influencing policies aiming at risk reduction of pesticide use.

Understanding how such non-biophysical factors can be taken into account to produce policies that more effectively support change and generate a conducive environment is the subject of our Policy Briefs (see “Policy Briefs - Insights into the conditions for successful implementation of IPM”).

At a more macro level, we also compared situations between member states in terms of national pesticide use trends and general policy approaches. When analysing national differences in pesticide use in wheat, we find that tradeoffs between yield and cost as well as interactions between climate, farm management and social and organisational factors are tackled in different ways in Europe (see “Explaining differences in pesticide use in wheat in four European countries”). Examining the national policies adopted by various member states allows us to extract lessons learned and promote sharing of national experiences (see “Comparative analysis of pesticide action plans in Europe / Addressing IPM in National Action Plans”). The Conference “IPM in Europe” will offer opportunities to hear testimonies from five governmental representatives involved in the development of their National Action Plans in Germany, France, the United Kingdom, Italy, and Lithuania.

And finally, we would like it to be known that we offer our services for assessments on questions such as those pointed out here that are relevant to policies promoting IPM implementation (see “The ENDURE Network of experts”).

FRAMEWORK CONDITIONS FOR SUCCESSFUL IMPLEMENTATION OF IPM IN EUROPE

For successful translation of IPM into agricultural practice, farmers and advisers must be given the appropriate motivation and knowledge. Therefore, there is a need for IPM-related educational and advisory services, including providing general information on IPM, applied research, introducing innovations, voluntary co-operations between farmers and stakeholders, incentives, and social recognition of IPM. Today the main obstacles are the lack of additional benefits for using IPM, consumer recognition (e.g. labelling is not valued by consumers) and difficulties in establishing and funding IPM advisory services. IPM implementation is certainly a challenge and a priority in the years to come, not only for farmers and advisers, but also for stakeholders in education, research, industry and retail as well as for policy-makers, environmental and consumer protection groups, and regulatory and funding agencies.

Conditions for IPM in the policy framework

The successful implementation of crop or sector-specific guidelines for IPM on a voluntary basis and under the existing economic farm conditions requires the building of a conducive context. This includes appropriate political, economic and social framework conditions including incentives, practically feasible and innovative solutions and decision support systems in plant protection to enlarge farmers' scope of action in plant protection, as well as adapted IPM advisory services. First of all, the Directive poses a challenge to policy-makers in member states to establish the conditions and instruments necessary for IPM.

The OECD as a global player, considering national governments as primary bodies prioritized recommendations for the worldwide spread of IPM. It focuses on the development of national policy frameworks, the facilitation of partnerships and discussion forums, increasing applied agricultural research and extension and further developing IPM guidelines and standards, improving education on IPM, and creating financial incentives for using IPM.

Policy framework conditions and economic development schemes face competitive goals such as use and risk reduction in plant protection vs. conservation or minimum tillage to protect soil fertility and reductions of energy consumption and costs. Sustainable tillage systems are often linked with more intensive plant protection (e.g. chemicals) than systems involving ploughing.

Establishment of IPM demonstration farm networks in the scope of the NAP is an important way to practice and communicate innovative and environmentally-friendly tools and obstacles for crop or sector-specific guidelines in IPM at farm level. These demonstration farms can strengthen extension and improve communication among farmers and between farmers and society (i.e. farms open to the public).

The societal consensus on IPM

It seems that with consultation on the new EU plant protection package from 2009, public opinion has strengthened its perception that the use of pesticides in agriculture is hazardous to human beings, animals and the environment and thus must be strictly regulated and reduced. Public debates on the registration and use of endocrine disrupting chemicals in plant protection products, chemical residues in foods, the use of GMOs, and bee health or biodiversity raise the suspicion that the public is concerned about plant protection in conventional farming. The fact that plant protection, including chemical plant protection products, is necessary for the benefits of society is ignored or only grudgingly acknowledged by the opinion-makers. There is an urgent need for more realism because organic farming can't feed Europe alone. Transparency and a broader implementation of crop or sector-specific guidelines in IPM must help to ensure that plant protection including pesticides as a last resort finds consensus in society.

How to protect bees in fields? Communicate with beekeepers and use appropriate plant protection measures © JKI.

IPM has the ability to maintain crop health and productivity, secure farm income, protect the environment and conserve biodiversity through accompanying measures for the benefit of farmers. All relevant groups should contribute to the development and implementation of crop or sector-specific IPM guidelines or to the implementation of already existing ones such as those published and updated by the IOBC.

All stakeholders should communicate the message that, in addition to plant protection in organic farming, IPM also represents a sustainable strategy in plant protection in conventional farming. A broad societal consensus will strengthen the motivation of all players to support targets and measures of NAPs.

How to protect fields from mice? Invite raptors to help © JKI.

Farm scale implementation of IPM

For full or at least partial uptake of IPM guidelines, the motivation and education of farmers and advisers in IPM is required. Farmers and advisers should be willing to acknowledge and take advantage of opportunities provided by the NAPs. All specified targets and measures of NAPs should be comprehensible and economically feasible for farmers. Efficient on-site advisory services to farmers with a special emphasis on IPM play an important role in the adoption of IPM methods. Therefore, independent advisory services, applied research and short- and long-term field experiments are essential. All means should be exploited to finance and establish these services.

A part of the IPM approaches are measures to compensate the impacts of plant protection in and outside the target fields. They can be based on voluntary cooperation agreements between agricultural and environmental stakeholders or well-functioning initiatives to strengthen conservation of the environment and biodiversity. These habitat or landscape management concepts include ecological enhancement of arable land through flowering or conservation strips, buffer zones around fields and in the vicinity of water bodies, field margins, fallow fields, bee pastures, diverse grassland and uncultured plots or strips within fields to protect arthropods, European hare, partridges or skylarks.

All non-chemical alternatives, including decision support systems, resistant cultivars, biological control agents, and crop rotations should be scrutinized without bias concerning their practicability in IPM systems. This means learning from each other.

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How to keep skylarks in field? Establish 2 to 3 undrilled patches of 20 m² per hectare and population will increase © LBV/Germany.

EXPLAINING DIFFERENCES IN PESTICIDE USE IN WHEAT IN FOUR EUROPEAN COUNTRIES

Two ENDURE case studies examined the current situation of pesticide use in winter wheat with respect to diseases and weeds (see Chapter 1). One significant contribution of the case studies was to provide comparisons between situations and practices in different EU countries. Regarding wheat, a remarkable conclusion was that there were very significant differences in pesticide use patterns between these countries. Understanding the reasons for such differences could help stakeholders, especially policy makers, to identify factors on which they could act to favour pesticide use reduction.

This investigation was undertaken by the ENDURE network of experts at the demand of the Committee which monitors the implementation of the French pesticide action plan ECOPHYTO 2018. Four countries were selected for this comparison: Denmark (DK), the United Kingdom (UK), France (FR) and Germany (DE).

Large differences in TFI (Treatment frequency Index)

Using TFI as the indicator, the current use of pesticides on wheat is markedly different in the four countries, both in total value and in each pesticide category (Table 1). These differences far exceed what could result from the disparities between the methods used for TFI computation in each country. The lowest values are observed in DK and the highest ones in UK. FR is similar to DK for herbicides and insecticides, but uses more fungicides and plant growth regulators (PGR). DE is intermediate between UK and FR. However, for large countries like FR and DE, average values conceal significant regional differences.

Four categories of factors that could explain these differences were examined: pest pressure linked to climatic conditions, technical choices, social factors, and economics.

	England (2006)	France (2006)	Germany (2007)	Denmark (2007)
herbicides	2.43	1.5	1.9	1.71
fungicides	2.26	1.6	1.9	0.56
insecticides	1.08	0.3	1.2	0.15
PGR	0.97	0.7	0.8	0.2
total	**6.74**	**4.1**	**5.8**	**2.62**
yield t/ha	8.0	6.9	7.3	7.3

Table 1 – Treatment Frequency Indexes (TFI) in wheat.
All countries (TFI measured based on product rate. Herbicides include glyphosate. Insecticides include molluscicides, except for Germany. PGR: plant growth regulators).

Differences in pest pressure

DK and UK, which have the most contrasting TFI values, also have opposite climates. In DK, cold winters limit the development of diseases, pest and weeds which find much more favourable conditions during the mild UK winters. Data from cultivar trials over 7 years in the four countries were used to quantitatively estimate disease pressure from the yield gain due to fungicide treatments (Figure 1). Results indicate that indeed, via pest pressure, there is a link between climatic conditions and TFI. This is confirmed by looking at regional differences within DE and FR. In FR, the maps of local values for TFI and for yield gain due to fungicides in cultivar trials show strikingly similar geographic distributions.

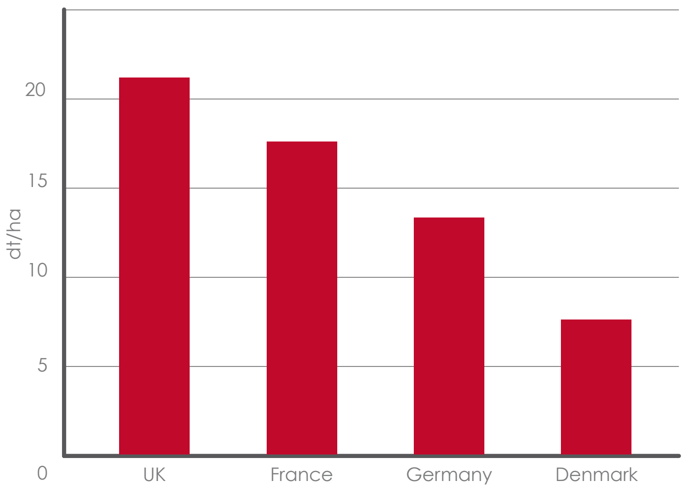

Figure 1 - Average yield gain from use of fungicides
(data originate from cultivar trials, Average of 7 years: 2003-2009).

Pest pressure differs qualitatively. While Septoria tritici blotch is the main disease in all four countries, brown rust is more important in Southern Europe, and tan spot and eyespot affect mostly DE. Because of mycotoxin risks, fusarium head blight induces late treatments, especially in FR and DE. Pesticide resistance, which generally results in higher pesticide use, is unequally distributed in pest populations. It is a greater problem in the UK than in the other countries for weeds. For fungicides it is an increasing problem in all 4 countries.

