EIP-AGRI Focus Group
Sustainable ways to reduce pesticides in pome and stone fruit production

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1. Introduction

Fruit growers face many challenges. To produce a competitive yield with desired quality, many growers rely on pesticides. Compared to other crops, fruit production uses a significantly higher quantity of pesticides to control pests, diseases, and weeds, and to regulate growth (e.g. apples are treated with various pesticides 20-30 times a year). Pesticides are also applied to meet consumer demand in terms of aesthetics, while maintaining nutritional value and hygiene standards.

These pesticides affect the environment (soil, water, air, biodiversity), non-target organisms, animals, and human health. It is estimated that only a third party of the pesticides that are used are effective against target-organisms, and two thirds end up on non-target organisms due to three transfer mechanisms of the spray application: drift, volatilisation or even wind erosion (Loquet, *et al.* 2008[(1)]).

Therefore, EU and Member State policies seek to reduce the reliance on pesticides in agriculture by designing and implementing more integrated and sustainable approaches, while at the same time safeguarding the competitiveness of EU agriculture. To reduce the risks and impact of chemical synthetic pesticides on human health and the environment, one of the concrete targets of the Farm to Fork strategy is to reduce the use and risk of chemical pesticides by 50% by 2030 at European Union level.

Developing and/or promoting non-chemical practices could, in addition to improving the usage of current pesticide tools, contribute to achieving this aim and to reducing the risks linked to the use of these chemicals. Sustainable techniques will range from preventive to curative strategies (e.g. breeding of resistant or tolerant cultivars, use of beneficial insects, pheromones, plant strengthening agents) and could include agro-ecological principles, practices from organic agriculture and even 'forgotten practices' that could be adapted in an innovative way. Also, monitoring, combined with decision support tools and precision agriculture to bring out pesticides where absolutely needed, could help to rationalise and limit the use of pesticides.

Although a great variety of different fruits are cultivated, apples are the dominant fruit crop in the EU. This Focus Group concentrated on two important fruit groups: pome (apple and pear) and stone fruits (peach, cherries, plum, apricot, almond). These fruits are present in all climate zones, and are under high pressure of pests and diseases, which impact quantity and quality and represent a significant part of the fruit area in the EU.

Objectives of Focus Group 44

The Focus Group discussed the following main question: "**How can alternative methods reduce the use of pesticides in pome and stone fruits and support the productivity of the sector in a sustainable way?"**

The main tasks of the experts were:

- **Identify good practices to deal with pests and diseases in pome and stone fruits which may be adapted to different conditions**, including prevention practices, early detection, diagnostics, and monitoring.
- **Take stock of preventive agro-ecological strategies and solutions** including current and forgotten methods as well as strategies of organic agriculture (indirect and direct measures) to further minimise the use of pesticides in pome and stone fruit production.
- **Make an inventory of IPM (Integrated Pest Management) strategies** (including biological control) to combat pests and diseases in pome and stone fruits.
- **Compare** these different management practices and strategies (agro-ecological practices and IPM), consider existing problems and opportunities, also bearing in mind practicability and costs.
- **Compile examples of 'good practice'**, i.e. a number of case studies, from farm level in particular, across different regions in Europe.

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- **Identify needs from practice (farming sector) and possible gaps in knowledge** on particular issues concerning the management of pests and diseases in pome and stone fruit production which may be solved by further research.
- **Propose priorities for relevant innovative actions / projects** including practical ideas for EIP-AGRI Operational Groups.

Organisation

Focus Group 44 was created by the European Commission, DG AGRI in 2021 as part of the activities carried out under the European Innovation Partnership for Agricultural Productivity and Sustainability (EIP-AGRI). It brought together 19 experts (**see Annex 1**) from across the EU to share knowledge and practices around the main question. Experts were selected to combine different backgrounds (farmers, advisors, researchers, and industry representatives). In order to address the main question, the Focus Group met twice:

First meeting: March 2022

Due to the COVID situation, this meeting was held online. In preparation to the meeting, a starting document was elaborated to give an overview of alternative methods in orchards and their combination to reduce the use of pesticides. In addition, a questionary was sent to the experts to make an inventory on: (i) the main pests and diseases on pome and stone fruits in their countries; (ii) the preventive and curative measures used in orchards and their efficacy levels; (iii) suggestions to develop alternatives to pesticides.

The two days of the meeting were dedicated to:

1) sharing practical experiences, showcases from Croatia, Portugal, France and Austria were presented;
2) discussing barriers that may impede the application of all the different alternative measures to reduce the use of pesticides (Agro-ecological system approach; preventive measures like mechanical techniques, physical barriers, plant-strengthening agents; biological/natural products; semio-chemicals, attractants, and repellents…);
3) identifying key topics for further analysis and discussion. This resulted in the decision to have 6 Mini papers dedicated to: Precision Agriculture; Functional agrobiodiversity; System approach and orchard redesign; Improve farmers position in the value chain with reduced use of pesticides; Genetics; Innovation.

Second meeting: June 2022

The two-day meeting was held physically in Bologna. The meeting allowed the experts to share and discuss Mini papers developed by groups of experts, and to elaborate recommendations, including ideas for Operational Groups or other innovative projects and needs for research from practice.

One afternoon was dedicated to a visit of two farms participating in the S.I.S.C.C.C.A. PROJECT "Sustainable integrated systems for the control of the "Brown Marmorated Stink Bug" (*Halyomorpha halys*). The trials were a "push & pull" approach, using "attract & kill" traps with pheromones outside the orchards, while in the orchards bio-insecticides, selected in laboratory tests, and diatomaceous earth were used to reduce the damages caused by insects that were not captured by traps.

This final report of Focus Group 44 builds upon the outcomes of the experts' discussions and six specific Mini papers on:

- Precision Agriculture
- Functional agrobiodiversity
- Combination of alternative methods and orchard redesign

- How to improve the position of farmers in the value chain by adapting alternative strategies and reducing the use of pesticides
- Genetics to contribute to pesticides reduction
- Innovative approaches for a sustainable future plant protection.

2. State of the art

To ensure that agricultural production can feed people, agriculture has long relied on the use of traditional synthetic phytosanitary products. However, even if the issues of quantity and quality are still relevant today, new problems have arisen.
These new challenges consist of environmental considerations (soil, water, air, biodiversity) and health aspects (Barzman *et al.* 2015). These points have led researchers, growers and technicians, supported by the European Union, to develop and put in practice new tangible and original strategies to limit the use of these pesticides while ensuring constant agriculture production.

To achieve this aim, several approaches are proposed:

1. Integrated pest management (IPM)

Integrated pest management (IPM) is based on the concepts of "plant protection methods" and "ecological justification". More precisely: "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" (Directive 2009/128/EC).

Eight principles have been developed and described in the review of Barzman *et al.* in 2015[(2)]:

1) Prevention and suppression. This first principle refers to preventive strategies to less likely experience the presence of pests and their consequences. The implementation of this principle can be observed by the establishment of resistant cultivars, crop rotation (not applicable to perennial crops), cultural practices or by the protection and enhancement of important beneficial organisms.

2) Monitoring. It enables realistic forecasts to be made and thus an accurate diagnosis, enabling an appropriate response.

