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AGRICULTURE & INNOVATION

EIP-AGRI Focus Group

Pests and diseases of the olive tree

STARTING PAPER

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1. INTRODUCTION: PURPOSE, GOALS AND TASKS OF THE FOCUS GROUP

The general aim of a Focus Group is to explore the potential for making effective use of a new policy instrument – the European Innovation Partnership for Agricultural Productivity and Sustainability (EIP-AGRI) – for building a bridge between farmers and researchers. EIP-AGRI Focus Groups collect and summarize knowledge on best practices in a specific field, listing problems as well as opportunities, take stock of the state of play in research and practice, and highlight possible solutions to the problems identified. Based on this, the EIP-AGRI Focus Groups suggest and prioritize innovative actions, identify ideas for applied research and for testing solutions in the field, involving farmers, researchers, advisers, the industry and other practitioners, and propose ways to disseminate good practices.

The purpose of this discussion paper supporting the first meeting of the EIP-AGRI Focus Group on “Pests and diseases of the olive tree” is to:

1. Establish a common understanding about the purpose and scope of the Focus Group.
2. Identify some preliminary points of discussion for the first meeting of the Focus Group, including:
 - Recognizing and understanding the nature of the main pests and diseases of olive
 - Tackling the whole cycle of olive pests and diseases including their prevention, detection, management and control.
 - Understanding the interactions between olive crop, environment and the pests and pathogens, and how they can be modified by climate change.
 - Identifying more sustainable farming practices, including the use of non-chemical pesticides.
3. Begin drawing together some relevant thoughts/materials as a preliminary basis for the Focus Group Final Report.

The focus groups will address the question: *How to increase the sustainability of olive growing, taking into account the risks brought by pests and diseases?*

The specific objectives of the focus groups are:

- **Make an inventory of the main pests and diseases affecting the olive tree**, including their geographical distribution and economic impact.
- **Summarize, 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 strategies and organic olive production. The Focus Group should take 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.

The Focus Group will start addressing the first four tasks, mostly focusing and in the identifications and description of strategies or practices. The remaining tasks, mostly around exploring new potential solutions and improving its adoption, will be addressed after the first Focus Group meeting. Overall, the members of the Focus Group are expected to favour/encourage out-of-the-box thinking in which new solutions, inter-linkages and approaches can flourish. This may include tacit knowledge, rediscovering and exchanging information on old and traditional solutions while at the same time developing innovative ways of keeping these valuable traditional systems alive.

2. OLIVE CROP AND CULTIVATION

2.1. Introduction: Main characteristics of the olive crop

Olive (*Olea europaea* L.) is a long-lived drought-tolerant species limited by frost and high temperatures, and to a lesser extent by soil fertility and water. Although cultivated almost exclusively in Mediterranean climatic conditions, olive orchards can be found under very different rainfall conditions, from the fringe of the desert in very marginal areas to more humid climates. Temperatures < -8.0 °C damage olive and limit its northward distribution, whereas annual rainfall < 350 mm per year limits its distribution in arid regions.

Olive production varies greatly and depends on the alternate bearing cycle of the olive tree (a good harvest followed by a poor one), farming methods (use of irrigation, fertilization), olive varieties, the soil (fertility, texture, etc.) and climate conditions (temperature, rainfall, etc.). Olive trees can grow in poor, stony soil where it would be difficult to grow other crops. Consequently, they play an important environmental role (fixing soils, biodiversity). The peak in activity occurs in Autumn, which makes it compatible with other agricultural and non-agricultural activities. Traditional olive-growing is labour intensive during particular periods of the year providing many partial-time employments, representing an important part of the heritage and socio-cultural life across Mediterranean rural areas.

Traditionally olive groves in the Mediterranean were associated with high biodiversity, being an example of a 'high natural value' agricultural system with important environmental role. This was possible due to low-intensity olive farming systems (i.e. low use of agrochemicals and low degree of mechanization), old olive trees with semi-natural herbaceous vegetation and their location in areas with different land uses. However, in recent years this ecological value has diminished due to the 'modernization' of olive grove farming which has been based on the expansion of olive grove area, resulting in olive monoculture systems in Europe such as large areas of Andalusia, and on the intensification of the olive farming systems (intensive use of fertilizers, pesticides and machinery).

2.2. Why olive is such an important crop for the European Union?

Olive has probably been in cultivation longer than any other tree species. It was domesticated around 3000 to 4000 BC in the eastern Mediterranean and from there was spread widely in northern Africa, the Iberian Peninsula, and the rest of southern Europe by civilizations that successively occupied the region.

