STRATEGIC RESEARCH AGENDA FOR IPM IN EUROPE

C-IPM Coordinated Integrated Pest Management in Europe

Funded by
the European Union

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Date: 1 June 2016

Foreword

The ERA-Net C-IPM would like to thank the people who have contributed to this document and in particular the members of the C-IPM Governing Board (GB) and Executive committee (Ex-Com). We are also thankful to the participants of the Strategic Research Agenda (SRA) and thematic workshops, those who contributed through public consultations, mapping meetings and other activities. We are grateful to representatives of the EPPO, other ERA-NETs and FACCE JPI who provided useful feedback on this document. A final word of thanks goes to the members of the coordination team.

The drafting and finalising of the SRA has been a long and fruitful process. Since the preparation of the first draft in mid-2014, the document was subject to both internal (within C-IPM Ex-Com and Governing Board members) and external (all relevant stakeholders) discussion. More specifically, a specific SRA workshop was organised in March 2015 during which a number of stakeholders from different fields met in Paris and discussed the content of the earlier version of the document and provided constructive comments. Subsequently, the draft document underwent two rounds of open public consultations in 2015 seeking comments with the aim of improving the content. Based on the feedback received from a wide range of stakeholders, the draft document was repeatedly revised until its finalisation in the current form.

This SRA document is designed, as specifically requested by the European Commission, to address the key concerns of improved coordination of national research efforts to enhance IPM implementation. The SRA provides recommendations on future European and national IPM research in terms of challenges for agriculture and crop production.

The activities described here have been financed by the European Commission (ERA-Net C-IPM project number 618110) under the seventh framework programme of the EU.

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Summary outline

The Strategic Research Agenda (SRA) of the European Research Area Network of Coordinated Integrated Pest Management (ERA-Net C-IPM) is designed to address the key concerns of improved coordination of national research efforts to enhance IPM implementation. The SRA provides recommendations on future European and national IPM research in terms of challenges for agriculture and crop production. The content of this document takes into account the previous initiative of the Standing Committee of Agricultural Research Collaborative Working Group (SCAR CWG) on Integrated Pest Management (2011-2014) and the outcomes of mapping national research priorities and needs as well as workshops on national research programmes and infrastructures performed within the C-IPM.

The ERA-NET C-IPM is the first transnational network of research programme owners and managers, funded by the EU that aims to align national research programmes on IPM in Europe. Thirty two organisations belonging to 21 EU-Member States (MS) and Associated Countries are collaborating in this network. In order to cope with the common future challenges encountered in European agriculture, the ERA-Net C-IPM aims to play a central role by coordinating joint research and transnational calls concerned with Integrated Pest Management especially in support of the requirements established by the Directive on the sustainable use of plant protection products (PPPs) (Directive 2009/128/EC) and the Regulation on placing PPPs on the market (1107/2009/EC) (1,2).

The overall objective of the C-IPM SRA is to delineate both short to medium as well as long term priorities for IPM research to identify gaps and enable enhanced IPM implementation in Europe. The short-term agenda aims to create a forum for exchange and identification of IPM research and development priorities, connect existing initiatives and coordinate joint transnational research calls. The SRA will lay the groundwork for the implementation of joint transnational research.

In this context, the SRA has the following specific objectives:

- Support network IPM-related research and create synergies based on a status quo survey of existing research activities on IPM within the EU;
- Identify overlaps and gaps to avoid duplications as well as opportunities and complementarities for improved transnational coordination and joint initiatives on research;
- Enhance pre-existing and establish new linkages between research programmes and initiatives towards coordination of IPM research and development (R&D) in Europe;
- Identify future challenges for European crop protection which require IPM solutions;
- Feed emerging research demands to meet these challenges into the Horizon 2020 framework program;
- Identify opportunities and mechanisms for knowledge transfer/ sharing; training & dissemination of information of IPM research.

Introduction

Today's agriculture faces multiple challenges: foremost ensuring food security by a highly efficient and sustainable plant production. Crop protection and IPM are cornerstones of preventing crop losses and ensuring high quality production.

What is IPM?

Integrated pest management (IPM; Box 1) is a dynamic approach, hence a continuously improving process in which innovative solutions are integrated and locally adapted as they contribute to reducing reliance on plant protection products (PPPs) in agricultural systems. Such improvements derive from the fact that the approach responds to diverse farming situations. An optimal decision process is based on sound knowledge of the entire cropping system and available information and tools which need to be combined or to be improved. This flexibility and resilience in space and time are strengths on one hand and challenges for its implementation on the other.

European legislation and the challenges for sustainable agriculture

Current pest management practices in the EU are based on the use of PPPs. However, due to increasing awareness of potential adverse impacts of PPPs on human health and the environment, the European Commission has introduced legislation on reducing these risks and impacts of pesticide use.

The Directive on the sustainable use of PPPs (2009/128/EC) requires from the European MS to set up National Action Plans to define objectives and measures to achieve risk reduction during the application phase of PPPs. Moreover, according to Article 14 of the Directive (2009/128/EC)(1), all professional users of PPPs have to apply the general principles of IPM, as laid down in Annex III, since 1 January 2014.

EU Regulation on placing of PPPs on the market (Reg. 1107/2009/EU) sets out the rules for a harmonised approach to regulate the authorisation of PPPs based on harmonised data requirements responding to risks concerning human health and the environment. This follows the EU re-evaluation of PPPs initiated in 1991 that resulted in the removal of 73% of the PPPs from the market. Moreover, the number of plant production products with new modes of action entering the market has been decreasing and there are a lot of registered PPPs that are no longer effective due to pest resistance problems. All these facts further increase the demand for IPM approaches and solutions.

Consequently pest[1] management alternatives to broaden the suite of applicable tools beyond the use of PPPs are sought.

Overall, European agriculture currently faces two major challenges. Firstly, for many crop/pest situations, no effective and economically feasible alternatives to PPPs are yet sufficiently available or are still under development (4). Hence, there is a need to put more effort into developing IPM strategies that significantly reduce reliance on the use of PPPs while maintaining crop yields and profitability. Secondly, in a number of cases, a range of IPM tools are available but their adoption still remains a challenge due to different climate, soils,

General concept and definition of IPM

The concept of Integrated Pest Management (IPM) was first officially defined in 1965 by the Food and Agriculture Organisation (FAO). Despite several definitions of IPM available in the literature, the FAO concept was further developed in Europe to a framework of Integrated Plant Production by IOBC-WPRS (3), providing the general principles for IPM as referred to in the European Union Framework Directive on the Sustainable Use of Pesticides (Directive 2009/128/EC).

The European Commission has defined IPM as follows:
"IPM means careful consideration of all available plant protection methods and subsequent integration of appropriate measures that discourage the development of populations of harmful organisms and keep the use of plant protection products and other forms of intervention to levels that are economically and ecologically justified and reduce or minimise risks to human health and the environment. IPM emphasises the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms" (1).

[1]Pest in this context covers pathogens, animal pests and weeds (ISPM- Standard No. 5)

cropping and farming systems (5). Highly diverse crop production systems across Europe, with even more diverse geographic and climatic conditions, increase the complexity in European crop protection. The competitiveness of European crop production may be challenged due to the decreasing number of available PPPs and put EU production at a disadvantage compared to competitors. This is a huge challenge that research and the farming community are facing.

