EIP-AGRI Focus Group
Pests and diseases of the olive tree

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1. Summary

Over 750 million olive trees are cultivated worldwide, 95% of which are in the Mediterranean region. Several insects, pathogens and nematodes affect olive trees, threatening olive production. Both the number of pests and diseases and their frequency has increased dramatically in recent years, causing serious damage to overall EU olive production. Trade and the movement of goods and people, climatic variations and changes in farming practices have facilitated the introduction, spread and establishment of some pests and diseases in olive production. To mimimise crop losses and economic damage and protect olive cropping systems in the future, it is essesential to recognise and understand the nature of these pests and pathogens and the interactions between the olive crop and the agro-ecological conditions in the different olive-producing regions in Europe. The potential impact of future climate scenarios on these issues will need to be taken into account.. Although pesticides are often used to protect olive crops against pests and disease attacks, there is increasing concern about the effects of pesticides on the environment, human health and product quality. In addition, olive farmers have to adopt new management practices for controlling pests and pathogens following the European directive on Sustainable Use of Pesticides (DIRECTIVE 2009/128/EC).

Within this general framework, one main question arises: *How can we increase the sustainability of olive growing, taking into account the risks brought about by pests and diseases?*

To answer this question, 19 experts from the five main EU olive producing countries were brought together in a Focus Group to explore more sustainable farming practices, including the use of non-chemical pesticides to tackle the main diseases and pests threatening EU olive production. The Focus Group worked together for around 12 months and met face-to-face twice to carry out the following main tasks:

- Make an inventory of the main pests and diseases affecting the olive tree, including their geographical distribution and economic impact.
- Summarise and provide their own perception on how climatic change is likely to impact the distribution and occurrence of such pests and diseases as well as their impact on olive growing, regarding current practices and environmental conditions.
- Take stock of good farming practices across different regions in Europe to manage main olive diseases and pests, including IPM strategies.
- Explore potential innovative solutions to manage pests/diseases based on agro-ecological principles such as biodiversity.
- Discuss these practices, highlight both existing success and fail factors in pest and disease management in olive production, including the socio-economic dimension.
- Identify needs from practice and possible gaps in knowledge, which may be solved by further research.
- Suggest innovative solutions and provide ideas for EIP-AGRI Operational Groups and other innovative projects.

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2. Introduction

The EIP-AGRI Focus Group on Pests and diseases of the olive tree

The Focus Group (FG) on Pests and diseases of the olive tree was launched by the European Commission in summer 2018 as a part of the activities carried out under the European Innovation Partnership 'Agricultural Productivity and Sustainability' (EIP-AGRI). The overall aim of this FG is to build a bridge between farmers and researchers for collecting and summarising knowledge and best practices for controlling pest and diseases of the olive crop, listing problems as well as opportunities, taking stock of the state of play in research and practice, and highlighting possible solutions to the problems identified. Based on this, the EIP-AGRI Focus Group suggested and prioritised innovative actions, identified ideas for (applied) research and for testing solutions in the field, involving farmers, researchers, advisers, the industry and other practitioners, and proposed ways to disseminate good practices for pests and diseases control.

The main question that the Focus Group addressed was *How to increase the sustainability of olive crops, taking into account the risks brought by pests and diseases?*

For this, this group of 19 experts from the five main EU olive producing countries (See **Annex A** for the complete list of members) discussed this main question and worked on the following specific objectives:

- **Make an inventory of the main pests and diseases affecting the olive tree**, including their geographical distribution and economic impact.
- **Summarise, where possible, how expected climatic changes are likely to impact** the distribution and occurrence of such pests and diseases as well as their impact on olive growing, regarding current practices, socio-economic results and environmental conditions.
- **Take stock of good farming practices across different regions in Europe regarding the whole cycle of diseases and pests in olive production**, including IPM (integrated pest management) strategies and organic olive production. Taking into account the experiences of farmers and advisers as well as the findings of potential innovation activities carried out by EIP-AGRI Operational Groups and research projects in this field.
- **Discuss these practices and highlight both existing success and fail factors** in pest/disease management in olive production, including the socio-economic dimension.
- **Explore potential solutions** to manage pests/diseases based on agro-ecological principles such as biodiversity.
- **Identify needs from practice and possible gaps in knowledge**, which may be solved by further research.
- **Suggest innovative solutions and provide ideas** for EIP-AGRI Operational Groups and other innovative projects.

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Olive crop importance and cultivation

The olive tree (*Olea europaea* L.) is a drought-tolerant species which can have an exceptionally long life-span. It can grow in poor, stony soil where it would be difficult to grow other crops, and it is limited only by frost and high temperatures and to a lesser extent by soil fertility. Traditionally olive groves in the Mediterranean were associated with the presence of high biodiversity, being an example of a 'high natural value' agricultural system with an important environmental role. This was possible due to the low-intensity of olive farming systems (i.e., low tree density, low use of agrochemicals and low degree of mechanisation), presence of semi-natural herbaceous vegetation in many areas with different land uses. However, in recent years this ecological value has diminished due to the 'modernisation' of olive plantations, based on the expansion of olive grove areas, resulting in olive monoculture systems in Europe, and on the intensification of the olive farming systems (intensive use of fertilisers, pesticides and machinery).

Historically, the cultivated olive has been, culturally and economically, the main oleaginous crop in the Mediterranean Basin, where around 9.5 million ha of olives are grown, accounting for 95% of the land used for growing olives worldwide (i.e., about 98% of the olive oil and 80% of table olive production are from Mediterranean countries). Only 1.5% of the global olive cultivation area is located in Asia, 0.8% in the Americas, and 0.01% in Oceania (FAOSTATS, 2018).

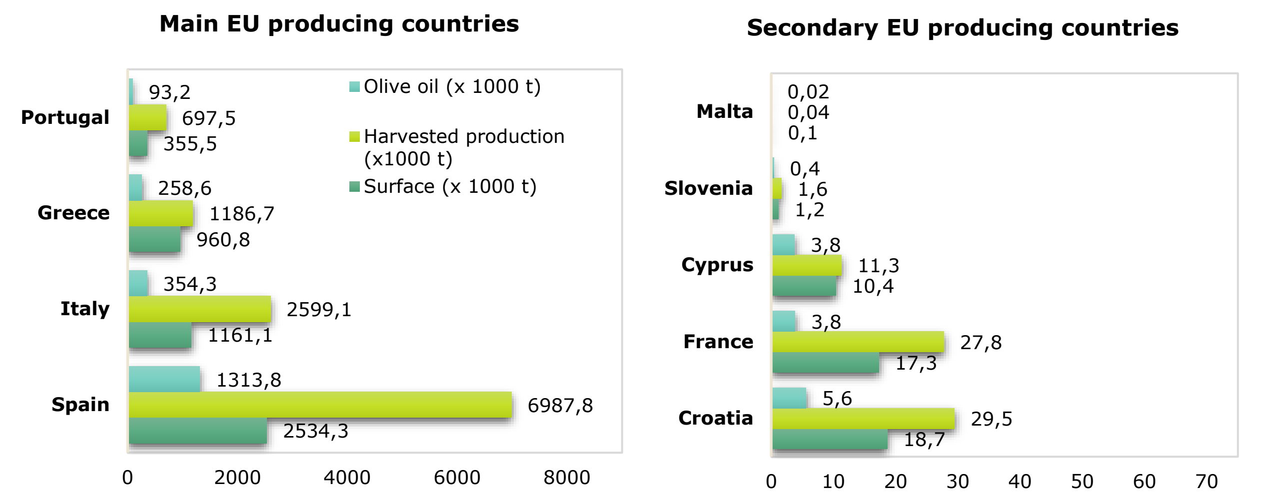

Figure 1. Yield production (average 2016-2018) and surface area (average 2016-2018) of olive crops and oil production (average 2015-2017) in the main and secondary EU producing countries (Source: EUROSTAT and IOC).