Nowadays, over 750 million olive trees are cultivated worldwide, 95-97% of which are in the Mediterranean region (IOC, www.internationaloliveoil.org/). Historically, the cultivated olive has been culturally and economically the main oleaginous crop in the Mediterranean Basin, where circa 9.5 million ha of olives are grown, accounting for 95% of the cultivated olive area 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 cultivation area of olive is located in Asia, 0.8% in the Americas, and 0.01% in Oceania (FAOSTATS, 2018; Rossi, 2017).

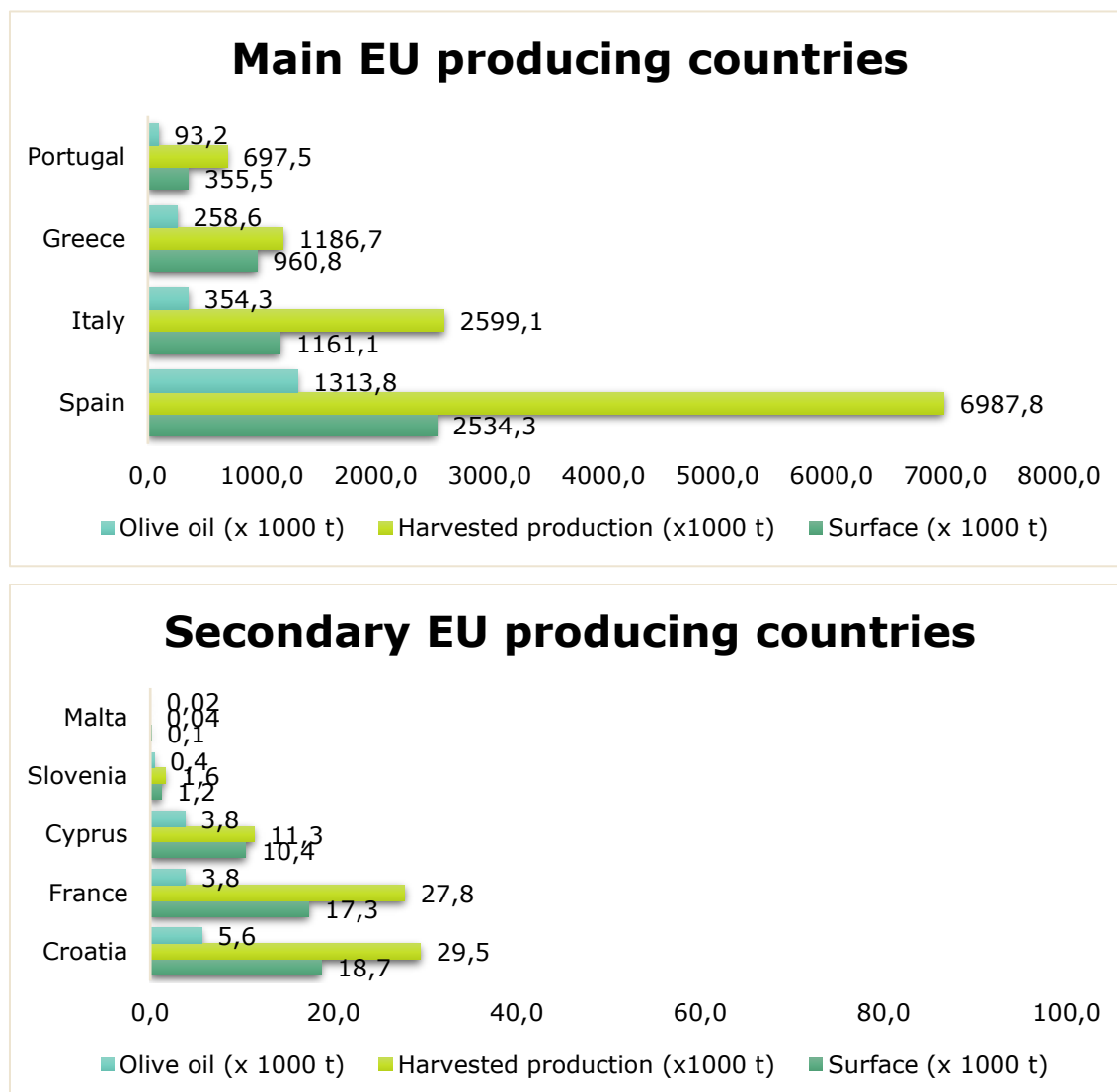


Figure 1. Yield production (average 2016-2018) and surface area (average 2016-2018) of olive crops and oil production (average 2015-2017) in the main and secondary EU producing countries (Source: EUROSTAT and IOC).

Olive crop is a primary element in the agricultural economy of the European Union's southern countries, with about 5 million hectares of plantations accounting for 70 to 75 % of world production of olive oil and more than one third for table olives, and with more than 7,000 million € 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; Fig. 1). These countries entail more than 5 million hectares of olive plantations, of which more than half are in Spain, mostly devoted to oil production. According to EUROSTAT's data, EU olive production reached 10,908,000 tonnes and an output value of 2,255 million € in 2016. 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.