3) Decisions based on monitoring and thresholds. This practice is well-established for insect pest control but not for weeds and to a lesser extent for specific pathogens.

4) Non-chemical methods. They are to be preferred over synthetic chemicals.

5) Pesticide selection. Strategies involving products with minimum side effects must be favoured. To this end, phytosanitary products need to specifically target the designated pest or disease.

6) Reduced pesticide use. Only the necessary number and concentration of pesticides have to be used. This implies reductions of doses and application frequency to the bare minimums.

7) Anti-resistance strategies. To avoid the development of resistances, strategies involving products with different modes of action are favoured.

8) Evaluation. Checking the effectiveness of the adopted strategy allows to step back and adapt it for the next production.

In 2018, T. Frische *et al.* [(7)] presented the basic principles of Integrated Plant Protection, often referred to as Integrated Pest Management (**Figure 1**), in their position paper for sustainable plant protection. IPM grants priority to preventative and biological measures, in combination with a strict adherence to the economic threshold principle, before a chemical PPP (Plant Protection Product) is used.

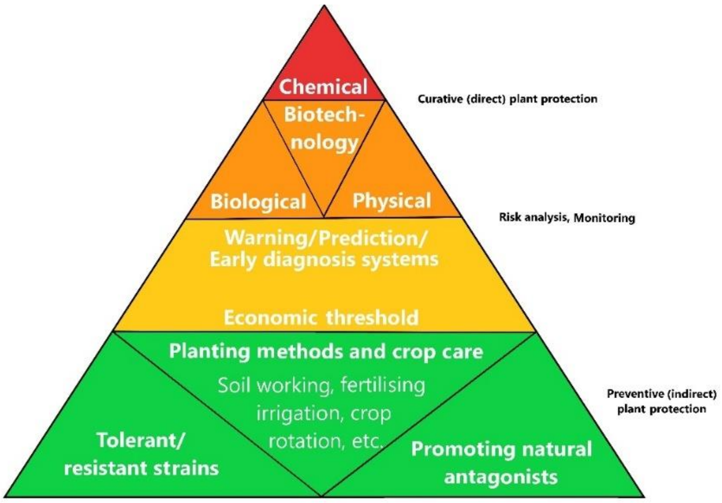

Figure 1: Basic principles of Integrated Plant Protection (Frische *et al.* 2018)

2. Organic production

While integrated plant protection allows the use of different synthetic products, organic farming is much more restrictive on their use in accordance with the EU regulation for organic production (Regulation (EU) 2018/848, Article 6, Of the European Parliament and of the council, 2018[(13)]). Furthermore, organic production is also based on:

- the maintenance and enhancement of soil life and natural soil fertility, soil stability, soil water retention and soil biodiversity;

- the maintenance of plant health by preventive measures, in particular the choice of appropriate species, varieties or heterogeneous material resistant to pests and diseases, appropriate crop rotations, mechanical and physical methods and protection of the natural enemies of pests;

- in the choosing of plant varieties, having regard to the particularities of the specific organic production systems, focusing on agronomic performance, disease resistance, adaptation to diverse local soil and climate conditions and respect for the natural crossing barriers.

Following IFOAM Organics International[(14)], organic agriculture has four principles: the principle of health, of ecology, of fairness, and care. "Health" concerns soil, plant, animal, human and planet. "Ecology" means to respect and sustain the environment.

As a result, organic production is a model that focuses on providing people with quality food and care for the environment (Hvozd, 2022[(9)]).

3. Agro-ecology

Agro-ecology is a transdisciplinary science (ecological, social, and economic) which aims to embed ecological standards into agricultural production to manage a sustainable agro-ecosystem (Francis *et al*, 2003[(6)]; Di Tommaso *et al*, 2016[(5)]). Agro-ecology is based on applying ecological concepts and principles to optimise interactions between plants, animals, humans and the environment. To reach this balance, seven core components were established (Pesticide Action Network UK, 2018[(12)]):

1) Adapting to local environments

2) Providing the most favourable soil conditions for plant growth

3) Promoting biodiversity

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4) Enhancing beneficial biological interactions

5) Minimising losses of energy and water

6) Minimising the use of non-renewable external resources

7) Maximising the use of farmers' knowledge and skills

These points imply, for example, a greater reliance on biological and sustainable interventions rather than the use of synthetic pesticides and fertilisers.

4. Environmental Sustainability

This concept takes into consideration the interactions between ecosystems at a given time and place. Hence, it involves not only the cultivated crop ecosystem but also includes the other ecosystems that are indirectly impacted by production. Therefore, Lewandowski *et al* (10) in 1999 defines an ecologically sustainable agricultural crop production as a production that can permanently maintain its productivity and its ability to function. This means that none of the components of the ecosystem should be altered. To ensure the balance of these ecosystems, eight approaches have been defined:

1) Identify emissions and other releases linked to different crop production practices.

2) Trace each different release from its source (the crop management practice) to its sinks (i.e. agro-ecosystems and other ecosystems or components of ecosystems directly or indirectly affected by these releases).

3) Select indicators that adequately describe the condition of the ecosystem affected directly or indirectly by crop production practices.

4) Determine threshold values for the selected ecosystem indicators (i.e. values which should not be exceeded if irreversible changes in the affected ecosystems are to be avoided).

5) Transpose the ecosystem threshold values to the farm level by retracing the impact pathways backward to crop production itself.

6) Derive farm-level indicators that point to separate or combined agronomic practices that could cause irreversible changes in affected ecosystems.

7) Determine farm-level threshold values for management-induced releases on the basis of ecosystem-level threshold values.

8) Identify production schemes that adhere to the framework set by the farm-level thresholds.

5. Alternative plant protection methods (preventive and curative measures)

These measures tend to limit the use of harmful agrochemicals by focusing on greener tools which will release environmentally sustainable active principles (Fortunati *et al.* 2018(8)). This includes "non-synthetic chemicals", living organisms, and physical methods as well as specific cultural practices. The two first measures are included into the term "biocontrol agents" (BCAs). The biocontrol agents are based on the use of natural mechanisms.

The principle of biological control means rather managing the balance of pest populations than eradicating them. BCAs include macro-organisms (mites, insects and nematodes), products which are composed of micro-organisms (bacteria, fungi, and viruses), semio-chemicals such as pheromones and kairomones, or natural substances from plants, animals, or minerals (following the French definition of the Ministry of Agriculture and Food Sovereignty, 2022(11)).

The physical alternatives regroup all the physical methods to avoid the presence of the bio-agressor, such as insect-proof nets (Bouvier *et al.* 2019(3)), clay, talc, etc. This method is also useful to remove or limit population density of the pest or disease (by heat treatments, UV. etc.).

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Among the cultural practices employed to limit the use of traditional chemicals, many solutions exist, such as resistant cultivars, cultivar associations, plant covers, etc. Many solutions are studied, including early defoliation, or high grafting (Brun *et al.* 2019(4)).

And finally, mechanical techniques have been adopted to manage weeds, but also to grind leaves in autumn to reduce apple scab inoculum, or to thin fruits on the trees.

3. Outcomes of discussions and recommendations of the Focus Group

Do the actual applied preventive and curative measures give good results?

