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Evolution and sustainability of the olive production systems

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Abstract. The olive tree counts among the most important oil-producing crops throughout the Mediterranean region. The century-long presence of olive trees in most producing countries can lead to misunderstanding as to the sustainability, hardiness, longevity and plasticity of their cultivation. At present, olive trees are planted in all regions of the globe between 30 and 45° latitude in the two hemispheres. Olive culture is a complex agrosystem with variability in production systems, cultivation techniques and genetic resources. The evolution of the olive growing sector over time revealed that until the 1950s, the olive culture expanded slowly. After that, traditional planting system have been transformed into more intensive groves. Since the 1990s the trend has been to reconvert traditional orchards into more intensive systems. In the new cultivated areas and in the new producers' countries, intensive and high density groves are proliferating with the objective of reducing both unproductive periods and costs. In many instances, these changes in the growing systems have been accompanied by irrational exploitation of natural resources and the introduction of new varieties. This report is a review of the different olive growing systems and the evolution from traditional to more intensive production systems.

Keywords. Genetic resources – Intensive orchards – Olive sustainable production – Mechanization – Pest and diseases control.

Évolution et durabilité des systèmes de production oléicole

Résumé. *La culture de l'olivier est l'une des principales spéculations agricoles pratiquées en Méditerranée. L'ancrage de cette culture depuis des siècles dans la plupart des pays avec des variantes climatiques et pédologiques est attribué aux caractéristiques : durabilité, rusticité, longévité et flexibilité. Actuellement, cet arbre est planté dans presque toutes les régions du globe situées entre les latitudes 30 et 45° des deux hémisphères. La culture présente une grande variabilité des systèmes de production, des techniques de plantation et d'entretien et une richesse génétique inouïe. Le suivi de l'évolution de cette culture dans le temps dévoile une progression lente jusqu'aux années 50 du siècle dernier. Par la suite, le système de conduite a évolué du mode traditionnel vers l'intensif. Depuis les années 90, il y a eu une tendance à la reconversion des vergers traditionnels vers l'intensif. Dans les nouvelles régions et dans les nouveaux pays producteurs, le mode intensif et hyper-intensif ont émergé dans l'objectif de réduire aussi bien la période improductive que les charges de production à travers la mécanisation de la cueillette. Ces mutations des systèmes de production sont accompagnées dans la majorité des cas par une exploitation irrationnelle des ressources naturelles avec l'introduction de nouvelles variétés. Le présent rapport décrit les différents systèmes de production et leur évolution du traditionnel à l'intensif.*

Mots-clés. *Durabilité – Intensif – Maladies et insectes – Mécanisation – Olivier – Ressources génétiques.*

I – Introduction

The presence of olives for centuries in most of the producing countries can mislead about the sustainability of its cultivation. Variability is a key concept in these lines. Although cultivated almost exclusively in Mediterranean clime conditions, olive orchards can be found under very different rainfall conditions, from the fringe of the dessert in very marginal areas to more humid climates. In the last few years olive oil and table olive production have increased because the development of modern orchards, intensification of the traditional ones and expansion into new crop 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 that who could be extinguishing (traditional olive orchards unable to reduce costs below the market price). Given the longevity of olive orchards the majority of olive producing countries presents a mosaic of typology of olive orchards (Fig.1).

Fig. 1. Different types of olive orchards.

These lines are a brief review about some sustainability issues related to some major aspects of olive cultivation.

II – Evolution of the olive production systems

1. Traditional growing system

Olive has been traditionally grown on extensive dry farming, in orchards characterised with densities up to 100 trees/ha and poorly mechanised. Their profitability is normally low and, even in some cases, oil production cost could be higher than oil market price. Most of the olive orchards worldwide are currently grown in this system, located in ancient olive growing areas and using local cultivars (Fig. 2).

A significant part of those traditional olive orchards are located in marginal areas (Table 1), with significant slopes and where the chances of intensification are low. Under such conditions, few efforts have been made to mechanize, at least in part, the harvesting operations. In some cases, growers are looking for more incomes different from direct production, as landscape or social uses. Organic farming is proposed as other option to increase their benefit margin.

In other cases, where the traditional orchards are located in flat or low slope areas, there is a room for reconversion to more intensive systems with a high level of mechanization.

2. Intensive growing system

From the 70's, the development of irrigation, management and harvesting techniques has dramatically changed the new olive production systems. Plantations in new areas with higher water availability and better edaphoclimatic conditions have been performed. This has allowed an intensification of olive growing with an increase on tree density, up to 400 trees/ha, with final spacing determined by water availability, edaphoclimatic conditions, harvest system and cultivar. The development of irrigation infrastructures has been one of the main factors boosting intensification.

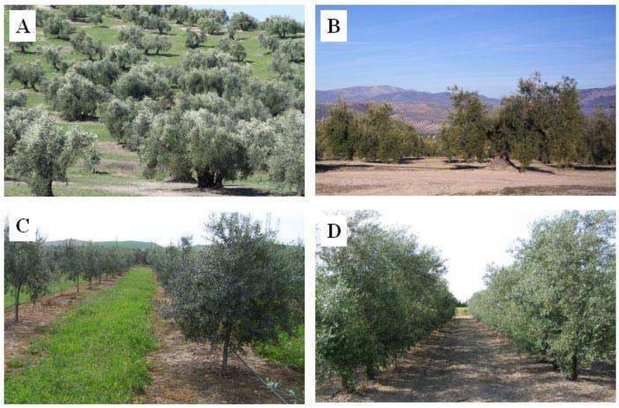

Fig. 2. Examples of different growing systems: traditional in marginal area (A), traditional able to be reconverted (B), intensive (C) and hedgerow (D).

Table 1. Percentage of the different growing systems in the world and in Spain

Growing system	World[1]	Spain[2]
Traditional marginal	20	24
Traditional able to mechanize	50	52
Intensive	29	22
Hedgerow	1	2

[1]According to Tous (2011); [2]According to AEMO (2012)

There is a strong tendency to mechanize the harvest in these intensive orchards with different type of shakers. For that purpose, trees are trained in a single trunk with the canopy developed at around 1m height. Continuous pruning from plantation up to the formation of the tree 5-6 year old is considered one of the key factors for having a well formed canopy. From that point, the main objective of the pruning is to keep the volume of the canopy within the limits to avoid excessive shading, which could depend on the cultivar and the edaphoclimatic conditions. The current trend is to have lower canopy volume per tree and increase density. The most efficient way to train the canopy seems to be a vase formed by two or three main branches, forming a structure able to efficiently transmit the shakers vibration through the branches in the tree. In plantations in new areas with reduce knowledge on olive growing, a proper pruning is one of the key factors to have a high an regular productivity. Most of the today existing olive cultivars could be grown in this system.

In the case of table olive, production systems are still very traditional. The low market prices in the last years in some countries have promoted the use of mechanical harvesting. The main problem for the mechanization of this system is the browning produced on the fruits but some strategies have been recently proposed to solve it. The success of this could lead on a change on the density and training of those orchards. New cultivars will also be needed for this intensification.

3. Hedgerow system

As a continuation of the intensification process, hedgerow orchards appeared in the early 90's as a system able to dramatically reduce the labour needed for harvesting. It was initially based in densities around 2,000 trees/ha and spacing of around 3.75 x 1.35 m, always with drip irrigation. Plants are trained in a monocone shape from the beginning of plantation. Three or four years after plantation, continuous hedgerows are formed on the tree lines. Straddle machines developed for vineyards with some modifications are used for harvesting, although, recently specific straddle machines for olive has been developed. The main advantages of this system are the low labour requirements at harvesting and the early entrance into commercial production, from three years after planting. Additionally, the faster and earlier harvesting could have a positive influence on the final olive oil quality. However, when large areas are planted with this system, enough milling capacity should be available to guarantee a good quality.

The large investment required by this planting system has promoted a reduction in tree density to around 1,200 trees/ha (4 x 2 m spacing). Other inconvenient is that the excessive vigour of the few cultivars currently used makes unpredictable the maintenance of long-term productive hedgerows with a convenient volume (De la Rosa *et al.*, 2007). In fact, many of the problems observed in the viability of those types of plantations are related to a deficient pruning, sometimes focused to have the maximum yield the first years after planting. On the contrary, the most convenient pruning strategy on hedgerow planting should be subjected to keep an adequate hedgerow size able to allow the straddle machine to harvest while maintaining a constant productivity at the same time. Therefore, pruning of hedgerow plantations is far different from vase-shaped trees of intensive orchards and labour should be specifically trained for that. Mechanical pruning has been proposed as another solution to reduce labour in both intensive and hedgerow systems and to keep the canopy volume within the convenient thresholds. However, some experiments performed advice to be complemented by selective manual pruning.

In the last years, irrigation management has been proposed as a convenient tool to control vigour in hedgerow olive. Other strategy to control the vigour is the development of new low vigour cultivars specifically designed for this growing system, as the case of 'Askal', 'Urano', 'Sikitita' or 'Tosca'. Also, dwarfing rootstocks could enlarge the number of varieties suitable to these systems. However, the vigour of a cultivar is largely influenced by environment, so specific trials should be developed to test the suitability of a given cultivar in a specific environment. This is especially important in those areas outside the Mediterranean Basin, where climatic conditions could dramatically affect vigour.

Some experiments of hedgerow orchards on dry farming at 7 x 2 m are currently under way with promising results. Again, this new strategy should be tested in several environments before it can be considered efficient.