2.3. How the olive cropping systems are evolving?

Within the EU different olive production systems coexists even within the same country, region or county. All of them have specific characteristics and play important agro-ecosystem services (Fernández-Escobar et al., 2013). In the EU olive cultivation tends to move from traditional low-density to new high-density cropping systems including super-intensive plantations established mainly in the main olive growing areas of Spain and Italy with the aim of maximizing yields and decreasing harvesting costs. All these changes have affected the incidence and severity of pests and diseases, and for some of these new olive production systems some problems have emerged or re-emerge as the consequence of the changes in crop management, for instance introduction of irrigation, increase in plant density, and mechanical pruning or use of cover crops.

Traditional growing systems. Most of the olive orchards worldwide are located in ancient olive growing areas that have been traditionally grown on extensive dry farming. This orchards are characterized by the use of adapted, local cultivars, low densities ≤ 100 trees/ha, and low or null mechanization. Their profitability is normally low and, in some circumstances, oil production cost can be higher than oil market price. Significant parts of those traditional olive orchards are located in marginal areas (extreme temperatures, poor soils), or areas with significant slopes, playing an important role in soil or landscape maintenance. Under such conditions, the chances of intensification or mechanization are low for those systems. Consequently, in those systems incomes different from direct production can be searched under landscape or social uses. Organic farming is also being adopted as an option to increase their benefit. When those traditional orchards are located in more flat or low slope areas, there is still a room for reconversion to more intensive systems or introduce some mechanization (e.g., introduction of drip irrigation, if water is available; partial mechanical harvesting), or conversion to organic farming.

Intensive growing systems. From the 70's, the development of irrigation, and new management and harvesting techniques has dramatically changed the olive production systems. Olive has been seen as a very profitable crop and new plantations have been established in new areas with higher water availability or with irrigation infrastructures (water reservoirs and fertigation equipment) and also by the use of soils with better edaphoclimatic conditions and more productive, previously devoted to other profitable crops. This mainly has

allowed the intensification of olive growing with an increase on tree density (up to 400 trees/ha); with the final tree density mainly determined by water availability, and in a lesser extent by the harvest system or the olive cultivar.

Super-intensive, hedgerow growing systems. In the early 90's, as a continuation of the intensification process mainly in Spain and Italy, hedgerow orchards appeared as a system able to dramatically reduce the labor needed for harvesting. It is mainly based in densities between 1,000-2,500 trees/ha with row spacing that may range between 3.75 x 1.35 m, and always with drip irrigation. Specific olive straddle machines are used for harvesting. The main advantages of this system are the low labor requirements at harvesting and the early entrance into commercial production, from three years after planting. One of the main inconvenience is the large investment required to establish the plantation, and the excessive vigor of some varieties that makes necessary a more frequent and severe pruning which affects the yields of the following year. Currently some experimental plots of hedgerow orchards on dry farming have been established at 7 x 2 m.

2.4. Which olive cropping systems will survive in the future?

The presence of olives for centuries in most of the EU producing countries can mislead about the sustainability of its cultivation. In the last years olive oil and table olive production have increased because the development of more modern orchards, intensification of the traditional ones, or the expansion into new producing areas. This has led a division between two types of olive farms: those that will survive (modern olive orchards producing at a lower cost than the market price) and those that might be extinguished (traditional olive orchards unable to reduce costs below the market price).

Thus, a mentality change has occurred and when a new a plantation is established the final objective is not to last indefinitely or maximize yields, but to obtain high productivity at the minimum cost producing olive oil with high quality to increase the profitability. Nowadays, most new orchards are established with a tree density around 500-700 trees/ha, designed for mechanical harvesting and with irrigation. 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 the trees per row or in-between rows. In cases where the olive orchards are located in marginal areas in fragile environments there is no chance of reconversion for intensification but organic farming can provide a choice to increase profitability as previously indicated.

Undoubtedly, the final decision to choose any cropping system will depend on the labor and water availability, financial support, and edaphoclimatic conditions of the area. Therefore, it seems probable that in the coming decades all the referred cropping systems will still coexists at the EU.

3. MAIN PESTS AND DISEASES AFFECTING OLIVE CROP

Trade and the movement of goods and people, climatic variations and changes in farming practices have facilitated the introduction, reemergence, spread, and establishment of pests and diseases along the history for many crops, including olive. 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 phytophagous and pathogen organisms that feed or develop/infect olive may determine not only the olive yields, but also if olive can be grown with profitability in certain areas or situations (Table 1).