Olives are an important agricultural crop for the economy of the European Union's southern countries. They account for 70 to 75% of the world's production of olive oil and more than one third for table olives, and with more than 7 billion € in production value every year. In the EU, olive tree plantations are found in nine EU Member States: Spain, Italy, Greece, Portugal, Cyprus, France, Croatia, Slovenia and Malta (EUROSTATS, 2018; Figure 1). These countries have more than 5 million hectares of olive plantations, of which more than half are in Spain, mostly devoted to oil production. According to EUROSTAT, EU olive production reached 10,908,000 tonnes. Average annual olive yield ranges between 2000-2500 tonnes per hectare. This variation reflects the effect of climatic conditions, good/poor harvest (alternate bearing cycle), or the cultivation system/management intensity.

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Within the EU, different olive production systems coexist even within the same country, region or county. They each have specific characteristics and provide important agroecosystem services. In the EU, olive cultivation ranges from traditional low-density to new high-density cropping systems including super-intensive plantations established in the main olive growing areas of Spain and Italy where the aim is to maximise yields and decrease harvesting costs. Another trend is to reconvert some of the traditional orchards to more intensive ones, installing new infrastructures (mainly fertigation systems and water reservoirs) and increasing the number of trees per row or in-between rows. Where olive orchards are located in marginal areas in fragile environments, reconversion for intensification is not possible but organic farming can be an option to increase production value. All these changes have affected the incidence and severity of pests and diseases, and for some of these new olive production systems, several problems have emerged or are re-emerging as a consequence of the changes in crop management, for instance introduction of irrigation, increased plant density, mechanical pruning or introduction of cover crops.

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3. The Focus Group process

The Focus Group met twice. The first meeting was held in Lisbon, Portugal on 15 – 16 January 2019, and the second meeting was held in Heraklion, Crete on 18-19 September 2019.

A 'starting paper' served as the initial reference to support the meeting and catalyse the discussion. The **starting paper** was prepared by the coordinating expert with inputs from the experts. It included results of a preparatory questionnaire to select the main pests and diseases of the olive crop. In addition, the experts prepared **17 case studies** that also helped inspire the discussion during this first meeting. The case studies focused on different aspects of the management of olive pests and diseases. Every case study indicated the management strategies and specific tactics used, pointing out the keys for success or failure of the selected approach. The case studies covered the following main subjects:

- **Management of olive diseases:**
  - The case of *Xylella fastidiosa* outbreak in Madrid (Madrid, Spain)
  - Olive anthracnose, a complex of fungal species (Apulia, Italy)
  - Alternatives to copper for control of olive peacock (Provence, France)

- **Management of olive pests:**
  - Olive fly, *Bactrocera oleae.*
    - Use of chemical ecology (*Athenolive* Project Aix-en-Provence, France)
    - Use of exclusion nets (Rhone-Alpes, France)
    - Use of hand-made traps with natural attractants (Alentejo, Portugal)
    - Integrated management under organic production (Crete, Greece; Campania, Italy)
    - Mass trapping combined with authorised insecticides (Catalonia Spain)
    - Enhancement of natural enemies by conservation of heterogeneous agricultural landscapes 'green infrastructures' (Trás-os-Montes, Portugal)
    - Development of an artificial intelligence system to predict risk of attacks (Andalusia, Spain)
  - Lepidopterous pests
    - Mating disruption technique using pheromones (Viotia, Greece)
    - Mass trapping combined with chromotropic traps and *Bacillus thuringiensis* (Madrid, Spain)

- **Description of specific farms:**
  - "The Garden of Biodiversity" farm (Palermo, Sicily, Italy)
  - Azienda Agricola 'Dora' (Enna, Sicily, Italy)
  - Il Giardino delle Belle (Caltanissetta, Sicily, Italy)
  - Gkisakis organic olive orchard (Larissa Greece)

During the first meeting, the experts selected a total of four pests (*Saissetia oleae, Parlatoria oleae, Bactrocera oleae* and *Prays oleae*) and four diseases (*Collecotricum* spp., *Verticillum dahliae, Pseudomonas savastanoi* pv. *savastanoi* and *Fusicladium oleaginum*) to focus the discussion on the success and fail factors of the different strategies and tools to tackle them.

They also discussed the following topics:
- Identify and discuss innovative IPM strategies to tackle olive pests and diseases.
- Biodiversity-based strategies (Functional biodiversity) to tackle olive pests and diseases
- Strategies for pest and diseases control under organic olive production and effect of climatic change on pest and diseases.

Finally they identified six topics for minipapers. The list of minipaper topics selected and the list of contributors are listed in **Annex B**:

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During the second meeting, the Focus Group experts addressed the following tasks:

- Explore potential consequences of climate change in pest and diseases.
- List agro-ecological principles for pest and disease management in olive orchards and discuss the main challenges and opportunities for their adoption at farm level.
- Discuss the factors that can facilitate the adoption of innovative pest and disease management practices by the olive growers.
- Identify needs for research from practice and Operational Group ideas.

The minipapers were presented, followed by a discussion on the potential effects of climate change on olive pests and diseases. Experts agreed that, currently it is very difficult to predict such consequences, as they are the results of complex interactions between the specific pathogen or pest, the olive variety, and the specific environment (climate, agronomic practices, etc.). Then, it was concluded that each expert would describe their own experience or observations on potential climate change effects on pests and diseases that may be already occurring in their regions.

Figure 2. Pictures from the field visit at olive orchards located in the Messara valley, Crete

In the afternoon of first day, the experts took a bus to visit the facilities of the Hellenic Mediterranean University of Crete. The experts visited a laboratory participating in *Xyllela fastidiosa* official monitoring and discussed different aspects with the scientists working there. Then, the experts visited two olive orchards in Messara valley where research on pest control was being conducted (Figure 2). One of the orchards was organic and the experts interviewed the owner of the orchard and learned about the agro-ecological practices that he was applying to control pests and diseases. In addition, one of olive orchards visited is included in the **Life project IGIC** (Improvement of green infrastructure in agroecosystems: reconnecting natural areas by countering habitat fragmentation). In this IGIC project 30 pilot fields located in 10 sites in the Western Messara plain, southern Crete, are developing a network of green infrastructure components in Natura-surrounded sites. The experts learned about the project objectives and the experience of the farmer participating in the project.

The experts identified innovative management practices focused on agro-ecological principles for controlling olive pests and diseases. Once the experts had identified the principles, they discussed the challenges and opportunities, and provided examples of use by farmers.

Finally, the experts discussed the needs for research and Operational Group ideas identified in the minipapers and the Starting paper.

4. State of play: Main pests and diseases affecting olive crops, and management recommendations

Historically, increased trade and movement of goods, climatic variations and changes in farming practices have facilitated the introduction, reemergence, spread, and establishment of pests and diseases for many crops, including olives. Several insects, diseases, nematodes and weeds affect olive trees, and the number of these occurrences has dramatically increased over the last years, causing serious damage to the overall olive production. The main pest and pathogen organisms that affect olive crops may not only influence olive yields, but also the profitability of growing olives in certain areas or situations in the EU.

Although there are more than one hundred invertebrate species, mainly insects and mites, known to feed or develop on the olive tree, they often have many different host plants in addition to olive trees. A second smaller group is composed of species which are closely and specifically adapted to olive. The species from the first group are usually occasional pests whereas species from the second group may cause economic losses and pose a serious risk for the annual olive yield.

There are also more than one hundred olive pathogens, although only a few of them cause serious economic losses on olive groves (Trapero-Casas et al., 2017; Landa et al., 2009). For instance, losses due to Verticillium wilt include high rates of tree mortality and reductions in fruit yield, especially in highly susceptible cultivars. Tree death due to Verticillium wilt tends to occur in young orchards, but adult trees are also affected, and reductions in fruit yield due to Verticillium wilt occur with nonlethal infections that cause drupes to shrivel, desiccate, and lose weight (Jiménez-Díaz et al., 2012). In Israel, yield reductions in irrigated "Picual" olives were estimated to be 75 and 89% at 3 and 5 years after planting, respectively (Levin et al., 2003).