4. Future prospects

Although the mentioned growing systems are the most popular up to now, new ones are appearing as a result of new harvesting solutions. This is the case of orchards with densities of around 500-700 trees/ha designed for a continuous mechanical harvesting by large straddle harvester machines in an over-the-row configuration (Ravetti and Robb, 2010). Trees are usually trained in an erected vase with two main branches formed perpendicularly to the hedgerow line. This constitutes an intermediate situation between intensive and hedgerow orchards. More cultivars could be adapted to this system, as the higher spacing between trees makes easy to maintain the hedgerow. As an inconvenient, the dimensions of the harvesting machine restrict its ability to move from one orchard to other and also to work on areas with high slopes. Other recently proposed harvesting solution, the lateral harvester could also have influence on the future growing systems and their pruning strategies.

Due to the current economic situation, new olive growing systems should not be devoted to last indefinitely or to maximize yield. The main objective should be to obtain high productivity at the minimum cost and to produce olive oil with added quality value to increase profitability. All solutions of intensification, from intensive to hedgerows of different densities, could be profitable. The decision from one or other would come from balance between pro and cons (Table 2). Labour availability, financial support and edaphoclimatic conditions could be critical for this decision. Therefore it is probable that in the coming decades all systems will coexist and the prevalence of one or other could depend on the development of new harvesting machines and new cultivars that could appear in the coming years.

Table 2. Comparison of vase-intensive and hedgerow olive systems. Advantage and inconvenients are relative from one system to other

Item	Vase intensive		Hedgerow	
	Advantages	Inconvenients	Advantages	Inconvenients
Planting cost	Lower			Higher
First crop		Later	Earlier	
Cultivars suitable	Many			Few
Need of labour at harvesting		Higher	Lower	
Need of pruning	Lower			Higher and specialized
Life span	Higher			Lower
Phytosanitary treatments	Lower			Higher
Invest recovery		Slower	Faster	

In many olive growing countries, there is a tendency to reconvert some of their traditional growing orchards to more intensive ones. Those efforts should be well planed, taking into account all the edaphoclimatic, economic and social aspects before being accomplished. For example, sufficient molturation capacity should be planned before large hedgerow plantings are designed and cultivar comparative trials should be performed before a foreign or new cultivar is used. Demonstration trials of the different growing systems accompanied with explanations of the pros and cons of any of them are the best advice that growers can have before deciding a new plantation. Additionally, growers' training is essential to impulse the accomplishment of this restructuring. One difficulty for the progress of restructuring olive orchards is the high amount of small farms (of less than 5 has) existing in many olive growing countries. Those farmers are not in good position to replant or install new infrastructures and, in many cases, they do not have skills for that. The average trees per ha, between 100-200 in many countries, indicate that the intensification of olive growing for a better management system is still in its early stages. In some cases, where olives are planted in marginal areas in very fragile environments, there is no possibility of reconversion, maybe only to optimize pruning. Organic farming could be a choice to increase profit on those cases. But in other cases, traditional extensive orchards are planted in areas where a shift to more efficient growing system could dramatically increase profit.

Special interest has the recent diffusion of olive growing in non-Mediterranean countries as Argentina, Chile, USA, Australia or South Africa. Growing systems in these areas must be based on high levels of mechanisation and low demand of manual labour, particularly due to the lack of tradition on olive growing. Although several problems of adaptation of olive to climatic conditions not exactly Mediterranean have been observed, the spreading of olive growing in new areas can have a significant influence on the olive oil market in the future due to their efficient productive systems.

In conclusion, a co-evolution of growing systems, mechanical harvesting solutions and new cultivars is expected in order to have more profitable olive orchards in the coming years.

III – Genetic resources

The genus *Olea* belongs to the *Oleaceae*, a family containing 29 genera and around 600 species of shrubs and trees. According to recent revisions of *Olea europaea* taxonomy, the species includes six sub-species based on morphology and geographical distribution (Green, 2002). Among them, the subsp. *europaea* is represented by two botanical varieties: cultivated olive (var. *europaea*) and wild olive (var. *sylvestris*), both present throughout the whole Mediterranean basin. Both wild and cultivated olives are diploid (2n=2x=46), predominantly allogamous and their genome size is about 2,200 Mb.

1. Traditional cultivars

Olive, along with grape, fig, date palm and pomegranate, belongs to the first group of domesticated fruit trees. All of them have in common their ability for vegetative propagation, initially by primitive methods requiring large propagules. The first olive growers selected individuals with better characters in wild olive forests, i.e. those showing higher fruit size and mesocarp proportion and higher oil content. Afterwards, with the spread of olive growing, this procedure might be repeated in the new growing areas leading to the first selected cultivars. In addition, these first cultivars could be enriched by the contribution of new genes (introgression) of local populations of wild olive, given the known interfertility between them. This domestication process probably occurred simultaneously at different places in the Mediterranean basin originating a large number of local cultivars which diffusion remained mainly restricted around its area of origin.

There have been efforts for cataloguing olive cultivars in most olive producing countries, although it is not exactly known yet the number and distribution of cultivars. Cultivar names difficult their correct cataloguing in many cases. Most cultivars, especially the most important, are known by different names depending on the area of cultivation (synonyms). In other cases the same name is given to cultivars that are actually different (homonyms). The identification of olive cultivars has been traditionally carried out by morphological descriptors. Besides, in the last years different molecular markers have been developed and applied for studying the variability of olive cultivars and their origin, providing a more powerful tool to guarantee varietal identification.

In Spain, a complete cataloguing work allowed the final identification of 262 different cultivars, classified in four categories (main, secondary, dispersed and local) according to their geographical distribution and economical importance. This high variability of cultivars is a common trait in all traditional olive-producing countries. A web data bank of the Olive Germoplasm developed by Bartolini *et al.* (http://www.oleadb.it) includes data on all the characters published extracted from 1,520 publications which have concerned about 1,250 cultivar denominations in 54 countries and conserved in over 100 collections.

2. Need for breeding

For many years, traditional olive orchard has been planted with the local cultivars above mentioned. However, in the last decades olive growing techniques have evolved considerably with new orchards designed to provide higher productivity and facilitate mechanical harvesting.

Tree shape, fruiting habit, fruit quality, production efficiency and resistance to diseases and pests should be improved for the future development of an economically viable industry adapted to modern agriculture.

In fact, changes in growing systems have been accompanied in many cases by the introduction of previously unknown varieties in these areas. The higher knowledge obtained in recent years about the agronomic characteristics of the most important cultivars have promoted that those cultivars having better performance (higher productivity, oil quality, mechanical harvesting aptitude, resistance to biotic and abiotic factors, etc.) replace traditional ones in many areas. As an example, in Andalusia, Southern Spain, according to nursery plant production data, over 90% of new plantations are being made by using only three cultivars ('Arbequina', 'Picual' and 'Hojiblanca'), which are spreading far from its traditional growing areas. The same situation applies for most olive producing countries. It should be noted that, in some cases, the introduction of cultivars has not been preceded by the experimentation to confirm their suitability to new areas, even though several studies show that the agronomic and quality characters of an olive cultivar can change dramatically depending on the area of cultivation. Comparative field trials are the most efficient way to determine the best suited cultivars in any specific area of cultivation. Unfortunately, the lack of previous experimentation has led in some cases to the commercial failure of new plantings.

High density hedgerow plantings represent a good example of the significant changes made in the olive grove in recent years. This planting system appeared in Spain in the mid-nineties based on high-density hedgerows (around 2,000 trees/ha compared to 200-400 trees/ha in standard olive orchards) collected by vineyard type straddle-harvesting machines, thus simplifying olive harvesting, the higher labor-demanding task in standard olive orchards (León *et al.*, 2007). However, unlike other fruit crops, in olive there are no specific low-vigor cultivars or dwarfing rootstocks adapted to this system. Due to the lack of specific cultivars for this system, very precocious cultivars such as ‘Arbequina’, ‘Arbosana’ or ‘Koroneiki’ have been mainly used, although they can not really be considered as low vigor cultivars (De la Rosa *et al.*, 2007). This could represent a problem particularly in very favorable growing conditions, since the hedgerow has to be kept under certain dimensions to allow the harvesting machine to pass over the top of the row.

Under these new planting systems, many of the traditional olive cultivars, which were empirically selected by growers centuries ago, display a number of undesirable traits for a sustainable modern olive industry. This situation has stimulated the development of breeding programs to obtain new cultivars that could increase the range of available cultivars adapted to modern olive growing systems.

3. Cross-breeding programs in the Mediterranean countries

Despite its importance, especially in the Mediterranean basin, breeding works in olive producing significant advances have not been carried out until the second half of the twentieth century. The long juvenile period (olive seedlings take more than 15 years before the first flowering under natural conditions) has been the main limitation for olive breeding. However, the development in the last years of simple methods to reduce this period by means of cultural techniques and adequate selection of parents has encouraged new olive breeding programs in many olive-producing countries.

Classical olive breeding programs are based in intraspecific cross-breeding between cultivars of known merit. Early bearing and high yield, increasing oil content and quality, tolerance to biotic and abiotic factors, suitability to different growing systems and mechanical harvesting aptitude are some of the main objectives. Initial works in these breeding programs were focused on the development of methodologies to shorten the juvenile period, the characterization of initial seedling progenies and the establishment of early selection criteria.

The selection procedure is carried out in several steps from the germination of seeds to the final registration of new cultivars (Fig.3). Promising genotypes are selected in the initial progenies populations and vegetatively propagated for further evaluation. Afterwards, new steps of selection are carried out in trials including a higher number of replications per genotype while the number of selected genotypes is reduced step by step. A final step of comparative field trial in several environments allows the final selection and registration of new cultivars.