The role of policy

The focus on sustainable agricultural production, the introduction of greening measures in the CAP and agro-environmental climate measures in the rural development programme might act as leverage for public awareness of the environmental actions of the farmers. Agro-environmental climate measures can be a means to voluntarily encourage farmers to environmental commitment and farming methods beyond legal obligations. Such additional measures could also support and accelerate the adoption of IPM.

It is unclear how readily IPM approaches and crop-specific strategies will be adopted, especially while knowledge and technology gaps still exist (6). While the implementation of the general principles of IPM is mandatory in Europe, adoption of crop specific guidelines remains voluntary, which increases the risk of slow adoption. Moreover, there is a high heterogeneity in the level of commitment among the MS. The interpretation and fulfilment of the principles and possibilities of the IPM principles' implementation into practice vary due to climatic and agricultural conditions but also due to existing knowledge and experience with IPM (5, 7). In this regard, understanding drivers of change, and how rapidly a transition in the crop protection paradigm from conventional to an IPM basis can be pragmatically achieved is of interest. Understanding the drivers of IPM adoption requires a broader and multidisciplinary approach since IPM covers a large set of principles and is, by far, not solely limited to reducing pesticide use.

A better understanding of the obstacles related to IPM implementation should be the focus of policy. Is IPM with its tools and priorities more costly than plant protection based on chemicals? Even if IPM measures do not cost more, not every farmer is willing to use them, often due to risk perception or habits. Costs are the most important driver to (not) implement IPM but risk perception, the social environment of the farmer and the public opinion are also important drivers in the choice of plant protection measures. Answers to these questions are central to the success of the evolution of farming towards the sustainable use of PPPs and to encourage the development of adequate policies to improve the level of IPM implementation and adoption throughout the MS.

Consumers and communication

Consumers are a stakeholder group which partially impacts on production schemes and market opportunities from the customer's perspective. The purchase behaviour of consumers does not always reflect the attitudes and concerns of the public on environmental effects from agricultural production. To extend the focus of the consumers on IPM-based products, there is a need for producers to actively engage with the retail sector.
Overall, retail chains currently represent a constraint on IPM because of their demand for zero or below the legal maximum residue level (MRL). Retail standards can be counterproductive to the IPM concept with regard to pest resistance management, the use of selective PPPs, the use of treatment thresholds and environmental sustainability. Therefore, there is a need for considerable engagement for training and communication with both retail chain partners and consumers. It is important for the farming community to engage in the public discussion with facts about sustainable production to ensure a broad and multidirectional discussion.

Better information, training and education on IPM approaches and its value in sustainable production is of importance to overcome perceived risk and better understanding of the production process for all concerned groups and the general public. Farmers and researchers can make more use of demonstration fields and field days to create an understanding for food production. The real risk vs. the perceived risks of consumers should be explained by science in "easy-to-understand" messages. All possible communication channels and media should be engaged in producing clear and simple messages for the general public.

The role of research

Success of IPM implementation will depend on the provision of novel, effective and reliable approaches and tools to the farmers. IPM is the systematic combination of preventive and cultural measures and a range of innovative tools which increasingly will need to be implemented or improved by joint approaches of the farming and scientific community. Other innovative tools still need to be developed and/or further advanced to become ready for use by research.

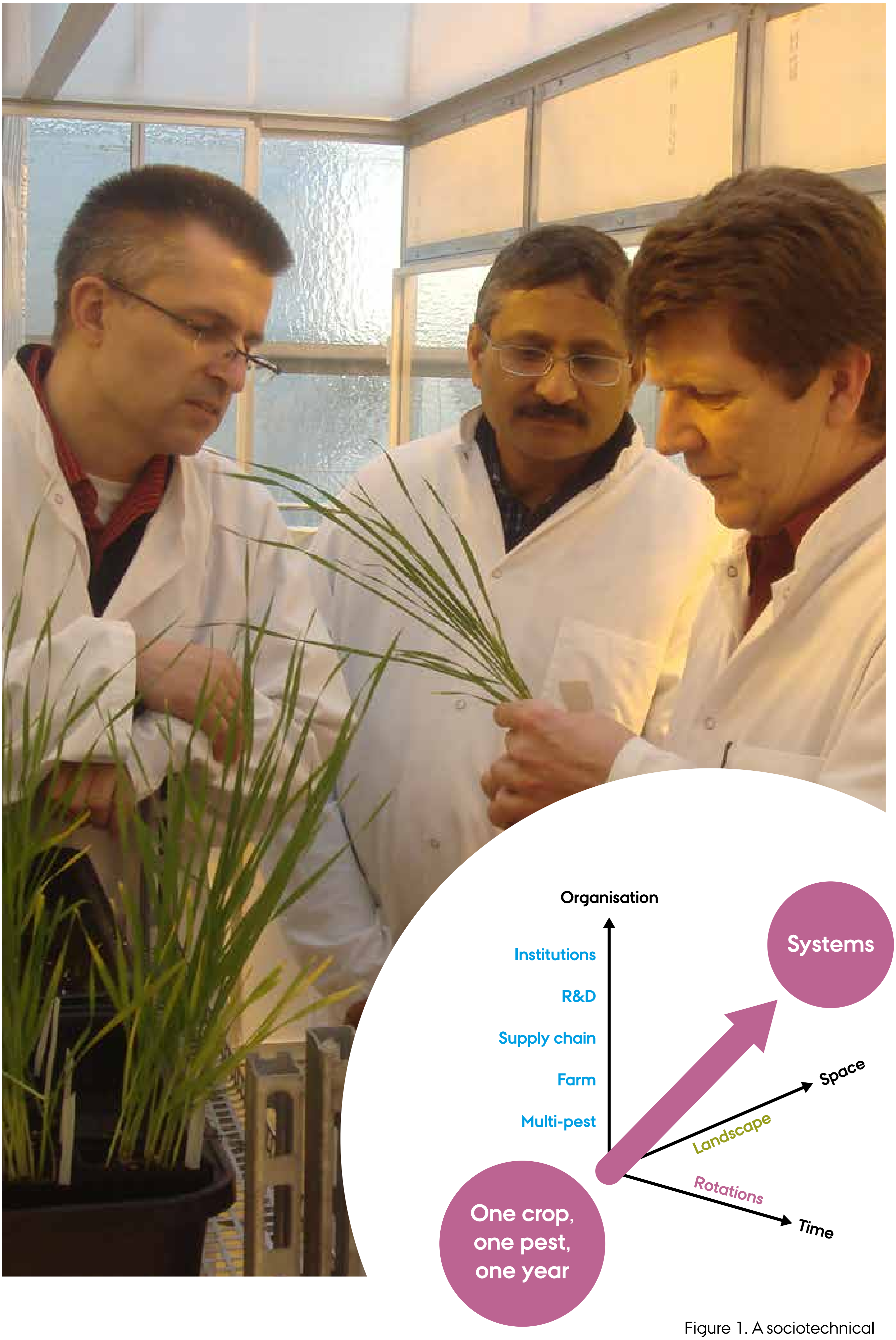

Figure 1. A sociotechnical perspective of the systems challenge.

Short term consequences of the farmer's choice are often critical for the decisions in practical management, but more focus on the long term consequences, e.g. of resistance development, might benefit IPM solutions as also highlighted by the ENDURE foresight study (8). A better communication of the benefits of IPM, based on actual data on benefits in the region in question, could help more farmers to implement a high level of IPM. Socio-economic research might play an important role to this objective.

Far-sighted research that focuses on the anticipation of future risks and development of sustainable systems to avoid pest problems and to prevent crops from pests is still not widely applied. To this aim, multidisciplinary research and a more wide-ranging perspective comprising the ecology, biology and evolution of pests as well as risk evaluation and prediction are needed.