3.1. Olive pests

Although there are more than one hundred of phytophagous invertebrates species, mainly insects and mites, known to feed and/or develop on the olive tree, a large group of them is composed of polyphagous species, each having many host plants in addition to olive. A second smaller group is composed of monophagous or oligophagous species, 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 (Table 1) (Fernandez-Escobar et al., 2013; Alvarado et al., 2017).

There are three main olive **key pests**. The **olive fly**, *Bactrocera oleae* is probably the main damaging olive pest in the Mediterranean Basin and California. This insect has several generations per year (up to 6 generations depending of the prevailing temperature and availability of fruits). The female can lay up to 10-20 eggs/day, producing several hundred eggs during her lifespan. The larvae feed within the fruit mesocarp damaging it, and diminishing its quality. Infestation can be severe enough to induce 100% fruit drop in years of low yield.

The **olive moth**, *Prays oleae*, is also widespread through the entire Mediterranean region and can complete three generations per year, only on the olive tree. Each of these generations may cause damage to a separate part of the olive tree: Larvae of the 1st generation (anthophagous) attacks the flowers, the larvae feed initially on the anthers and ovaries damaging several flowers (up to >90%). In the 2nd generation (carpophagous), the most damaging one, the eggs are laid on the calyx of a young fruit and the larvae enter the fruit endocarp, that makes the fruit be dehydrated and drop, or induce a loss of oil quality, causing severe losses. The 3rd generation (phyllophagous), feeds on the leaves boring mines like a leafminer during the first larval instars

The **black scale**, *Saissetia oleae* (Homoptera: Coccidae) main damage is due to the secretion of very large amounts of honeydew that is colonized by sootymold fungi, covering fruits and leaves by a thick black mass. As a result leaves drop, fruit may be reduced in quality and twigs dry up.

Some other **secondary pests** that sometimes also may become key pests are the oleander scale, *Aspidiotus nerii*, the two olive scolytids, *Hylesinus oleiperda* and *Phloeotribus scarabaeoides* (Coleoptera: Scolytidae), and the olive pyralid moth, *Euzophera pinguis*.

3.2. Olive diseases

Olive pathogens also exceed one hundred, although only a few of them cause serious economic losses on olive groves (Fernandez-Escobar et al., 2013; Trapero-Casas et al., 2017) (Table 1).

The quarantine bacterium *Xylella fastidiosa* has emerged as a global threat for olive production, and has been associated with a novel and severe disease in olive named **Olive Quick Decline Syndrome**, that is spreading and killing thousands of olives in Apulia, southern Italy. Olive trees are characterized by severe branch desiccations and rapid death of olive trees. Although the bacterium has also been detected in Spain associated to olives, it seems that the genotypes of the bacterium, different from the Italian ones, are not so virulent (Landa et al., 2017).

The main soilborne fungal disease of olive is **Verticillium wilt** that is caused by the vascular fungus *Verticillium dahliae*. Although this disease was unknown 30 years ago, nowadays it is also considered the most serious fungal disease and the main challenge for olive growing in the olive-growing Mediterranean regions, such as in southern Spain, specially due to a defoliating pathotype of the pathogen that is highly virulent and cause high reduction of yields and tree mortality (Jiménez-Díaz et al., 2012).

Another important group is composed by a complex of fungal leaf and fruit diseases, mainly **scab or peacock spot** caused by *Fusicladium oleagineum*, anthracnose due to *Colletotrichum* spp. and cercosporiose due to *Pseudocercospora cladosporioides*. These diseases cause heavy defoliation and weakening of olive trees, reduce plant productivity and quality of olive oil (Trapero-Casas et al., 2017).

There are other diseases having a moderate impact on olive orchards in the Mediterranean basin, although under specific environmental conditions, crop management systems or for specific very susceptible varieties may cause important losses.

The **olive knot or tuberculosis**, caused by the bacterium *Pseudomonas savastanoi* pv. *savastanoi*, causes hyper-plastic growths (tumorous galls or knots) on the stems and branches of the host plant and, occasionally, on leaves and fruits.

Other soilborne pathogens include **root and crown rot** caused by several species of the oomycete *Phytophthora* that are especially prevalent in water-logged soils. However, in last decade *P. palmivora*, a pathogen of tropical origin, has been reported in several olive-growing areas as causal agent of root rot of olive trees in nurseries and commercial new plantations (Sánchez-Hernández et al., 1998).

Several species of the root-knot nematode *Meloidogyne* spp. and the root-lesion nematode *Pratylenchus* spp. are prevalent in many soils with higher sand content of the Mediterranean (Castillo et al., 2010). Both types of soilborne pathogens induce water stress and nutrient deficiencies as the plant root system fails to adequately explore and exploit the soil; inducing tree decay and reduction of yields.