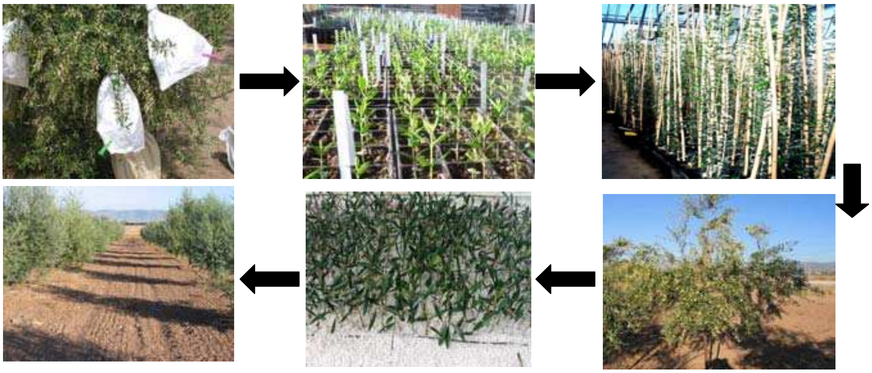

Fig. 3. Main steps in olive cross-breeding programs.

In the last years, breeding attempts have been initiated in several countries. However, due to the long period needed, only some of them have been able to complete the breeding process. As a consequence, several new cultivars and advanced selections, coming from different breeding programs, have been described.

4. New cultivars from breeding programs

Several new cultivars have been released in the last years as a consequence of breeding works (Table 3). However, only a few of them have been already marketed with relative success both in their countries of origin and abroad.

'Barnea' (Lavee *et al.*, 1986) originated from a mixed seedling population and was originally selected as part of an olive tree breeding program aimed to develop olive cultivars suitable for intensive conditions. It was characterized by its rapid and erect growth, early fruit bearing after planting and high yield under irrigated conditions. The oil is characterized by a medium content of oleic acid and polyphenols and its quality and taste is greatly appreciated. Since 1980, 'Barnea' has been planted in Israel as the major variety for the new intensive olive orchards for oil and also widespread in Australia, New Zealand, South America and USA.

'Fs17' (Fontanazza *et al.*, 1998) was selected in progenies from free pollination of 'Frantoio'. It was characterized as a new cultivar with early bearing, high and stable production and high oil content. With medium-low vigor, it was recommended for high density plantation or as a rootstock to reduce the vigor in high vigorous cultivars such as 'Giarraffa' or 'Ascolana tenera'. However, it should be noted that, in Spain, 'Fs-17' has shown lower productive performance than 'Arbequina', 'Arbosana' or 'Koroneiki' in high density hedgerow orchard trials. A high incidence of fruit rot caused by *Alternaria alternata* was also observed, a pathogen that is generally characterized as weakly virulent. These observations underline the importance of performing comparative field trials before the introduction of new cultivars in any specific area of cultivation.

‘Chiquitita’ / ’Sikitita’ (Rallo *et al.*, 2008) was obtained in a cross-breeding program in Córdoba, Spain derived from a cross carried out between ‘Picual’ and ‘Arbequina’. The results of the agronomical evaluation carried out in Córdoba allow the final selection of ‘Chiquitita’ as a new olive cultivar with early bearing, high oil content and yield efficiency. ‘Chiquitita’ showed a compact and weeping habit of growth, with dense canopy and branches trending downwards with crop so that canopy volume remains low. Its low vigor and natural trend to adopt a monocone shape with a central leader form make it particularly adapted to high density hedgerow orchards to ensure ease of management for a longer period.

Table 3. New olive cultivars released from breeding programmes

Cultivar	Origin	Country	Year
‘Kadesh’	F1 unknown	Israel	1978
‘Barnea’	F1 unknown	Israel	1984
‘Maalot’	F1 unknown	Israel	1995
‘Fs-17’	‘Frantoio’ free-pollination	Italy	1998
‘Arno’	‘Picholine’ x ‘Manzanilla’	Italy	2000
‘Tevere’	‘Picholine’ x ‘Manzanilla’	Italy	2000
‘Basento’	‘Picholine’ x ‘Manzanilla’	Italy	2000
‘Askal’	‘Barnea’ x ‘Manzanilla’	Israel	2003
‘Kadeshon’	‘Kadesh’ self-pollination	Israel	2004
‘Sepoka’	‘Kadesh’ self-pollination	Israel	2004
‘Masepo’	‘Manzanilla’ self-pollination	Israel	2004
‘Chiquitita’	‘Picual’ x ‘Arbequina’	Spain	2007
‘Tosca’	F1 unknown	Italy	2007

In the coming years, the continuation of breeding works with new crosses and continuous evaluation of the generated progenies will provide new olive cultivars obtained by genetic improvement that may change the current cultivar distribution in many countries.

5. Genomics tools

Recently developed genomic tools could be helpful to improve several aspects of olive growing. The most practical use of genomics nowadays is the authentication of plants in nursery. This consists on comparing a sample of the nursery plants to be used in a new orchard with a reference sample of the cultivar used. The comparison is made using molecular markers, mainly SSR (also called microsatellites), which analyze specific fragments of the DNA to test if the nursery plants are genetically identical to the reference sample. Reference sample are normally coming for cultivar collections existing in almost all olive growing countries (Bartolinie *et al.* Olea databases: http://www.oleadb.it/olivodb.html). Additionally there are three International Olive Germplasm Banks (in Córdoba, Spain, in Marrakech, Morocco and a third one scheduled to be set up in Turkey) hosting cultivars from all the Mediterranean Basin. As planting a new olive orchard is very costly, and errors on the cultivar used are only evident after 3-4 years of field growth, cultivar authentication is a very advisable operation, especially when foreign or not well known cultivars are used. Additionally, there are some molecular and serological tests to check if the nursery plants are carrying fungi (as *Verticillium dahliae*), bacteria or virus. Those test are also very convenient as, for example, the use of infected plants is considered as one of the ways of dissemination of *Verticillium* wilt. For these reasons, certification programmes are underway in several olive growing countries to offer to the growers nursery plants tested for cultivar trueness-to-type and free of diseases. However, up to now, there has been not a great demand of certified plants in most of the olive growing countries.

As mentioned above, molecular markers are also used in the management of Cultivar Collections in order to detect synonyms and homonyms. In this way, reference trees for the main cultivars could be identified. In the International Germplasm Banks molecular markers are also used to compare the authenticity of the foreign cultivars hosted with the country of origin. Microsatellite are again the marker of choice for those purposes, although high-throughput markers as DArTs and SNPs, recently developed for olive, are very promising for germplasm management in the future.

Apart from that, molecular markers and studies of expressed genes are being used to uncover the genetic basis of the most important olive agronomic traits as oil content and quality and resistances to biotic and abiotic stresses. In the future, these studies could significantly speed up the breeding programs as could greatly facilitate the selection process. However, marker assisted breeding is still far to be ready for use. One of the main reasons is that most of the agronomic traits of interest are quantitative and likely controlled by many genes. Additionally, the wide genetic base of the different breeding programs makes difficult transfer of marker-trait associations in the different crosses performed.

In the long term, transgenic olive is other challenge that could come to practice. In many countries, transgenic plants do not count on high popularity. Moreover, in olive, the concept "healthy", normally used in olive oil marketing would be difficult to link to "coming from transgenic plants". However, some intermediate solutions could be feasible in not so long term. For example, transgenic rootstocks resistant to diseases as *Verticillium* wilt could be of interest. In those cases, the olive oil from the scion will not come from transgenic plants and, in the future, it might be acceptable by the consumers. In other hand, cisgenesis (transformation with genes coming from other genotype of the same crop) is not considered as real transgenesis in some countries and could be an easy way to transfer genes from, for example, wild olives to high-yielding cultivars.

In conclusion, from identification to gene expression and transgenesis, different DNA analysis techniques could offer several tools very useful for the future olive growing.

IV – Sustainability and management in olives

1. Soil management and soil degradation

Soil degradation, most frequently soil erosion but also a decrease of soil nutrients and organic matter, and soil compaction, is systematically quoted as one of the major threats to sustainability of olive cultivation. Losses of top soil in areas characterized by shallow soils means a reduction of soil water storage capacity, which is critical for survival and productivity of rainfed olives (Fig. 4). They threaten olive cultivation rather by yield decrease or by the increasing production costs to compensate this degradation with additional inputs (e.g. fertilizers…). However the "off site", damages created by the runoff, sediment and agrochemicals transported downstream are what usually creates a major concern in the short term. Decrease of water quality in water courses by excess of sediment and agrochemicals has been noted as a major environmental problem in some olive growing areas. The high sediment load also increases the damage during floods and reduces the effective life of infrastructures (such as dam reservoirs due to silting).

Fig. 4. Examples of soil erosion in olive orchards.