Knowledge transfer from research results to practice is often hindered especially when practical implementation issues are not considered. Research driven by practical questions can help to overcome such obstacles. Farmers face complex crop management and crop protection issues, including the multiple interactions between crop nutrition, crop growth and pest development. Therefore research should not only be limited to the different partial aspects of pest control, nutrition, etc. but also look especially at interactions. In some countries the scope is broadened and IPM is put in resilient and sustainable systems. Knowledge exchange, focused on the whole production chain, allows farmers to have a better basis for the implementation of IPM.

Farmers should be ensured that the available knowledge is accessible to them. MS should increase their efforts to overcome the gap between research and practical management. Advisory services have an important role in this process and demonstration farms can form a bridge between applied research and farmers. Experience from employing the principles and practices of co-innovation shows that if farmers are effectively involved in the development of new tailor-made solutions the buy-in into changing practice has more impact. There is a need for knowledge-sharing among farmers and other stakeholders to define future research activities/needs and to better understand how the local contingencies – ecological, social, economic and technological – influence the ease and willingness of IPM implementation.

In addition, there is a need to mobilise theoretical frameworks such as the sociology of organisations, institutional economics, and public choice theory. Research that explores socio-economic links between the different actors — ranging from pesticide producers to pesticide users and from cooperatives, traders, consultants and unions to consumers — are essential to help implement IPM. It is also important to re-think the production system that provides increased performance.

In national and European research over the recent years much effort has been invested to generate new knowledge, develop innovative approaches and tools. Nevertheless, this kind of research has been fragmented and addressed via specialised research disciplines. The integration and adaptation of available knowledge into the holistic approach of IPM is still insufficient or lacking.

Hence, the current IPM research organizations are challenged. Future research should link generic research and applied practical solutions and increasingly shift from mono-disciplinary to multi-disciplinary system-based approaches (Fig. 1). Farming systems research and research approaches employing a theoretical view on systems could provide new insights as they both look at farming as a systemic, socially and practically constructed entity. This kind of IPM research could integrate the multidisciplinary and trans-disciplinary aspects of IPM research. The research approach should move from "product-based to chain-based and regional" and from research driven to question driven. Only choices based on the whole chain or regional needs lead to the successful implementation of IPM. To fill this gap, the role of extension and demonstration farms is of paramount importance as an "interface". The IPM system approach and co-innovation methods are envisioned to better interlink knowledge capacities of farmers, extension and research to generate and advance robust and sustainable solutions and strategies.

The organisation of research programmes is very diverse and varies between the MS. To avoid overlapping research and make most efficient use of national and European funding, joint trans-national research (JTR) can play a vital role in IPM research development and implementation. There are a number of identified research areas within IPM of common interest at regional, national and trans-national levels. In such cases, JTR is of central importance to benefit from trans-national collaboration and work sharing.

Methodology – inputs to the Strategic Research Agenda

Different activities enforced the C-IPM process to move toward a trans-disciplinary and participative approach. The analysis of current and future national research programmes led to collect information to be integrated into the European Scientific Research Agenda. A number of mappings identified needs, gaps, weaknesses, strengths and challenges of IPM. Based on the outcomes of these surveys, a long list of potential research topics was prepared and further discussed during the C-IPM annual meeting. All this information led to the development of this SRA. The research strategy was developed via stakeholder discussions, thematic workshops as well as activities dedicated to the analyses of infrastructure and platforms, capacity building, education and training, knowledge exchange and communication, and dissemination. Joint knowledge sharing activities and trans-national calls are planned to implement the SRA. An overview of C-IPM activities that contribute to the SRA is shown in Figure 2.

Needs and gaps based on the mapping and results of surveys

The main objectives of the mapping were to provide information to identify research and development needed to support National Action Plans (NAPs) and IPM in particular, to assess the added value and opportunity of jointly addressing needs and finally, to make recommendations on coordinated trans-national research initiatives. Overall, the outcome of mapping activities highlighted the following strengths and weaknesses of IPM research:

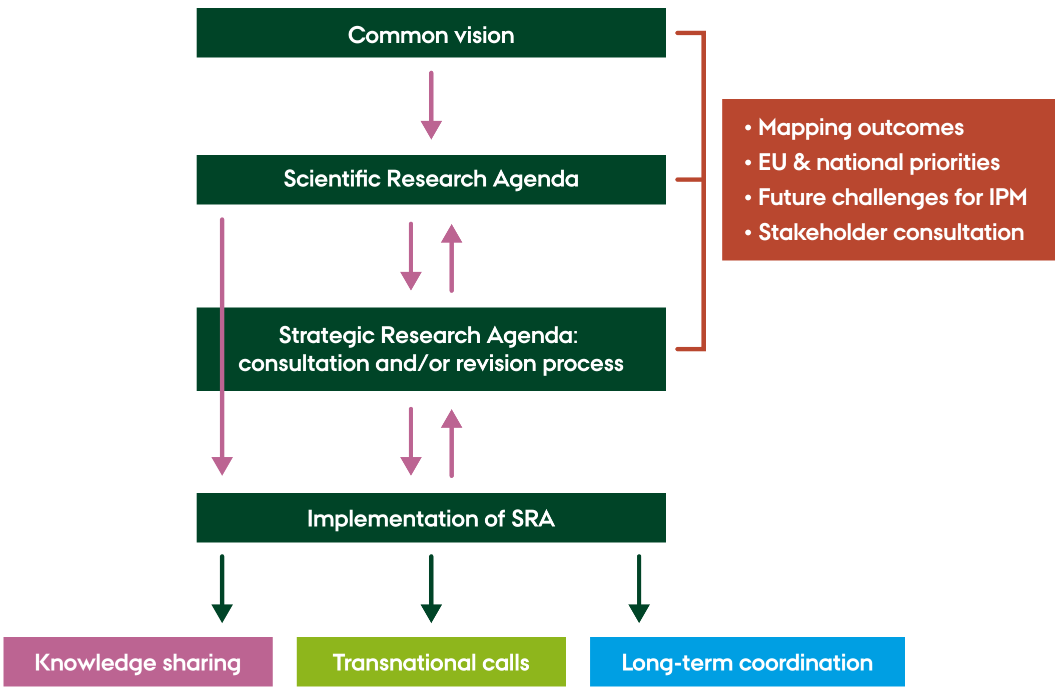

Figure 2. C-IPM activities contributing to the Strategic Research Agenda.

Strengths

- Coordinated research at European level has been emphasised by all partners as essential for the progress of IPM in Europe;
- The need for developing multi-disciplinary projects that could address long-term and future key issues and identify priority subjects has been acknowledged by all partners;
- Sharing of experience in IPM implementation in practice has been emphasised by all partners. Countries who have implemented IPM for long time have acquired important experience and are ready to share their experience with countries where IPM development and implementation are at the initial stage;
- IPM demonstration farms exist in several MS and offer a good option to engage in a European network.

Weaknesses

- Lack of collaboration between funders of IPM research, limited transfer of research knowledge into practice and lack of communication and collaboration in IPM throughout the MS are current problems in Europe that hinder IPM adoption;
- Short term and project-based funding dominates and does not support the long-term development of IPM farming systems;
- The socio-economics of IPM implementation is yet poorly addressed.