Finally, some **viruses** with different taxonomic affiliation have been identified in the Mediterranean associated to deformations of fruits and leaves and foliar discolorations ranging from chlorosis to bright yellowing. The economic impact of infections has not been determined although recent reports indicate that some viruses seem to affect the yield and the quality of the oil (Martelli, 2013).

Table 1. Major olive pests and diseases in the Mediterranean Basin

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

<i>Phytophthora, Cylandrocarpon, Fusarium, Pythium spp.</i>	Fine root rots	*
<i>Nepovirus, Cucumovirus, Oleavirus</i>	Yellowing, malformations	
<i>Meloidogyne spp.</i>	Root knot	*
<i>Pratylenchus spp.</i>	Root lesion	

4. WHICH TOOLS ARE AVAILABLE FOR OLIVE PESTS AND DISEASE MANAGEMENT

Pesticides are often used to protect the olive crop against pests and disease attacks. However, there is increased concern about the effects of pesticides on the environment, non-target organisms, human health and product quality. The EU seeks to reduce the reliance on pesticides for olive production by fostering agricultural strategies of low environmental impact, and new management systems such as integrated production and organic farming are being promoted to reduce negative environmental impacts of the excessive use of pesticides and fertilizers.

4.1. Current tools available for olive pests and disease management

Preventive control measures for the management of pest and diseases in olive may include: (i) site selection to avoid planting into high risk areas where pathogens or pests are prevalent; (ii) use of certified planting material; (iii) reduction or elimination of inoculum/propagules in soil; (iv) use of resistant/tolerant cultivars and rootstocks to main pests and diseases. **Post-planting control measures** for direct control/management may include: (vi) cultural practices; (vii) organic or biological amendments; (viii) use of pesticides.

Choice of site for establishment of new orchards. Selection of a proper 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 should be avoided if possible or analyzed in advance to plantation establishment to test for presence and levels of pathogen inoculum.

The **use of certified planting material** will optimize the efficiency of selecting planting sites for establishing new orchards, and is crucial, not only to ensure the identity of the olive variety or the quality of the plant, but also its health. 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.

Soil disinfestation including soil fumigation, soil solarization, and organic amendments, either individually or in 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 desinfectants either alone or in mixtures are normally not used in olive and many of them have been banned in the last years. Indeed, in some countries there are no commercial soil fumigants or disinfectants available. Bio-fumigation may be used as an alternative.

Use 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 the core of integrated disease management strategies. Although there are more than 2000 olive tree varieties around the World, genetic resistance has not been used on purpose as a pre-planting measure for the control of olive pests and diseases. This is mainly due to the fact that the productivity and environmental adaptation are the main criteria taken into account when choosing a variety for planting, or the existence of “certified” or “typical” or “protected” (protected designation of origin) olive oil production, which require a specific varietal composition in some regions. The choice of a tolerant cultivar makes integrated pest management easier and can reduce production costs by reducing chemical inputs or the cost of application of other control measures.

Some **cultural practices** may be very useful for the management of several pests and diseases in olive. 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 incidence of some insects and pathogens, it is important to avoid severe wounds caused by pruning or by beating at harvest and protect the injuries to decrease the incidence of some pests and diseases. In addition, it is very important to manage adequately the pruning remains for not favoring the increase of some olive bark beetles. Adequate management of irrigation (frequency and doses) may help in reducing the incidence of those pests and diseases.

Currently, the control of several olive pests and some foliar diseases are still based on the use of **chemical pesticides**, applied normally following ‘calendars’ (calendar-based pest control) more than based on monitoring or forecasting systems. This is a fact both for traditional and or intensively managed Mediterranean olive plantations. However, increasing public sensitivity towards environmental pollution in this key Mediterranean agro-system, problems derived from the side effects of these products, as well as EU policies have contributed to a reduction in the number of authorized active ingredients for olive pest and disease control. Therefore, the sustainable use of pesticides, and the use of non-chemical alternatives or Integrated Pest Management (IPM) is being promoted.

The use of **biopesticides** or **biological control** are considered as one of the alternatives for olive pest control. 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).

Nowadays **natural insecticidal compounds** are being explored to be incorporated in pest and diseases control programs in IPM, since they degrade more quickly and possess a different ecotoxicological profile. Example of this inclusion is spinosad that is already used. 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).

4.2. Integrated Pest Management in olive

IPM as defined by FAO (<http://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 minimize risks to human health and environment. IPM emphasizes the growth of healthy crop with the least possible disruption to agroecosystems and encourages natural pest control mechanisms”.

IPM involves prevention, cultural and physical control strategies to minimize pest and disease entry and their spread in space and time, or to destroy infested/infected material, and also promote the use of resistant cultivars when available. Biological control through natural enemies such as predators, parasites, insect pathogens and non-pathogenic antagonistic or competitive microorganisms is preferred to chemical options (Figure 2).