Soil management in olive has been oriented for centuries to insure productivity and survival of the plantation under conditions of limited, and highly variable, rainfall using a combination of low plant density, limitation of tree canopy size by pruning and elimination of adventitious vegetation to limit competition for soil water. Traditional extensive systems in which weed control was pursued by tillage by animal traction were limited by available power (and the cost of tillage). This resulted in a mixed system in which the soil was covered by vegetation (or their stubble) during part of the year. Evaluation of similar systems today based on limited plowing (once a year or once every two years) suggests that this systems were subjected to moderate soil losses, specially if performed in a mosaic type of landscape where the orchards were surrounded by areas of natural vegetation or some retention structure. Topsoil in many of these orchards present values of some key soil properties within acceptable range and not far from those in undisturbed areas with natural vegetation. Traditional systems based in an integrated use of the orchard as intercropped with a field crop or with grazing at low density seemed to be in a similar situation with soil erosion rates not damaging sustainability in the medium term if performed at low intensity. However, erosion rates become higher and unsustainable when olive cultivation was pursued systematically on sloping areas and in a homogeneous, olive covered landscape. Van Walleghem *et al.* (2011) determined from field observations a cumulative loss of 450 mm of topsoil in old orchards during a period of 183 years, equivalent to 43 t ha/year.

The availability of tillage all year round due to mechanization combined, years later, with the availability of herbicides allowed a complete elimination of adventitious vegetation. This happened in a period of intensification with abandonment of other uses of the orchards. Measurements at small catchments also indicate high losses, ranging from 10 to 16 t ha/year (Taguas *et al.*, 2012), rates affecting quality of surface waters. The extrapolation from regional analysis or metanalysis to areas with similar conditions and soil managements indicates that this is a widespread problem around the Mediterranean basin, where most of the olive cultivation is still concentrated (Gomez *et al.*, 2008). The major effort during these decades regarding erosion control in olive orchards has been the development and expansion of the use of ground cover in the orchard lanes to prevent erosion and improve soil properties. Most of the change in soil management has been based on the introduction of cover crops that are sown along the lanes and are controlled by mowing or herbicides in late winter or spring to prevent competition for soil water with the olives. The cover crops can be sown every few years by the farmers (usually are cereals but leguminous are also been used) or are composed by adventitious vegetation naturally present at the farm. These cover crops have been studied for decades and their management and impact is relatively well understood in the more humid parts of the Mediterranean where it has been possible to achieve equilibrium between soil protection and competition for water, and their use has been incorporated into the environmental requirements of the Common Agricultural Policy of the European Union. However, even in these regions their effective use for erosion control in commercial farms is still achieving uneven results. In many farms, obtaining an effective ground cover remains a challenge due to the severity of soil degradation combined with the intensive traffic in the olive lanes, especially during harvesting. It also remains a relatively large uncertainty about the impact of the competition of the cover crop in areas different to those where the experimental studies with cover crops were performed, in years of limited rainfall (specially in spring), on orchards with different plant densities or under changing climate scenarios with higher temperatures and scarcer precipitation (Gucci and Caruso, 2011). Current research in Southern Europe seems to be focused on the development of new varieties better adapted to the role of cover crop in olive orchards, which can provide also additional benefits such as biological plague and disease control and increase of biodiversity; a comprehensive design of farm management to achieve an effective cover crop with limited risk of yield reduction (combining early harvest, controlled traffic and bands of cover crops of varying width and orientation) and the development of operational water balance models to predict the optimum date for cover crop killing in specific conditions. Related to water balance and the use of cover crops, the expansion of irrigation in olive growing areas provide a margin of safety to implement cover crop soil management without limiting significantly olive yield that does not seem to be completely explored. It has been also demonstrated the beneficial impact of a mulch of pruning residues, which had a similar effect to that of cover crops without the risk of water competition, although the amount of pruning residues to be prevent erosion can not be always achieve in the less productive orchards, and it also presents some limitations if some plagues and diseases are present. Overall, there is a need for a better understanding of the impact of these new uses of mulches and vegetation on pest and diseases in olives. There are some preliminary studies trying to use a biogenic crust of mosses, but their effectiveness or viability under the conditions (especially of machine traffic) of olive orchards is still to be demonstrated.

Little information is available on high density hedgerow orchards. These plantations occupy less sloping areas and provide an increased grown cover compared to traditional plantations, so it can be expected that this plantations might present a reduced erosion risk. Nevertheless, a comparison with systems that are conceptually similar (vineyards) suggests that if this plantations are implanted in areas with non-negligible slopes (e.g. >2 %) the erosion rates might be significant since they will present long lanes that will be probably compacted by the repeated pass of farming equipment. In these plantations, the use of mulch might be very efficient as an erosion control technique. Probably a mulch of pruning residues might be a viable option under these conditions.

The anthropization and simplification of the landscape that have resulted of the extension and intensification of olive orchards have also resulted, in some areas, in severe gully erosion (Fig. 4). This problem has severe consequences for the sustainability of olive cultivation. The techniques based on increasing ground cover to prevent erosion at hillslope scale are of little effect to prevent gully erosion. This is counterintuitive at first glance, but it can be easily grasped if we understand that mulches and cover crops are much more effective in reducing soil losses that in reducing runoff and that gully erosion results of concentration of overland flow (what will always happen in olive landscapes in the heavy rains that occurs periodically in Mediterranean climate) and the fragilization of the drainage network due to the elimination of vegetation that protects the stream sides. The use of vegetation at landscape for gully control, open the use of these measures as a tool to enhance biodiversity and landscape value in many olive growing areas.

2. Irrigation and sustainability

Irrigation can be considered a relatively recent practice in olive growing. Although some kind of irrigation has been traditionally applied to olives in very arid areas as an auxiliary practice, the most part of farm water supply was typically assigned to other less drought-tolerant crops. The appearance of drip irrigation in the 60's opened up the door for easily irrigating orchards on sloping terrains. The good response of olive yield to irrigation which, together with an increasing demand of olive oil, has made irrigation spread during the 80's and 90's. Of the 2.5 Mha of Spanish olive plantations, 0.52 (20%) are formally irrigated, and this share is almost certainly underestimated. New plantations –in Spain as in the rest of the world– are mostly irrigated, suggesting that the fraction of irrigated olive growing is very high worldwide and this fraction is increasing. One of the reasons that decreed the success of irrigated olive cultivation is that the tree yield responds strongly even to relatively small amounts of irrigation water. An evapotranspiration-yield function indicates an increase of 5 kg/ha of olive oil for each mm of water evapotranspirated during the season (Fig. 5). This is an average value, but the relationship is not linear. This means that the marginal productivity of water, i.e., the increment in yield for each incremental unit of water used by the crop, is higher under low water use and smaller when approaching the full water requirement of the tree. Olive is usually grown in arid and semiarid environments, where irrigation water supplied to the farmers is the main limiting factor to crop production; under these circumstances farmers naturally tend to apply less water than what needed for full production and to distribute it to the maximum surface, but trying to avoid water stress when the crop is more sensible (e.g. flowering or oil filling). This strategy is called "regulated deficit irrigation" or RDI.

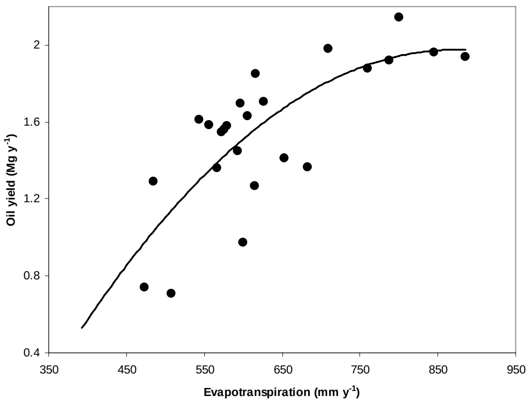

Fig. 5. Relationship between olive evapotranspiration and oil yield. Redrawn from Moriana *et al.* (2003).

Although irrigation of olive is profitable even under deficit supplies, the surface planted has nevertheless increased so much in the last decade that many olive growing areas are already unable to fit the water demand of olive groves. This is quite a big issue, as this situation is already drawing out non-renewable water resources. For example, in southern Spain some subterranean water bodies are depleting, many springs are disappearing or their flow has become discontinuous. The excess of water demand is a major risk associated to olive irrigation, as olive growing areas are located mainly in zones that are already at risk of desertification. The water requirements of olive growing areas must therefore be defined as precisely as possible; but olive orchards are very heterogeneous, in size, planting density, irrigation frequency, etc. which hindered the application of traditional calculation methods like the standard FAO Crop Coefficient technique. The problem has been addressed from a scientific point of view by measuring in various experiments all the sources of water evaporation from olive orchards (leaves, soil and wet soil spots under localised irrigation), which gave the possibility of developing a model of orchard ET (Testi *et al*., 2006), that was then used to simulate all the possible types of olive orchards and derive a calculation method to obtain the maximum evapotranspiration of a given orchard and site (Orgaz *et al.*, 2006). This method helps in both irrigation scheduling and in problems of dimensioning and balancing the area invested and its water assignment. Nevertheless, the information must be sided by good water policies at the right scale, with the object of assisting farmer's incomes while enforcing a sound environmental protection, by close monitoring of any environmental indicator involved.

The shift from rainfed to irrigated olive farming encompasses more than the implementation of irrigation. Removing water limitation means that olive production meets other constraints, more often the amount of radiation intercepted. Irrigated orchards find their optimum production under more dense systems to obtain the maximum potential from irrigation water the system requires more inputs and investments. Shifting from rainfed to irrigated olive groves entails intensification of the cropping system. If the target is making the best possible use of a limited resource (water) we should change the paradigm of olive growing: in marginal areas, where soils or climate are the main limiting factors, intensive input farming is spoiled. The maximum return from water investment can be found only routing it to the more productive environments, capable to support high-density, intensive and productive olive farming.