Stakeholders

The contribution of stakeholders to the ERA-Net C-IPM is of fundamental importance to achieve the goals of the SRA. To this aim 267 different Resource Groups (RG) in eight C-IPM RG Categories have been identified. The RG Categories comprise research funders, research managers, national-, regional-, and transnational research networks, transnational plant protection related organizations, research providers, national SUD implementing authorities, advisory and extension services, organisations/associations of farmers, consumers and industry. The members of the RGs will either be invited to actively contribute to C-IPM, be consulted, or be informed about activities and processes on a case-by-case basis.

Strategic Research Agenda

The analysis of current and future national research programmes led to the identification of the most important topics which have been categorised in 4 core themes (Figure 3). Each core theme includes more than one topic and several sub-topics. These core themes include topics that reflect the current priorities and future research needs of the partners and consequently represent short to mid-term IPM priorities.

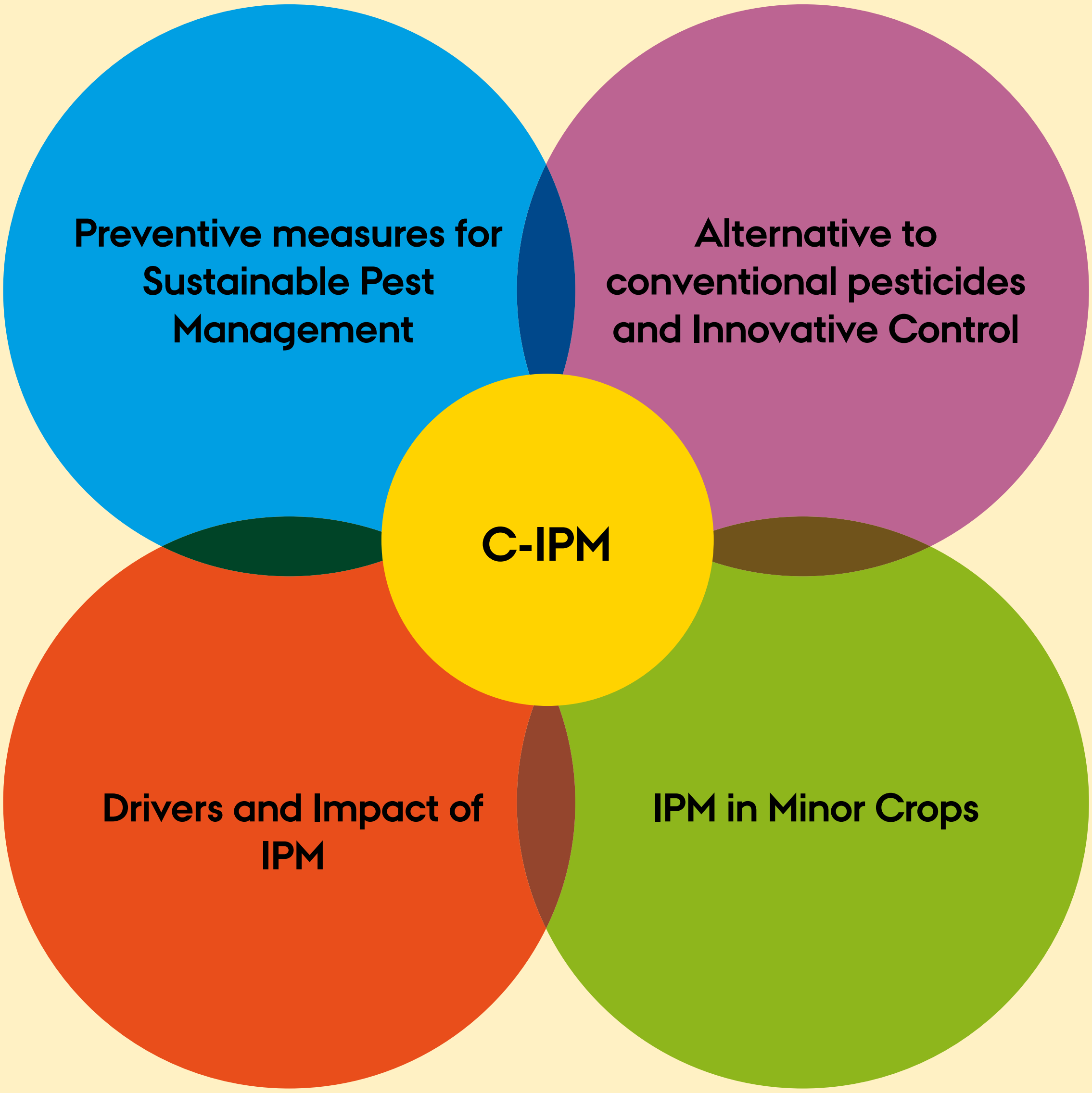

Figure 3. Four core themes.

Core theme A: Preventive and sustainable (pest) management

Background

One of the major parameters to be considered to design effective and sustainable cropping systems is the reduction of chemical input to manage crop damage due to pests. A substantial reduction of PPPs is feasible only by integrating a range of strategies that help to better manage potential yield losses due to the pest. Interventions based on chemical control are often effective only for short term relief. Long term solutions can be achieved only by restructuring and managing these systems in ways that maximise the array of "built-in" preventive strengths, with chemical tactics serving strictly as backups to these preventive measures. Hence, a total system approach partly based on prevention is essential as the guiding premise of pest management.

Integrated solutions for crop protection, that integrate application of new technology, risk mitigation measures, crop management to increase and favour the resilience of the agro-system, development of low input systems, and application of low risk PPPs, are needed since they contribute to decreasing the use of chemical PPPs and implementing innovative IPM solutions. Many agronomic/cultural approaches may prove beneficial as a single strategy or as part of an integrated systems approach. For example, choice of variety, time of sowing, seeding rate (plant density), nitrogen management etc. warrant further research either as single factors, or particularly as part of systems which could reduce the need for pesticide input. Similarly, soil cultivation systems may impact on disease/pest carryover from season to season.

Genetic improvement of plants, to acquire greater resilience and resistance, can be accomplished by more precise and rapid breeding techniques, such as marker-assisted selection. For example, pest and disease resistance can be engineered based on advances in understanding the plant immune system (9). Pyramiding resistance genes combined with monitoring of the occurrence of new virulence genes in pest populations under field conditions will be the basis for future durable resistance management, and a key for advanced IPM (10). Deployment of pest resistant and/or tolerant plant genotypes to pests at a landscape level is one of the key levers for the reduction of pesticide reliance in agriculture. This approach also represents the most robust one among the IPM tools, given its direct impact in avoiding and or/containing yield losses. The importance of considering resistance durability in a landscape context has received increasing emphasis (11) and is an important future area of research. Experimental systems are being developed to test resistance gene deployment strategies that previously could be addressed only with logic and observation. Questions such as how to design pest suppressive landscapes that are environmentally sustainable and how to get land managers to collaborate need to be addressed.

The use of resistant cultivars in general and those having a high level of durability of resistance in particular is an important tool for pest management. A widespread use of such cultivars is hindered as the number of cultivars that possess high levels of resistance/durability of resistance to key pests is very limited. New DNA technologies (gene stacking, transfer and editing) are considered as one alternative option to improve pest resistance of crops, by 'awakening' resistance in a plant. Such crops offer potential to contribute to the establishment of sustainable crop protection systems only when they are integrated within the framework of IPM, rather than applied as "a stand-alone pest control measure".