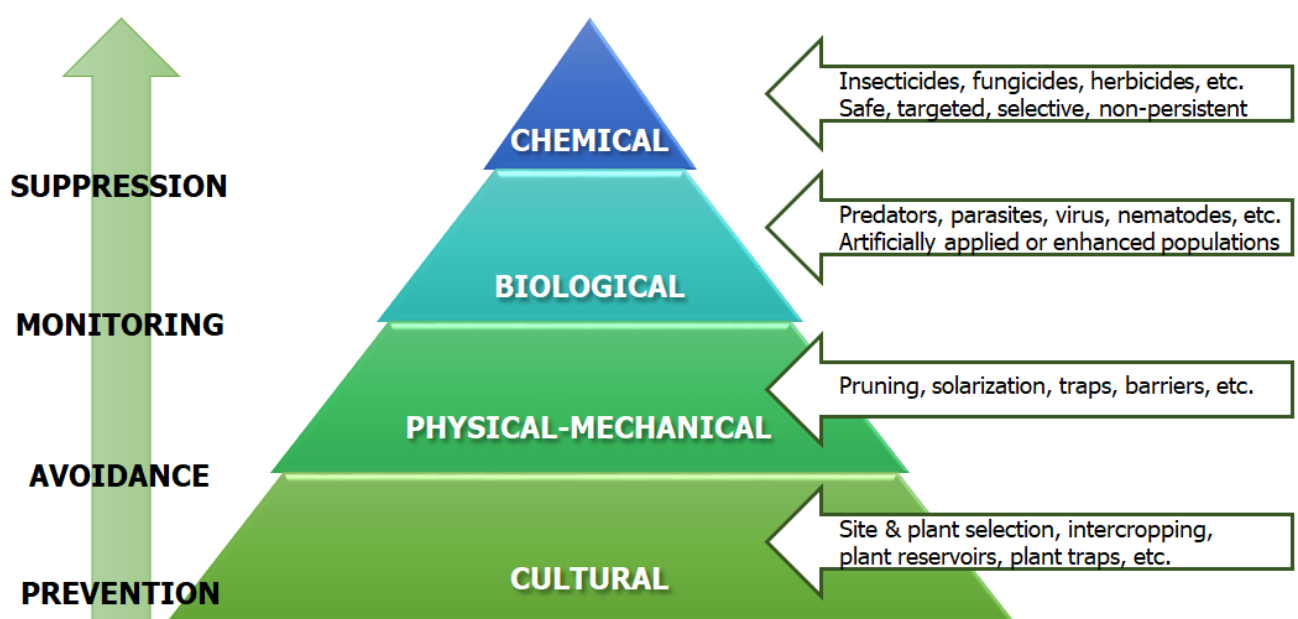


Figure 2. IPM management strategies and control measures for olive pest and disease control.

The major **components of IPM systems** are: (i) identification of pests, diseases and natural enemies (Knowledge); (ii) selection of the best varieties and agronomic practices to avoid their damage (Prevention); (ii) monitoring of pests, diseases, damage and natural enemies (Observation); (iii) selection of one or more management options on the basis of monitoring results and action thresholds (Intervention) from a wide range of non-pesticide options. 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 emphasized 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) (Figure 3).