Depending on climate conditions, pests and diseases may occur at different levels on pome and stone fruits, but in general, on pome fruits the main problems are apple scab, codling moth and aphids, and to a lesser extent storage diseases and psylla on pears. On stone fruits, the prevalence goes to *Monilinia* rots, followed by the fly *Drosophila suzukii* (cherries) and also aphids and thrips (peaches, nectarines). The disease "leaf curl" due to *Taphrina deformans* is less frequent.

The experts made a general appreciation for their countries regarding preventive and curative measures that are applied in practice. Tables 1 and 2 present the type of alternative methods, the pests and diseases targeted, and the efficiency level (green = good, black = average, red = insufficient). If the experts were farmers, they were asked to mention their practice under "farmer strategy".

Type	Alternative methods	Pests and diseases	pome fruits	stone fruits	Farmer strategy
BC	Granulosis virus	codling moth	😊😐☹		😊😐
BC	entomopathogen nematodes	codling moth, sawfly	😊😐		
BC	Bacillus thuringiensis	Pandemis, leafroller, Archips, Cydia pomonella, Operopthera brumata, Grapholita molesta, Anarsia lineatella, Adoxophyes orana	😊😐	😊😐	😊😐
BC	Lacewings and lady beetles	aphids	😐		
BC	Typhlodromus pyri, Amblyseius andersoni	mites	😐	😐	
BC	Amblyseius swirskii	thrips		😐	
BC	Trissolcus japonicus	*Halyomorpha halys*	😐		
BC	Bacillus subtilis, Bacillus amyloliquefasciens, laminarine	Fire Blight, Bacteriosis (apricot)	☹	😐	
BC	Yeast	Monilia (peach)		😐	
Natural products	Neem oil, Paraffin oil, soap Rapeseed oil	aphids Overwintering pests	😊😐☹		😊
Natural products	Potassium bicarbonate Hydrogenocarbonate	apple scab, leaf curl (peaches), Monilia (apricots), pseudomonas (apricots)	😊😐	😊	😊
Natural products	Amino acids	?	😊		😊
Natural products	Lime sulphur (calcium polysulfur)	apple scab, mites, codling moth leaf curl, powdery mildew, tetranychus, Anarsia lineatella, codling moth, scale insects, Otiorynchus and thrips (nectarines)	😊☹	😊😐	
Natural products	cupper, cupper sulfate, sulphur	apple scab, Monilia, Pseudomonas (apricots), leaf curl (peaches)	☹😐	😊	😊
Natural products	spinosad (toxin produced by a bacteria)	earwigs, Drosophila suzukii			😊
Natural products	Botanical extracts	aphids, mites, beetles, scale	😐		
Natural products	Dissicant products	aphids	😐		
Natural products	clay	pear psylla, Cacopsylla pruni, thrips	😊😐	😐	
Semio-chemicals	mating disruption	A. orana, C. pomonela, C. pyrivora, L. Scitella, G. molesta, A. lineatella	😊😐	😊	😐
Semio-chemicals	mass trapping	Rhagoletis cerasie		☹	☹

Table 1: Alternative methods used in practice against pests and diseases in pome and stone fruits: examples of biocontrol (BC) agents, natural products, and semio-chemicals (according to the Focus Group experts)

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Type	Alternative methods	Pests and diseases	pome fruits	stone fruits	Farmer strategy
physical barriers	glue on trunk stick traps	earwigs (apricots, peaches), ants Otiorhynchus, thrips		☺😐	☺
physical barriers	exclusion netting	Codling moth Drosophila suzukii	☺☹	☺😐	
physical barriers	rainproof cover	apple scab, storage diseases Monilia (apricots)	☺😐☹	☺	
physical treatment	Hot water (fruits)	storage diseases (apple, peaches)	☺	☺	
physical treatment	Hot water (plants)	phytoplasma, bacteria		☹	
mechanical techniques	different equipments for weeding and mulching	weeds prevent transfer of thrips and aphids, Otiorhynchus	☺😐	☺	😐
mechanical techniques	equipment for mechanical thinning	fruit production	☺		
mechanical techniques	equipment for leaf shredding (inoculum reduction)	apple scab (leaf litter)	☺😐		
genetics	cultivar resistance	Sharka, Shot hole, leaf curl, bacterial blight Apple scab	☺😐	☺😐	😐
Cultural techniques	removal of mummy fruits, contaminated organs	insects pests (codling moth, Agrilus, Zeuzera) Monilia, Powdery mildew, canker	😐☹	😐	😐
Cultural techniques	summer pruning	to permit more light and air into the canopy to prevent diseases	☺		
Cultural techniques	2D training system	Light penetration and air circulation with the best spray efficiency	☺	☺	
Cultural techniques	irrigation & fertilisation	little amounts of nitrogen fertilisers control aphid infestation	☺		
Cultural techniques	Grafting of the stone fruit cultivars onto less susceptible (interspecific) rootstocks	nematods, bacterial canker		☹	
Agroecology	alternance of host and non-host crop plants	aphids (vecteor sharka), psylla (vector phytoplasma)		☹	
Agroecology	landscape management of the orchards : avoiding contigous orchards of stone fruits crops. Separate nurseries (> 100 km) from production zones	Sharka		☹	
Decision tools	monitoring traps (pheromones) optical traps (ethanol)	moths Xyleborus disparate	☺😐	☺	
Decision tools	weather monitoring and infestation monitoring	apple scab Rhagoletis cerasi, aphids			☺

Table 2: Alternative methods used in practice against pests and diseases in pome and stone fruits: examples of physical barriers and treatments, mechanical and cultural techniques, genetics, agro-ecological measures, decision tools (according to the Focus Group experts)

<u>On pome fruits:</u>
Biocontrol agents (micro-organisms, macro-organisms), natural products (oils, minerals, plant extracts), semio-chemicals (pheromones) and genetics (resistant cultivars) are the most used with average to good results. Physical barriers (nets, rainproof covers) and physical treatments (hot water) are almost not applied. The results with mechanical technics are various.

<u>On stone fruits:</u>
In general, alternative methods seem to be less applied. Semio-chemicals and physical barriers give the best results. Biocontrol agents, natural products and genetics have more average to good results.

Getting more into details (**Table 1**), the results for biocontrol agents, natural products and semio-chemicals are:

- various (3 different colours): granulosis virus against codling moths; different oils on aphids
- good (green): potassium bicarbonate, copper, sulphur on stone fruits (to protect against *Monilinia*, bacteria); mating disruption for *Grapholilta molesta*
- average (black): the use of beneficial insects against mites and thrips; botanical extracts on different insects and mites or yeasts against *Monilinia; mating disruption for Cydia pomonela*
- insufficient: in case of mass trapping against cherry flies.

And if we look to the more physical, cultural, or agro-ecological measures (**Table 2**), we have the same situation:

- various results (3 different colours): rainproof covers
- good (green): hot water against storage diseases (apples, peaches), most of the cultural techniques
- average (black): removal of mummy fruits, contaminated organs
- insufficient: alternance of host and non-host crop against aphids and psylla (virus vectors).

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Which are the barriers impeding the use of alternative methods?