A number of agronomic practices — including crop rotation, cover crops, companion planting, intercropping, mixture of varieties etc. — can reduce pest pressure in our cropping systems (5). These practices enable alteration of patterns and timings of soil disturbance, light transmission through the crop canopy and natural enemies living in the crop, thereby diversifying the selection pressure on pest populations and making it more difficult for one pest species to dominate. Other practices, such as tillage when used in conjunction with cover crops and crop rotations, can markedly reduce pest (weed in particular) population densities in the soil (12).

Crop loss assessment due to pests is another important factor to be taken into account. Reliable estimates of economic losses caused by pests are indispensable both for optimal crop management at the farm level as well as for basic decisions on broader issues such as research priorities and pesticide use. Crop loss assessments have been made for major annual staple and cash crops (13) although data inadequacies are particularly acute in the case of perennial crops. Economic thresholds are rarely based on rigorous quantitative estimates of how pest numbers at different crop growth stages are related to resulting yield, and as importantly, to quality. More specifically to crop loss in terms of quality, these are often of primary importance for food industry and for international trade. Therefore, economic thresholds need to take into account crop physiology and the ability of crop plants to compensate for damage at different growth stages.

Reducing the use of PPPs requires a better knowledge of pest population dynamics, including the possible impact of antagonists, as well as of economic threshold values. Such information is essential when developing IPM strategies and in decision-making related to pesticide treatments. It is not possible to minimise the use of chemicals in agriculture without effective early warning systems based on the forecasting of damages by pests. Such information is also necessary to evaluate economic feasibility of a given intervention. Early warnings and forecasts allow time for managing incoming pest attacks and can thus minimise crop loss (qualitative and quantitative), optimise pest control and reduce the cost of cultivation. Crop yields and net returns can be maximised by using prevailing and anticipated weather information, which can help in crop planning and spray scheduling and other farm operations. Furthermore, weather information can also help minimise the use of PPPs.

To this end, decision support systems (DSSs) have been emerging as essential tools to bridge the gap between science-based technology and farmers who make day-to-day management decisions. Web-based models and DSSs are an important requirement for an effective implementation of IPM in Europe, provided that farmers are encouraged to adopt such tools. DSSs are an important tool to take strategic decisions for pest control even under complex and uncertain conditions (14) with direct and concrete implication in terms of pest control and significant reduction on the reliance of PPPs. Effective implementation of DSSs requires efficient pest monitoring systems in order to assess the actual pest profile and pest pressure at different spatial and temporal scales. Although the organization and the scientific basis of existing pest monitoring systems/DSSs widely vary from the type of pest problems and countries, there are many similarities between European Member States in terms of crops and pests, the content of information conveyed to farmers, and the organisation of the communication systems.

Recent advances in molecular technologies for detecting and identifying pests offer new perspectives in this regard which could greatly improve the accuracy and efficiency of existing pest monitoring systems. Pest forecasting — including population dynamics, and improvement and validation of models based on field observations — includes research in pest biology, pest life cycles and the key factors that could limit pest populations. Several current DSSs are negatively affected due to the limited number of observation points for most pest monitoring systems and their use to predict the risk in a given area. To overcome these constraints, epidemiological models may play an important role and there is a need to put more effort into this. There should be a clear understanding on the biotic and abiotic co-variables to be collected and used to redress this sampling, extrapolation of the results to other situations and prediction of the local level of risk, thus supporting tactical or strategic decision-making. The concept of threshold levels — commonly used in current DSSs — should be extended to better understand the effect of the environment and agricultural practices while predicting damages. The relevance of such threshold levels widely depends on the context of their use, particularly in crop protection strategies implemented at the cropping system scale.

Research needs in core theme A

- Engage in research on prevention as main IPM resource tool and core of resilient cropping systems;
- Develop new phenotyping, new screening methods and markets to breed varieties based on the current needs taking into account the specific climatic conditions of Europe;
- Build strategies to introduce sustainable resistance by promoting durable resistance management and by improved monitoring of the virulence spectrum and the emergence of new virulence genes in the field;
- Further develop the knowledge on endophytes and their introduction on/into seeds and planting materials to develop more resilient plants;
- Enhance diversification of cropping systems by promoting the adoption of crop rotation, intercropping and use of cultivar mixtures;
- Improve, in terms of sensitivity and their specificity, currently available tools for early detection and identification of pathogens from seed and propagation materials;
- Integrate existing tools for qualitative and quantitative monitoring of soil and substrate for the presence of pests;
- Establish the necessary scientific infrastructure and scientific advisory capabilities to support modernisation of the monitoring and regulatory systems for pests;
- Develop, improve and implement pest monitoring systems at large scale (landscape level), including non-agricultural areas, besides at crop or field level;
- Put in place EU-regional-wide harmonised monitoring and forecasting systems at field and landscape levels for those regions facing common pest problems;
- Implement web-based tools in such a way that favour sharing of data coming from the harmonised monitoring activities from different areas of Europe;
- Develop quantification methods for pest damage to crops to set up a reliable/robust threshold level;
- Include socio-economic aspects as a part of DSSs in order to understand constraints and obstacles of farmers while implementing such tools;
- Fill the existing communication and knowledge exchange gaps between research and field application (growers);
- Investigate sustainable crop protection strategies to address minor use issues on major crops.

Core theme B: Alternative to conventional pesticides and innovative control

Background

A growing need for alternatives to chemical/synthetic PPPs has led to the intensified development of mechanical, biological or physical tools which can be implemented in pest control. The decreasing availability of new chemical/synthetic PPPs has led growers and crop protection specialists to reassess that there are alternatives to chemical/synthetic PPPs that can be effective in pest control. The integration of these practices has led to markedly reduced reliance on the use of PPPs in minor crops grown in a protected environment. However, chemical tactics still play an important role in IPM. For this reason, there is a need to complement chemical solutions with non-chemical ones rather than substitute the former with the latter. It is only in this way that an effective pest management can be ensured. An example is fruit trees in orchards and grapevines where a range of non-chemical tools, such as the use of resistant/tolerant cultivars, timely elimination of infected plant parts, pheromone-based pest monitoring methods and the promotion and protection of natural enemies and antagonists have been successfully combined with selective chemical measures to control pests.

The use of bio-control agents (BCAs) in effective pest control has been reported from several parts of the world. However, the effectiveness of BCAs, especially those of fungal isolates, often depends on the climatic conditions (15) which represent a severe constraint for bio-control. For this reason, any development of new innovative and biological control tools should also include the development of new strategies for optimised application of both old and innovative BCAs. In several cases, existing BCAs that currently show low or inconsistent activity only need to be used in different ways (e.g., different timing or targeted pathogen stage) or in combination to have a better performance. To improve the effectiveness of BCAs, the development of weather-driven models both for bio-control agents and for the tritrophic interactions (plant – pest – BCAs) may be very useful to support decision-making about the optimal use of bio-control agents. Likewise, the combination of biological control methods with cultural and physical control methods is essential to have a better performance rather than using bio-control as "a stand-alone pest control measure".

The use of biological-PPPs (bio-PPPs) could lead to a substantial broadening of the suite of tools in production systems and simultaneously reduce the potential risks arising from pesticides for human health and the environment. However, the approval and registration of bio-PPPs have been facing several problems due to the application of similar registration criteria to all bio-PPPs (16). Nevertheless, the latest decision of the EC has led to a partial simplification of the registration process which is expected to encourage more focus on the development of bio-PPPs. In addition to bio-PPPs, elicitors, multiple plant defence primers, semio-chemicals, repellents etc. represent interesting alternatives to PPPs.