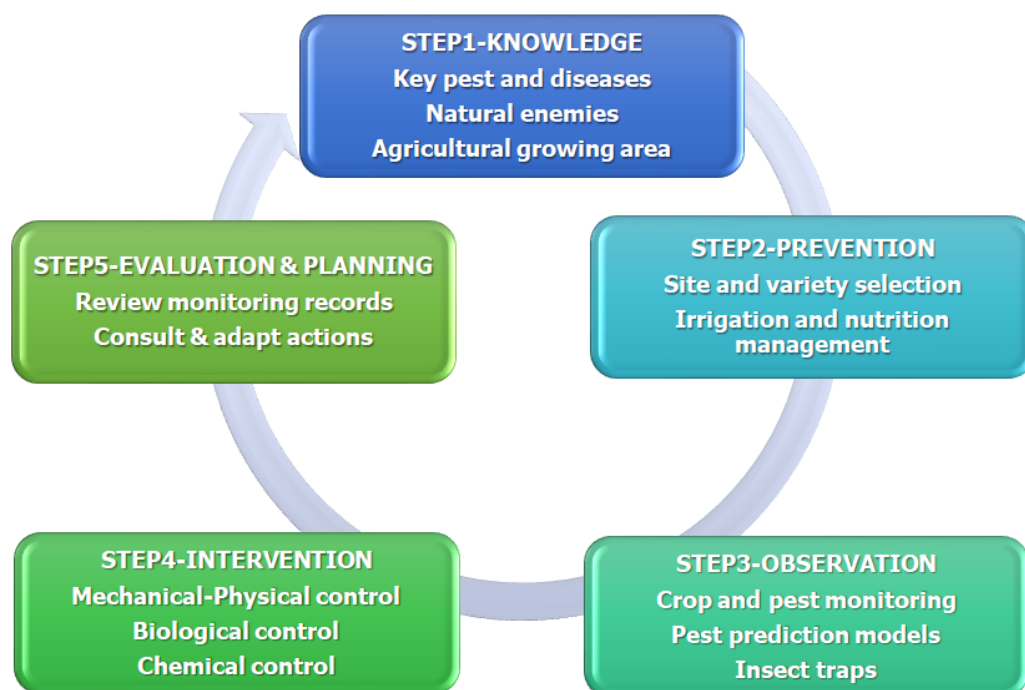


Figure 3. Steps in an IPM model for olive pest and disease control based in continual implementation and improvement.

Currently, there are many **diagnostic tools** available for pathogen detection in soil including traditional techniques for nematode extraction or fungal propagule counting and molecular tests that can be used in the assessment of the potential

inoculum present in soils and help in the decision of choice of site for establishment of new orchards.

Similarly, there are many molecular and serological tests available 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 pathogens of olive. As indicated above, these tests are especially important for pathogens that cause vascular infection and may have an infection phase asymptomatic.

The **pest monitoring by pheromones** is a key to determinate the presence of some olive pests and the flight curves, establish the population level and decide the correct timing for the phytosanitary treatments, always with authorized products in accordance with current legislation and in a rational way. The **mass trapping programs** with traps with pheromones are effective to manage and reduce the population levels and the pest pressure, keeping this one under the tolerance level.

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. They have been or are being developed for some pests (*B. oleae*) and (*C. oleaginum*) diseases of olive (eg. Petazzi et al., 2002; Romero et al., 2018). Nowadays, the availability of Information Technology (IT) tools, wireless sensors to constantly monitor climatic and vegetation data will allow to implement in some regions/farms precision plant protection techniques. Although IT tools are available in several EU regions they are rarely used directly by the olive farmers, but in the future and more often, are used by advisory services. For instance, for the olive pests *B. oleae* an internet-based monitoring network has been implemented in some regions, allowing several technicians distributed in a region to share the same **Geographical Data Base Management System** that includes fruit fly infestation data, meteorological data and the coordinates of the monitored points. Data collected weekly by technicians are processed by a GIS linked with the database. GIS produces several outputs used to support decisions in pest control: (i) optimize the distribution of monitored points; (ii) visualize pest dynamics; (iii) evaluate the linkage between entomological data and geographical factors (i.e. distance from the sea, altitude); (iv) forecast infestation, using a spatial interpolator.

5. HOW EXPECTED CLIMATIC CHANGES ARE LIKELY TO AFFECT OLIVE GROWTH AND ITS PESTS AND DISEASES?

5.1. Effect of climate change on olive growth and productivity

The Mediterranean basin is the largest world area having specific climatic conditions suitable 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 the warming is projected to be greater than the global average, with also a large percent reduction of

precipitation and an increase in its inter-annual variability. 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, with longer dry periods and bursts of intense rainfall (IPCC WGII, 2007).

Cultivation areas: Some research has indicated that the potentially cultivable areas for olive growth are expected to extend northward and at higher altitudes and to increase by 25% in 50 years.

Flowering and fruit production: The olive flowering is likely to be anticipated while inflorescence emergence delayed. These changes in the olive reproductive cycle, will have subsequent consequences on the medical impact of the pollen release timing (allergic population), and an agronomic impact related to olive fruit production. In parallel, those pests and pathogens that feeds or develops on flowers and fruits will be affected by those phenological changes (García-Mozo ET AL., 2015).

Water availability: Olive crop evapotranspiration and irrigation requirements are predicted to increase. In parallel, effective evapotranspiration of rainfed olives could decrease in most areas due to expected reduction of precipitation and increase of evapotranspirative demand, thus making it not possible to keep rainfed olives' production as it is at present (Tanasijevic et al., 2014). This fact could lead to changes in landscape, water redistribution among the economic sectors and within the agricultural uses. Therefore, the future of olives cultivation in the Mediterranean would face a great challenge: *how to keep sustainable development of two very different growing systems:*

- The traditional olive orchards, located in semi-arid and arid areas characterized by water scarcity, and using minimum deficit irrigation amounts or remaining rainfed.
- The intensive and super-intensive olive orchards, located in more sub-humid regions, or areas with water availability, where large irrigation volumes are needed.