For the olive moth (*P. oleae*) a 28-year study of olive trees grown in Granada, Spain, revealed that under high infestation levels, economic losses can be very high (Ramos et al., 1998). The olive fly (*B. oleae)* causes severe economic losses to olive producers, causing olive oil yield losses up to 11.5% and 18%, in spite of the fact that pesticide treatments are widely applied every year to control the fly population. Additionally, sensorial and chemical oil characteristics can be severely affected meaning that the oil cannot be classified as extra virgin or virgin oil.

A recent **report** by the JRC estimates that *Xylella fastidiosa* full spread could ultimately cost the EU over €5.5 billion per year due to production losses, with potential export losses of €0.7 billion per year. Furthermore, if *Xylella* were to fully spread across the EU, it could affect over 70% of the EU's production value of olive trees which are more than 30 years old, and 35% of younger trees. This could put nearly 300,000 jobs related to olive trees, citrus, almonds and grapes production at risk.

Pesticides are often used to protect the olive crop against pests and some diseases. However, there is increasing concern about the effects of pesticides on the environment, non-target organisms, human health and product quality. The EU is seeking to reduce reliance on pesticides and fertilisers for olive production. It is fostering agricultural strategies with low environmental impact and new or low input management systems such as integrated pest management (IPM) and organic farming.

Integrated Pest Management (IPM)

IPM as defined by FAO (**www.fao.org/agriculture/crops/**) is "the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimise risks to human health and the environment. IPM emphasises the growth of healthy crops with the least possible disruption to agroecosystems and encourages natural pest control mechanisms".

IPM is based on accurate identification of the target pest or pathogen. Biological control through natural enemies such as predators, parasites, insect pathogens and non-pathogenic antagonistic or competitive microorganisms is preferred to chemical options. The Focus Group experts considered that for the main pests and diseases, an

IPM approach should be practiced in order to obtain a reliable level of plant protection. The Focus Group experts also noted that in their experience, this is also the general opinion of most olive farmers.

The major **components of IPM systems** are: (i) accurate identification of pests and diseases and their natural enemies (*Knowledge*); (ii) involves mainly cultural and physical control strategies to minimise pest and disease entry and their spread in space and time [i.e., selection of the best varieties and agronomic practices to avoid their damage] (*Prevention*); (iii) early detection and accurate monitoring of pests, diseases, and their damage (*Observation*); (iv) direct control and intervention when needed based on selection of one or more management options on the basis of monitoring results and action thresholds (*Intervention*), giving priority to a wide range of non-pesticide options.

In IPM systems, emphasis is given to **preventive measures** to suppress or prevent pests and diseases. **Preventive control measures** for the management of pest and diseases in olive crops may include: (i) site selection to avoid planting in high risk areas where pathogens or pests are prevalent; (ii) use of cultivars and rootstocks which are resistant/tolerant to main pests and diseases; (iii) use of certified planting material; and (iv) reduction or elimination of inoculum/propagules in soil; v) use appropriate and timely cultivation practices. When possible, these preventive measures should be exploited fully to reduce the need for direct control measures.

Direct control measures should only be taken if they are economically justified, i.e, the crop has to be monitored to establish economic damage thresholds to determine if, when, and what treatments are needed for effective control. **Post-planting control measures** for direct control/management may include: (vi) cultural practices; (vii) organic or biological amendments; (viii) use of pesticides. Preference is given to non-chemical control measures such as physical interference (nets or traps, mechanical weed control, etc.) and biological control (the use of natural enemies–predators, parasites, pathogens, competitors and pheromones to control pests and their damage) if they can provide satisfactory pest control or are available. The use of selective pesticides targeted at the pest or disease or only at infested trees or parts of trees may be used when no other available control measure is available and at minimum doses if possible. IPM also emphasised the need to continuously get feedback from the results of interventions and adapt or modify them as a consequence of the outcome (evaluation and planning).

Another important element of IPM is the continuous monitoring, evaluation and planning cycle. The results of IPM interventions need to be measured and evaluated, so that they can be adapted or modified to improve the results if needed.

Preventive practices for olive pests and disease management

- **Choice of site for establishment of new orchards.** Selection of a field site to establish an olive orchard should be done with care. Accurate information on the disease or pest history of the soil to be planted or of neighboring fields is helpful. Soils with higher levels of pathogens such as *Verticillium dahliae* or *Phytophthora* spp. should be avoided, if possible, or analysed in advance to plantation establishment to test for presence and levels of pathogen inoculum.

- **Use and selection of resistant cultivars or rootstocks** is the best long-term and economically efficient control measure for controlling many diseases and some pests of olives, and should be at the core of integrated pest/disease management strategies. The experts indicated that although there are many olive tree varieties around the world, the main criteria taken into account when choosing a variety for planting is the previous knowledge of the variety in the region, farmers prefer to continue planting what they know. Normally, the main factor to select a variety is the productivity and environmental adaptation. In areas where the olive oil produced locally has a "certified" or "protected" designation of origin, farmers may be required to use a specific local variety or a combination of varieties. The choice of a tolerant cultivar makes integrated pest management easier and can reduce production costs by reducing chemical inputs or the costs of other control measures. In some circumstances, chemical control is not possible and the use of resistance/tolerance is one of the few options, as in the case of Verticillium wilt.

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- The **use of certified planting material** is crucial, not only to ensure the identity of the olive variety or the quality of the plant, but also its health status. The use of certified material from officially licensed producers is particularly important to avoid later problems associated with scales, mealybugs and other biting sucking insects, or pathogens that cause systemic infections, which can remain asymptomatic in the plant for several months or years after planting until appearance of symptoms, such as is the case of *V. dahliae* and *Xylella fastidiosa*. However, the experts pointed out that a appropriate certification scheme and legislation for olive crops is lacking. They also noted that sometimes farmers prefer to save money by buying cheaper plants, despite the fact that the the plants may not be guaranteed to be healthy and free of pests. To limit potential future problems due to lack of good phytosanitary status, and until a certification system is developed for olives, farmers should acquire the planting material only from nurseries which are properly accredited and registered, since they are the only ones that are subjected to inspection.

- **Soil disinfestation** including soil fumigation, soil solarisation and organic amendments, either individually or a combination, are useful for reducing inoculum of pathogens and some pests eggs laid in the soil. However, many of the broad-spectrum soil fumigants or desinfestants either alone or in mixtures are normally not used in olive plantations and many of them have been banned in recent years. The experts indicated that in most EU countries there are no commercial soil fumigants or disinfectants available for olive plantations. Although bio-fumigation may be used as an alternative, information on how to perform this process is lacking as is the exchange of information to farmers in a practical way, this means implementation remains scarce.

Early detection, diagnostics and monitoring tools

- Currently, there are many **diagnostic tools** available for pathogen detection in olive plantation soils. These include traditional techniques for nematode extraction or fungal propagule counting and molecular tests that can be used in the assessment of the presence of pathogen propagules in soil and help identify appropriate sites for establishment of new orchards. The experts indicated that some of these techniques are expensive and farmers may be unaware as to where to send samples or how to take them. There are several molecular and serological tests available which have been specifically developed for certification of pathogen-free plant material that can be used by the producing sites or by plant protection inspectors to check the presence of the main olive pathogens including fungi, bacteria and viruses. These tests are especially important for pathogens that cause vascular infection and may have an infection phase asymptomatic such as *V. dahliae* and *Xylella fastidiosa.*
- **Monitoring of pests and pathogens** is essential for Integrated Pest Management. Good knowledge of the physiology and morphology of the olive plant, and the biological cycle of the pest/disease is a basic requirement to plan and implement an efficient monitoring system. Monitoring can be done with simple visual inspections, but normally traps are used for capturing pest individuals or fungal spores. The **pest monitoring by pheromones** is key to determinate the presence of some olive pests and their flight curves, establish the population level and decide the correct timing for phytosanitary treatments (e.g., *Bactrocera oleae*, *Prays oleae*), always with authorised products in accordance with current legislation and in a rational way.
- **Forecasting systems** are used to identify the risk level linked to the attack of a pest or a disease and to decide the tool and moment to apply some management practice mainly a plant protection product, which is usually an insecticide for pest control (i.e., pyrethroids for *B. oleae*), or copper for some pathogens (*V. oleagina*, *P. syringae* pv. *syringae*). These forecasting systems have been or are being developed for some pests (*B. oleae*) and (*C. oleaginum*) olive diseases (eg. Petazzi et al., 2002; Romero et al., 2018). Nowadays, the availability of Information Technology (IT) tools such as wireless sensors to constantly monitor climatic and vegetation data will enable the implementation of precision plant protection techniques in some regions/farms. The experts pointed out that although IT tools are available in several EU regions, they are rarely used directly by the olive farmers since availability of weather stations, climatic sensors, and some expertise in the interpretation of data is needed. However, the experts believe that in the near future these tools will increasingly be used by advisory services.