Barriers can be technical, economic, socio-cultural, or environmental, etc. The experts analysed them in relation to four different types of preventive and curative measures:

- **Agro-ecological system approach:** management of the habitat, increasing biodiversity, soil fertility, enhancement of natural enemies, proper distances between trees, balanced fertilisation, using adapted cultivars, …
- **Other preventive measures:** mechanical techniques (weed management, inoculum reduction, thinning, sanitation measures, tree training) and physical barriers (excluding nets, plastic covers), plant strengthening agents,…
- **Chemical, biological/natural, biotechnical biocontrol agents:** macroscopic (insects, mites, nematodes) and microscopic (bacteria, viruses, fungus) organisms; natural products (from plants, animals or minerals); semio-chemicals, attractants and repellents and physical treatments (hot water, UV-light)
- **Application techniques:** equipments, dosages

Performance barriers

- Lack of sufficient references and field trials (e.g. Can nutrition help to reduce the impact of pests and diseases?; How do plant defence enhancers improve plant health?; To prevent pests and diseases, could we use biostimulant products?)
- Research gaps for the right use of alternative products (missing information on: the optimal stage of the plant and pest biology to apply alternative productions, the best conditions, decision tools like models and monitoring traps, release of beneficial insects in open space like orchards, modes of application,…)
- A low availability of alternative products, equipment, machinery to substitute or complete the chemical protection strategies
- On average, the effectiveness of alternative measures is medium to insufficient and can be limited in time (e.g. Apple scab resistance can be broken, or pest resistance to micro-organisms like the granulosis virus can be developed).
- Alternative methods that are used alone often have a partial effect on pests and diseases, which is not sufficient regarding the damages. They have to be combined.
- Regulatory status (e.g. The release of sterile insects is actually not allowed in several European countries; Fix spraying systems applications have to be registered for specific uses) and specific employment conditions (e.g. Products are registered for one crop and not for others, making it difficult to protect plants in a new systemic approach based on different crops and/or mixed species.)
- The efficiency of mechanical techniques depends on climate conditions and type of soil.
- Control of new or emerging pests and diseases may not be possible with various techniques.

Economic barriers

- Biocontrol products are generally more expensive and with higher risk than "conventional" chemicals, and they tend to focus on one or a few target organisms.
- Physical techniques (like exclusion netting, rainproof covers or hot water post-harvest treatments) and mechanical techniques (weeding, mulching, leaf shredding) represent high costs.
- New sprayers and application equipment to reduce drift and ground losses are expensive.
- Adopting changes in a perennial crop requires mid to long-term investment due to timing of the first harvest and related capital expenditures.

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- Changing an orchard design or layout is not possible after planting without significant expense and crop loss.
- A new production system must be economically viable, considering the balance between production costs and yield, quality, and fruit value, in accordance with the market demand.
- Low return of investment for research (e.g. to register a product or to conduct research within rootstocks and cultivars).
- High risk in adopting new technologies.

Labour needs

- Establishing new orchards (e.g. 2D training) needs intensive labour in the first years.
- Preventive measures, like sanitation practices (e.g. removal of mummy fruits, summer pruning, to lower disease pressure), but also the use of physical and mechanical techniques leads to high economic labour costs.
- Biocontrol products often require multiple sprays for similar control as "synthetics" (limited persistence, no mixing with other products).
- Spreading beneficial insects on fields and distributing pheromone dispensers is time-consuming.
- Agriculture, as other areas of activity, is suffering from a labour shortage.

Socio-cultural aspects

- By adopting more technical production systems, farmers face knowledge gaps and express fears of changes (e.g. accepting threshold levels is taking a risk).
- Insufficient farmer education and advisory services to support farmers.
- Missing communication between growers and consumers to promote the consumers' acceptance (e.g. new cultivars, landscape modifications).
- Area-wide incorporation of strategies does not typically occur, reducing the effectiveness of pest management methods such as mating disruption or beneficial organisms.

Environmental impact

- Impact of mechanical hoeing on higher nitrate release, nitrogen imbalance in the tree, yield loss and weed growth.
- Areas of high biodiversity may also be potential alternative hosts for pest species.
- Glue application on trunks or stick traps are not specific and also trap beneficial insects.
- Physical barriers in orchards have an impact on bees, beneficial insects, birds, and bats.
- Plastic waste is generated by exclusion netting, rainproof covers, pheromone dispensers, weed control, and microplastics are found in the soil (from exclusion netting).
- Hot water treatments require a lot of energy and water.
- Mechanical weeding may have a long-term impact on soil quality.
- The impact of introducing exotic natural enemies and micro-organisms in the agro-ecosystem has to be examined.

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Which alternative strategies could be developed?

Based on experiences from practice and experimental results, case studies to reduce the use of pesticides have been discussed during the meetings. They were presented in the Mini papers of Focus Group 44.

The field of action is wide-ranging. It includes changes in the ways to protect current existing orchards against pests, diseases, and weeds without changing the cultivar, tree training or planting distances, to new orchard concepts which are still at an experimental stage. Here are some examples:

- **Promoting natural enemies in orchards** (*source: Mini paper – "Make your orchard a good home for beneficials against pests. Importance of implementing functional agrobiodiversity in pome and stone fruit and recommendations for an active role of the farmer herein"*):
    - Develop Functional Agrobiodiversity elements like: non-crop plant species, either perennial shrubs, trees (usually arranged in planted hedges), or herbs (flowering strips), with successive flowering periods. This involves a total change in soil management (elimination/reduction of herbicides, changes in tillage practices,…).
    - Use a decision support system for the optimal timing and positioning of control treatments to reach maximum control levels on the pest, and choose the right product regarding negative side effects on beneficial insects.
    - Redesign the orchard by crop diversification and ecological intensification by increasing plant diversity, installation of companion plants, or habitats for beneficial insects in order to achieve a pest-suppressive system. The ALTO project (France) is a circular orchard (1.7 ha) composed of several different groups of fruits, where apple trees are occupying 50% of the plantation surface and the other 50% are composed of apricots, peaches, plums, figs, soft fruits, hazelnuts, and almond trees. (*source: expert communication*).

- **Using plant cultivars and rootstocks with resistance or tolerance to pests and diseases** (*source: Mini paper – "Plant Genetic to contribute to pesticide reduction - Towards an ideal genetic program to get closer to the resilient orchard"*). Breakdown of resistance has been observed after ten years for apple scab resistant cultivars. To ensure durability of the resistances, sanitation measures and specific fungicide treatments that focus only on the primary contaminations of the major apple scab are essential.

- **Combining alternative methods** (*source: Mini paper – "Towards a comprehensive approach to achieve pesticide reduction in fruit production systems - From the combination of alternative methods to orchard redesign"):*
    - Take advantage of interactions between practices to create a microclimate that makes fruit trees less affected by climate changes, and to optimise pest and disease management. Good results were achieved in a peach orchards (Greece) with preventive measures like 2D systems, green pruning and rootstock choice to limit plant growth, and green mulching for soil quality and weed management.
    - In the BioREco experiment (France), an overall decrease in pesticide use of 45% was observed in systems that combine a range of measures, compared to conventional systems in a six-year survey. In this experiment, the cultivar alone reduced pesticide use by about 20% in the conventional system. But, when combined with other alternative methods and sanitation, the decrease was reinforced up to 38-45%.
    - In the Ecopeche project, underground irrigation in peach orchards (France) was a means to modulate the orchard microclimate and to limit grass within the tree rows. A less humid microclimate is a way to limit the incidence of the brown rot post-harvest disease, and to decrease or even remove herbicide use.