Differences in technical choices

Cultivars are specific to each country and differ significantly. This partly explains the differences in fungicide use. In the five most popular cultivars for each country, yield gains due to fungicide treatment are below 10 dt/ha for DK and near or above 20 dt/ha in FR and UK. The differences in gain between the most and least resistant cultivar are respectively around 10 and 4 dt/ha. Indeed, the use of resistant cultivars is markedly different. In DK, it is a widespread practice. In FR, farmers include them in their assortment but frequently treat all varieties alike. In DE, they are available but seldom cultivated because of priority to yield. In UK, yield is also the main criterion and the response to fungicides in all of the most cultivated varieties is significant.

Other factors in the cropping system and practices influence TFI. In FR, different types of crop management systems are correlated to different TFI levels. Systems with late drilled wheat, low N input, and hardy wheat cultivars or with long diversified rotations in connection with livestock breeding have a total TFI around 3. In contrast, systems using high N inputs, minimum tillage and short rotations or wheat monoculture exhibit TFI near or above 4. A diversity of cropping systems is also observed in DE. In DK, restrictions on N input for water conservation resulting in low risk of lodging and aversion of cattle breeders to PGR, low sowing densities and a common practice of hand weeding wild oats encouraged by the regulation all contribute to a decrease in the use of particularly PGR and herbicides. In contrast, UK's tradition of early drilling when combined with minimum tillage and continuous autumn-sown crops results in higher pest problems.

Social and organisational factors

Here we find factors that show a highly contrasted picture between UK and DK and have a conspicuous effect on how crop protection operates.

The average farm size in UK is larger than in DK. Large farms tend to have less available manpower, are more likely to use contractors, remote managers or crop consultants. This reduces the ability to monitor pests and the flexibility to finely adjust treatments to needs, but it also has an indirect effect by favouring early drilling and minimum tillage.

Advisory services are privatised in both countries. However, in UK individual consultants are often linked to the agrochemical industry or, when independent, are highly risk-adverse to satisfy their clients. In DK, a comprehensive and independent agricultural advisory service targets ca. 85% of the farmers and focuses on optimising the farm economic output; it has a tradition of collaborating with research.

In DK, the history of reducing pesticides doses dates back 25 years and has been steadily supported by successive national action plans. These objectives are also supported by a strong system of field trials producing the substantial amount of experimental data needed to convince farmers.

Economic factors

Variations in wheat prices create uncertainty for farmers who are prone to maximise their yield in all circumstances. However, when they are given proper information, they tend to adjust their pesticide use to maximise net returns. Data from F show indeed that the decreasing price of wheat over the 1994-2004 decade was accompanied by a decrease in fungicide TFI which rose again in 2008 together with wheat price.

The cost of pesticides varies significantly between countries, mostly as a result of taxes. DK imposes a 33% tax (54% on insecticides) which results in higher costs for chemicals. In comparison, UK has a 17.5%VAT, DE a 19% VAT, and FR a 5% VAT plus a pollution tax of 3 €/kg active ingredient. Economists have calculated that achieving a significant impact on pesticide use would require much higher taxes.

Conclusion

The four countries show contrasting situations in many factors that have a bearing on pesticide usage. As these factors are not independent, the reasons that may account for the large differences in pesticide use in wheat are multiple and complex.

Climate conditions obviously have a major role in determining the level of pest pressure and, when under high pressure, farmers cannot take the risk of avoiding treatment. Cropping management system, cultivar choice and other practices can, to some extent, mitigate the effect of climate on pest pressure and allow for reduced direct control.

However, such technical choices are linked to social and organisational factors. As farm size tends to increase in most countries, it is worth noting that larger farms do not facilitate the reduction of pesticide use, as the situation in UK shows.

Attention should also be given to the role of the advisory system and the need to collect large amounts of experimental data needed to convince farmers to change practice.

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REDUCING PESTICIDE DEPENDENCE: a matter of transitions within the agro-food system as a whole.

The social sciences team of ENDURE analysed the conditions of transition towards more sustainable crop protection practices at different levels in the agro-food system: farmer practices, interactions between farmers and advisers, retailer strategies, governance of research and extension, and involvement of civil society. The work is based on a variety of qualitative interviews (n=188) as well as documentary and press corpus analysis carried out by the various sociologists of the project in France, Switzerland, the Netherlands, the UK, Denmark, Italy and Hungary.

The "paradigm of intensification": a path-dependency analysis

The *path dependency* theory suggests that an innovation trajectory may become dominant and strengthened by the feedback of its implementation, despite the existence of alternative innovations which could have offered higher sustainability on the long run. Based on this theory, we analysed how the agro-food system gradually embraced, from the 1960s on, the "paradigm of intensification", due to a convergence of innovations (registration of new pesticide, selection of cultivars, changes in farming practices, etc.) and of actors' strategies. Regarding wheat production, in a model where the main aim was to maximise yields, we observe a strong coherence between the changes in fertilisation methods (early fertilisation) and in dates and modes of sowing (earlier and at higher density) at the farm level, linked to changes in technical advice, the prevalence of varieties which were disease sensitive on the breeding and seed markets, the registration of new insecticides, growth regulators, fungicides and systemic herbicides in the 1970s, the changes in industrial processes in the milling industry. All this led to a change from a curative use of pesticides to a more systematic one (preventive) and to "lock-in" effects which today impede significant transitions towards IPM. These "lock-in" effects can still be assessed today when we consider the different components of the agro-food system: farmers, advisers, research, retailers and civil society.

Current lock-in effects at the farm scale

To analyse changes in farmer practices, we studied the trajectories of apple and wheat producers through an approach combining a sociological analysis of transitions, networks and learning processes and the ESR (Efficiency - Substitution – Redesign) framework aimed at characterizing changes in crop protection practices (Hill and McRae, 1995). Most farmers only applied part of the IPM principles: for example, regarding wheat production, they used resistant cultivars and/or decision support systems for their treatments, without any major changes in their sowing and fertilization methods and in their crop rotations. Their practices could be related to the Efficiency paradigm, combined with the Substitution paradigm for apple growers who often used some alternative techniques such as biological control. These transitions towards IPM appeared as rather reversible and highly dependent on the economic context. However, such practices were probably more environmentally-friendly than conventional ones and it should be easier for these farmers to shift to IPM were the regulations to change. On the other hand, farmers who implemented all or a large part of IPM principles could be said to be undertaking a systemic change in their practices and therefore be characterised by the paradigm of system Redesign. Their transitions were more gradual and more robust and often linked to collective dynamics. We can conclude that learning processes among farmers are a key factor and require public support, which the case of the transition of Swiss agriculture towards IPM also demonstrates.

Lock-in effects in the advisory and research sectors

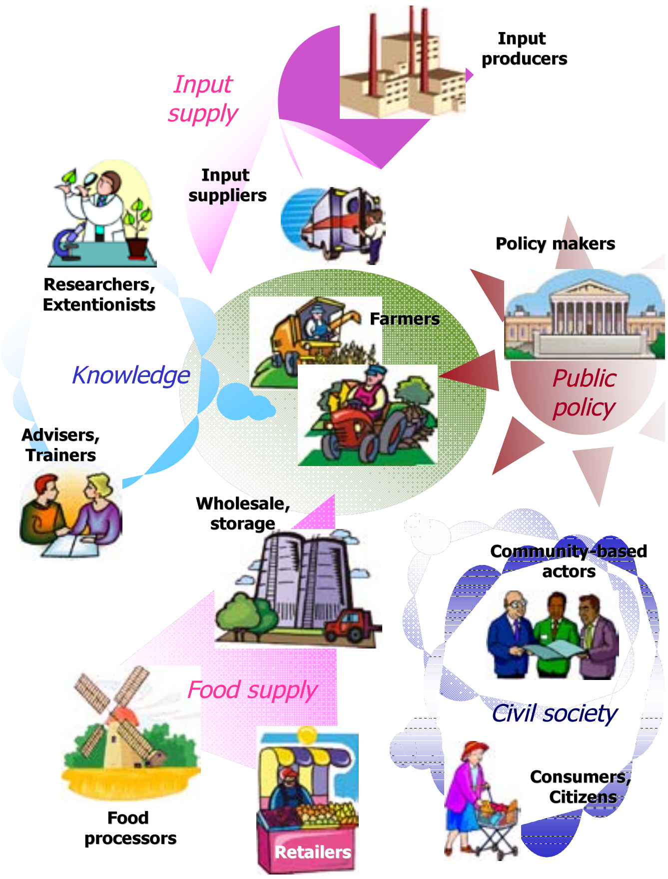
Regarding the advisory and research sectors, these are undergoing a reduction in public involvement and broad transformations in their organisation throughout Europe. As advisory systems become increasingly market-led, farmers constitute clients that extension services do not want to lose. Advisers thus become risk-adverse and reluctant to promote alternative strategies which could lead to lower yields. Nevertheless, some actors often said to provide advice tied to their "sale and purchase" business interests (input suppliers, farmers' cooperatives and trade partners) have begun a switch with more positive attitudes towards low-input practices.

Interviews with institutional and research actors show that these endorsed the economic constraints that seemed dictated by the current system and favoured the improvement of techniques (e.g. precision agriculture) rather than more radical changes of agricultural and agrifood systems. Agronomic research dealing with long-term environmental impact of agricultural practices is not receiving sufficient attention and-funding compared to other fields such as molecular biology.

Lock-in effects at the market level

Does the increasing power of retailers with their claim to environmental-friendliness represent an avenue toward change? The quality schemes developed since the mid 1990s, such as GlobalGap or other private schemes, are mostly devoted to products traceability and safety. They are generally poor in terms of IPM and environmental aspects and focus mostly on record keeping of practices and Good Agricultural Practices. They are mainly seen as commercial tools imposed on

producers as a precondition to gain market access and therefore probably tend to exclude non-competitive farmers rather than include more environment-friendly ones. Nevertheless, some schemes do include environmental impact standards, a positive list of authorized pesticides, compulsory monitoring procedures and thresholds for pesticide use, or the use of alternative techniques such as biological control. Moreover they might have led some growers to implement alternative techniques thanks to a collective organization, initially built up for marketing purposes, which provides them with professional advice.