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- Decision support systems (DSS) have been developed by combining forecasting systems, the availability of IT tools and Internet of things technologies to guide farmers/practitioners in the efficient implementation of management practices. For example, in some regions of the EU, DSS have been developed for the olive pest *B. oleae* based on an internet-based monitoring network, allowing several technicians distributed in a region to share the same Geographical Data Base Management System that includes the fruit fly infestation data (population levels), meteorological data and the coordinates of the monitored points. Data collected weekly by technicians are processed by a Geographical Information System linked with the database. GIS produces several outputs used to support decisions in pest control (DSS): (i) optimise the distribution of monitored points; (ii) visualise pest dynamics; (iii) evaluate the linkage between entomological data and geographical factors (i.e. distance from the sea, altitude); and (iv) forecast infestation, using a spatial interpolator. **Case study N1** provides a good practical example on how to effectively use IPM for olive crops. The Phytosanitary Information and Warning Network (RAIF) of Andalusia, Spain is a platform that provides information on the phytosanitary status of the main crops in Andalusia. The network receives information from more than 650 field technicians and some 4,600 Biological Control Stations. All data collected in recent years for olive fly monitoring is being used to develop an automated analysis of data by artificial intelligence techniques with the objective of predicting the evolution of the percentage of pest damage. In this way, the risk of pest damage can be predicted up to four weeks in advance providing reliable information for decision making.

Post-planting control measures for direct control/management

- Several **cultural practices** may be very useful and can help to prevent, suppress or at least mitigate the development/impact of pests and diseases in olive production. The Focus Group experts emphasised the fact that the use of cultural practices may reduce the need to apply methods and tools for direct control.

- An adequate management of pruning may have huge impact on the incidence and control of pests and pathogens. Although favoring tree aeration through pruning reduces the incidence of some insects and pathogens, it is important to avoid severe wounds and protect the injuries to decrease the incidence of pests and diseases. In addition, pruning the branches which have been attached may help to reduce inoculum of pest and diseases, but it is very important to manage the pruning remains adequately so as not to favour the increase of olive bark beetles or the spread of pathogens (e.g., *V. dahliae*). For example, **Case study N6** describes how in the 'Garden of biodiversity' farm in Sicily, Italy, the branches from pruning (performed within 20 days after the harvest) are left in the field as a trap for the pest *Phloeotribus scarabaeoides,* and once the beetle is found, they are burnt. In **Case study N9**, in the Gkisakis organic olive orchard in Thessaly, Greece, pruning is considered one of the key elements for pest and disease control. Nevertheless, pruning is labour intensive for the farmer and it is costly, however, this may be offset by the reduction of damage by pests, as well as the lower inputs needed for pesticides or fungicides, and the general improvement of the overall health of the orchard. The **Case study N7** 'Azienda Agricola DORA' located in inner Sicily, Italy, describes an additional way to manage pruning remains and obtain extra benefits: all the leftovers from pruning and oil production are recycled as biomass and fertilisers favouring the use of renewable energy.

- Adequate management of irrigation (frequency and doses) may help reduce the incidence of pests and diseases. In the case of soils infected by *V. dahliae* in which a susceptible variety is planted, daily irrigation resulted in greater Verticillium wilt development than plants irrigated weekly, biweekly (with same amount of water), or with deficit irrigation **Case study N11** describes how in several olive orchards in Crete the rational use of irrigation water management and irrigation networks in combination with adequate ground management are very important for management of the olive fly. The experts indicated that sometimes management of irrigation is difficult due to water scarcity, or the allocation of a specific time (days and hours) to the farmer for irrigation.

- The use of **biopesticides** or **biological control** is considered as one of the alternatives for olive pest control that should be reinforced in the future. Viruses, bacteria, and protozoa biopesticides have to be ingested with food, whereas entomopathogenic fungi can enter the insect via the exoskeleton, a mode of action by contact which makes them an attractive alternative to chemicals for the biological control of several olive pests (Quesada-Moraga and Santiago-Álvarez, 2008). The experts indicated that although there are some commercial products available (e.g., *Bacillus thurigiensis* against *Prays oleae*) sometimes more than one strain is commercialised and farmers do not know which one to choose. Furthermore, there is a big knowledge gap concerning the identification of factors affecting its efficacy, which makes it difficult to adopt as a common control approach. Similarly, the experts indicated that use of natural enemies (parasitoids, predators, etc.) was a method with high potential, this includes creating favourable conditions for natural enemies or releasing them. However, there is still a big knowledge gap on how to best maintain sufficient populations in the orchard during cropping season. For all these cases, the experts indicated the need to create a network of experimental plots for testing the effectiveness of biocontrol agents against olive pests and diseases, covering different agro-climatic conditions to guarantee the reliability of results. Finally, most of the experts considered the use of commercial biopesticides or biocontrol agents challenging due to economic constraints, since these products are usually more expensive than normal pesticides.

- Nowadays **natural insecticidal compounds** are being explored to be incorporated in IPM pest and diseases control programmes, since they degrade more quickly and possess a different ecotoxicological profile. An example of this is the inclusion of spinosad that is already used. However, several of the experts indicated that it should be used with caution since resistance to spinosad has been already identified on *B. oleae* populations. Use of mineral oils, kaolin etc. have been proven effective against several olive pests (Pascual et al., 2010), they are effective and affordable. However, sometimes the lack of efficacy is due to: poor canopy coverage, lack of adequate machinery for application, a timeframe to act which is too short, environmental conditions not appropriate. Finally, some secondary metabolites with insecticidal properties produced by entomopathogenic fungi may be developed in the near future as new insecticide molecules of natural origin for pest control (Quesada-Moraga and Santiago-Álvarez, 2008).

- A special group of natural substances - **semiochemical substances** - have a function in communication between organisms, mainly pheromones and other attractants, deterrents, repellents, etc. Semiochemicals are been used in monitoring systems as one of the most effective methods for detection and quantification of pests. Additionally, mass trapping programmes using traps with food baits are also effective to manage and reduce the population levels and pest pressure, keeping them tolerance level. **Case study N4**, describes the Athenoliva project that is focused on finding new attractive and repellent signals that exist between the olive plant and *B. oleae*, and produce them commercially with the aim of obtaining a more targeted control of the olive fly.

- Currently, the control of several olive pests (e.g., *B. oleae, P. oleae*) and some foliar diseases (e.g., *Collecotricum* spp., *Spilocea oleagina*) are still based on the use of **chemical pesticides**. The experts specifically pointed out the fact that these pesticides are still applied in many olive growing areas following 'rotas' (calendar-based pest control) rather than based on monitoring or forecasting systems. This is a fact both for traditional and intensively managed Mediterranean olive plantations and is still preferred in certain areas because it has been used for decades and does not require specific observations or knowledge. The experts also indicated the need to promote and implement more forecasting systems and DSS to guide farmers in the efficient implementation of the use of treatments. The increase of public sensitivity towards environmental pollution and problems derived from the side effects of these products, as well as EU policies, have contributed to a reduction in the number of authorised active ingredients for olive pest and disease control. Therefore, the sustainable use of pesticides based on a better application schemes in time, space and doses, and the use of mainly non-chemical alternatives following Integrated Pest Management (IPM) approaches will be the future of sustainable control of olive pests and diseases (Fernández-Escobar et al., 2013).