5.2. Effect of climate change on olive pest and diseases and potential adaptation strategies

Abiotic diseases of olive 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 northward extension of olive culture in the boreal hemisphere as a consequence of climate warming may modify the geographical distribution of some widespread fungal and bacterial diseases and pests. On the other hand, climate change could enable certain pathogens and pests to survive outside their habitual ranges. It should also be noted that the emergence of a new disease in

a traditional olive-growing areas may be a consequence of the introduction of an exotic pathogen such the case of *Xylella fastidiosa* in Puglia, Italy. By contrast, the emergence of a disease in an area where olive cultivation has been introduced recently may be a consequence of the adaptation of a pathogen already present on other hosts.

It is clear that the climate affects both spatial and temporal distribution, as well as reproduction and dissemination of plant pests and pathogens since temperature, light and water are major factors influencing their growth and development. Consequently, climate change is expected to affect the incidence and severity of **infectious diseases and pest** attacks in olive. However, it is difficult to predict such consequences, as they are the results of complex interactions between the specific pathogen or pest, the olive genotype, 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 generalized.

An excessive moist atmosphere, as well as recurrent rains, favor epidemics and prevalence of **fruit and foliar fungal and bacterial diseases** of olive trees. Milder winters, higher nocturnal or overall temperatures may increase overwintering of some pathogens and pests on the olive tree or favor sporulation of some pathogens. Heavy rains can cause water saturation of soil and will increase long-term problems of root rot caused by several soil-borne pathogens and also may cause significant movement of soil from an infested to a healthy area, increasing dissemination of soil-borne pathogens. Conversely, dry and warm conditions can favor a higher number of insect generations or favor growth and spread of insect vectors increasing epidemics of insect-transmitted diseases.

Olive pests, such as the obligate olive fruit fly (*Bactrocera oleae*) and its interactions with olive will be affected by climate change. Thus, it has been estimated that climate warming will affect olive yield and fly infestation levels across the Mediterranean Basin, resulting in economic winners and losers at the local and regional scales. At the local scale, profitability of small olive farms in many marginal areas of Europe will decrease, leading to an increase in the cultivation abandonment. These marginal farms are critical to soil and biodiversity conservation, as well as for reducing fire risk in these areas (Ponti et al., 2014).

An increase of the olive fruit anthracnose epidemics by *Colletotrichum* spp. in many olive orchards of southern Italy have been attributed in part to climate warming. Heavy rain at the flowering stage and warm temperatures in autumn increase the number of latent and secondary infection cycles and reduce the incubation period of drupe infections and increase the number of secondary infection cycles. Additionally, the increase in temperature favors the overwintering of the pathogen on mummified drupes, which do not fall to the soil, thus providing higher inoculum for the following season (Graniti et al., 2011). Of great epidemiological concern is the prevalence and spread of the highly virulent defoliating pathotype of *V. dahliae* that has optimum temperatures higher than

the less virulent non-defoliating pathotype. However, since the severity of Verticillium wilt attacks is favored by moderate air temperatures during spring, and high summer temperatures suppress further development of the disease it could be speculated that the incidence of Verticillium wilt could be higher in northern latitudes that nowadays (Calderón et al. 2014).

Finally, a significant limitation to assess the impact of climate change on plant pests and diseases is the uncertainty in predicting how technological and economic forces will shape olive cultivation in the future. Independently from climate change, management of olive diseases has to face new challenges as a consequence of changes in production systems. On a local scale, olive cultivation systems may have a greater impact than climate change on the incidence and severity of pests and diseases.

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, fertilization, 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). Probably, there will 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.

6. QUESTIONS TO DEBATE

- Is there something missing in the inventory of pests and diseases?
- What prevention practices are successful for olive pest and disease control and why?
- Are you aware of some source of olive resistant/tolerant varieties and rootstocks to the main pest and diseases of olives?
- Do you know of any early detection/diagnostic/monitoring tools being successfully applied in olive? Are some farmers using them in practice?
- What are the main methods and tools used for direct control/management of olive pests?
- Do you know of some biological control agents or new plant protection products to control olive pests and diseases?

- Do you know of some successful examples of IPM in olive? How to make IPM strategies more widespread applicable and cost effective?
- Which role do biodiversity plays in olive growing systems? Have farmers, advisers and researchers enough knowledge of its role?
- Are there some adaptation strategies to face the impact of climatic change on olive pest and diseases?

7. ACKNOWLEDGEMENTS

The useful comments provided by the Focus Group members F. Nigro, W. Couanon, and P. Milonas, the EIP-AGRI Facilitation team members S. Didicescu and A.M. García Lamparte, and to P. E. Ganci and A. Seregélyi from from European Commission-DG AGRI that contributed to improve this starting paper are acknowledged.

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