We all have to work together

Lock-in effects at the market level

Does the increasing power of retailers with their claim to environmental-friendliness represent an avenue toward change? The quality schemes developed since the mid 1990s, such as GlobalGap or other private schemes, are mostly devoted to products traceability and safety. They are generally poor in terms of IPM and environmental aspects and focus mostly on record keeping of practices and Good Agricultural Practices. They are mainly seen as commercial tools imposed on producers as a precondition to gain market access and therefore probably tend to exclude non-competitive farmers rather than include more environment-friendly ones. Nevertheless, some schemes do include environmental impact standards, a positive list of authorized pesticides, compulsory monitoring procedures and thresholds for pesticide use, or the use of alternative techniques such as biological control. Moreover they might have led some growers to implement alternative techniques thanks to a collective organization, initially built up for marketing purposes, which provides them with professional advice.

More generally, quality criteria are a major bottleneck to increasing the sustainability of farming practices. For fruit production, part of the pesticide use is linked to the criteria of size and visual aspect (zero-defect). However, some alternative systems such as community supported agriculture "box" schemes show that consumers can accept product irregularities when this is perceived to reduce or eliminate pesticide use, which is confirmed by the focus group organized in 4 countries within ENDURE.

The possible role of civil society

Finally, civil society has today a key role to play through the construction of the environmental impact of agriculture as a public issue. In recent years, the public debate evolved from concerns about the environmental impacts of pesticides to concerns about the cumulative impacts of pesticides on human health, which has influenced changes in pesticide risk regulation. On the other hand, transitions towards IPM have not been put forward mainly because the civil society's main spokesmen (NGOs, medical doctors or scientists) mostly think in terms of zero-pesticide rather than low-input practices.

Obstacles and opportunities for robust transitions

Our sociological studies show that reducing the dependence on pesticides is not only a matter of changes at the farm level. Whereas many actors stress the reluctance of farmer to consider non-chemical alternatives, we show that market conditions, governance of extension and research and public debates are framing stakeholder perceptions and actions and impeding change. Where farmers themselves talk, often in a rather fatalistic way, of market and legislation as the most if not only factors determining (or preventing) change, we show that these factors cannot play a role independently from others. Changes in crop protection practices involve a large socio-technical system. There is therefore a need to tackle its interdependencies and somehow coordinate the whole.

Seen from a positive perspective, the different and interdependent aspects we studied also constitute the main conditions for significant change towards IPM: collective dynamics among farmers, translation of changes in farming practices into marketing strategies, involvement of research and extension, strong public policies, and the involvement of the civil society. In the case of Switzerland we could demonstrate that if a major change towards IPM was gradually achieved in the last decades, it is precisely because all these conditions were present.

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THE ROLE OF NGOs IN REDUCING PESTICIDE RISKS

NGOs played a decisive role in the public debate on pesticides and crop protection in Europe. A case study in the Netherlands showed how campaigns and lawsuits of the NGOs resulted in new arrangements for compliance with Maximum Residue Limits and new legislation for the registration of pesticides. Similar patterns were found in an analysis of the public debate in France. The strong focus on pesticide risks for consumers and for the environment popped up in EU legislation later.

Introduction and political context

Pesticide-related campaigns and lawsuits of NGOs in the Netherlands lasted for eight years (1998-2006) and gave both private and public policymakers grey hair. The major subjects addressed included what they perceived as frequent exceedances of Maximum Residue Limits (MRLs) in fruit and vegetables and frequent infringements of the environmental criteria for the registration of pesticides, especially regarding pesticide applications in minor crops. The success of NGOs in the Netherlands in the public debate can be explained by their political support enjoyed in Parliament and by the changes in power relations between producers and retailers which took place in the 1990s.

Campaigns on MRL exceedances in fruit and vegetables

The involved NGOs bought boxes of strawberries (2000), grapes (2002) and nectarines (2003) in randomly selected supermarkets, had them analysed for pesticide residues by a well-known laboratory and found the presence of several unauthorised pesticides and a large number of instances of MRL exceedances. They filed complaints against supermarket companies and took them to court. The supermarket companies were very reactive to these campaigns and made agreements with the NGOs on MRL compliance. The supermarket companies forced their supply chain partners to comply with MRL regulations. In fact, they took over from government actual inspection for MRL compliance. In 2004 the NGOs pushed the Minister of Agriculture to disclose the MRL data of the Food Inspection Authority. With these data, the NGOs monitor and publish the MRL performance of the various companies. Figure 1 shows an example of how NGOs bring attention to the MRL issue.

Lawsuits on infringements of the environmental criteria

The NGOs initiated lawsuits in 1998, 1999, 2000, and 2002 against the Ministry of Agriculture on the grounds that pesticide authorisations did not satisfy the required environmental criteria. An important political debate on the economic necessity of pesticide authorisations for minor crops arose. The chemical industry became frustrated with the constantly increasing dossier requirements and decided to merely comply with the less demanding EU regulations for registration. The court refused anticipation of European authorization: 150 pesticides were involved. Consequently the Dutch registration policy ended up in an impasse and the Minister of Agriculture announced the development of a new Pesticide Law, adjusted to the European legislation. The new Law on Crop Protection and Biocides came into force in 2007.

Figure 1 - Would you enjoy fruits, if you saw the pesticides?

NGOs as spokesperson for the general public

The analysis of the public debate on pesticides and crop protection revealed two opposing social systems (actor groups), as shown in figure 2.

The two social systems are separated by a difference in wording: the general public refers to pesticides while the agri-food system prefers to refer to crop protection. The NGOs enjoyed political support of various Ministries (Environment, Public Health and Labour) and of the left wing parties in Parliament. This explains their success in getting the focus on the reduction of pesticide risks.

GENERAL PUBLIC

- Ministry Environment
- Ministry Public Health
- Ministry Labour
- NGOs – Environment
- NGOs – Consumers
- Left wing parties

Keyword: pesticides

AGRI-FOOD SYSTEM

- Ministry Agriculture
- National Farmers Org
- Crop Protection Ass'n
- Right wing parties

Keyword: crop protection

Figure 2 - Opposing coalitions in the public debate on pesticides in The Netherlands.

Changes in power relations in the 1990s

In the 1990s crucial developments took place in the socio-political landscape in the Netherlands. NGOs were recognised (1995) as representative of the general public in lawsuits against government decisions and the powerful Agricultural Board was abolished (1996). Owing to overproduction the power in agricultural supply chains moved from producers to retailers. The chain reversal was marked by a report by AT Kearney in 1994: 'Missed the Market'. This report opened the eyes of the sector for consumer interests. The success of the consumer strike against Shell (organized by Greenpeace against the plans to sink the Brent Spar oil storage facility in the Atlantic Ocean) in 1995 confirmed the changes in the power relations between the business world and the general public. All these changes together facilitated and necessitated the development of new practices and legislation on pesticide risk reduction.

The role of NGOs in France

In France exceeding Maximum Residue Limits in vegetables and fruit and pesticide authorization for minor crops were also major topics in the public debate. Owing to campaigns of ARTAC (an NGO with a background in medicine) health effects and phasing out of carcinogenic, mutagenic and repro-toxic pesticides were rising issues in the pesticide debate in France. The debate on these topics provided context for the 'Grenelle de l'Environnement' and 'Ecophyto 2018', two recent milestones in policymaking on pesticides and crop protection in France.

Implications for public policymakers in Europe

NGOs are unattached actors which can play a very useful role in bridging the gap between the general public and the agricultural community. NGOs can only play this role as long as they enjoy the political support of the ministries and political parties representing the interests of the general public. The role of NGOs further depends on their legal recognition and on latent changes in the power relations in supply chains. The socio-political landscape of the Netherlands of the 1990s was prone to a shift to pesticide risk reduction. The conditions for such shifts can be fully or partly grasped and created by public policymakers, in the Netherlands but also in other EU countries.

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POLICY BRIEFS – Insights into the conditions for successful IPM implementation

The ENDURE group working on scientific-support-to-policy conducted work on the drivers and contextual conditions conducive to IPM implementation. The main idea is that progress in IPM implementation requires long-term and coordinated action to ensure that interdependent stakeholders – policy-makers, research, extension, farming, input supply, retail, consumers, and environmentalists – move together in a compatible fashion. This work is encapsulated in a set of policy briefs specifically formatted for decision makers.

The challenge of IPM implementation

"Member States shall establish or support the establishment of necessary conditions for the implementation of integrated pest management"

(Directive 2009/128/EC, Art. 14.2)

Over the past 20 years, European pesticide legislation was subject to radical change. The position on pesticide use taken by the new EU legislation emphasises the promotion of IPM and non-chemical alternatives and requires the mandatory implementation of the '*General principles of Integrated Pest Management*' by 2014. The ENDURE group working on scientific-support-to-policy conducted work on the nature and the importance of the "necessary conditions", i.e., the contextual conditions conducive to IPM implementation. Our work is encapsulated in a set of policy briefs specifically formatted for decision makers at national and European levels.

We look at a number of technologies, drivers and requirements and consider their potential to contribute to successful on-farm IPM implementation and how they can be translated into levers for action in the policy sphere. Innovation in agriculture responds to a range of interacting drivers and impediments related to the biophysical and technological factors but also to knowledge, the market, regulations, environmental and health issues and socio-economics. We collected examples illustrating major drivers and impediments to IPM implementation based on a collection of experiences and a selection of outcomes from several research projects. Even though IPM is multidisciplinary by nature, the historical compartmentalisation of disciplines has meant that many constraints are only addressed in separate fields of specialised research.

The results underpin the main idea that progress in IPM implementation requires long-term and coordinated action to ensure that interdependent stakeholders – policy-makers, research, extension, farming, input supply, retail, consumers, and environmentalists – move together in a compatible fashion. Our intent is to provide a more coherent and multi-facetted picture of the challenge of IPM implementation with the policy briefs on: Biological control in integrated crop protection, on real-life examples of successful IPM implementation, and on IPM implementation from the point of view of social scientists.

Paris November 2008: Sustainable Agriculture and Pesticides - a European policy seminar sponsored by the French presidency of the Council of the EU with the scientific support of ENDURE.

The role of interdependent stakeholders

IPM strategies can be competitive only when they are used in a conducive context. Many components of the cropping system and a wide range of components in the socio-technical environment, ranging from varietal crop development to retail need to converge in a compatible fashion. A policy environment enabling such coordinated changes needs to emerge.