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Agro-ecological principles and functional biodiversity

Biodiversity maintenance and enhancement of the associated ecosystem services provided is an objective of the European Union, implemented through different agri-environmental programmes including the Common Agricultural Policy. Consequently, one of the main discussion points within the Focus Group was about the role that functional biodiversity and agro-ecological principles may have on olive pests and diseases.

The conservation and management of biodiversity in agricultural ecosystems is often considered within the so-called 'agroecological approach' in agriculture. **Agro-ecology** applies ecological principles to the design and management of biodiverse, productive and resilient farming systems and defines, classifies and studies agricultural systems from an ecological, as well as socio-economic perspective. **Functional biodiversity** can be defined as the biotic components (at the gene, species or habitat level) that stimulate the ecological processes driving the agroecosystem and that provide the ecosystem services (Moonen and Bàrberi, 2008; Gkisakis et al., 2018). For the olive crop, functional biodiversity includes the microorganisms, insects, flora, etc., present and living in the soil and in the tree, whose growth and survival is affected by the orchard management (pesticide use, irrigation, soil tillage, etc.).

One good example of the use of agro-ecological principles and functional biodiversity to manage olive pests is presented in **Case study N16**. This Case study describes how research efforts for controlling *B. oleae,* the key pest of the olive tree in the Trás-os-Montes region in Portugal, are focussing on developing environmentally friendly methods based on conservation biological control strategies through improvement of the community of natural enemies of the pest, which is usually diverse in the crop. Aspects such as the conservation of a heterogeneous agricultural landscape are seen as part of this strategy that will promote biodiversity and ecosystem services in olive groves. Thus, the presence of adjacent seminatural areas, microhabitats (e.g. hedgerows, stone-walls, and stones on the ground), and spontaneous vegetation may increase the number of shelters, and provide valuable supplementary food resources for the natural enemies of the pest.

Research and policies aimed at biodiversity conservation in agricultural ecosystems are often less successful than expected. The experts agreed that more research is needed to develop improved measures and indicators of biodiversity, specifically for olive crops. In general, although it is assumed that the promotion of functional biodiversity can help to create a more resilient olive cropping system, as it can help to both prevent and fight pests and diseases, the experts noted that there is often a lack of understanding of how functional biodiversity works. Some of the main points addressed included:

- **Specificity of agro-ecological principles:** Each olive orchard is different, with huge differences among olive regions and cropping systems. Consequently, agro-ecological principles should be site or location specifically applied.
- **Green infrastructure**: Include the use of hedgerows, stone walls, field margins, shelters, etc. The experts agreed that although there are positive effects such as preventing erosion, it is not sufficiently clear what role these features play for controlling olive pests and diseases. Olive growers could take advantage of existing CAP greening elements to promote the diversification of the landscape in areas where large-scale olive cultivation takes place, maintaining linear elements (hedges, stone walls, etc.), and areas of natural vegetation, such as Mediterranean scrublands. This has potential to positively impact tourism activities in the areas concerned. However, there is a lack of practical advice to farmers on how to implement it (Ortega and Pascual, 2014).
- **Cover crops**: They are mainly used for preventing soil erosion, but there is insufficient knowledge on their potential impact on olive pests and diseases. They can also enhance soil biodiversity and create habitats for natural enemies of some pests. However, care should be taken since some plant species may have antagonistic effects for pathogens (e.g., Brassica/*V. dahliae*), whereas others can be pathogen hosts (e.g., *V. dahliae*) or of the vectors transmitting them (e.g., *X. fastidiosa*). There is a lack of knowledge on the use of species mixtures, they are difficult to maintain, especially during the summer, and may compete for water under water scarcity or drought. Sown cover crops also represent an additional cost for farmers.
- **Cooperation between farmers and administration**: There is a need to exchange and improve the existing knowledge with farmers on the impact of maintaining biodiversity in agroecosystems as a key factor

for improving its impact. The experts indicated that experimental farms where the methodology has been/can be applied for a period of time and where farmers and consultants can learn the impact of increasing biodiversity on pest control would be very useful.

- **Indicators to measure biodiversity and its effect:** The development of reliable measurable indicators is a crucial factor to translate scientific knowledge to farmers. However, these indicators should be easy and cheap to collect and analyse, giving some conclusions of the biodiversity and its possible impact on farms relatively rapidly.
- **The increase in biological diversity does not always lead to an increase in functional diversity:** because several studies on parasitoids are showing that some species considered polyphagous are instead complex of mono or oligophagous cryptic species.

Finally, the experts agreed that the main challenge is to establish general rules to explain how biodiversity may affect pests and diseases control in the olive agroecosystem, as well as the way to adapt practices to promote biodiversity to the specific local conditions of each olive orchard and cropping system. Taking into account the importance of biodiversity generally, not only for biological control, green infrastructures and agro-ecological principles are important. These can contribute to promote functional biodiversity in the olive orchards.

Main pests and diseases affecting olive crop

The Focus Group experts discussed which pests and diseases are currently the most relevant for EU olive production (**Annex C**) and selected a few of them to discuss in detail. The following data sheets summarise the experts' opinions and experiences including the most sustainable management approaches.

Overview of symbols

Regions/countries where it is reported as problematic

Climatic conditions that lead to higher impact

General information

Soil and location conditions that lead to higher impact

Olive management practices that lead to higher impact/risk

Focus Group recommendations for Integrated Pest Management

Olive fly
Bactrocera oleae

All countries

Mild summers with temperatures <36ºC, mild winters and autumns, allowing higher pupae survival and activity for longer periods, respectively

Non-tilled soils favours pupae survival in winter

Late harvesting favours autumn generation that will rise next year generation increase

The main damaging olive pest in the Mediterranean Basin. This insect has several generations per year (normally from 2 to 4, but up to 6 depending of the prevailing temperature and availability of fruits). The female can lay up to 20 eggs/day on the fruits, producing several hundred eggs during her lifespan. Fruits are damaged by the egg lay. The larvae feed within the fruit mesocarp damaging it, and diminishing its quality. It also can induce premature fruit ripen or fall and a loss of oil quality, or complete loss of damaged fruits for table olives. Infestation can be severe enough to induce 100% fruit drop in years of low yield.

- Soil tillage after harvesting and keeping orchards clear of fallen fruits to reduce overwintering population in soil
- Some cover crops or specific plants (e.g., *Dittrichia viscosa, Capparis spinosa*) and natural hedges favour establishment of parasitoids.
- Excess of nitrogen fertilisation induces a denser canopy that can induce a more favourable microclimate
- Irrigation can induce a more favourable microclimate especially in summer, use drip irrigation or underground systems
- Use of tolerant varieties
- Mass trapping with attractants (food baits or pheromones) combined with insecticides
- Effective timely application of spinosad (used as spintorfly sprayed only on a little part of olive trees) causes less impact on non-target fauna
- Mass release of reared parasitoids
- Field monitoring to treat with insecticides only over the economic threshold

Picture credits: Arambourg, A. (INRA); http://ephytia.inra.fr/

Olive moth
Prays oleae

All countries

Mild summers with temperatures <30ºC

Lack of soil vegetation coverage decrease natural enemies of *P. oleae*

Lower number of flowers buds may result on a decrease in fruit numbers

Widespread through the Mediterranean Basin. The second main olive pests of in the EU. Can complete three generations per year on the olive tree, causing damage to flowers, leaves and fruits. Larvae of the first generation (anthophagous) attacks the flowers, the larvae feed initially on the anthers and ovaries damaging several flowers (up to 90%). In the second generation (carpophagous), the most damaging, the eggs are laid on the calyx of a young fruit; the larvae enter the fruit endocarp, dehydrating the fruit and making it drop, or inducing a loss of oil quality, causing severe losses. The third generation (phyllophagous) feeds on the leaves, boring mines like a leaf miner during the first larval instars.

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- Monitoring of populations with traps (with pheromones) to establish threshold levels for treatments
- Use of general pesticides after good estimation of threshold levels (pyrethroids)
- Use of Biological control (e.g., *Bacillus thuringiensis*) mainly in organic production and anthophagous population.
- Use of more specific pesticides, trying to avoid targeting natural enemies.
- Increase natural populations of enemies (parasitoids, predators) using permanent cover and flower strips
- Use of mating disruption control (so far only has been experimentally tested in Portugal and Greece)
- Release of predators (chrysopids), but it is expensive.