This change of paradigm should be taken with caution, as high input farming may carry environmental risks in vulnerable areas. The environmental risks associated with olive irrigation are more dependent on intensification of the cropping system rather than irrigation itself. One of the more common negative effects of irrigated agriculture is the contamination of water bodies due to pollutants (either fertilizers or pesticides) carried with runoff and percolation. Olive groves are less prone to leak out agrochemicals than many other crops, as new plantations are all drip irrigated (with minimise runoff even on sloping terrain) and irrigation in excess is found very rarely. A correct scheduling and calculation of the irrigation amount will reduce this risk to a minimum.

As many olive orchards are deficit irrigated and they typically occupy semi-arid zones, soil salinisation is often an environmental risk. This risk is further increased because the tree is salt tolerant, and farmers tend to use bad quality water under the pressure of increasing water scarcity; besides, drip irrigation also helps in reducing salt accumulation in the root zone. The use of saline water in olive irrigation is not necessarily detrimental for the environment, but the soil evolution must be closely monitored for sustainability. In very arid environments rainfall could be insufficient to remove salts through the natural soil flushing at the rate they are added by irrigation water; this could lead, in the long period, to push already vulnerable areas beyond the border of desertification.

Salinity effects on yield depend on the concentration but even though tolerance is a cultivar-dependent characteristic, most of the cultivars under semiarid conditions may develop well with no significant reduction of yield with an ECe in a range between 3 and 6 dS m^{-1}. Salt tolerance is mainly associated to salt exclusion mechanisms operating in the roots, preventing salt translocation rather than salt absorption. Olive trees are less sensitive to leaf Cl^- than Na^+, and Ca^{2+} play an important role in Na^+ exclusion and retention mechanisms. Results obtained from a long term experiment under field conditions (Melgar *et al.*, 2009) suggest that a proper management of saline water, supplying Ca^{2+} to the irrigation water to prevent Na^+ toxicity, using drip irrigation until winter rest and growing a tolerant cultivar, can allow using high saline irrigation water for a long time without affecting growth and yield in olive trees.

Irrigated olive growing is a new cropping system, with specific characteristics, that was mainly unknown only a short time ago. But new knowledge is required about the water use of high-density/hedgerow plantations, and the specific irrigation strategies for these high-investment orchards; the possibility of tailoring specific cultivars for specific irrigation/climate/management combinations through the new breeding programs launched recently; the modelling of the carbon dynamics of olive plantations linked to the water use, to explore new scenarios under the effects of changes in the water supply and climate.

3. Fertilization, crop quality and environment

Fertilization is a common practice in olive growing because it aims to satisfy the nutritional requirements of trees when the nutrients required for its growth are not provided in sufficient amounts by the soil. Since soils may differ in fertility, and nutrient requirements may vary among different olive orchards depending on tree age, variety and olive production system, it would be illogical to provide general recommendations for olive fertilization. The annual fertilization program may vary among orchards and among years within an orchard. However, repeated fertilization programmes are customary in many olive-growing areas.

A survey of olive fertilization practices in the Mediterranean region (Fernández-Escobar, 2008) revealed that in 77% of cases the fertilization programme was repeated every year and generally involves applying several mineral elements, which always included nitrogen, even when in most cases the nutritional status of the orchard was unknown. This approach tends to apply more mineral elements than necessary, some of which may already be available to the tree in sufficient amounts to guarantee a good crop, and, at the same time, it may cause mineral deficiencies if a specific element is not applied in sufficient amounts. The farmer attempts to return to the soil the nutrients removed by the crop in order to maintain soil fertility and provide a good nutritional status of the trees. However, this replacement fertilization did not always prove satisfactory since it did not take into account luxury consumption, the reuse of elements by the tree, the elements applied by irrigation water or rain, mineralization of the organic matter, tree reserves or nutrient dynamics in the soil exchange complex. Also, it has been proven that if an element is available in the soil in sufficient amount for the plant, there is no response to fertilization with this element. Accordingly, the excessive application of non-needed fertilizers increases growing costs, contributes unnecessary to soil and water pollution and may have a negative effect on the tree and crop quality. Today it is considerer that a rational fertilization tends to: (i) satisfy the nutritional needs of a orchard; (ii) minimize the environmental impact of fertilization; (iii) obtain a quality crop; and (iv) avoid systematic, excessive application of fertilizers.

Predicting the amount of fertilizers required annually to support optimum productivity is not simple. Under a rational point of view, a nutrient must be supplied only when there are proves that it is needed. For this purpose, leaf-nutrient analysis provides an indication of tree nutritional status and represents an important tool for determining fertilization requirements. Interpretation of the results of leaf analysis is based on the relationship between leaf nutrient concentration and growth or yield. Comparing actual leaf nutrient concentration to reference values allows the diagnosis of nutrient deficiency, sufficiency or excess. Optimum tree nutrition could be achieved combining this information with soil and environmental factors that affects tree growth and symptoms of nutrient deficiency or excess (Fernández-Escobar, 2007). Leaf analysis has proven useful as a guide to fertilizer management of olive trees, and may promote more environmentally responsible use of fertilizers. In a long-term experiment carried out in four olive orchards established on different types of soils, that compared the fertilization practice based on foliar diagnosis versus the current fertilization practice in the area based on the annual application of several nutrients, it was obtained that the current practice in the area increases in more than 10 times the cost of fertilization without an increase in yield or vegetative growth; on the contrary, this practice negatively affects oil quality due to a reduction of total polyphenols in olive oil. Despite that, recent studies indicate that leaf analysis is being underutilized in olive growing, since few growers perform leaf analysis annually.

Sixteen elements have been recognised as essential for plant growth: carbon (C), hydrogen (H), oxygen (0), nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), sulphur (S), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), boron (B) and chlorine (Cl). Nickel (Ni) is also considered essential for some authors. They are essential elements because the plant is unable to complete its life cycle without them; no element can substitute for another; and the element has a direct impact on growth or metabolism. The first three elements, C, H and O are non-mineral and represent approximately 95% of the dry weight of an olive tree. They are not added in fertilization because the tree can get them from the carbon dioxide (CO_2) present in the atmosphere and spread it to the leaves through the stomata, and from the water (H_2O) in the soil, taken up by the roots, whose combination by photosynthesis forms carbohydrates, the major plant nutritional component. The others are mineral elements and they are the reason why we fertilize. Together they only represent 5% approximately of the olive tree dry weight; therefore we can easily cause an excess of one of them. These elements are uptaken by the olive roots from the soil solution where they occur as ions. Perennial plants like the olive have nutrient storage organs to help them easily reuse nutrients. This is why nutrient needs of these plants are lower than annual plants.

Potassium deficiency is the major nutritional disorder in rainfed olives because the low soil moisture limits the spread of the potassium ion through the soil solution and prevents its absorption by the roots. It is worse when yields are high because is the element removed in largest amounts by the crop, around 4.5 g K/kg olives. Potassium deficiency is difficult to correct in olive orchards because the potassium fertilizer is uptaken in smaller amounts by trees suffering from a deficiency. Tentative doses for soil application in such cases are around 1 kg K/tree, provided that soil moisture is not a limiting factor. In rainfed olive orchards, between two and four leaf applications of 1%-2% K have given satisfactory results, although it is usually necessary to repeat the applications in following seasons until K reaches an adequate level in the leaves. Applications should be done in the spring because young leaves absorb more K than mature leaves.

In calcareous soils, iron and boron deficiency may occur in addition to potassium deficiency. Trees suffering from iron deficiency, known as *iron chlorosis*, display a characteristic series of symptoms such as yellow leaves, small shoot growth and lower yield. These symptoms are the means of diagnosing iron deficiency as leaf analysis is of no use in such cases because iron accumulates in the leaves even when deficiency occurs. Iron chlorosis is difficult and costly to correct. The best solution for new orchards is to choose a variety that tolerates this anomaly. In established orchards the remedy is to apply iron chelates to the soil, which makes iron available to the plant for a moderately long period in comparison with other products, or to inject iron solutions into the tree trunk. Olives are considered to have high boron requirements. Soil availability decreases under drought conditions and at higher soil pH values, particularly in calcareous soils. Boron deficiency can be remedied by applying boron to the ground at a rate of 25-40 g per tree. In calcareous soils with a pH>8 and in rainfed orchards, it is preferable to apply soluble products to the leaves at a concentration of 0.1% boron, prior to flowering.

Calcium deficiencies are to be expected in acidic soils. In these situations it is necessary to apply a limestone amendment, i.e. applying calcium carbonate or calcium oxide to neutralize the acidity. The amount required depends on the soil texture and pH, and has to be calculated on the basis of soil analysis results.

Finally, nitrogen is the mineral element required in the largest amounts by plants and consequently, it is commonly used in the fertilization programs of horticultural crops. Since it is lost easily through leaching, volatilization or denitrification, there is the perception that an increase in nitrogen fertilization always results in increased yield. However, long-term studies dealing with the optimization of nitrogen fertilization in olive orchards have demonstrated that annual applications of nitrogen fertilizers are not necessary to maintain high productivity and growth. On the contrary, this practice resulted in negative effects on the tree, on crop quality and on the environment (Fernández-Escobar, 2011). These studies recommend that the best strategy to optimize nitrogen fertilization in olive orchards, as well as other nutrients, is the application of nitrogen fertilizers only when the previous season's leaf analysis indicates that leaf nitrogen concentrations have dropped below the deficiency threshold.