In setting up a governance strategy to promote IPM, the interests of all stakeholders should be identified. Concerted action of all stakeholders is needed to ensure that farmers operate within an IPM-friendly context. Supermarkets are sometimes expected to function as drivers of change toward more environmentally-friendly production practices. An ENDURE study shows that their contribution can only be modest, contributing mainly to optimising pesticide use and limiting MRL exceedances. In that study, apple growers did not perceive supermarket IPM schemes as paths toward better environmental practices, but rather as prerequisites for market access or for recognition as the preferred supplier. Based on factual information, consumers could become sensitive to production methods but, in contrast to organic production, it is difficult to communicate on IPM to consumers.

Governance and research strategies

Policies that support long-term research and lasting networks involving farmers are more likely to be effective drivers. Developing cropping systems less vulnerable to pests and diseases – and therefore less dependent on pesticides – cannot be achieved over the short term. To develop IPM, there is no standardised and ready-made solution. IPM is more site-specific than chemically-based protection. IPM therefore requires the development of practices which must be adapted to specific regions, ecological conditions, crops and economic situations as well as take into consideration practices already implemented locally. Regional networks could be supported to implement regionally customized IPM thereby contributing to the adoption of IPM on a national scale. Advances in IPM will be more successful if they are supported by funding programmes that provide research a certain degree of freedom from present-day market requirements and emphasise long-term programs. Sociological studies conducted by ENDURE researchers show that the most robust and far-reaching transitions along the IPM continuum come from farmers involved in lasting collective dynamics. Farmers adapt and gain a sense of ownership of new technologies via a collective learning process. Their active involvement in networks thus plays a major role in the adoption of IPM methods.

Integration of biological control methods

One important component of IPM holds a high potential but is under-utilised: biological control, one of the major alternatives to pesticide use. Biological control agents are widely available and adopted in some sectors but in others such as arable crops, they are not well covered. Biological control agents need to be developed rapidly in Europe. Beyond traditional R&D, this includes associated efforts at the advisory and user level in education and training to support the adoption of bio-control whose use requires qualitatively different skills from those required by pesticide use.

Brussels, European Parliament, April 2009:
Presentation of ENDURE foresight study to European stakeholders.

The Policy Briefs offer clues on how to integrate positive drivers and better coordinate interdependent stakeholders for the creation of an environment conducive to IPM implementation.

Policy briefs:

- Implementing IPM: A gradual path involving many stakeholders
- Consumers and production systems
- Creating space for innovation and for the circulation of knowledge
- Real-life examples in IPM. What are the drivers?
- Bio-control in integrated crop protection

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COMPARATIVE ANALYSIS OF PESTICIDE ACTION PLANS IN EUROPE – Addressing IPM in National Action Plans

Several European countries launched initiatives to reduce pesticide use or risk. The ENDURE group on scientific support to policy looked at how Denmark, Germany, the Netherlands, France and the United Kingdom addressed goal setting, stakeholder involvement and the role of research and extension in their programmes. At the close of the ENDURE 2010 conference, we will update this material with input from governmental representatives from Germany, France, the United Kingdom, Italy, and Lithuania.

A number of European countries have launched national initiatives to reduce pesticide use or risk. These experiences offer valuable insights for future programmes. The ENDURE group working on scientific support to policy looked at how Denmark (DK), Germany (DE), the Netherlands (NL), France (FR) and the United Kingdom (UK) addressed goal setting, stakeholder involvement and the role of research and extension in their programmes.

The ENDURE scientific-support-to-policy team, Broom's Barn, UK, May 2010.

Goal-setting

There are different ways overall progress was measured in the policy initiatives studied. The nature of targets and indicators range from evaluation of volume, treatment frequency, emissions, to environmental impact, each with its own advantages and drawbacks. In DK, DE, NL and FR, an overall quantitative and time-bound target served as a national rallying point around which multi-faceted initiatives were built. The historical trend seems to be to move away from volume targets in favour of environmental impact reduction. The UK Pesticides Strategy, however, did not adopt overall quantified and time-bound targets. Instead it developed six action plans according to a set of six qualitative objectives. Although this more qualitative and detailed approach makes it more difficult to evaluate progress, it may allow the Pesticides Strategy to place increased communications attention on a broader set of more specific and subtle indicators which may carry more information for the wider public.

Stakeholder involvement

In all five countries studied, stakeholder involvement in the policy-making process is taken seriously to avoid rejection of the policy. The process, which goes beyond mere consultation, involves trust-building, long-term commitments and — except in the UK case - rallying behind collectively agreed upon quantitative reduction targets. NGO involvement, which is a somewhat more recent development, is a challenge for governments but probably worthwhile in terms of long-term societal buy-in. There are noteworthy initiatives in the UK (e.g., the Voluntary Initiative) and NL (the "Covenant" national alliance on sustainable crop protection) where non-governmental groups are handed over partial responsibility for implementation of the plan.

Research and extension

All national plans studied are associated with substantial research and extension efforts. Much of the research in Denmark focused on optimising pesticide use based on existing technology. Current French research is set to look at how to achieve major breaks at cropping systems level and is engaged in long-term and on-farm experimentation. Some of the German research is explicitly targeting the development of IPM. In all cases, the classic diffusion model of research and extension – where knowledge is generated by research, then handed over to advisory services which then "transfer" it to farmers – is increasingly replaced by more collective and participatory approaches. The mainstreaming of practices contributing to a reduction in pesticide use or risks is an innovation process where new knowledge, tools and services need to be generated and shared among multiple actors. The process is not self-generating, it requires substantial investment and promotion.

At the close of the ENDURE 2010 conference, two sessions, "The ingredients for successful IPM practice – learning from innovative farmers" and "Addressing IPM in National Action Plans", will enrich this material with input from IPM farmers from France, Denmark and the UK and from governmental representatives involved in the development of their National Action Plans in Germany, France, the United Kingdom, Italy, and Lithuania.

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THE ENDURE NETWORK OF EXPERTS OFFERS SCIENTIFIC ASSESSMENTS ON IPM IMPLEMENTATION

The ENDURE Network of Experts provides science-based collective assessments drawing upon the competencies existing within ENDURE. It is an on-demand service responding to requests from groups seeking technical, advisory or institutional support on a specific question regarding IPM implementation.

The ENDURE Network of Experts was set up in January 2009. It is a service provided by ENDURE in response to requests related to IPM implementation in terms of scientific support to policy or scientific and technical support for the practical application of IPM.

It provides science-based collective assessments drawing upon the competencies existing within ENDURE in response to requests from groups seeking technical, advisory or institutional support on a specific question related to IPM implementation.

It is a live expert component that complements the body of information available from the online ENDURE Information Centre. It responds to a need for European-level quality technical recommendations, collective assessments and advisory support that can be called upon on relatively short notice.

Pooling European expertise.
Shown here are Jozsef Kiss (Hungary), Per Kudsk (Denmark), Franz Bigler (Switzerland), Piet Boonekamp (The Netherlands).

The Network of Experts' achievements to-date

- Since June 2009, the Network of Experts is a member of and contributes expertise to the Expert Group on the Thematic Strategy on the Sustainable Use of Pesticides. Chaired by DG Sanco, this group facilitates the exchange of information and best practices in the field of sustainable use of pesticides and integrated pest management, it monitors the implementation of the measures proposed in the Thematic Strategy and provides guidance where required.
- In August 2009, it delivered upon request from DG Environment a contribution to the EC's document "Implementation of IPM principles - Guidance to Member States". The contribution is available at http://www.endure-network.eu/about_crop_protection/endure_position_papers
- In February 2010, it accepted a request from the Italian National Committee on Integrated Crop Protection to conduct a comparative analysis between the parts of the draft Italian National Action Plan that specifically address IPM and other action plans.
- Since February 2010, the Network of Experts is a member of the French national Ecophyto Committee of experts, a stakeholder group providing recommendations on the implementation of the French National Action Plan.
- In June 2010, it delivered upon request from the Ecophyto Committee of experts two comparative studies: one on goal-setting, stakeholder involvement, and role of the knowledge chain in pesticide action plans in five EU countries, and another on explaining differences in Treatment Frequency Indices in terms of pest management in winter wheat in four European countries.

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6 A FUTURE FOR ENDURE

Maintaining a reference point in Europe and linking with other continents

When creating Networks of Excellence, the European Commission made clear its ambition to build durable cooperation at the European level. ENDURE was one such Network of Excellence. Its overall objectives were to (1) restructure European research and development efforts on the sustainable use of plant protection products and (2) to become a world leader in the development and implementation of durable pest control strategies.

During the four years of EC funding, the Network has developed tools to integrate its research capacities and to organise and disseminate its produced and assembled knowledge to its different targets. To reinforce integration among its partners, it has implemented an extensive mobility programme. In addition, with consideration to the global challenge of crop protection and in order to increase its visibility worldwide, ENDURE has developed specific links with Partners Outside Europe (POE). All these actions have contributed to the two main objectives of the Network and their future has been envisaged in the perspective of the durability of the Network. The Network has started to prepare itself to be a reference point that will last beyond the period of EC financial support, and this will be made possible by the creation of a durable structure that will perpetuate and strengthen the integration and visibility gained so far.

INTEGRATING RESOURCES AND KNOWLEDGE AND ENSURING FURTHER DEVELOPMENT OF THESE TOOLS IN THE FUTURE

ENDURE has worked on integrating its tools and databases into a single system in order to build a central point of reference in European crop protection. Gathering all the different information and data into one single system allows researchers to share knowledge, techniques, methods and consequently best practices. Integrated Knowledge Management participates to ENDURE's objective of becoming durable as the tools developed ensure the perpetuation of the integration built during the four years of EC funding between the members of the Network. Technical solutions have been implemented to ensure that the tools can be improved, adapted and maintained in the future. All ENDURE applications have been integrated into a single common server at JKI that will continue to be operational after the end of EC funding.