Precision agriculture, based on innovative technologies, is a promising approach to optimize crop yield and reduce the impact of pesticide use. In particular, methodologies applied for the site-specific application of PPPs and traceability of plant tissues affected by pests have a huge potential to reduce pesticide use, thereby reducing the economical expenses and ecological impacts in agricultural crop production systems (17). For example, to optimize the use of pesticides there are several innovative nozzle types available and farmers can improve pesticide application efficiency by careful selection of spray nozzles to minimize drift and improve spray retention. As for the detection of early changes in plant physiology, for instance, thermography, reflectance and fluorescence measurements are currently the most promising innovative techniques to improve management decisions and help reduce pesticide use in agriculture. (18). In addition, drone monitoring of accurate pesticide use represents an innovative tool to reduce the use of pesticides in agriculture.

Alternatives to herbicides, such as mechanical weed control and biodegradable mulches, have proven to be effective on a range of crops depending on soil characteristics and conditions. The development and application of robotic weed control is likely to boost the reduction of PPPs in agriculture, although only a few complete robotic weed control systems have demonstrated the potential of the technology in the field (19).

Increasing reports of pest resistance development to PPPs have been a serious matter of concern in the last decades. To date, many cases of resistance have been reported among all pest categories (5, 20). This issue is particularly acute for weed management because very few new herbicidal modes of action remain available, further increasing the likelihood of over-reliance on a narrow spectrum of molecules. Historically, resistance of insect pests to insecticides was a major initial driver for the development of IPM (21) which provided the basis for an improved subsequent development and implementation of IPM tactics to better manage such problems. In particular, there needs to be a focus on prevention or at least slowing down of the accumulation of resistant lines of pest populations in order to preserve the effectiveness of available PPPs in the short term while alternative control measures to PPPs need to be developed in the long term. However, the reduction of selection pressure for resistance while providing the necessary level of pest control using PPPs remains a challenge. IPM therefore constitutes a fundamental approach to resistance management by minimising selection pressure.

Research needs in core theme B

- Promote application of mechanical weed control;
- Identify bottlenecks in the application of biological control in arable crops where an intensive use of PPPs is still the basis of the protection;
- Encourage further research to examine to what extent non-crop habitats promote or inhibit the movement and distribution of natural enemies and pests and how habitat manipulation can improve the level and reliability of pest control;
- Foster co-operation between organic farming and IPM to promote the development of new innovative and biological control tools and to enhance a more systemic understanding by also involving the industry and farmers;
- Transfer scientific knowledge into practice, taking into account development of bio-PPPs or biological pest control;
- Monitor the occurrence of resistance development to guide decision-making in sustainable pest resistance management strategies in order to slow down or prevent the development of resistance within the targeted pests;
- Use the available knowledge on the potential of natural enemies on pests under different field contexts;
- Identify and assess parameters that reduce or enhance multi-trophic relationships in order to consider them for integrated control programmes;
- Develop precision sensing and spraying for optimised use of pesticides;
- Evaluate the possible use of nanotechnologies in plant protection
- Develop effective application methods of BCAs in order to increase their efficiency in large field crops (e.g. field vegetables, cabbage, brassica, potatoes, oilseed crops, maize)
- Promote knowledge exchange programmes between partners in MS about existing research projects on biocontrol methods and disseminate information about successfully implemented field application methods.

Core theme C: IPM in Minor Crops

Background

While many major crops, such as cereals and maize, benefit from the access to a variety of PPPs, a wide range of crops (commonly known as minor crops) grown in Europe suffer from a lack of PPPs (4). In particular, vegetables, fruits, nursery stock and ornamentals are high-value crops representing more than 20% of the value of EU's total agricultural production. Sustainable production of such crops is vital for both human health and European economies. For these crops the availability of crop protection solutions has been rapidly decreasing in Europe. This is mainly due to the introduction of new crops and pest species into Europe and the lack of PPPs. The direct economic impact due to the absence of viable plant protection solutions for minor crops has been estimated to be over a billion euros per year, impacting nine million hectares throughout Europe. IPM can serve as the basis to develop long-term solutions to reduce the reliance on PPPs also within the context of minor crops.

In order to overcome the increasing scarcity of potentially available minor uses solutions, several initiatives within the EU are ongoing. Examples are the EU Technical Working Group on minor uses, several Commodity Expert Groups and the recently set up minor uses Coordination Facility jointly funded by the EU and the governments of France, Germany and the Netherlands (4). The current EU Minor Use Database (EUMUDA; http://www.eumuda.eu/Apps/WebObjects/PSInfoEU.woa), already provides a basis to enable and improve cooperation between the EU Member States in the field of minor uses. Some of the ongoing initiatives in this respect refer to the creation of a common list with commonly observed problems for minor uses. This database will also relate to the work on the other priority actions in the short term.

Hence, there is a need of complementarity between the ongoing minor uses activities at the European level and the ERA-Net C-IPM. Likewise, many non-European countries, such as the USA and Canada, have IPM programmes for minor crops and some of them have a strong collaboration with European programmes. For this reason, a link with non-European countries on minor uses issues is essential, in particular with the North American IR4 and global minor uses summit programmes.

Mapping and analysis of minor crops problems and possible IPM solutions have been performed within this ERA-Net which resulted in the preparation of an inventory. The latter aimed to establish a table of needs for IPM solutions for minor crops in Europe. The inventory made is part of the ERA-Net C-IPM and is complementary to the work already done by the existing EU minor use groups (the latter is not part of the ERA-Net). The list of inventory with commonly observed minor use problems, a result of work package 3 of the ERANET C-IPM, is available to the stakeholders through the EUMUDA database. Further elaboration of the core topics by ERA-Net C-IPM partners will result in calls for future research.

There is a need for breeding programmes for minor crops as breeding for resistance represents a potential tool for pest management also in minor crops. However, breeding for resistance is too cost intensive and lengthy and as such cannot be considered as an effective approach to solve minor uses issues in the short term. For this reason, all other control measures need to be prioritised (see core theme A).

European agricultural research has mainly focused on the production of arable crops. Thus, the „small" productions, with very high added value, have been often side-lined. Hence, there is a need for a re-investment in research, in general, on minor crops. While the research gap in Europe is widening between major and minor crops, southern countries have continued to invest and consequently minor crops in these countries represent a very important component of their trade balance because of the added value of these productions, which are very often also a very important component of the diet in very well identified systems (e.g. household gardens).

Research needs in core theme C

- Put in place a European network to harmonise all ongoing activities related to minor uses;
- Create a European inventory of minor use problems and available solutions and rank them in order of importance in collaboration with EUMUDA;
- Encourage knowledge-sharing with stakeholders on a selected number of topics;
- Develop alternative solutions based on inventory and interests of international stakeholders;
- Promote the development of alternative solutions to chemicals and their application;
- Liaise with non-European programmes on minor uses in order to share knowledge and solution-finding;
- Foster activities and initiatives related to breeding for resistance for minor crops;
- Re-investment in research for minor crops and knowledge-sharing between southern and northern countries.

Core theme D: Drivers and impact of IPM

Background

Farmers are not always free to adopt new practices and their choice is often influenced by a diversity of external pressures. In addition to technical aspects, farmers have to take into account broader social and economic constraints of adopting a new crop protection practice and ensure that such a practice fits within the entire food chain. Taking into account the transition phase, the socio-economic drivers that lead to a successful implementation of IPM throughout the Member States need to be identified and promptly applied in practice. In particular, focus is needed on understanding factors that have a direct impact on the choices of farmers and consumers. Farmers operate within a social environment which influences their values, attitudes and behaviours. For example, retail chains have a strong influence on farmers' practices and on production schemes. Besides MRL, other demands of supermarkets to the purchasing of products, such as environmentally sound production and ecological or carbon footprints per unit of product can be relevant and such demands help promote IPM. In addition to the producers, the increased focus on IPM needs to be extended to the consumers which force the retail sector to take this into consideration in their assortments.