These are the nutritional imbalances that can affect the majority of olive orchards and which it is advisable to monitor through testing. Nevertheless, it is unusual for these imbalances to coincide all at once in the same orchard. A good diagnosis of the nutritional status of olive orchards by leaf analysis, and good fertilizer application techniques can lead to a sustainable and responsible use of fertilizers. In this sense, fertigation and foliar fertilization -particularly in rainfed orchards-, may increase nutrient use efficiency. Also, since sufficient know-how is available in this cultural technique, we can conclude that more knowledge must be transferred to the olive sector in order to obtain safe, quality products.

V – Sustainable mechanical harvesting of olive orchards

The economic sustainability of olive production goes through reducing their production costs, which is only possible with integral mechanization. Harvesting can be up to 40% of the costs related to the crop. In each type of olive orchard it is possible to choose between several solutions for mechanization and none of them is completely generalized.

Planting systems have been completely transformed in recent years from traditional olive to high-density olive orchards thanks to advances in mechanization. In the Mediterranean area, the traditional olive orchard remains the most widespread crop system. However, in the new cultivated areas and in the new producer countries, intensive and high-density groves are proliferating due to their better adaptation to mechanization. The olive orchard typology determines the type of harvesting systems to be used and presents significant incidence on harvesting costs as shown in Table 4. This information suggests the need to convert the traditional olive orchards into modern ones. However, this change is very difficult for the high costs and the high risk in non-irrigated Mediterranean areas that represents and because it is not viable for olive orchards located in high slope areas.

Table 4. Costs of the olive oil harvesting systems used in the different type of olive plantations

Olive plantation typology	Yield (kg/ha)	Harvesting system	Harvesting cost (€/kg fruit)
Traditional orchards unable to mechanize	1.500-3.000	Branch shaker and manual harvesting with rods	0.15-0.25
Traditional orchards adapted for mechanization	4.000-6.000	Trunk shaker mounted in a tractor	0.14-0.19
Intensive olive orchards	5.000-10.000	Self propelled trunk shaker	0.09-0.12
High-density olive orchards	8.000-10.000	Straddle harvester	0.04-0.06

1. Mechanical harvesting of olive orchards located in high slope areas

Current advances made in olive harvesting systems have not focused on traditional olive orchards, despite its economic importance in the Mediterranean basin. This type of orchards, designed for manual harvesting, present several difficulties for integral mechanization due to the high slope where mechanization is not feasible. The harvesting systems used in this kind of plantation include manual aids such as branch shaker and combing machines that perform the removal of the fruit using flexible rods that combs the branches of the tree, and are carried by the operator.

The olive groves located in slope presents an additional problem, the risk of being crushed by tractor rollover or machinery for harvesting or other tasks. Another important factor of this type of olive that directly affects crop costs and environmental pollution is the misuse of pesticides application systems such as spray and treatment machines. There is a total disregard of the need to maintain and calibrate those equipments periodically for distribution of agrochemicals and know for certain minimum requirements covering manufacturing. The available equipments are not adapted to traditional olive orchards so in many cases application is not performed properly resulting in high product losses drifts (Fig. 6).

Fig. 6. Drift losses in traditional olive groves.

2. Mechanical harvesting of high yield traditional olive orchards by shaking

Vibrating systems have been and are the most common harvesting methods in olive oil orchards (Fig. 7). In olive oil orchards with high yields the current trend is to use trunk shakers for removing the olive fruits on canvas or nets placed under the trees. The removal fruit is manipulated by a group of workers who perform the loading and transport with the help of loaders and trailers. This harvesting system is the most versatile because it can be either used in traditional and in intensive olive orchards. However, harvesting efficiency in this kind of groves is reduced because their high trunk diameters, the number of trunk per tree, and the tree structure adapted to manual harvesting that strongly influence on transmission of vibration.

Fig. 7. Trunks shaker mounted on a tractor (left) and self-propelled trunk shaker (right).

Harvesting should be done as soon as possible to prevent the fall of the fruits on the soil. Although it is possible to remove the fruit on the soil and then sweep them, this practice is discouraged because the tendency is to get quality oils.

The olive harvest is very dependent on the use of labor for harvesting, manipulating, loading and unloading the fruit down by vibration that not only limit yields overall operation but the increase of costs. New trends in integral mechanical harvesting have to do with managing the removed fruit more than remove the fruit. In recent years, the Department of Rural Engineering of the University of Cordoba is making a great effort to modify and develop the integral mechanical harvesting of traditional olive orchards using canopy shakers. Oxbo 3210 canopy shaker (Fig. 8) designed for citrus harvesting has been tested on traditional olive orchards working in circles around the tree. The removal efficiency exceeded the 80% using the optimal work speed and beating frequency (1.5 km/h and 5 Hz). These first and good results were obtained without pruning adaptation and also suggest the possibility of incorporating a system for catching and loading the fruit, opening a promising way.

The broad tree separation of the traditional olive groves and the rounded shape of the canopy allow the continuous harvesting of fruit around the trees. Although there are olive harvesters that use this removal system, none of the commercial machines can be used in traditional olive. The development of such harvester would provide an alternative for integral mechanization for most of the traditional olive orchards.

Fig. 8. Canopy shaker and catch frame adapted for traditional olive.

One of the most important research lines in olive harvesting is to maximize the percentage of fruit removed. The harvesting efficiency in many cases is dictated by the operational parameters of the machines used and the tree adaptation to mechanical harvesting. The most important parameters are the duration, frequency, acceleration and amplitude of the vibration generated. In recent years, several studies have been performed to get new developments that allow increase harvesting efficiency and minimize damage to tree fruit (Gil-Ribes *et al.*, 2010). Frequency values between 1700-1800 rpm and acceleration values close to 200 m/s^2 are recommended using trunk shaker. The vibration time should not exceed 15 s to limit damage and maximize the removal fruit. Furthermore, it is essential to adapt the olive to mechanization with proper planting design, training and tree pruning, depending on the harvesting system chosen. It has been determined that moderate and severe pruning, leading to a lower canopy density, improve harvesting with trunk shaker because larger and better distributed fruits are obtained. Moreover, this kind of manage reduces olive potential yield, mainly in fertile and irrigated areas.

3. Integral mechanical harvesting of modern olive orchards

Olive integral mechanical harvesting includes three methods: trunks shaker with inverted umbrella, side by side trunk shaker and canopy shaker. The inverted umbrella trunk shaker is the most commonly used. The trees must be adapted with a vertical trunk with more than 1 m long to facilitate clamping and the use of the intercepting structure. Side by side trunk shaker are another alternative based on vibration and fruit interception (Fig. 9). This machine comprises two separate catch frames moving parallel to both sides of the row of trees and one trunk shaker mounted in one of them. This system is only valid for intensive orchards with a row separation higher than 6-7 meters. These systems incorporate continuous discharge on trailer or pallet containers for semiautomatic fruit handling.

Fig. 9. Inverted umbrella trunk shaker (left) and side by side trunk shaker (right) in intensive olive orchard.

Olive straddle harvesters are originated from the grape harvesters (Fig. 10). These machines are self-propelled with hydrostatic transmission and their structure cover the external surface of the trees. Fruit is removed by a number of beating heads formed by curved rods, radial arranged on one or several axes, which transmit the vibration directly to the fruit bearing branches with high frequency and low amplitude. The interception of the olives takes place in the bottom of the tunnel where the fruit is driven by a circulating conveyor with deformable mechanisms that allow folding and sealing with the tree trunk. They also have cleaning systems and storage hoppers.

Fig. 10. Straddle harvester for intensive (left) and high-density hedgerow (right) olive orchards.

The main advantage of the straddle harvester is that it develops a continuous operation with a speed of 0.4-3 km/h. The vibration parameters of these machines are very effective, obtaining greater fruit removal, with efficiencies ranging from 90 to 95% of the fruit production, even for small-fruited varieties and with high fruit retention forces. The small size of the tree canopy, not exceeding 2.0-3.5 m high and 0.80 to 1.20 m wide, is necessary for the use of this machines that move over the tree rods. This is one of the major problems posed by harvesters because it is difficult for many of the varieties to maintain this small size. Giant harvesters such as those used in intensive olive have not been successful in Europe. However, they are commonly used and widespread in the new modern olive groves located in Australia and Argentina. The results are promising, but its size and cost can only be used on large farms, without slope, and with low amounts of rain during the harvesting period.

The canopy shakers have been designed and adapted to various crops such as citrus and vineyard, and currently are being developed for intensive table olives. These systems allow continuous harvesting of the tree, applying vibration on the fruiting branches and reaching high harvesting efficiency levels. Table 5 summarizes the harvesting efficiencies and work yields for different harvesting methods and their application depending on the type of olive orchard.

Table 5. Harvesting efficiency of different harvesting methods according to the type of olive plantation typology

Harvesting method	Olive typology	Harvesting efficiency (%)	Work capacity
Hand harvesting	Traditional and intensive table olive	> 95	105-175 kg men/day
Hand harvesting with rods	Traditional olive	> 95	200-250 kg men/day
Branch shaker and shaker comb	Traditional and intensive olive	> 95	400-500 kg men/day
Trunk shaker mounted in a tractor	Traditional and intensive olive	80-90	0.12-0.20 ha/h
Side by side	Intensive olive	70-85	90-180 tree/day
Giant straddle harvester	Intensive olive	80-90	0.15-0.25 ha/h
Lateral canopy shaker	Traditional and intensive olive	70-80	0.30-0.40 ha/h
Straddle harvester for hedgerow	High-density olive	90	0.70-0.80 ha/h

Canopy shakers systems are based on the same operating principle as the hand harvesting with rods. They are formed by one or more drums rotating rigid horizontal or inclined shafts, radially arranged, which perform the removal by beating the branches. The rods partially penetrate and perpendicular to the tree, shaking branches by oscillatory horizontal motion with low frequency (3-5 Hz) and high amplitude (10-20 cm), sufficient not to break branches or cause serious damage to trees. The vibration is applied to the outer branches where olive production is concentrated resulting in high accelerations in the fruit capable of causing their detachment. The vibration generated parameters are crucial for a good result. Therefore, the shaking process must be adapted to the characteristics of the olive through the characteristics of the vibration generated by the adaptation and crop, mainly by pruning. The damage to branches and fruit are inevitable, but can be reduced by proper system design.