The necessity of ensuring the future use of the tools developed by ENDURE has led to the development of dedicated Intellectual Property tools and recommendations. The main achievement is the development of a generic agreement that can be used for any ENDURE tool to license in material from external contributors. This way, maximal use of material is enabled and users have the additional benefit of knowing exactly where they stand legally with respect to the use of the material.

the ENDURE network of excellence shares the fruit of 4 years research with the Crop protection community

SUCCESSFUL STAFF MOBILITY PROGRAMME AND DEDICATED WORK TO CONNECT WITH NEW PARTNERS WORLDWIDE IN VIEW OF CHALLENGING GLOBAL ISSUES

The ENDURE staff mobility programme contributed to the integration among its members by supporting the mobility of 64 scientists from ENDURE, and supported the creation of specific links with POE as well by allowing eight scientists from POE to undertake collaborative work in ENDURE laboratories. Nearly all Endure partners participated in the internal mobility plans as sending and/or hosting institutions. External mobility targeted POE scientists holding a position which allowed them to establish a lasting collaboration with the ENDURE hosting institution. Mobility has been successful in improving integration within the network and is therefore one of the activities that will be perpetuated in the ENDURE ERG.

Along with these specific mobility actions, links with Partners Outsides Europe (POE) has been forged through several initiatives including the invitation of POE scientists to attend workshops, PhD Summer Schools and the International Conference. The production of dedicated tools encouraged the creation and maintenance of these links (online communication tools and Forum of POEs 'beyond 2010'). After forging the initial links between ENDURE and POEs during the four years of EC funding, a new structural approach has been designed by initiating four regional networks in the perspective of the durability of the ENDURE network (beyond 2010): the European Network should now have counterparts in China, Brazil/Latin America, the Mediterranean area and Sub-Saharan Africa.

CREATING A EUROPEAN RESEARCH GROUP AS THE NEW PERENNIAL ENDURE ENTITY TO TAKE UP FUTURE CHALLENGES

Throughout its four years of existence, the ENDURE Network has contributed to build a durable community of excellence within the European crop protection landscape and beyond. Thinking 'long-term' has led to the creation of the ENDURE European Research Group (ERG) which will maintain the four major activities that will ensure ENDURE durability:

1. Joint consultation to identify gaps and overlaps of crop protection research in Europe to be promoted at the European level.
2. Maintenance and sharing of research capacities and tools for the research community including databases, education and mobility programmes.
3. Provide scientific expertise in support of policy development and implementation.
4. Provide a portfolio of ENDURE-validated documents and information useful to advisors and extension services.

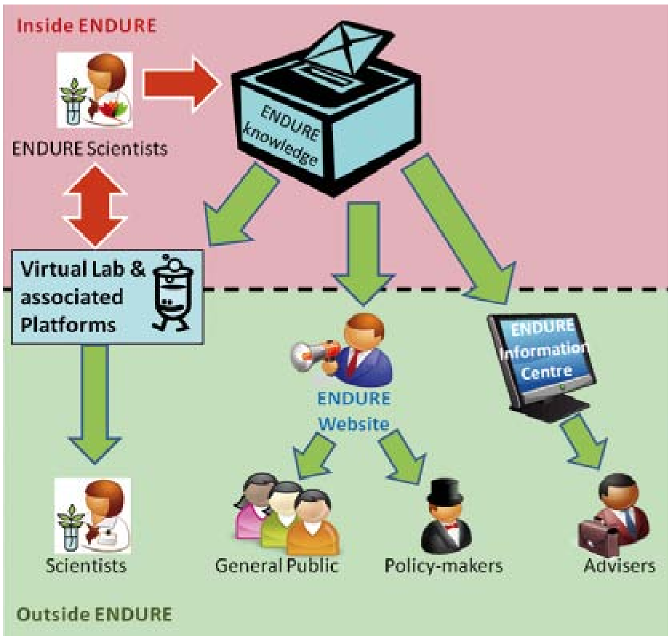
Over the past four years, the ENDURE Network has actively prepared the creation of the ERG based on its Partners' own funds. This shows political willingness and understanding of the new challenges in crop protection as well as the relevance of the European scale and international cooperation to tackle new issues which have gone beyond national boundaries.

INTEGRATED KNOWLEDGE MANAGEMENT: IKM IN IPM.

ENDURE has worked on integrating its tools and databases into a single system. This is an entire part of its strategy to continuously assemble and integrate knowledge to build a central point of reference in European crop protection.

An African proverb says, "Knowledge is like a garden, if it isn't cultivated, it cannot be harvested." A lot of scientific knowledge has been accumulated in crop protection; however its fragmentation is a limit for its full use. In order for science and end-users to build on this existing knowledge, all the relevant information needs to be stored, managed – cultivated – and made available to the scientific community and agricultural world.

Just as ENDURE has integrated researchers across the fragmented European research area, the Network has also made specific efforts to integrate its tools and knowledge in a single system. This also contributes to the establishment of ENDURE as a point of reference in crop protection. As the different case studies have proved, there is much valuable information to be found across all European countries, including data and tools, but the gathering of these pieces of information has been lacking. ENDURE has functioned as a prototype in this area of crop protection by collecting and assembling experimental data and analysis of different crop situations in different countries.



What is at stake in ENDURE IKM?

Gathering all the different information and data into one single system creates added value as it allows researchers to share knowledge, techniques, methods and consequently best practices. This is also a way to improve analysis by comparing available data, to fill gaps and avoid redundancies, and to improve dissemination. This also saves time and thus favours innovation.

ENDURE has developed tools such as the ENDURE Information Centre (EIC), the Virtual Lab (VL) and a number of platforms (such as QuantiPest, EuroWheat, etc.) all destined for different targets and therefore adapted to them. At the same time, a Technical Task Force has been set up to study the integration of all ENDURE tools and databases and to ensure their compatibility.

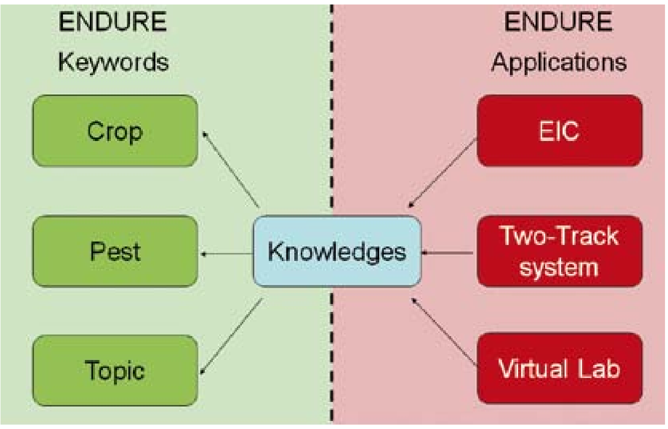
Managing knowledge to disseminate it

The internal system feeds the Virtual Lab to provide useful tools to researchers. In addition, the ENDURE website and external dissemination tools make it possible to inform policy makers and the general public of ENDURE results, and the EIC is designed for advisers and trainers, and consequently has a educational role.

Collaboration between ENDURE tools

To ensure collaboration between the ENDURE tools (VL, EIC, Two-Track System, etc.), the Technical Task Force introduced a general 'Knowledge' type, that has been extended to all ENDURE tools. ENDURE databases store information about various crop protection issues: scientific reports, experts, decision support systems, projects, research facilities, etc. Each of these elements can be considered part of the Knowledge type, and can be associated to several ENDURE keywords.

These keywords are organised in four categories: crops, pests, topics and geographical regions. Each category is a hierarchy of keywords, in this way users can associate each database element with general or specific terms (e.g. 'Insect > Diptera > Fruit Flies' for pest or 'Preventive measures > Variety/Cultivar choice > Tolerant cultivar' for topics).



These keywords are the base of the ENDURE project taxonomy. In order to improve data exchange with other repositories, the taxonomy has been designed to adopt other existing standards. Specifically all taxonomies related with species (crop and pest) have been extracted, where available, from the EPPO Plant Protection Thesaurus. Users using the ENDURE taxonomy to describe new elements can add new keywords if the existing ones do not fit their purpose. Knowledge managers, using a specific interface called Tree Manager, can then evaluate these new keywords and integrate them in the ENDURE hierarchical classification.

The tools sharing a common database with this original structure are therefore able to categorise any kind of data with keywords from the categories provided by ENDURE's common database. Accordingly this general 'Knowledge' type allows cross-application search without knowing details about a certain result type. Searching for a specific pest, topic or crop returns as results any data from all the ENDURE applications related with the requested keyword.

The creation of this approach enables the ENDURE Information Centre to act as a kind of central search engine, providing access not only to its own content but also to the content offered by all the ENDURE tools (VL, Two-Track System, etc.).

Preparing the future

Integrated Knowledge Management participates to ENDURE's objective of becoming durable. The members of the Technical Task Force have structured and implemented a system which takes into account the constraints linked to time: how to ensure that these tools will be perpetuated, that data will be added, and that a validation process will be applied to new information. Technical solutions have been implemented to ensure robustness with the cooperation of each tool developer. It has also encouraged the elaboration of guidelines and documentation to ensure that the tools can be improved, adapted and maintained in the future.

All ENDURE applications have been integrated into a single common server at JKI that will continue to be operational in the ENDURE ERG.

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HOW TO ENSURE FUTURE USE OF ENDURE TOOLS? A contribution from the Intellectual Property, Use and Dissemination Committee.

The necessity of ensuring the future use of the tools developed by ENDURE (such as documentation, data, software available from the EIC and Virtual Lab) has led to the development of dedicated Intellectual Property tools and recommendations, which have been made general enough to cover a broad range of situations and should therefore be reusable by other EU projects. The aim of this work is that the ENDURE tools will still be available in the future.

A dedicated licensing-in agreement for materials for the EIC

The licensing-in agreement comes from the need of the ENDURE Information Centre (EIC) to disseminate information that has not been developed inside ENDURE through its website. This agreement can be used whenever information providers who are not members of ENDURE agree to provide information of any kind (document, data, pictures, etc.) to ENDURE to disseminate this information to the public through the ENDURE tools (EIC or Virtual Lab for example).

When EIC users register themselves, they agree to an electronic version of the agreement which allows them to instantly download the material collected under this agreement. The agreement acts as a kind of cascade of links the signatories (see Figure 1). This way, maximum use of material is enabled by allowing users of the EIC to access original documents for free with the same terms under which the author agreed to provide its documents to the EIC.

The users have the additional benefit of knowing exactly where they stand legally with respect to the use of the material. For example, publication rights are given provided there is attribution. There is no need to acquire advance permission from the owner of the material, with the problems this can create.

Figure 1 – What the licensing agreement allows.