To increase the visibility of IPM, a simple indicator which informs about societal, environmental and economic benefits could help to create an understanding; e.g. an environmental view, eco-toxicity and other footprints could be used as indicators compared to the carbon footprint or usage of harmonised environmental risk indicators. Actions such as IPM-related policies may have important social consequences. However, our knowledge is poor as to whether incentive-based policies might enhance the level of IPM implementation in Europe. More focus on socio-economic research can help to better understand potential impediments to such policies and regional interactions between stakeholders which support farmers. This encourages programmes based on farm-to-fork strategies for key commodities.

Socio-economic performances that facilitate IPM implementation need to be horizontally addressed in research and directed not only to producers but to the entire value chain. This is pivotal to presenting evidence that the more complex combination of tactics performs equally. Research on IPM should therefore be designed from a multi-actor perspective and address not only availability of approaches and tools, but also socio-economic factors determining their acceptance. There is a need to analyse the behaviour of professionals and public actors as well as research on the scientific knowledge and technical solutions. Apparently, there is a mismatch between sustainability of crop protection strategies as perceived by consumers (NGOs and retailers), farmers, and scientists. This calls for a better insight into the impact of strategies on different sustainability indicators, as well as the mitigating effect of measures on these impacts. To date, there is a lack of an inventory of experiences and research that shows how and why a change in practice can take place. As there are many IPM tools available with a rather low implementation rate, it would be interesting to have an EU inventory of these IPM tools with good perspectives for implementation in practice. Do these tools meet the criteria important for farmers and deserve more attention? In particular, their usefulness to solving a problem, to meet value chain requirements, economic win and convenience need to be considered. In addition, it is important to know what factors hamper their implementation (e.g. consequences of scale, labour need, costs etc.).

Research needs in core theme D

- Foster interdisciplinary research including human and social sciences to work at the level of the entire food chain;
- Develop research programmes in universities and institutes with multi-actor perspectives and transfer stakeholder input and research results to end users immediately;
- Perform multi-criteria assessment to understand how changes from conventional to IPM systems affect environmental, economic and social criteria including farmer behaviour and constraints;
- Encourage research on “lock-in” and transition phase to examine to what extent agricultural organisations are locked in by “past socio-technical choices” and identify possible mechanisms of transition to IPM that consider multi-actor perspectives;
- Consider the importance of public-driven behaviour of NGO’s across Member States and take it into account for research programmes on scientific social/political aspects;
- Communicate promptly to stakeholders about success stories of IPM based on local or regional experiences and focus on how IPM would be implemented at scales beyond the farm;
- Identify socio-technical and socio-economic impediments behind IPM implementation and means to cope with them;
- Produce more knowledge on economic aspects of IPM viability;
- Develop quantitative indicators for implementation of IPM principles and to assess consumer and environmental protection measures and encourage qualitative research to understand how the process is perceived and what are the success stories or obstacles of adopting new practices in plant protection;
- Involve demonstration farms and open farm days for the dissemination process and convey clear messages to consumers, retailers, advisers, suppliers and NGOs about the added value of IPM practices.

Collaboration with other ERA-Nets

A number of additional topics have been identified through the mapping as well as through discussion with C-IPM partners and stakeholders. It has been agreed that these topics are pertinent to IPM, but that because of time and resource limits C-IPM cannot deal directly with them. Consequently, it is essential that C-IPM collaborates with other ERA-Nets and JPIs within which several activities related to these topics are ongoing. This is important to avoid any overlapping of activities as well as for the rationalisation of funding. Figure 4 reports on such sub-topics and their links with other ERA-Nets and JPIs.

International collaborations

IPM covers a broad range of topics which markedly increase the possibility of collaboration with ongoing initiatives at an international level. This is an important advantage for the ERA-Net C-IPM to position itself not only at the European but also at the global level. To this aim, C-IPM is open to any kind of international collaboration that helps identify opportunities and mechanisms for knowledge transfer/sharing; training and dissemination of information of IPM-related research. For example, issues related to monitoring, detection and control of invasive pests, obstacles related to IPM implementation, minor uses and speciality crops are some of the potential topics for which the ERA-Net C-IPM may foster collaboration with other international projects.

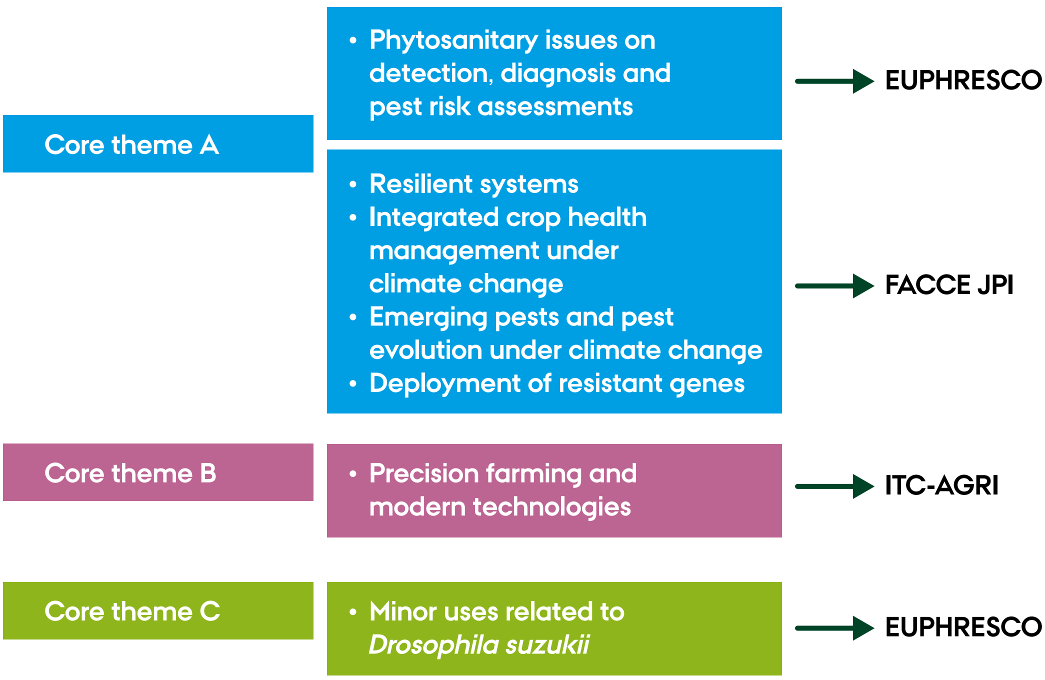

Figure 4. Main thematic complementarities between C-IPM and other ERA-Nets and JPIs.

Calls for transnational research projects

In order to facilitate joint transnational calls within the framework of the ERA-Net C-IPM, questionnaires were sent out to potential partners who could provide funding. At least two calls are foreseen within the ERA-Net C-IPM and most partners agreed to fund them: the first call in 2015 was funded in 2016 and the second call in 2016 to be funded in 2017.

The implementation of the calls is accomplished through: i) decision on the time line of the implementation, ii) proposal submission, peer review process, funding decision, and iii) funding organisations supporting the call.