Picture credits: Arambourg, A. (INRA); http://ephytia.inra.fr/

Black scale *Saissetia oleae*

All countries

Mild summers increase survival of crawlers

Soils without cover crops reduces populations of natural enemies

Excess of nitrogen fertilization induce many new shoots facilitating neonate nymphs find suitable settlements

Widespread through the Mediterranean Basin. Usually, one complete generation per year, although a second generation (normally incomplete) may occur per year. Females lay 1000-2000 eggs under their own shells. Direct attacks of leaves and twigs (by sap sucking), resulting in leaf drop, reduced tree vigour and twig dieback in severe infestations. Main damage is due to indirect attacks by the secretion of very large amounts of honeydew that is colonised by sooty mould fungi, covering fruits and leaves in a thick black mass. As a result, leaves drop, fruit may be reduced in quality and twigs dry up.

- Sprays should be directed at crawlers and young nymph stages
- Increase natural populations of enemies (parasitoids, predators) using permanent cover and flower strips
- Good pruning helping canopy aeration enhancing nymph mortality in the summer, but not too drastic to favour excessive new shoots
- Use of certified plant material to avoid introducing infected plants
- Use of mineral oil at right time is effective and affordable (mainly for first and second stages of development)

Picture credits: Coutin, R. (INRA); http://ephytia.inra.fr/

Olive scale *Parlatoria oleae*

All countries

Mild summers increase survival of crawlers

Soils without cover crops reduces populations of natural enemies

Dense tree canopy favour protection of adults in summer

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Widespread through the Mediterranean Basin. Up to two generations may occur per year. Scales infest leaves and twigs and, sometimes, fruit. No honeydew or associated ants or sooty mould occurs. Can cause fruit marking or pitting and scale-encrusted fruit. Leaf fall and twig dieback can occur in severe infestations.

- Sprays should be directed at crawlers and young nymph stages
- Local application of insecticides (summer oils) after sampling and checking the presence of young females
- Increase natural populations of enemies (parasitoids, predators) using permanent cover and flower strips.
- Good pruning helps canopy aeration enhancing mortality in summer, but not too drastic to favour excessive new shoots
- Use of certified plant material to avoid introducing infected plants
- Good management of nitrogen fertilisation
- Release of parasitoids or predators (some are not available)

Picture credits: Manuel Ruiz Torres, Laboratorio de Producción y Sanidad Vegetal, Jaén, Spain.

Verticillium wilt
Verticillium dahliae

Most countries

Mild summers and autumns favours symptom development

Tilled soils favour inoculum movement

Movement of machinery from infected areas introduce the pathogen in inoculum-free areas with soil particles

Widespread through the Mediterranean Basin. The main soilborne fungal disease of olive. The disease was unknown 30 years ago. Nowadays is considered the main challenge for olive growing in the Mediterranean regions due to a defoliating pathotype of the pathogen: it is highly virulent over some cultivars resistant to the non-defoliating pathotype. Causes high reduction of yields and tree mortality. It needs lower inoculum threshold in the soil to cause severe epidemics. Efficient dispersion within and among olive orchards in production areas thorough infected leaves and infested irrigation water.

- Use of certified plant material
- Use of appropriate species of cover crops (e.g., *Sinapis alba* ssp. *mairei, Brassica carinata*) (some may increase inoculum in soil such as *Portulaca, Xanthium, Amaranthus, Chenopodium*)
- Use of tolerant/resistant varieties or rootstocks with resistance
- Soil solarisation of soil after removal an infected tree and replacing it with a tolerant variety
- Removal of leaves falling from infected trees (especially if infected with the defoliating pathotype)
- Use of drip irrigation to avoid inoculum movement and a good planning of irrigation (frequency and doses)
- Balanced nitrogen fertilisation (Not excessive)

Picture credits: Juan A. Navas Cortés, Instituto de Agricultura Sostenible, CSIC, Spain.

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Scab-peacock spot
Venturia oleagina

All countries

High humidity and rain

Non tillage favours prevalence of inoculum on leaves

Avoiding spring treatments when inoculum level is high

Widespread through the Mediterranean Basin. A fungal disease. Spots of 2-10mm in diameter mainly on the upper surface of the leaf, and occasionally on the stems and fruits. Affects mainly the photosynthetic efficiency of the plant. Severe infection causes defoliation, which kills the new wood, and reduces production in the following year. Young leaves may remain symptomless for months favored by high humidity and rain.

- Use of tolerant/resistant varieties
- Good pruning helping canopy aeration, broad tree spacing
- Balanced nitrogen fertilisation (not excessive)
- Use of drip irrigation or underground systems
- Effective timely application of fungicides (mainly copper) based on risk models (under development). However, there is a need to reduce copper doses (i.e., since the beginning of 2019

  EU authorities reduced the maximum applicable dose of copper from 6kg to 4kg/ha per year or a maximum of 28kg/ha in 7 years)
- Removing leaves from the soil to reduce inoculum pressure

Picture credits: Manuel Ruiz Torres, Laboratorio de Producción y Sanidad Vegetal, Jaén, Spain.

Anthracnose
Collecotricum spp.

All countries

Humid climate, mild and rainy autumns

Not described

Late harvesting favours autumn generation that will increase next year generation increase

Widespread through the Mediterranean Basin. Main disease of olive fruits. Endemic in some areas (e.g., Spain, Southern Portugal and several regions of Italy). Caused by several cryptic species. Develops during fruit development and ripening. Can have several disease cycles per year. Also causes leaf necrosis, branch dieback, and defoliation (toxins). Reduces plant productivity (estimated at >75m€) and quality of olive oil.

- Use of tolerant/resistant varieties
- Good pruning helping canopy aeration, broad tree spacing
- Removal of mummified fruits and affected branches
- Early harvesting
- Use of preventive chemical treatments (mainly copper); however, there is a need to reduce copper doses as indicated above
- Use drip irrigation or underground systems
- Need to develop risk models

Picture credits: Juana Páez, Laboratorio de Producción y Sanidad Vegetal, Sevilla, Spain.

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Tuberculosis/Olive knot *Pseudomonas savastanoi* pv. *savastanoi*

All countries

Humid climate, mild temperatures

Not described

Harvesting causing branch injuries

Widespread through the Mediterranean Basin. Olive knot is present wherever olives are grown; although losses are difficult to assess. Causes aerial tumours instead of the foliar necroses and cankers characteristics. Symptoms of infected trees include hyperplastic growths (tumorous galls or knots) on the stems and branches of the host plant and, occasionally, on leaves and fruits.

- Use of tolerant/resistant varieties
- Use of certified plant material free of inoculum
- Removal of affected branches
- Avoid causing injuries during harvesting and avoid harvesting when branches are wet
- Use of preventive chemical treatments (mainly copper); however there is a need to reduce copper doses as indicated above

Picture credits: Juan A. Navas Cortés, Instituto de Agricultura Sostenible, CSIC, Spain.

5. Impact of climate change on olive pest and diseases and potential adaptation strategies

The Mediterranean basin is the largest area in the World which has the specific climatic conditions for olive cultivation, but this region might be particularly affected by climate change, which could have extensive impacts on ecosystems and agricultural production. In the Mediterranean region, temperatures are projected to rise more that the global average temperature increase, while precipitation is expected to decrease substantially, and interannual variability will increase. A pronounced decrease in precipitation over the Mediterranean is expected, except for the northern areas in winter (Giorgi and Lionello, 2008). Climate change has already begun to manifest in some Mediterranean areas, where temperatures are rising and rainfall declining, and extreme rainfall events are also becoming more frequent (IPCC WGII, 2007).