Current confusions held by the scientific community about 'open source' and 'released into the public domain'

'Public domain' is different from 'published document'. If something is public domain, either its period of copyright

KEY RIGHTS	RESPONSIBILITIES
Right to incorporate the Materials into one or more Collective Work (limited to a database located in the EIC or to work conducted under the ENDURE Trademark)	Attribution must be given to the original creator/ owner of the Materials
Right to reproduce the Materials as incorporated into the Collective Work	No right to make Derivative Works (= recycle parts of one work) but writing abstract is OK as long as access to the original work is indicated or provided
Right to non-commercially publish, distribute, archive, perform or otherwise disseminate the Materials or the Materials as incorporated in any Collective Work, to the public in any material form in any media whether now known or hereafter created - provided that the distribution is on the same terms as this agreement	The duty to report how the Materials have been used (for this point, users of the EIC will have to register to download the documents for example)

The agreement gives a number of key rights to the ENDURE Partner who collected the information and as a result to EIC users, but it also has a number of responsibilities:

has expired or the copyright owner has gifted it to the public domain, perhaps via CC0 (Creative Commons Zero) or other means. Copyright may still subsist in published documents, and patents may cover the use of the ideas in the papers. That said the ideas in those published documents, will, in a general sense be in the public domain, despite not being public domain documents per se. For this reason caution is suggested when using the term 'public domain'.

'Open access' documents mean different things to different people. It is clearer if a licence giving wide access is provided to third parties (licensees) by the Owner of the document (licensor).

Open source normally relates to software licences such as the General Public Licence, however a wider, looser understanding of it exists in some circles, applying the concept to material transfer agreements for biological materials for example (CAMBIA-BIOS).

Recommendation for disseminating ENDURE tools

All software produced in ENDURE can be registered by its developer if possible (e.g. APP, Agence pour la Protection des Programmes in France: http://app.legalis.net).

Software should be disseminated under a licence, even if it is an open source (e.g. GPL, LGPL, Apache). If not, it cannot be considered as properly released. A licence allows other researchers to clearly understand under what terms they can use it, and allows for a responsibility disclaimer. ENDURE suggests using the licenses indicated in Figure 2.

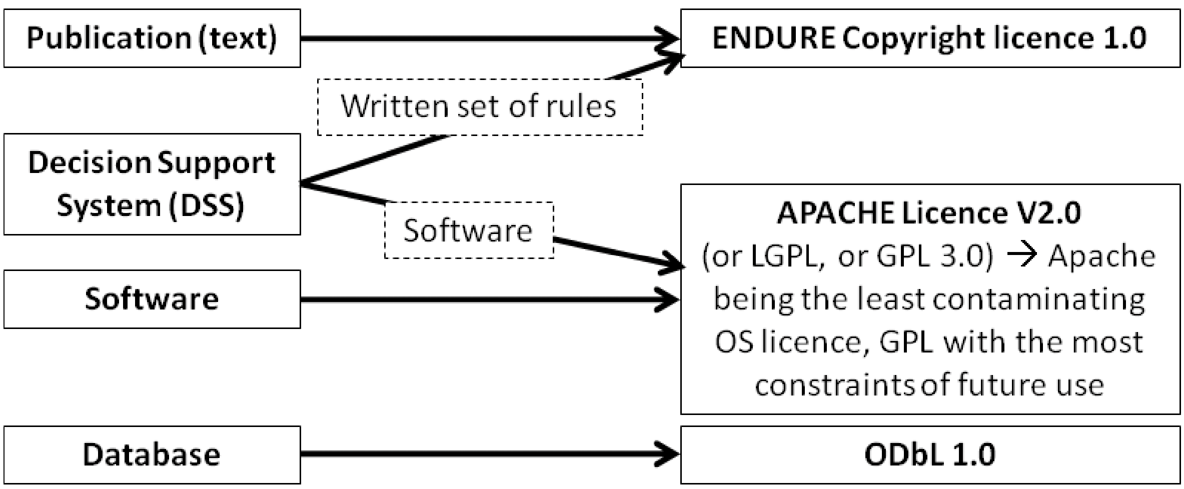

Figure 2 – Recommendation of licences in function of the nature of the material.

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PROMOTING THE MOBILITY OF HUMAN RESOURCES TO BUILD THE NETWORK IN IPM

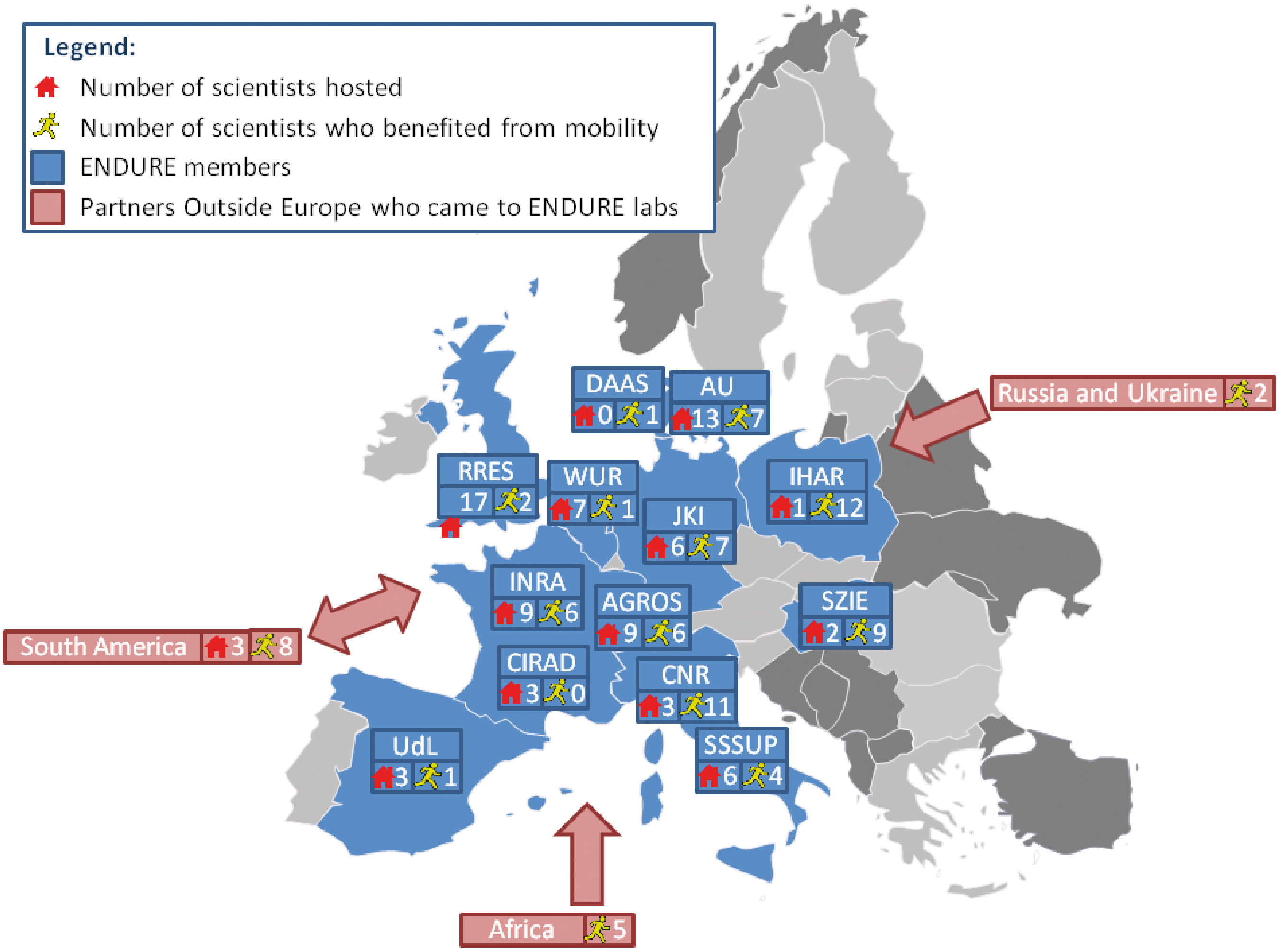
The objective of ENDURE staff mobility was to contribute to the capacity and competitiveness of crop protection research in Europe through implementing efficient mobility actions targeting both experienced scientists and young researchers. Besides promoting job opportunities, ENDURE successfully organised and supported the mobility of 64 scientists from ENDURE participating institutions and 14 from Partners Outside Europe (POEs) visiting ENDURE labs, for an average of two months per visit.

Fragmented and localised capacities in Integrated Pest Management (IPM) research hamper competitiveness and prevent us from fully benefiting from the available human resources in Europe. Mobility programmes in education demonstrate the **need for and success of exchanging scientists.**

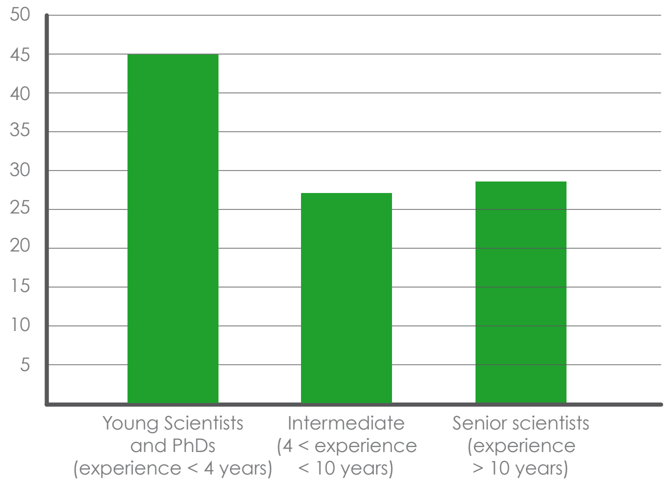
The objective of ENDURE staff mobility was to contribute to strengthening the capacity and competitiveness of crop protection research in Europe, with emphasis on IPM implementation, by encouraging, supporting and coordinating staff mobility within and into the network.

ENDURE adopted various strategies to make movement more attractive. At a practical level, it eased mobility by providing information about opportunities, administrative procedures and available accommodation through connections with the European Network of Mobility Centres EURAXESS. At a strategic level, it provided opportunities for staff exchange amongst the ENDURE members as well as with external organisations through internal and external calls.

The **internal mobility** actions targeted both experienced scientists and young researchers from ENDURE members.