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- On an almond farm (Portugal), alternative practices are used, such as insect trapping to better time treatments, reduced risk/natural insecticides, cover crops to limit weed development and increase plant health, and winter sanitation to remove overwintering pests and diseases. These practices help the farm to reduce pest pressures and production costs. Every spray they choose not to apply, saves about 60 euros/ha. However, annual crop losses due to diseases and insects are estimated to be around 7%. (*source: expert communication*)

- **Developing modern precision agriculture systems in fruit production to limit pesticide use** (*source: Mini paper on: "Precision Agriculture – An Enabler for Pesticide Use Reduction"*):
  - Cloud-connected orchard sprayers, so called Smartomizers – some of which are able to automatically adapt vertical crop sprayer parameters to tree dimensions and plague levels – can help to significantly reduce pesticide losses into the environment. Furthermore, some Smartomizers carry a pro-active system, which sends real-time warnings to the sprayer operator in case any of the critical spraying parameters are not correct, which in the sequel can be quickly corrected and therewith avoids larger spray job mistakes. Various related case studies demonstrate pesticide saving results:
  - Test results in an olive orchard (Portugal) led to a reduction of pesticides and spray water by 17.65% (from 850 L/ha to 700 L/ha).
  - An Early Detection System integrated with a Decision Support System, as well as a Smartomizer "smart" sprayer which modulates the amount of pesticides based on canopy structure, saved 23% pesticides in comparison to conventional spraying in an apple orchard (Spain).
  - In another case study, the use of a high-end precision agriculture sprayer with crop sensing capabilities made it possible to save 25% water and plant protection products in another apple orchard (Poland).
  - Furthermore, "electronic eyes" on spray rigs to spot vegetation can reduce the amount of material sprayed per hectare, while also reducing pesticide drift. In the presented case study on a large almond plantation in Portugal, electronic eyes have reduced pesticides by 20 to 30% during the first two growing seasons while the trees were small.

What could be done to achieve a significant reduction of pesticides?

The following three figures summarise ideas of the Focus Group to develop the use of alternative protection strategies:

- **Get more registered alternative products and know how to use them** (Figure 2). This involves several different actors from industry to advisory services, to the end-users, the farmers and farm workers. Evaluation processes should be more adapted to biocontrol products, natural products and biostimulants, to get them registered more quickly. There should be a larger information and training offer that is easily accessible to farmers/farm workers, to put these products in practice and achieve their optimal efficiency. Digital solutions must be developed to help advisors and farmers to take the right decisions.

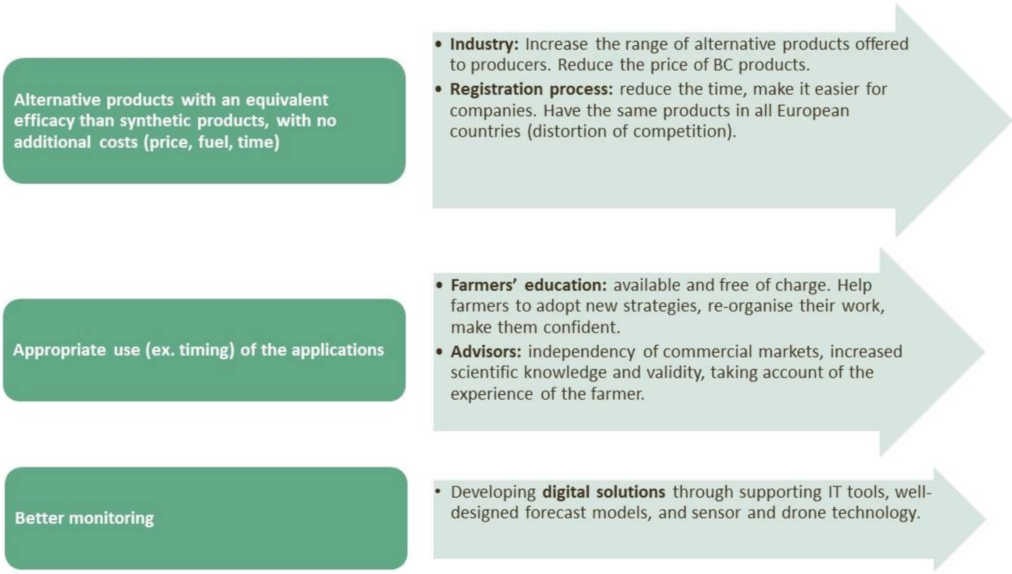

Figure 2: Have the good alternative product, applied in an optimal way

- **Promote Agro-ecological principles** (Figure 3) by increasing biodiversity in orchards to manage weeds, pests and beneficial insects, giving more consideration to the soil in the production system, how to adapt fertilisation and water needs, and developing cultural practices. This leads to new innovative orchards that are redesigned in terms of their plantation and the choice of cultivars, rootstocks, and implantation of plant diversity.

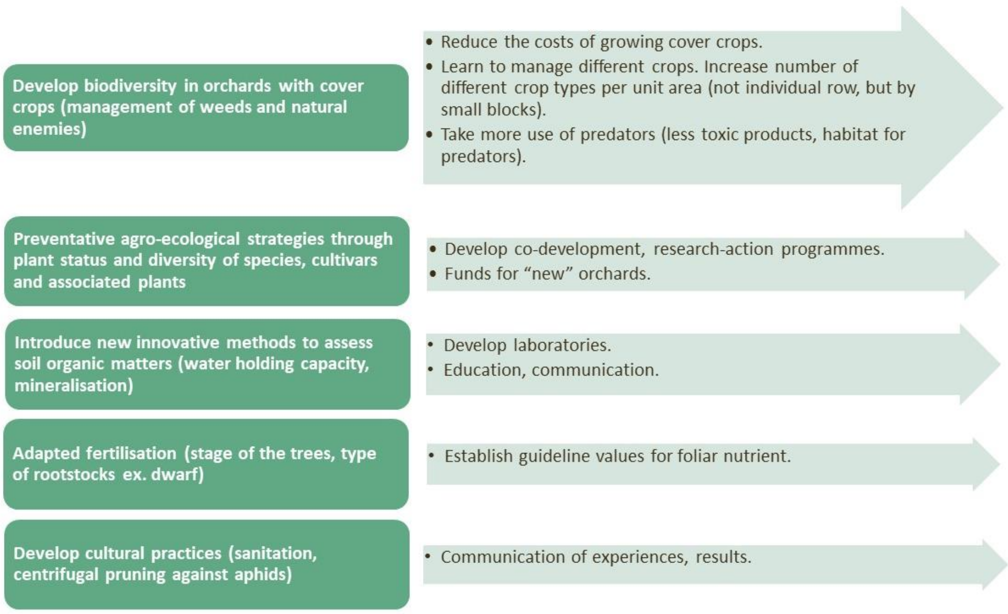

Figure 3: Develop agro-ecological practices

- **Innovate alternative techniques,** elaborate their use in practice (in combination with other measures and by integrating them in a protection strategy) and remunerate them (Figure 4). The Mini paper "Innovative approaches for a sustainable future plant protection" describes some of them, including: enhancing the fitness of the plant by influencing their phytobiome, reducing the fitness of pest populations via a replacement by sterile and incompatible insect lineage, influencing the mating behaviour via biotremology, or direct application of bacteriophages.