There are only a few research studies focusing on the analysis of the effects of climate change on the olive agrosystem including the development of pest and diseases. However, even if there are no clear figures, the overall forecast (Graniti et al., 2011; Ponti et al., 2014) is the following:

- The potentially cultivable areas for olive growth are expected to extend northward and at higher altitudes, which could produce a change in the pests and diseases causing problematic situations.
- The olive flowering is likely to happen earlier while inflorescence emergence is delayed; consequently, the pests and pathogens that feed or develop on flowers and fruits will be affected by those phenological changes.
- Changes in temperatures, CO_2 concentration and rainfall will modify the geographical distribution of some widespread fungal and bacterial diseases and pests enabling certain pathogens and pests to survive outside their usual ranges.
- Changes in temperatures, CO_2 concentration and rainfall will induce changes in the biological cycles of pests and diseases.
- The increased difficulty in forecasting due to extreme variation in climatic conditions will make the development of pests and diseases more unpredictable, and consequently more difficult to control.
- Abiotic olive diseases associated with the occurrence of extreme values of environmental factors are expected to increase in their incidence as a consequence of the impact of climate change (Graniti et al., 2011).

The experts agreed during their discussions that climate change is expected to affect the geographical and spatial distribution of olive pests and pathogens and that the incidence and severity of **infectious diseases and pest** attacks will be modified. However, currently it is very difficult to predict such consequences, as they are the results of complex interactions between the specific pathogen or pest, the olive variety, and the specific environment (climate, agronomic practices, etc.). Thus, the life cycle (survival, reproduction, dispersal, infection) of a given pathogen or pest, and their specific relations with the host can be affected in very different ways, and cannot be generalised until new knowledge is gained. Consequently, further research efforts are needed in this regard.

Nevertheless, the Focus Group experts were asked to think of their own personal experience as farmers, scientists, farmer consultants, etc. about the potential effect of climate change on olive pests and diseases:

- Have you perceived some change(s) due to factors associated to climate change (increase in mean temperature, shorter cold periods, less or more erratic rainfall, etc.) in your region?
- Have these changes brought/will they lead to consequences on olive pests and diseases development or their control?

Interestingly, all of the Focus Group experts gave examples for the olive fly, *B. oleae*. The experts provided these examples and insights as the most important:

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Country	Region	Change observed	Consequences for pests/diseases
Italy	Central	• Fewer days of frost • Hotter and drier summers • Exploring new areas for olive crops (e.g., Alpine range)	• Improve the chance of survival of olive fly in winter • Reduce the intensity of fly attacks in summer • Unknown
	South (Campania)	• Very high summer temperatures • Milder winter temperatures • Olive crop is exploring new areas (Higher altitudes)	• Decrease of fly attacks in summer • Reduction of winter mortality pupae and prolonged cycle • Increase of attacks next season due to an increase of olive flies that overwinter
	Sicily	• Some microclimate change to more 'tropical' weather with several afternoon rains	• Increase spread and population levels of olive fly
Spain	South-East (Hellín)	• Less and more erratic rainfall • Changes in the number of days with frost and the month occurring • Warmer maximum temperatures in winter	• Changes in olive phenology (mainly sprouting) • Unknown effect of pests and diseases
	North-East (Catalonia)	• Increase in temperatures in summer • Less or more erratic rainfall • Early flowering • Shorter periods of cold, warmer and less rainy autumns	• More damage of olive fly in warmer autumns
	Central	• A general increase of temperatures all year round (specially in Autumn)	• Extension of the activity period of olive fly adults and prolonged damage • Higher survival of pupae overwintering in soil • Lower survival of adults and especially immature stages in summer
France	South (PACA and Occitanie)	• Higher temperature increase in summer	• A decrease in the number of olive flies and appearing later in summer, as compared to normal flight curves
Portugal	Alentejo	• Fewer rainy days, especially in rainy months (April & November) • Fewer days with frost and warmer minimum temperature in winter than usual • Spring season is shorter and maximum summer temperatures are warmer than usual • Flowering is delayed and lasts longer	• Olive trees are water stressed • Olive fly will be affected by all these changes: Time of action in late summer will be longer and warmer winters will facilitate survival of pupae. • Extreme hot weather in summer resulted in lower infestation levels likely due to death of immature stages

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A significant limitation to assess the impact of climate change on olive pests and diseases is the uncertainty in predicting how technological and economic forces will shape olive cultivation in the future. Potentially, successful **adaptation to climate change** may involve significant changes of current agricultural systems, some of which may be costly and unaffordable, especially for traditional olive farming. Irrigation, fertilisation, pruning, soil management and plant variety and density are practices that may have major effects on both the spectrum and relative importance of the pests and diseases affecting olive trees in the near future and can also be used as adaptation strategies to counteract some effects due to climate change (Graniti et al., 2013). There will probably be a need for investment in new technologies and infrastructures, and new irrigation systems may be required to counteract aridity or precipitation instability. Selection of or replacement by new olive varieties more adapted to aridity or with differences in phenology (flowering to fruit maturation) to diminish the effect of pests and diseases will be needed. Finally, change in timing and doses for application of some chemical or biological products may be needed, since rainfall intensity and timing and temperature may affect persistence and effectiveness or induce degradation of plant protection products.

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6. Recommendations

Taking into consideration the main challenges and bottlenecks in the protection of olive crop against pests and diseases, the experts listed a set of recommendations for:

- Innovation projects that can be implemented at local level through **Operational Groups**, to make use of the knowledge and skills already available but often underexploited.
- **Research projects**, on topics where the available knowledge is still missing and where research efforts should be focus.

Ideas for local Innovation Projects and EIP-AGRI Operational Groups

- The proposed topics and contents recommended by the experts for Operational Groups are:
- *Harmonisation of pest/pathogen monitoring techniques and development of new systems/approaches of monitoring:* Significant efforts on the development and adoption of monitoring techniques have been made mainly for the olive fly, but there is still a lack of such systems for other pests and none for olive pathogens. The development and adoption of new technologies based on the Internet of Things, and different field sensors, could allow the automatic, remote, massive and real time detection of the presence of olive pests and diseases. This should be accompanied by data processing systems that will determine if the conditions for application of control strategies have been reached.
- *Optimisation of cover crops:* Selection of species composition and best methods to favour the establishment of cover crops, as well as development of adequate equipment, etc., are needed to favour use of cover crops in olive plantations with the aim of enhancing biodiversity and preventing soil erosion. Ecological and socio-economic variables should also be measured and knowledge transfer and field networks established to ensure its promotion and maintenance.
- *Quantification of the effect of agro-ecological principles/green infrastructure on pest and disease control:* Establish experimental farms and field networks for testing and monitoring the effect of agro-ecological principles oriented to pests/diseases control. Perform biodiversity assessment and field monitoring of the entomological diversity, focusing on natural pest enemies (predators and parasitoids), measure crop damage, yield and quality of harvest to establish relationships among all factors measured.
- *Increase the knowledge of farmers/stakeholders on use of agro-ecological principles oriented to pests/diseases control:* This can be combined with the establishment of field networks, diffusion activities, demonstrative fields, leaflets, etc. The idea is to make farmers aware of the potential benefits of adopting agro-ecological principles in their orchards.
- *Experimental and demonstration farms and field networks for testing BCAs for disease control:* Perform field assays to test biocontrol agents (BCAs) of olive pathogens under different pedo-climatic areas by establishing a network of experimental plots. This may help to estimate optimal conditions to maximise biocontrol effectivity when using harmonised application protocols.
- *Introduction of use of big data and artificial intelligence to help in decision-making for treatment application:* The idea is the acquisition of information from farmers on pest and pathogen populations and damage/yield losses to be analysed by machine learning tools with the aim of developing models to develop forecasting systems for main olive pests and diseases to help farmers and advisers to decide the best moment for application of control measures.
- *Local/regional collection of olive germplasm and knowledge for pests and diseases management:* Although there are currently several olive germplasm collections, the idea is to collect local varieties potentially not included yet on this repositories, or spontaneous mutations and new lines that farmers can identify as interesting to stablish an European collection. In parallel, it would be desirable to record/capture the traditional management practices applied for decades for olive pests and disease control to document and preserve farmer's knowledge.