Integral harvesting mechanization necessarily involves adaptation, conversion or restructuring of the olive groves, as appropriate. Pruning is the second most expensive operation just after harvesting because basically is performed by personal equipments, so mechanization of pruning is another issue to resolve in order to ensure the future of this crop. Pruning tests have been performed to compare mechanical pruning against manual pruning, in terms of production and harvesting efficiency using trunk shakers. Dias *et al.* (2008) determined that production over a period of four years is not affected, but harvesting efficiency was reduced in the case of mechanical pruning. Although mechanical pruning is not a widespread practice, it is a future alternative to achieve integral mechanization and cost reduction of the crop. It indicates the importance of accompanying mechanical pruning with thinning of interior branches and dries every 3-4 years to prevent excessive density of the canopy and the accumulation of dead branches.

Among the new advances in research related to the integral mechanization highlights the introduction of new technologies of precision agriculture that has been almost unknown in this sector. These techniques include Global Positioning Systems (GPS), Geographic Information Systems (GIS), automatic control and remote control of the machine, that allow a real time tracking of equipment from a computer, PDA or Tablet connected to network (Perez-Ruiz *et al.*, 2011). Knowledge of the spatial and temporal variation of olive production, tree level, along with the properties of the plot and the distribution of inputs, will carry out a rational decision making to optimize available resources and economic returns olive farms. Fig. 11 shows the first yield mapping and a machinery tracking determined by agriculture precision techniques in traditional olive orchards. The machine tracked was the canopy shaker Oxbo 3210 with a catch frame working in circles around the trees. Through these techniques was possible to determine all olive production per tree and the position of the machine in every moment, obtaining the yield map.

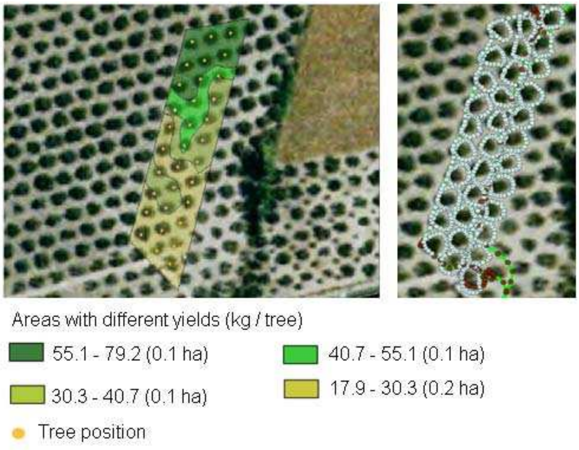

Fig. 11. Yield mapping (left) and machinery tracking (right) obtained using agriculture precision techniques in a traditional olive orchard.

Optimize the machine work is key factor to reducing costs. These technologies provide the ability to perform remote monitoring of equipment and know their real field capacities (Table 6).

Table 6. Work capacities and field efficiencies with the different harvesting systems determined by agriculture precision techniques

Harvesting method	Field capacity (ha/h)	Field efficiency †
Giant straddle harvester	0.15 – 0.20	0.55 – 0.65
Lateral canopy shaker without catch frame	0.35 – 0.40	0.80 – 0.90
Lateral canopy shaker with catch frame	0.30 – 0.40	0.65 – 0.75
Straddle harvester for hedgerow	0.70 – 0.85	0.60 – 0.75

†Useful work time.

4. Mechanical harvesting of table olives

Table olive crop presents specific limitations to mechanical harvesting due to the early time for harvesting in which fruit are harvested prior to coloration. The major impediments are the high incidence of bruising, the high fruit removal force and the risk of tree damage (barking). Also, table olive orchards show low adaptation to mechanical harvesting. Therefore, developing mechanical harvesting will require identifying a successful removal technology that allows at the same time fruit and tree damage reduction and increase of fruit removal.

Table olive crop presents specific limitations to mechanical harvesting due to damage to the tree by barking, because of its early time for harvesting and the damage to the fruit (bruise) that require specific developments adapted to their conditions: the low adaptation of the table varieties to mechanical harvesting and the greater retention force.

The percentages of table olives removed using the best commercial trunk shakers are between 70 and 75%. If the machine is adapted to the tree and vice versa, it is possible to achieve 85% of harvesting efficiency acting on the following aspects: (i) reducing the fruit retention force; and (ii) increasing the transmission of vibration from the trunk shaker to the fruit bearing branches by adjusting frequency, acceleration and vibration time required to maximize the amount of harvested fruit, and pruning adaptation to crop harvesting machinery.

There are several possible options to reduce the amount of fruit damaged by mechanical harvesting: (i) vibration less aggressive; reducing unjustified long vibration times; (ii) the employment-promoting fruit abscission, reducing the contact time of the fruit to the tree and therefore damage; (iii) eliminate or reduce the level of impact of the fruit using padded surfaces near the tree; and (iv) improving the management conditions of the fruit after mechanical harvesting: organization of activities, processing and transport at cold temperature, bruise retardants until processing in the industry.

VI – Olive pest and disease management

1. Olive pests and diseases: present status and future prospects

The olive is a woody crop representing a complex agroecosystem in which many organisms from different trophic levels are well balanced. Some of them are phytophagus or pathogens of the olive tree while some others are entomophagous, predators and parasitoids, antagonists of pathogens and even there are some species looking for shelter. The phytophagous or pathogen organisms that feed and/or develop on olive may determine to a great extend if olive can be grown economically in certain situations. Effective olive crop protection thus becomes essential to minimize the losses caused and to ensure that full benefit is drawn from other production inputs. Unfortunately, pest control operations may very often break off the above mentioned agroecosystem balance, giving rise to unsustainable olive farming.

The phytophagous invertebrates species, mainly insects and mites, known to feed and/or develop on the olive tree exceed one hundred, with a rather large group of them being composed of polyphagous or oligophagous species, each having many to a few host plants, respectively, in addition to olive. Some of them have evolved populations or strains adapted to olive so that in those areas olive is preferred to other hosts. A second, smaller group is composed of monophagous or oligophagous species closely associated with the olive tree, and with a few other Oleaceae of the Mediterranean Basin. The species from the first group are usually occasional pests whereas species from the second group that have either evolved on *Olea europaea*, or have populations that in recent times have adapted to olive, may cause economic losses comprising the smooth running of the crop and posing a serious risk for the annual yield. Table 7 gives most of the species from the second group and few from the first one. Most of the thousands of publications on olive insects around the Mediterranean basin concern fewer than a dozen species which are major pests, at least in those countries where olive growing is a key crop. Among them are the key pests, the olive fly *Bactrocera oleae* (Diptera: Tephritidae), the olive moth *Prays oleae* (Lepidoptera: Yponomeutidae), the black scale *Saissetia oleae* (Homoptera: Coccidae), and some secondary but sometimes also key pest such the oleander scale *Aspidiotus nerii* (Homoptera: Diaspididae), the two olive scolytids *Hylesinus oleiperda* and *Phloeotribus scarabaeoides* (Coleoptera: Scolytidae) and the olive pyralid moth *Euzophera pinguis* (Lepidoptera; Pyralidae).

Table 7. List of the most important phytophagous insect and mite species infesting olive tree

Order/ Subclass	Parts of the tree attacked				
	Roots	Stem and branches	Shoots	Inflorescences	Fruit
Hemiptera (Heteroptera - Homoptera)		*Stictocephala bisonia Kopp & Yonke* *Hysteropterum grylloides* (F.) *Saissetia oleae* (Olivier) *Hysteropterum grylloides* (F.) *Cicada barbara* Stalf. *Lepidosaphes ulmi* L. *Parlatoria oleae* Colvée	*Aleurolobus olivinus* Silvestri *Saissetia oleae* (Olivier) *Euphyllura olivina* (Costa) *Parlatoria oleae* Colvée *Cicada barbara* Stalf. *Aspidiotus nerii* Bouche	*Calocoris trivialis* Costa *Euphyllura olivina* (Costa)	*Parlatoria oleae* Colvée *Aspidiotus nerii* Bouche
Thysanoptera			*Liothrips oleae* (Costa)	*Liothrips oleae* (Costa)	
Coleoptera	*Vesperus xatarti* Mulsant *Anoxia villosa* F. *Melolonta papposa* Illiger *Ceramida cobosi* (Báguena)	*Phloeotribus scarabaeoides* (Bernard) *Hylesinus oleiperda* F. *Leperesinus varius F.= L. fraxini* Panzer *Sinoxylon sexdentatum* Olivier	*Otiorrhynchus cribricollis* (Gyllenhall)	*Anoxia villosa* F. *Rhinchites cribipennis* (Desbr.)	
Lepidoptera		*Euzophera pinguis* Haworth *Cossus cossus* L. *Zeuzera pyrina* L.	*Prays oleae* (Bernard) *Margaronia unionalis* (Huebner)	*Prays oleae* (Bernard)	*Prays oleae* Bern.
Diptera		*Resseliella oleisuga* (Targioni-Tozzetti)	*Dasineura oleae* (F. Loew)		*Bactrocera oleae* (Rossi)
Acarina			*Aceria (Eriophyes) oleae* Nalepa		

Olive pathogens also exceed one hundred, although only a few of them cause serious economical losses on olive groves. The main olive diseases described around the world and their relative importance in the Mediterranean basin are given in Table 8. One important group is the 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 three diseases cause heavy defoliation and weakening of olive trees, reduce plant productivity and quality of olive oil, and are responsible for regular fungicide treatments in the olive groves. Another important disease is *Verticillium* wilt caused by the vascular fungus *Verticillium dahliae*. This disease was unknown 30 years ago, and currently is considered the most serious disease and the main challenge for olive growing in some Mediterranean regions, such as in southern Spain. Other diseases having a moderate impact on olive groves in the Mediterranean basin are tuberculosis or olive knot caused by the bacterium *Pseudomonas savastanoi* pv. *savastanoi*, which is associated with wounds on leaves and branches, and a root and crown rot caused by several species of the oomycete genus *Phytophthora*, especially prevalent in water-logged soils (Trapero and Blanco, 2010).