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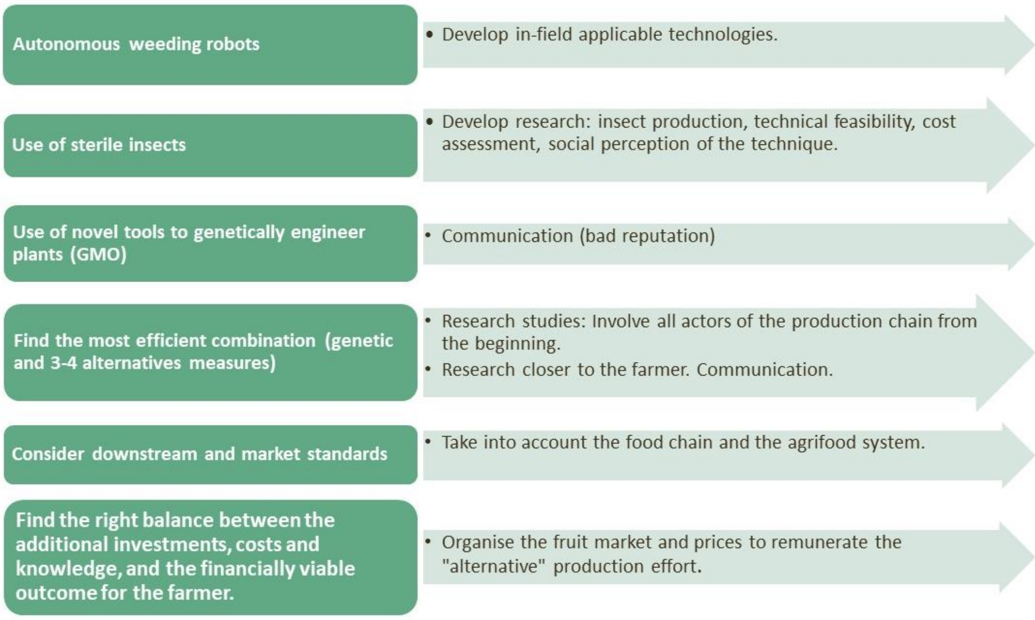

Figure 4: Innovate economically viable production systems in line with environmental constraints and fruit market expectations

Furthermore, by changing practices in response to societal demands to reduce the use of plant protection products, producers run the risk of production losses. The Mini paper "Improve farmers position with reduced pesticide use" presents various strategies that may increment fruit production with less use of pesticides, while they may at the same time have the potential to improve the farmer's position in the value chain.

Different ways have been identified:

- diversification on farm levels, and labels (e.g. processing fruits and direct sales)

- education at several levels: for farmers and advisors to develop and transfer alternative methods, and for the public/consumers to provide them with agricultural knowledge

- cooperation and networks of growers to share experiences, risks, and promote companionship

- increased connection between research and farmers

- insurance and finance to reduce risks for growers.

Ideas for Operational Groups and other innovative projects

The goal of Operational Groups is to bring together farmers, advisory services, and researchers to advance innovation on a specific topic.

As a follow-up of the outcomes of Focus Group 44, experts propose the following ideas (**Table 3**) in the field of:

- Diagnosis, decision tools, sensors
- Biodiversity
- Specific alternatives against pests
- Plant strengtheners and soil composition
- Transition to organic production
- Innovative spraying application techniques and equipment; increasingly autonomous precision agriculture
- Economics, strategy costs
- CO_2 output, impact on environment
- Shortening the value chain by direct sales to the consumers
- An EU advisers' network

Topic	Description of the problem	Actions
Innovative ways to monitor plant health	Pests and diseases are difficult to diagnose, and when symptoms /damages develop the protecting interventions are usually late. Monitoring tools of plant health exist, such as gas exchange, hyperspectral imaging, or volatile-organic compound monitoring. However, practical validation to tailor pesticide application is missing.	Apply different monitoring tools to detect multiple stresses to compare their efficacy, to create tools for tailoring pesticides.
Accurate disease measurement and forecasting	Application of fungicides for disease control, e.g. *Venturia inequallis*, is based on a preventive protection program. This involves spraying by calendar dates which is expensive and maybe unnecessary.	Robust, effective, and in-time disease forecasting models to predict fungal diseases, to facilitate management of orchard decision making. Ultimately, reduction in the number of fungicide applications with the same control.
Sensor testing for recording standard management strategies	Optimise the management strategies (irrigation, weed control).	Soil sensors, measuring field capacity in different depths. Irrigation and rain affects the evaporation. Monitoring the dynamics with the standard management.
Biodiversity	Biodiversity is expected to increase resilience in agro-ecosystems. Information on changes in farm management is lacking, especially at local scale.	Help farmers to establish ecological infrastructures in the farm (e.g. a selection of companion plants in orchard alleys; avoid introducing potential reservoirs for other pests and diseases) and evaluate different soil

		management strategies (including wood wasting).
Transition towards agro-ecological practices	How to implement agro-ecological measures in orchards? How to re-organise their designs by adding hedgerows and intercropping plants (companions or annual crops). How to choose species to be associate to the orchard, avoiding reservoirs for both diseases and pests.	Landscape evaluation of the orchards. Phytosanitary and environmental assessment, locally, in the orchards. Modelling of crop association for hedges/intercrops. Redesign orchards and evaluate the expected modification in ways to cultivate (machinery, spraying, irrigation).
Sustainability on healthy agro-ecosystems	Intensive agriculture leads to decreased biodiversity worldwide. Increasing biodiversity in the orchard will lead to an increase in abundance of natural enemies of pest species. However, the potential of natural agro-ecosystems to control and reduce pest species is underestimated and often not considered by farmers.	Specific training and education of farmers and advisors is needed. Farmers should be advised on how to increase biodiversity on their farm, with outcomes and effects. Biodiversity on farms should be evaluated by scientists.
Sustainable/alternative methods to control earwigs in stone fruit	Increasing population of earwigs causes serious problems in stone fruit (especially in orchards with little or no insecticide, e.g. organic) No sustainable and practical methods with good efficacy are available.	Field trials with specific biocontrol agents that have shown good results under laboratory conditions. Testing the application of biotremology to control earwigs.
Successful alternative methods for green leafhoppers (*Empasosca vitis*)	In peach orchards, leafhoppers are currently a growing problem in France, linked to the withdrawal of products that had a secondary effect on leafhoppers. In young orchards, growth is impacted.	Alternative methods such as Kaolin are used in vineyards with good success and may be adapted in young peach orchards that have no fruits yet. Other repulsive methods may be tried out, or combined with push/pull methods.
How can plant strengtheners improve plant protection?	Some plant strengtheners are proposed to farmers to enhance resistance of plants to pests and diseases and abiotic factors. How to use them? How to integrate them?	List of plant strengtheners (target, mode of action). Elaborate treatment programmes together (research, advisors, farmers). Apply them in commercial orchards and promote the results.
Soil for the future	The soil in perennial crops lacks organic matter and microbial activity to support good plant growth and plant health. Growers don't know how to improve this. Scientists don't know what should be targeted for particular local situations.	Farmers with different soils and different practices (organic, conventional,...) have to apply measures to improve the soil. Research support in measuring the effects (water holding capacity, organic carbon & mineralisation, fungal/bacterial communities,...)