Number of scientists from ENDURE members and POEs who benefited from mobility.



Experience of the participants of the mobility.

The **external mobility** actions targeted scientists from International Cooperation Partner Countries (ICPC) holding a position allowing them to establish a lasting collaboration with the ENDURE hosting Institution.

Twelve job opportunities in crop protection, integrated pest and weed management, targeting experienced scientists, young researchers and other laboratory staff were published on a dedicated web page.

Mobility has been a useful instrument to develop common experimental or desk research activities and initiatives, contributing towards forming an effective and efficient network in the field of IPM. This success has lead to the planning of future mobility activities in the ENDURE ERG that will perpetuate some of the ENDURE activities after EC funding is finished.

A specific task will promote any opportunity for the mobility of scientists among the ERG members and facilitate the aggregation of institutions to implement common mobility plans. It will facilitate staff secondment between ENDURE members by enquiring about the availability of mobility grants offered by the ENDURE institutions. It will also inform and encourage ENDURE institutions to apply to calls for mobility grants financed by external sources. This will be achieved by identifying and putting in contact those institutions willing to participate in a common project. Ad-hoc tools such as web pages, mailing lists, and online forms for the promotion of mobility offers will be developed and regularly updated.

Funds from external sources will be identified in order to transform the willingness to exchange scientists among laboratories into a concrete mobility plan for scientists between the network of ENDURE members.

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IPM, THE GLOBAL CHALLENGE: ENDURE fosters worldwide collaboration.

European agriculture is not isolated, especially in the context of an increasingly globalised world. Therefore, easing the integration of research teams from Partners Outside Europe into the ENDURE network has been a major priority. In such a rapidly changing context several key points have been taken into consideration in building ENDURE's strategy for developing international links for future partnership:

- **The increasingly important role of countries with emerging economies**
- **The specific place of the Mediterranean area in relation to Europe**
- **The recent changes initiated in the International Agricultural Research system (CGIAR) in a more open way.**

The international context of Agricultural Research for Development (ARD) has changed significantly in the past five years, especially after the World Development Report published in 2008, along with increased awareness of extremely important global issues such as climate change and food security. In addition, plant pest and disease problems are of great concern in tropical and subtropical countries which are facing major development challenges and the responses of such countries to these challenges are very likely to impact significantly on Northern countries, through import of products and possible invasion by alien pests.

Concrete building of links with Partners Outside Europe

During the four years of ENDURE activities, links with Partners Outside Europe (POE) have been forged through several actions:

1) POE workshops with invited partners have been organised. The first one was organised in June 2008 in Rothamsted, U.K (see Figure 1). A second took place in October 2008 in La Grande Motte, France, back-to-back with the International Conference (see below). A third was held in October 2009 in Wageningen, Netherlands where the Forum of POE was officially launched.
2) The International Conference held in La Grande Motte (12-15 October 2008) provided an occasion at which 25 Partners Outside Europe representing 14 countries were gathered. Apart from valuable individual contacts and discussions, they presented three communications and nine posters.
3) Specific mobility actions for POE scientists: There have been three calls (one in 2008 and two in 2009) allowing seven applicants from seven different countries to spend two-to-three months in the laboratories of ENDURE partners. In addition, a specific call for Argentinean partners was launched in 2010, allowing six scientists from Argentina to visit ENDURE members' laboratories.
4) Participation of POE students in the Summer Schools. Two POE students attended the first Summer School in 2007, five attended the second and 10 (two-thirds of the participants) attended the third (September 2010). In addition, the theme of the 3rd Summer School was extra relevant for POE: 'New and emerging agricultural pests, diseases and weeds'.
5) Inclusion of partners in ENDURE's activities: CARBAP, West Africa, has been active in the banana cases study and the University of Talca, Chile, in the grapevine case study.
6) The Two-Track System (TTS) has been created as a general platform for exchanges between ENDURE scientists and researchers from outside the Network. The latest release of the TTS has been implemented with new types of data, which includes 1) existing working groups and experts working on crop protection, and events related to crop protection; and 2) funding sources for developing specific projects or actions with POE.
7) Development of communication tools specifically targeted at POEs through the development of dedicated pages on the ENDURE website. Supporting literature has been produced to raise awareness of ENDURE among POEs, in the form of a poster for the Annual Meeting in Wageningen in 2009 and a specific POE leaflet.
8) Creation of the Forum of POE in 2009: During the Annual Meeting in Wageningen the Forum of Partners Outside Europe was officially launched. By allowing a permanent communication between members, this Forum will be a useful tool for linking the ENDURE network with the countries outside Europe beyond 2010.

Figure 1: First POE meeting in RRES (UK) on 16- 17 June 2008 with invited POEs from Embrapa (Brazil), ZAAS (China), ICIPE (Kenya), and NARO (Uganda).

Twinning initiative with Argentina

In May 2009 the European Commission, DG-RTD, together with Argentinean and MERCOSUR authorities co-organised a workshop to launch a twinning initiative between selected European and Argentinean projects. As a result of this initiative a group of five Argentinean scientists were invited to participate in the 2009 ENDURE Annual Meeting and to be members of the Forum of POE. They also visited laboratories of four ENDURE partners: AU, WUR, RRES and CIRAD. Several areas of mutual interest were identified including pest modelling, pest outbreak forecasting, pesticide resistance management and weed management.

Toward regional networks

As a result of the various POE activities and the contacts established, several regional networks are being considered in the perspective of the durability of the ENDURE network beyond 2010 (see Figure 2):

Figure 2 - Regional networks inspired by ENDURE in the perspective of its durability.

China: The Zhejiang Academy of Agricultural Sciences (ZAAS) participated actively in all our workshops. There is a very strong commitment from ZAAS to build an ENDURE-like crop protection network in China and to develop strong links with ENDURE in Europe.

South America: Embrapa is a large body for plant protection research and is influential on the global platform. It places international collaboration as a high priority and has developed a unique mechanism for achieving this through the 'LABEX' (External Laboratory) concept. Several LABEX platforms are now in place across Europe (CIRAD, INRA, RRES and WUR). Embrapa has expressed considerable interest in working more closely with ENDURE, and the possibility of developing a regional network in the Mercosur area will be assessed through discussions with Embrapa and Argentinean partners.

Meditteranean Area: In September 2009, CIRAD and INRA met several Mediterranean partners at ICARDA (member of CGIAR) during an IPM workshop aimed at developing links and regional projects. During that workshop the ENDURE Network was presented and a concept note was written about the building of a circum-Mediterranean IPM Network.

Sub-saharan Africa: Up to now, contact with African partners has been based on personal contacts and the present situation of agricultural research in Africa is not ideal for developing concrete joint actions. However, the growing strength of FARA (Forum for Agricultural Research in Africa) is giving new hopes for developing more fruitful links with Sub-Saharan Africa.

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ENDURE BEYOND THE EC FUNDING

From the very beginning, the European Commission has had great ambitions for the ENDURE Network of Excellence. The first goal of the Network was to strengthen scientific and technological excellence in crop protection through the durable integration of its partners' research capacities. ENDURE has worked on this challenge since it was launched in 2007. After four years of EC funding, ENDURE has found a way to continue, relying on 14 of its own members' funding and commitment: the ENDURE European Research Group (ERG) was born in July 2010!

Transition from EC financial support to a self funded Network

When creating the Networks of Excellence, the European Commission made it clear its ambition to build durable cooperation at the European level to overcome a fragmented European research world and in fine to promote European research excellence on the global scale. The context is more challenging than ever for crop protection which must address both the need for mitigating the negative environmental impacts of pesticides and the need for increasing productivity coupled to increases in the world population while ensuring food safety. The European Commission has placed high expectations on ENDURE: "the Network *should establish itself as a world leader for the development and implementation of durable pest control strategies, and should become recognised as the first point of reference in Europe not only for scientists but also for legislators and users*". This ambition has guided all ENDURE activities since the beginning.

Throughout its four years of existence, the ENDURE Network has contributed to build a durable community of excellence in the European crop protection landscape and has developed its activities according to its ambition of excellence and sustainability. Thinking 'long-term' has led ENDURE to organise its strategy for sustainability around four major activities:

Research agenda: Joint consultation on research priorities

Based on a foresight study on the future of crop protection by 2030 and on the consultation of non-research stakeholders via the proposed ENDURE Club of Interest, ENDURE ERG will identify gaps and overlaps in crop protection research in Europe. It will help promote research priorities in the national agenda and, in the longer term, strategic programmes of the EC to impact the content of future calls. Maintaining collaboration with Partners from Outside Europe (POE) will allow the Network to coordinate national actions in relation to ENDURE's research agenda and to have a worldwide visibility by continuing to be a point of reference.

Support to the research community: Maintenance and sharing of research capacities and tools for the research community

The tools and databases developed by ENDURE Activities (including the Virtual Laboratory and its research platforms (EuroWheat, EUResist, QuantiPest), common databases (including GIS database) and other research tools and databases (WheatPest, WTDB, WeedML, etc.) represent a valuable resource for the international scientific community and can facilitate joint research programmes. These tools will be maintained and their content updated to bring support to the crop protection research community. In addition to these tools, education programmes aimed toward young scientists and mobility between partners' laboratories for senior scientists will be organised.

Scientific support to policy: Provide scientific expertise in support of policy development and implementation

The existing ENDURE Network of Experts has started to provide support in the development and implementation of crop protection policies. Because the new Directive on the sustainable use of pesticides has to be implemented in the coming years, policy makers at the European and national levels will continue to seek the services of ENDURE. The network will produce expert studies upon request from the policy-making sphere.

Extension: Provide a portfolio of ENDURE-validated documents and information useful to extension

The ENDURE Information Centre (EIC) provides a central point of reference to extend technical information on IPM practice. The EIC content will be continuously updated and will actively interact with the ENDURE Network of Advisers who will contribute to the updating and improvement of these learning materials.

This structure also aims at identifying new funding opportunities and at gathering expertise to make the most competitive applications. Successful new projects will have access to ENDURE facilities and will strengthen the ENDURE initiative at the same time. Fourteen European organisations have decided to gather and coordinate their efforts around these main points, using their own funding. All these features will make create a point of reference in crop protection in Europe but will depend on the capacity of the ENDURE ERG to federate all the relevant European organisations around crop protection issues.