The calls launched within the C-IPM will help foster further research collaboration among the European researchers. In addition to the calls on topics of common interests, sharing results, coordination of European research, dissemination of the research based on the DSS, meta-analysis and networking of demo farms, and knowledge-sharing workshops (on biocontrol, breeding for IPM, demonstration farms and *Drosophila suzukii*) will be the activities promoted by this ERA-Net.

Concerning the calls, it is agreed to contribute to common “coordination costs” via a virtual common pot. Each funding organisation will fund research groups from its country depending on its own national rules. A two-step competitive call procedure including an internal evaluation of the pre-proposals and external evaluation of the full project proposal is used to ensure the scientific excellence of the conducted research. The Joint Call Secretariat will be hosted by INIA, Spain.

Delivery of the strategic research agenda

Communication and dissemination

The ERA-Net C-IPM intends to foster communication between all the players who directly or indirectly can contribute to the objectives of this network. They include the scientific community, policy makers, stakeholders and/or growers and funders. Most of the communication activities are performed through the website: http://c-ipm.org.

A large number of stakeholders identified previously are informed on a regular basis via electronic newsletters. Progress achieved within the different work packages and the strategic decisions made by the executive committee are conveyed to all interested players related to the C-IPM activities. The main aim is to encourage relevant stakeholders in an active exchange and to receive their feedback on critical research needs.

Conclusions

The ERA-Net C-IPM aims to promote IPM implementation in Europe in the short term, while for the long term initiatives are designed to shape the future European Research Area. This will be done by pooling national resources and avoiding fragmentation and overlapping of research efforts related to IPM. The ERA-Net C-IPM will also play a crucial role in providing the scientific background by feeding European policies on IPM issues of relevant importance, both in the short and long term. By working together at European scale, the ERA-Net C-IPM is expected to foster the exchange of existing tools and infrastructures as well as to contribute to the development of new solutions.

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Annex 1. Background and scope of C-IPM

Background

Most European countries are investing in research to reduce reliance on pesticides and the risks associated with their use. They must do this to implement the principles of Integrated Pest Management (IPM) as called for by Directive 2009/128/EC. Coordinating national research and extension efforts and pooling existing resources can create added value and synergies. The C-IPM project creates a forum for exchange and identification of IPM research and development priorities, provides recommendations on national and European research, connects existing initiatives, and coordinates joint transnational research calls.

C-IPM positions IPM in the future European innovation landscape. It provides an overall picture of ongoing and desired R&D efforts and of the resources available for IPM implementation. It proposes a common research agenda on IPM and on sustainable solutions in the context of minor uses. It generates European-level added value by sharing outputs of ongoing national and regional research, and by disseminating R&D methods, experience and expertise. It creates knowledge hubs by linking R&D resources in the field of IPM and minor uses. In addition, it develops and implements joint transnational calls.

Problem

C-IPM came at a time of change for crop protection in Europe. In the past, efforts mostly focused on reducing the detrimental effects of pesticides on human health and the environment while continuing to rely on chemical control. The European Union is now placing greater emphasis on plant health and plant protection policies in order to ensure the protection of human health and the environment without compromising food production and competitiveness of the agricultural sector. The Regulation 1107/2009, on the placing of plant protection products on the market, and the Directive 2009/128/EC regulating the use phase of pesticides and establishing a new framework to promote IPM and alternative approaches or techniques, mark a turning point.

In the future, farmers will no longer have access to the entire range of pesticides they use today and will have to adopt IPM, incorporating alternative approaches or techniques to reduce their dependency on pesticide use. From January 2014 onwards, EU Member States are required to implement the principles of IPM. This can only be achieved through a concerted effort to share existing knowledge and experience, as well as developing alternative sustainable crop protection systems.

Aim

The overall goal of C-IPM is to ensure a higher level of implementation of IPM among European farmers by creating synergies from national investments in research and extension. C-IPM supports the formulation and implementation of national research programmes dedicated to the development of IPM strategies and contributes to the implementation of National Action Plans (NAPs), by facilitating the sharing of national experiences on pesticide-related policies.

Potential applications

C-IPM is not a research project and does not produce exploitable results but creates a framework which facilitates relevant innovations to help implement IPM in Europe.

Target groups

Beneficiaries include programme funders and managers, research and development organisations and stakeholders involved in IPM implementation (from industry to farmers).

Support to policy

C-IPM contributes to the definition of more targeted research through the development of a Strategic Research Agenda for IPM in Europe, which will be relevant for both individual countries and the EU at large. The project is in support of EU policies and in particular the Sustainable Use Directive, the regulation on placing of plant protection products on the market, and the Water Framework Directive.

Annex 2. C-IPM governance and membership

Country	Last name	First name	Affiliation
Austria	Bluemel	Sylvia	AGES
	Fuhrmann	Elfriede	BMLFUW
Belgium	Jansen	Jean-Pierre	CRA-W
	Maes	Martin	ILVO
	Dewasmes	Veronique	SPW
	Pelgrims	Ellen	VLAIO
Czech Republic	Jerabek	Ladislav	MZE
Denmark	Andreasen	Claus Bo	DAFA
	Kudsk	Per	
	Vintersborg	Karina	
Estonia	Pärenson	Helena	MEM
Finland	Vänninen	Irene	LUKE
	Jern	Tove	MMM
France	Kao	Cyril	MAAF
	Gautier-Hamon	Gerard	
	Colleu	Sylvie	INRA
	Lamichhane	Jay Ram	
	Messean	Antoine	
	Moatti	Antoine	
Germany	Fuchs	Annika	BLE
	Zornbach	Wolfgang	BMEL
	Dachbrodt-Saaydeh	Silke	JKI
Hungary	Kiss	Jozsef	SZIE
Ireland	Forristal	Dermot	TEAGASC
Italy	Galassi	Tiziano	RER
	Marzetti	Annamaria	MIPAAF
Lithuania	Semaskiane	Roma	LRCAF
The Netherlands	Boonekamp	Piet	DLO
	Zweep	Annet	EZ
	Arendse	Wilma	NVWA
Norway	Anker-Nilssen	Kirsti	RCN
Poland	Arseniul	Edward	IHAR
	Michalczuk	Lech	IO
	Danielewicz	Jakub	IOR PIB
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Spain	de La Peña	Anabel	INIA
Sweden	Svensson	Jan	FORMAS
Switzerland	Zweifel	Juliana	FOAG
Turkey	Akbaş	Birol	MFAL-GDAR
UK	Cuccato	Giulia	DEFRA

Annex 3. Abbreviations and definitions

BCAs	Biological Control Agents
C-IPM	Coordinated Integrated Pest Management
CWG	Collaborative Working Group
DSS	Decision Support System
ERA-Net	European Research Area Network
EU	European Union
FACCE	Agriculture, Food security and Climate Change
IPM	Integrated Pest Management
JPIs	Joint Programming Initiatives
JTR	Joint Trans-national Research
MRL	Maximum Residue Levels
MS	Member States
MU	Minor uses
NAP	National Action Plan (Directive on the sustainable use of PPPs (2009/128/EC)
NGO	Non-governmental Organization
Pests	Collectively refers to animal pests, weeds and plant pathogens (ISPM- Standard No. 5)
PMS	Pest Monitoring Systems
PPPs	Plant Protection Products
R & D	Research and development
RG	Resource Groups
SCAR	Standing Committee of Agricultural Research
SRA	Strategic Research Agenda

C-IPM Coordinated Integrated Pest Management in Europe

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Funded by the European Union