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Organic production	Transition from conventional to organic production in orchards: practical aspects and steps, changing existing orchards.	Create transition paths for the modification of existing applications.
Integration of safe, accurate pesticide measuring tools on the farm	When preparing pesticide applications, specific rates are provided by the manufacturer and by regulations. Often farmers do not accurately follow these guidelines due to a variety of reasons, leading to increased pesticides use or failed control. Accurately measuring the required pesticide dose can decrease pesticide use or increase their efficacy.	Integration of automatic or semi-automatic measuring systems at the farm's spray rig fill station.
Harmonising fixed over-canopy pesticide sprayers with decision support systems/prediction models	Fixed spraying systems (FSS) are an emerging technology for pesticide application. FSS will be used in accordance with disease and pest risk models.	Deploy FSS on apple/pear/cherry orchards. Compare with air blast sprayer. Reduce applications by using FSS.
DSS2Spray – Seamless connection between DSS (Decision Support System) and variable rate application sprayer	The interface and information flow between variable rate application (VRA) sprayers/smartomizers and DSSs (Decision Support Systems) are often not ideal and need to be refined to achieve the goal of pesticide reduction without putting crop yield and therewith growers' income at risk.	DSS2Spray implements application programming interfaces (APIs) for seamless bidirectional information exchange for precise VRA and full spray job traceability.
Economic evaluation	Acquire a better understanding of the different costs of strategies to reduce plant protection products.	Identify strategies and quantify the cost of each strategy.
CO_2 output on the farm	How to reduce CO_2 output at farm level?	Identify production systems and quantify CO_2 output.
Establishing agro-ecological orchards and shortening of the value chain for an environmentally, socially, and economically sustainable food chain.	Consumers demand pesticide-free fruits and farmers demand higher prices for their products. But products without a label and free of pesticides meet so many intermediaries that the food chain cannot be sustainable.	Establishing orchards with less pesticides and with agro-ecological practices. Explore opportunities for direct selling to consumers.
Advisory services	Lack of practical knowledge of advisors who will work together with farmers who produce fruits with 'low pesticides' methods. The advisor should earn the farmers' trust by providing them with the applicable knowledge and technology.	Create an EU network of advisors on reducing pesticides in pome and stone fruit.

Table 3: Ideas for Operational Groups on reducing the use of pesticides

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Research needs from practice

Precision Agriculture

Modern Precision Agriculture systems that are applied in orchards contribute to a better management of the different "production inputs" like pesticides, fertilisers and water. There are two types of methods:

- Direct methods: precision sprayer to adapt the spray application to the crop dimension, decision support systems, forecasting models, early disease detection systems, monitoring spores and insects by traps.
- Indirect methods: adapt irrigation for shoot and weed growth, optimise nutrition with sensors or drone detections, precision weed control, precision blossom thinning to regulate fruit production.

In this field of activity, more research is needed for:

- Innovation in robotics from a technical point of view and social aspects on the effect of the use of robotics, including ergonomics.
- Remote trap monitoring in combination with a decision support system that helps to indicate the need for spraying and that even provides the spray job orders in the cloud, which can afterwards be downloaded to the Smartomizer sprayers.
- Improved models that are based on more epidemiological studies regarding pest and disease timing and that consider the applied cultivation practices.
- Fully autonomous sprayers which will favour the adoption of biocontrol products that often require more frequent and very timely spraying operations.
- And finally, more prospective soil sensing to determine the soil microbiome (plant pathogens, soil micro-organisms) combined with chemical analysis and a decision support system.

Moreover, precision agriculture should be adapted to all type of farms, bigger ones and especially smaller ones.

Biodiversity

Biological control is the reduction of pest populations by natural enemies. There are four strategies of biological control: classical, inoculation, inundation, conservation. Conservation biological control arises as one of the most promising strategies to be used in fruit orchards. Although recent works also reveal the influence of landscape structures in the enhancement of pest control services, growers often cannot readily influence the landscape context of their farms, limiting their potential to capitalise these ecosystem services. Knowledge is lacking on what should be done at both levels: landscape and farm. The multiple and "long-term" effects of measures like hedgerows, flower strips and cover crops are not well known; Not much is known about the risk to increase re-emerging or new pests and diseases either. On the other hand, side effects and persistence of chemicals on natural enemies need to be investigated.

To improve the ecosystem services, digital aids need to be developed to simulate the presence of beneficials in function of weather conditions, cultural practices, and plant protection strategies.

Soils are home to more than 25% of the earth's total biodiversity and they support life on land and water, nutrient cycling and retention, food production, pollution remediation, and climate regulation. Soil biodiversity integrates solutions for a sustainable future, but more research on soil in perennial crops, in particular the relationship between soil richness and the tree genotypes or species, should be investigated. Soil organic matter is a key element which forms the basis for sustainable fruit growing. The use of soil organic matter fingerprinting could be an option for adapted fertilisation and irrigation.

Biocontrol agents

The production chain of beneficials faces economic problems (high costs and low turn on investment) and the quality between batches of released beneficials is varying. The production processes must be improved. Moreover, the potential negative side effects of released beneficials in the long term have to be explored.

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Besides macro-organisms, biocontrol agents comprise beneficial micro-organisms, pheromones, plant extracts, and minerals. In case of micro-organisms, research is needed to find specific living organisms, selected for crops and targets and possibly for regional use. The soil compartment is still to be explored for beneficial soil organisms (micro and macro).

Research should be done on:

- adjuvants that increase the effectiveness of bio-insecticides, improve their efficacy, protect against adverse conditions, and prolong their activity;
- attractants and baits used together with pesticides at low doses and with low application rates;
- natural products that boost plant defence mechanisms;
- manipulating plant microbiome and synthetic communities to enhance plant resistance;
- modification of the pathogen population structure by releasing permanently avirulent strains which would replace the "wild", virulent forms.

To achieve a better knowledge, round validation trials (pilot farms) and an EU trial network would be interesting to implement in order to share experiences, results and to elaborate recommendations together. Therefore, it would be good to use common standardised efficacy and risk assessments.

Genetics

When it comes to genetics, the research programme is a long and expensive process. In the last ten years, participative evaluation research came up. The question is: what does and doesn't it permit?

Furthermore, would it be possible to have equal access to plant material in European nurseries?

The observation is that there is a lack of multiple, complex resistance mechanisms; a low rate of producing new resistant cultivars; and different tools for "fast breeding" still need to be implemented. Which factors are important for growers to plant a resistant cultivar? How to deploy the use of resistant cultivars in a systemic approach? Which traits need to be combined in order to secure durability for the resistance? What is the effect of landscape management on the durability of resistance? Deleting susceptibility genes would be a safe way of modifying crop plants without a real impact on the rest of the genome. However, the technology is not applicable (yet) for all tree species, and it still requires deregulation at the European level.

Another under-studied topic that still requires investigation is the interaction between scion and rootstock, and its effect on fruit tree health. Such interaction is expected to have an effect on plant growth, fruit yield, but also on the response of the tree to pest and pathogen attacks, by inducing direct or indirect mechanisms of resistance or tolerance to soil-borne and air-borne pathogens and pests. Those mechanisms can be direct, because one of the tree components is genetically resistant, or indirect by triggering defense pathways, by inducing a better tree vigour or by determining a tree architecture that will, by the end, limit the multiplication and dissemination of pathogens.