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Research needs from practice

- The proposed topics and contents recommended by the experts for research needs were:
- *Effect of Climate Change on olive pests and pathogens*: The main aim is to assess or predict the potential effect of climatic change on the distribution and incidence of olive pests and pathogens, as well as the effect on the effectivity of the management strategies to control them. These studies should be conducted mainly under controlled conditions at growth chamber or greenhouse level. The use epidemiological models can help to predict and extrapolate this information at field scale. This will help in the modification or adaptation of the different management strategies accordingly with the new patterns of pathogen/pest attacks.
- *Development of new systems for pests and diseases monitoring:* Specifically making use of new technologies (IT tools and Internet of Things technologies) and estimation of pest and pathogen damage thresholds more accurately as well as the treatment doses for controlling them.
- *Development of new biotechnological phytosanitary tools (semiochemicals, attractants, deterrents, repellents, etc.) to control olive pests*: Search for new semiochemicals and other substances that could be applied to the control of pests in the olive tree to increase its use in IPM programmes. Formulation, synthesis process, application equipment, and cost/benefit studies should be conducted in parallel.
- *Optimisation of cover crops:* There are still knowledge gaps concerning selection of species composition for different agro-climatic areas and the most suitable plant species to promote functional diversity. It is also necessary to optimie the agronomic practices applied to the management of the covers to favor their efficiency, establishment, and avoid competition by water with the olive tree. Finally, it is needed to estimate cost/feasibility of cover crop establishment/improvement and the associated benefits (ecosystem services) provided after its implementation.
- *Quantification of the effect of agro-ecological principles/green infrastructure on pest and disease control*: It is necessary to develop research to gain a better understanding on how enhancement of the functional biodiversity can affect potential natural enemies of the key pest of the olive tree, in order to develop tools for conserving and enhancing the performance of the resident predators and parasitoids in the olive orchard agroecosystem.
- *Perform field assays to test BCAs of olive pathogens under different environmental conditions (estimate optimal conditions to maximise effectivity)*: Research is needed focused on conducting biocontrol tests in the field or in conditions similar to those prevailing under natural field conditions to achieve a better understanding of the interactions that take place among the olive tree, the pathogen, the biological control agent and the environment. The aim is to determine the main factors influencing the biocontrol efficacy of selected biological control agents against the main pests and diseases of the olive tree.
- *Search for new BCAs:* There is a need to identify and isolate BCAs from new niches, adapted to different environments that can expand the few BCAs currently available commercially. Also, studies should be conducted to determine their potential application in combination with chemicals or other microorganism (establish microbial consortia).

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Annex A: Members of the EIP-AGRI Focus Group

Name of the expert	Profession	Country
Ricardo Alarcón Roldán	Civil servant	Spain
Belén Álvarez	Researcher	Spain
Umberto Bernardo	Researcher	Italy
António Brito	Farmer	Portugal
Marion Canale	Other	France
Willy Couanon	Advisor	France
Vincenza Ferrara	Farmer	Italy
Vasileios Gkisakis	Researcher	Greece
Ana Gouveia	Farmer	Portugal
Emmanouil Kabourakis	Researcher	Greece
María Teresa Martínez Ferrer	Researcher	Spain
Panagiotis Milonas	Researcher	Greece
Franco Nigro	Researcher	Italy
Tania Nobre	Researcher	Portugal
Juan Olivares	Advisor	Spain
Susana Pascual	Researcher	Spain
Sónia Santos	Researcher	Portugal
Fabio Tinelli Roncalli	Farmer	Italy
François Warlop	Researcher	France
Facilitation team		
Blanca Landa Del Castillo	Coordinating expert	Spain
Sergiu Didicescu,	Task manager	Romania
Andrés M.García Lamparte,	Backup manager	Spain

You can contact Focus Group members through the online EIP-AGRI Network.
Only registered users can access this area. If you already have an account, you can log in here
If you want to become part of the EIP-AGRI Network, please register to the website through this link

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Annex B: List of mini-papers prepared by experts

All mini-papers can be downloaded from the **'Pests and diseases of the olive tree' Focus Group page** on the EIP-AGRI website

Minipaper topic	**Coordinator**	**Contributors**
Effect of crop intensification on olive pests and diseases	Ricardo Alarcón Roldán	Antonio Brito
Socio-economic and ecological sustainability of traditional olive groves	Ana Carla Gouveia	Vincenza Ferrara, François Warlop, Sónia Santos, Fabio Roncalli, Emmanouil Kabourakis
Biocontrol agents and cropping systems to control olive diseases	Belén Álvarez,	Willy Couanon, Juan Olivares, Franco Nigro
Biological and Biotechnical methods for olive pest control	Marion Canale	Umberto Bernardo, Panagiotis Milonas, Sónia Santos
Biodiversity and pest management	Susana Pascual	María Teresa Martínez Ferrer, Tânia Nobre, Vasileios Gkisakis, François Warlop, Juan Olivares

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Annex C: Major olive pests and diseases in the Mediterranean Basin

Pest type	Scientific name	Common name	Importance[1]
Insects	*Prays oleae*	Olive moth	**
	Bactrocera oleae	Olive fly	**
	Saissetia oleae	Black scale	**
	Aspidiotus nerii	Oleander scale	*
	Phloeotribus scarabeoides	Olive bark beetle	*
	Hylesinus toranio	Ash bark beetle/Olive borer	*
	Euzophera pinguis	Pyralid moth	*
	Zeuzera pyrina	Leopard moth	
	Palpita vitrealis	Jasmine moth	
	Lepidosaphes ulmi	Oyster-shell scale	
	Parlatoria oleae	Olive Parlatoria scale	
	Euphyllura olivina	Olive psyllid	
	Otiorhynchus cribricollis	Olive weevil	
	Melolontha spp./Ceramida spp.	White worms	
	Liothrips oleae	Olive thrips	
	Resseliella oleisuga	Olive bark midge	
	Cicada spp.	Cicada	
	Dasineura oleae	Olive leaf gall midge	
	Rhynchites cribripennis		
Mites	*Aceria oleae*	Eriophyid mites	*
Pathogens	*Xylella fastidiosa*	Olive quick decline syndrom	***
	Pseudomonas savastanoi pv. savastanoi	Olive knot/tuberculosis	*
	Verticillium dahliae	Verticillium wilt	***
	Fusicladium oleaginum (tel. *Venturia oleagina*)	Olive leaf spot/peacock spot	**
	Colletotricum spp.	Anthracnose	*
	Pseudocercospora cladosporioides	Cercospora leaf spot	*
	Martamyces panizzei	Infectious leaf scorch	
	Cladosporium herbarium, Limacinula oleae, Alternaria tenuis, Aureobasidium pullulans, Capnodium elaeophilum	Sooty mold	
	Botryosphaeria dothidea	Dalmatian disease	
	Phlyctema vagabunda (tel. *Neofabrea alba*)	Leprosy, cylindrosporiosis	
	Alternaria, Aspergillus, Cladosporium, Diplodia, Geotrichum, Fusarium, Phomopsis, Neofusicoccum spp.	Other fruit rots	
	Neofusicoccum spp., *Eutipa lata, Phoma incompta, Diplodia* spp.	Cankers (wilting)	
	Lecythophora lignicola, Pleurostomophora richardsiae, P. cava, Phaeoacremonium spp.	Emerging tracheomycotic diseases	*

	Fomes, Fomitiporia, Stereum	Wood decay	
	Armillariella mellea, Rosellinia necatrix, Dactylonectria spp.	Woody root rots, , crown rots, foot rot	***
	Phytophthota, Cylindrocarpon, Fusarium, Pythium spp.	Fine root rots	*
	Nepovirus, Cucumovirus, Oleavirus	Yellowing, malformations	
	Meloidogyne spp.	Root knot	*
	Pratylenchus spp.	Root lession	

[1] Importance: As reviewed in the literature and ratified by experts of the Focus Group.

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AGRICULTURE & INNOVATION

The European Innovation Partnership 'Agricultural Productivity and Sustainability' (EIP-AGRI) is one of five EIPs launched by the European Commission 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:

1. the EU Research and Innovation framework, Horizon 2020,
2. 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:

2. to take stock of the state of play of practice and research in its field, listing problems and opportunities;
3. to identify needs from practice and propose directions for further research;
4. 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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