With scientific coordination ensured by INRA, contracts for the ENDURE ERG have been signed on 1st July 2010 for an initial duration of four years and will start with a first consortium meeting in Berlin in September 2010. The new structure is promising: ENDURE's future is exciting!

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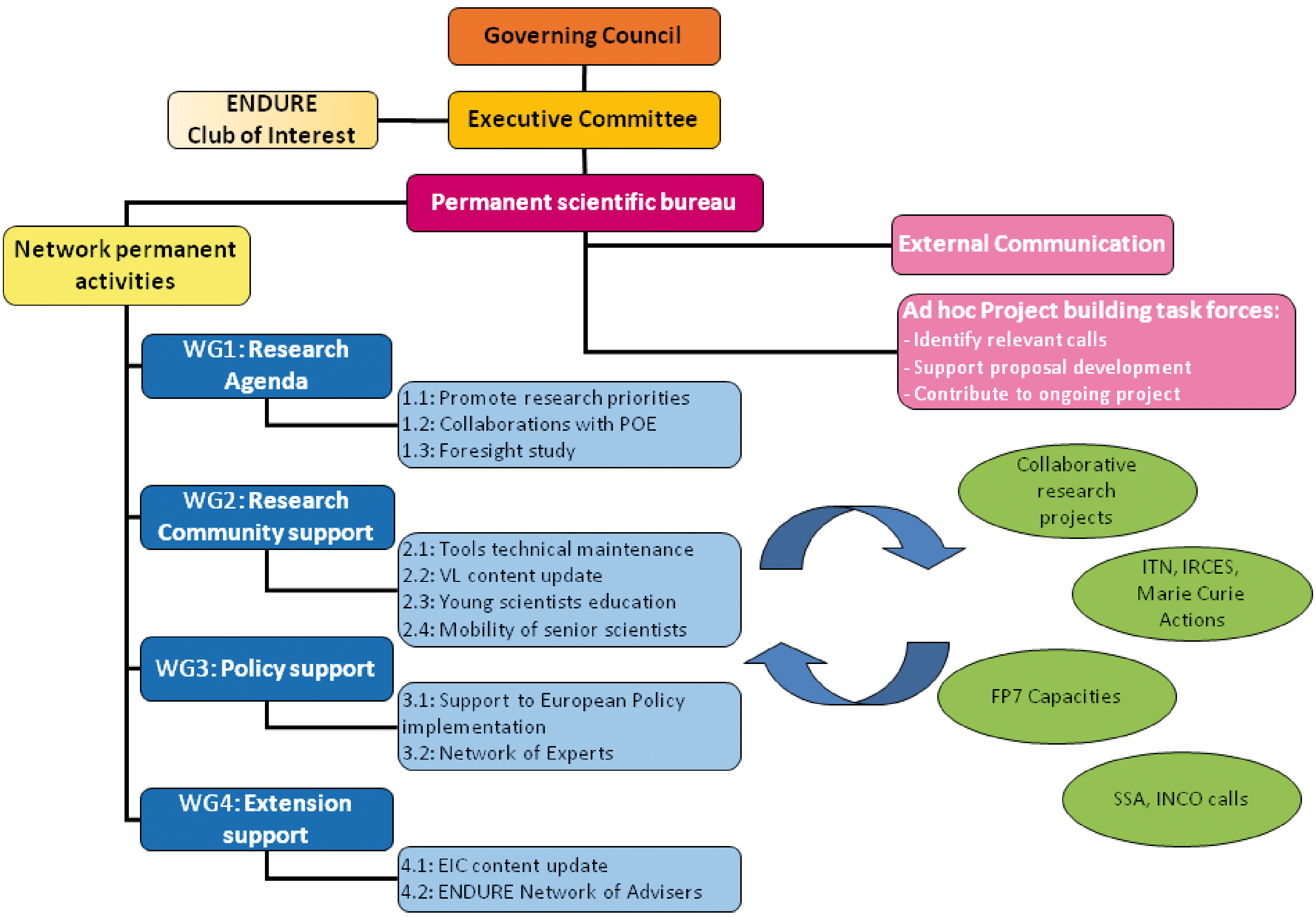

Structure of the ENDURE ERG

LOOKING AHEAD

ENDURE is now looking ahead to build on the success of the last four years supported by EC funding. Its member institutions are pooling their resources to create a permanent European Research Group (ERG). In the years ahead, the ambition is to become a major resource for our three target audiences – advisors, policy makers and researchers – who are now mobilised throughout the 27 member states by the new and challenging policy context.

For advisors, ENDURE endeavours to become a central point of scientific and technical reference. The ENDURE Information Centre will further develop to become a key source of practical information and training materials in several languages across Europe. The network of crop advisors that ENDURE is setting up across Europe will make it possible to share diverse national experiences, know-how and to discuss the new challenges arising from the new demands. New training material will support farmers in their transition towards IPM.

ENDURE is committed to providing science-based support to policy, in particular in the context of the implementation of the Framework Directive on the sustainable use of pesticides and Article 13 that makes the implementation of Integrated Pest Management compulsory for all EU agriculture by 2014. In this regard, it has begun and will continue to provide support for the development and implementation of National Action Plans in member states and to produce expert studies of interest to the policy-making sphere.

For researchers both in Europe and internationally, broadly available research tools, cross-national mobility and participation in educational initiatives are creating an operational community of practice around IPM. The stage is also set to become an institutional space dedicated to long-term strategic thinking and coordination of EU and national research efforts. The ENDURE ERG will strive to become a platform for the launching of European and international initiatives and projects and will promote research priorities in national and European agendas. It will maintain the European level momentum to create synergies from national efforts to reduce pesticide dependence while preserving the competitiveness of European agriculture.

And for all research and non-research stakeholders concerned by crop protection and the pesticide issue, this European Research Group will function as a forum for the identification of future initiatives in research, extension and policy to advance sustainable approaches to crop protection.

ACTIVITIES	INSTITUTION	NAME	FIRST NAME
INTEGRATING ACTIVITES			
• Ensure long-term strategy of ENDURE	INRA	Ricci	Pierre
Ensure long-term strategy of ENDURE	INRA	Ricci	Pierre
Network of experts	INRA	Barzman	Marco
European Crop protection in 2030	INRA	Latxague	Emilie
Cross-linking with networks and projects	CIRAD	Sarah Hugon	Jean-Louis Rémy
Network durability	IT	Troillard	Vincent
• Creation of a networked "virtual" laboratory in crop protection			
Sharing of resources, facilities and protocols	RRES	Evans	Neal
Development of a modelling platform and integration of DSSs	AU	Rydahl Nielsen	Per
• Human Resource Exchange	CNR	Sattin Piccolo	Maurizio Federica
• Integrated knowledge and communication within the Network			
Tools for integrated knowledge management	JKI	Dachbrodt-Saaydeh	Silke
Reinforce Communication within the network	IT	Troillard	Vincent
JOINTLY EXECUTED RESEARCH ACTIVITIES			
• Optimising and reducing pesticide use based on existing approaches			
> Identification, configuration and evaluation of case studies	AU	Kudsk	Per
> Implementation of the case studies			
Wheat (ended)	AU	Nistrup Jørgensen	Lise
Potato (ended)	PRI	Schepers	Huub
Integrated weed management (IWM) (ended)	AU	Melander	Bo
Pomefruit (ended)	PRI	Heijne	Bart
Tomato (ended)	UdL	Gabarra Arno	Rosa Judit
Banana (ended)	CIRAD	Cote Risede	François Jean-Michel
Field Vegetables	INRA	Lucas	Philippe
Maize	AGROS	Mouron	Patrik
Grapevine	INRA	Gary	Christian
• Optimising and reducing pesticide use based on existing approaches			
Prevention of pest damage at the cropping system level	INRA	Aubertot	Jean-Noel
Exploitation of innovative technologies for implementing crop protection strategies	PRI AU	Zijlstra Thysen	Carolien Iver
Exploitation of landscape and community ecology	INRA	Lavigne	Claire
Design of crop protection strategies through modelling and experimentation	INRA	Messéan	Antoine
Orchard system study - Phase 1	PPO	Heijne	Bart

ACTIVITIES	INSTITUTION	NAME	FIRST NAME
Designing Innovative crop protectin strategies in arable rotations	INRA AU	Messéan Kusk	Antoine Per
Winter Crops Based Cropping Systems (WCCS)	AU RRES	Melander Evans	Bo Neal
Maize Based Cropping Systems (MBCS)	SZIE CNR	Kiss Sattin	Jozsef Maurizio
Meta-analyses of rotational effects on weeds and pests	RRES	Bohan	David
• **Multi-sector evaluation of crop protection methods & cropping systems**			
Assessment of crop protection strategies based on multicriteria methods	AGROS	Mouron	Patrik
Analysis of economic driving forces related to crop protection systems	AGROS	Mack	Gabriele
Environmental risk and benefit assessment	JKI	Strassemeyer	Jörn
Life Cycle Assessment	AGROS	Gaillard	Gérard
Societal assessment of current and novel low input crop protection strategies	INRA	Lamine	Claire
• **Improving the basic understanding of the biology of the crop-pest systems**			
Exploitation of plant genetic resistance	INRA	Durel	Charles-Eric
Exploitation of natural biological processes	IBMA CNR	Blum Ruocco	Bernard Michelina
Weed biology and management	AU	Holst	Niels
SPREADING ACTIVITIES			
• **Joint training and education programmes**			
Joint Programme of training research, key staff and end-users	SZIE	Kiss	József
Joint Educational Programme	SSSUP	Bàrberi	¨Paolo
• **Technology Transfer**	IT INRA	Lenée Barbier	Philippe Pascale
• **External Communication**	CIRAD	Nouaille	Christine
• **Development of ENDURE-Information Centre for use by Advisors**	PPO	Schoorlemmer	Herman
• **Development of a framework for interaction between research and policy making**	JKI	Dachbrodt-Saaydeh	Silke
• **Management of the Consortium**	IT	Troillard	Vincent

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CNR / IT
AGROS / CH
WUR (PRI, PPO, LEI) / NL
IHAR / PL

Education & R
SSSUP / IT
SZIE / HU
UdL / SP
AU / DK

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VFL / DK
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Agroscope Liebefeld-Posieux Research Station ALP
Agroscope Reckenholz-Tänikon Research Station ART

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