System approach

Experiments and trials are often conducted to answer analytical questions. In case of systemic approaches, the main difficulties are to study a combination of alternative methods and to analyse the whole production system. Several methodology questions are still unanswered. Which type of research can consider a global approach? Which are the "best" indicators to describe the technical, environmental, economic, and social performances?

Agroforestry, mixed vegetable-orchards, intercrop fruit trees with rotational crops, are different prospective system approaches. The complexity and practicability, the sanitary risk due to multi-products need to be studied in depth. It is noted that the market demands lead to specialisation in fruit production and this is difficult to achieve in diversified systems.

If we implement interspecific orchards or higher diversification in the orchards, studies on the plant-plant or species-species interactions are needed to limit competition and increase yield/efficacy of the mixing. Working on ergonomics and decision making in such complex systems is also relevant.

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Research is needed on the transition phase from "conventional" orchards to agro-ecological production systems. How to change the system on the farm? Which factors are important?

Social aspects

To improve the farmer's position in a reduced pesticide use management, how to change the mindset of the farmers? How to take away the risk from farmers? Research studies should also investigate which factors are important for the next generation of farmers.

The relationship with consumers, and society in general, is also an important key to success. Social perception studies of the farmer's job can help to develop a positive perception and restore trust. Could information on labels be a solution to communicate in a positive way? Therefore, studies on consumer behaviour to the act of buying are essential. Are aesthetic changes on fruits acceptable if they do not affect fruit quality?

Conclusion

Focus Group 44 worked on sustainable ways to reduce pesticides in pome and stone fruits. Several levels have been identified:

- substitute synthetic chemicals by alternative practices (biocontrol agents, natural products, pheromones, physical barriers, mechanical technics, cultural methods);
- improve plant protection by using decision support tools and modern Precision Agriculture systems, like precision sprayers and sensors detection;
- redesign production systems based on biodiversity with hedgerows, companion plants and on favouring the plant's defenses by genetics, cultural practices, tree training.

In fact, there is not one solution, but a range of solutions. There is not one strategy, but a range of strategies to limit the use of pesticides. The solution will come from applying several tools/strategies simultaneously in a complementary way, depending on:

- the crop species, and the pest and disease pressure;
- its environment (type of soil, climate condition, possibility to irrigate or not, already existing biodiversity or not…);
- the size and economic level of the farm;
- the growers' risk taking and acceptance to produce less;
- the consumer acceptability to have a more expensive fruit.

Basic and applied research is still needed to find new and innovative measures to protect orchards, to understand how to use them in an optimal way, and elaborate the best combinations in order to maximise their efficacy and minimise negative effects on the organisation and workload, as well as the yield and quality of the fruit.

To achieve the goal of reducing pesticides, technical and financial support is needed to transform the orchards, from the first steps to post-installation, especially for small farmers, but also for the industry in plant protection products to find more "ecological" ones.

Knowledge and support are necessary for the farmers to engage in the transition towards new practices and to face more complex production systems. But since the orchard is a perennial culture, only short-term strategies can be implemented. For long-term strategies, orchards have to be redesigned.

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Annex 1: Experts of Focus Group 44

Mr/Ms	First name	Family name	E-mail address	Country	Professional background
Ms	Judit	Arnó	judit.arno@irta.cat	Spain	Researcher
Mr	Lars Torsten	Berger	info@fedepulverizadores.com	Spain	Industry
Ms	Esther	Bravin	esther.bravin@agroscope.admin.ch	Switzerland	Researcher
Mr	Dany	Bylemans	dany.bylemans@pcfruit.be	Belgium	Researcher
Ms	Veronique	Decroocq	veronique.decroocq@inrae.fr	France	Researcher
Mr	David	Doll	daviddoll@rotaunica.com	Portugal	Farmer
Ms	Claire	Gorski	clairegorski.cg@gmail.com	France	Researcher
Ms	Valentina	Hazic	tina.hazic@gmail.com	Croatia	Farmer
Mr	Ioannis	Iordanidis	agriordani@gmail.com	Greece	Advisor
Mr	Kieran	Lavelle	Kieran.Lavelle@daera-ni.gov.uk	United Kingdom	Advisor
Ms	Marlene Ariana	Milan	marlene.milan@fibl.org	Germany	Researcher
Mr	Michał	Pniak	m.pniak@biocont.pl	Poland	Advisor
Mr	Hannes	Schuler	hannes.schuler@unibz.it	Italy	Researcher
Mr	Peter	Schweiger	peter.schweiger@global2000.at	Austria	Representative of an NGO
Ms	Elisabeth	Schwitzky	elisabeth.schwitzky@googlemail.com	Germany	Other
Ms	Sylvaine	Simon	sylvaine.simon@inrae.fr	France	Researcher
Mr	Michal	Skalský	michal.skalsky@seznam.cz	Czech Republic	Researcher
Mr	Francesco	Spinelli	francesco.spinelli3@unibo.it	Italy	Researcher
Mr	Marco	Tasin	marco.tasin@gmail.com	Italy	Farmer
Ms	Franziska	Zavagli	Franziska.zavagli@ctifl.fr	France	Researcher / Coordinator of Focus Group 44

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The European Innovation Partnership 'Agricultural Productivity and Sustainability' (EIP-AGRI) is one of five EIPs launched by the European Commission in a bid to promote rapid modernisation by stepping up innovation efforts.

The **EIP-AGRI** aims to catalyse the innovation process in the **agricultural and forestry sectors** by bringing **research and practice closer together** – in research and innovation projects as well as *through* the EIP-AGRI network.

EIPs aim to streamline, simplify and better coordinate existing instruments and initiatives and complement them with actions where necessary. Two specific funding sources are particularly important for the EIP-AGRI:

- ✓ the EU Research and Innovation framework, Horizon 2020,
- ✓ the EU Rural Development Policy.

An EIP AGRI Focus Group* is one of several different building blocks of the EIP-AGRI network, which is funded under the EU Rural Development policy. Working on a narrowly defined issue, Focus Groups temporarily bring together around 20 experts (such as farmers, advisers, researchers, up- and downstream businesses and NGOs) to map and develop solutions within their field.

The concrete objectives of a Focus Group are:

- ✓ to take stock of the state of art of practice and research in its field, listing problems and opportunities;
- ✓ to identify needs from practice and propose directions for further research;
- ✓ to propose priorities for innovative actions by suggesting potential projects for Operational Groups working under Rural Development or other project formats to test solutions and opportunities, including ways to disseminate the practical knowledge gathered.

Results are normally published in a report within 12-18 months of the launch of a given Focus Group.

Experts are selected based on an open call for interest. Each expert is appointed based on his or her personal knowledge and experience in the particular field and therefore does not represent an organisation or a Member State.

*More details on EIP-AGRI Focus Group aims and process are given in its charter on:
http://ec.europa.eu/agriculture/eip/focus-groups/charter_en.pdf

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servicepoint@eip-agri.eu | +32 2 543 73 48 | Koning Albert II laan 15 | Conscience Building | 1210 Brussels | Belgium