These olive pests and diseases represent a clear restriction on olive oil production due to the reduction in yields and to the increase in total production costs. It is estimated that losses associated with the action of olive pests and diseases account for approximately 30% of the olive production, with 10% being allocated to the two major insect pests, *B. oleae* and *P. oleae*, and more than other 10% due to three diseases, peacock spot, *Verticillium* wilt and anthracnose. Accordingly to the International Olive Oil Council, approximately 30% of the olives produced in the Mediterranean region are lost to pests and diseases, with an annual control of pests and diseases of olive exceeding 200 million euro, 50% of which are for insecticides and fungicides, regardless of the cost of the side effects that these entail. Therefore, given the economic and social importance of this crop, olive-growing and olive protection practices should be carried out timely and under the criteria that encourage sustainability in agriculture.

Table 8. Major olive tree diseases

Disease	**Pathogen**	**Importance[1]**
FUNGAL AERIAL DISEASES		
Peacock spot	*Fusicladium oleagineum* (=*Cycloconium oleaginum, =Spilocaea oleagina*)	H
Anthracnose	*Colletotrichum acutatum* *C. gloeosporioides (=Gloeosporium olivarum)*	M
Cercosporiose	*Pseudocercospora cladosporioides* (=*Cercospora cladosporioides*)	M-L
Sooty molds	*Capnodium elaeophilum* *Botryosphaeria dothidea* *(= Camarosporium dalmaticum)*	L
Dalmatian disease	*Phlyctema vagabunda* *(=Gloeosporium olivae)*	L
Leprosy	*Alternaria, Aspergillus, Cladosporium, Diplodia*	L
Other fruit rots	*Geotrichum, Fusarium, Phomopsis,* etc.	W
Other leaf diseases	*Leveillula, Phyllactinia, Stictis panizzei,* etc.	W
Cankers	*Neofusicoccum mediterraneum* *Eutypa lata, Phoma incompta*	L
Wood decay	*Fomes, Fomitiporia, Phellinus* *Polyprous, Stereum,* etc	L
FUNGAL ROOT DISEASES		
Verticillium wilt	*Verticillium dahliae*	H
Woody root rots	*Armillaria mellea, Rosellinia necatrix* *Omphalotus olearius*	L
Fine root rots	*Phytophthora, Cylindrocarpon* *Fusarium, Pythium,* etc.	M-L
BACTERIAL DISEASES		
Tuberculosis or olive knot	*Pseudomonas savastanoi* pv. *savastanoi*	M
VIRUS AND PHYTOPLASMA DISEASES		
Foliar and fruit malformations	Unidentified virus and phytoplasma species	W
Latent infections, Yellowing	*Nepovirus, Cucumovirus*, *Oleavirus,* etc.	W
NEMATODE DISEASES		
Root knot, root lesion	*Meloidogyne, Pratylenchus,* etc.	W
PARASITIC PLANTS		
Mistletoes, Dodder	*Viscum, Cuscuta*	W
ABIOTIC		
Nutrient deficiencies	Boron, Iron, Potassium, etc.	M-L
Different damages	Frost, drought, soil water-logging, etc.	M-L

H = high; M = moderate; L = low; W = without general practical importance, although severe attacks have been observed occasionally.

One key issue in olive growing is the threat of new and/or emerging pests or pathogens which can potentially cause significant losses. The most predominant way is by invasion of alien species or pathogenic races which is usually related to human activities (i.e., trade) and/or natural migration, but in olive crops it is more commonly detected the emergence of new pests or pathogens due to the transformation of an indigenous species from an organism of minor significance to an important pest or disease. This could be related to various human activities affecting the established equilibrium in the olive agro-ecosystem, with emphasis in cultivation practices (high density plantations) or crop management practices (pruning, intensive application of insecticides, etc). Finally, it is not well known how the global warming could affect the incidence of the actual olive pest or pathogens and the emergence of new ones.

2. Olive growing and pest or pathogen incidence

In general, biodiversity tends to be high in traditionally managed olive plantations as their structural diversity (trees, under storey, patches of natural vegetation, dry-stone walls, etc.) provides a variety of habitats. The older trees support a high diversity and density of insects and microorganisms which, together with the tree's fruit, provide an abundant supply of food. The low level of pesticide use allows a rich flora and insect fauna to flourish which in turn provides a valuable food source for a variety of bird species. However, the intensive application of techniques for increasing production (especially frequent tillage and heavy herbicide and insecticide use) has a strongly detrimental effect on ground flora, microorganisms and on insect populations and results in a very considerable reduction in the diversity and total numbers of flora and fauna. Some of the agro-chemicals used in olive farming have been found to cause a dramatic reduction in a wide spectrum of insect species, including several which have a beneficial role in controlling pest species.

It is mandatory using **certified material** from officially licensed producers which is particularly important to avoid later problems associated with scales, mealybugs and other biting sucking insects. Certified material is crucial, not only with regards to the variety or quality of the plant, but also regarding its health. This is especially important in the case of pathogens that cause systemic infections (*V. dahliae*, viruses and phytoplasmas), as well as those remains associated to the plant material and cannot be easily detected, such as the epiphytic stage of *P. savastanoi*, the latent infections due to *F. oleagineum* and the infections caused by fungi or nematodes on roots. This is no rare that symptoms of some of these diseases appear months or years after planting the trees.

The incidence of **fertilization** on insect pests incidence is notorious in olive crops. It has been observed that excessive use of nitrogen fertilizer results in the emergence of many new shoots that facilitates a high percentage of neonate nymphs of *S. oleae* to find suitable settlement sites. Thus, regulation aims at reducing nitrogen fertilization as a measure to reduce the incidence *S. oleae*. Nonetheless, balanced mineral olive nutrition improves not only the nutritional status of the trees but also their defense mechanisms, avoiding those herbivores that develop easily on weakened trees such as *E. pinguis* or *H. oleiperda*. Likewise, it is accepted that the excess of nitrogen and the deficiency of potassium increases the susceptibility of olive trees to fungal foliar pathogens (mainly peacock spot) and verticillium wilt.

Irrigation may also exert influence both on olive vegetative state that promote the development of mites, scales and olive fly and on soil microclimate that may help *O. cribricollis* and white grubs incidence. With regard to diseases, irrigation increase activity of root pathogens (*V. dahliae*, *Phytophthora* spp., etc) causing more severe infections. Furthermore, irrigation water can contribute to pathogen dispersal. Both possibilities have been confirmed for the verticillium wilt of olive, so this disease is especially severe in irrigated olive groves.

Soil management system has been revealed to influence not only phytophagous populations and soil-borne pathogens but also the predator, parasitoids and antagonist ones. For this purpose, information of the effect of different olive soil management strategies such cover crops and organic amendments on pest and disease incidence and efficiency and abundance of natural enemies is scarce, although some well known effects of cover crops are the reduction of soil-borne inoculum of *V. dahliae* due to some crucifer species and the increase of leaf infection by *F. oleagineum* due to the higher humidity on the lower parts of tree canopy. Nonetheless, conservation of natural vegetation boundaries, hedges, isolated trees, edges, etc., is mandatory in the Spanish regulation.

Overall, conventional olive crop management has a negative impact on the abundance of canopy spiders and to a lesser extent on their diversity whereas they would benefit from an Integrated Pest Management (IPM) strategy. Likewise, cover crops also promote spider populations, whereas this effect is higher in the natural than in the planting ones. In general, plowing may help eliminating different stages of soil dwelling pests and reducing inoculum of pathogens that survive on fallen leaves, but also destroying nests of natural enemies that limits their beneficial action and favoring inoculum dispersal of some soil-borne pathogens such as *V. dahliae*.

Pruning is an agronomic practice with large impact on the incidence of pests and pathogens and even on their control. Its effect on phytophagous insects and aerial pathogens is due to the modification of the microclimate of the tree canopy and also to the reduction of inoculum after removing affected parts of olive tree. Favoring tree aeration through pruning reduces incidence of insects *S. oleae*, *P. oleae, L. ulmi* and the aerial pathogens *F. oleagineum*, *Colletotrichum*, *P. cladosporioides* and *P. savastanoi*. Besides, high pruning intensity may cause intense growth of tender shoots and finally promote olive scales activity. Avoiding pruning wounds will decrease the incidence of *E. pinguis* and wood decay fungi; for this purpose it is very important to protect wounds against pests and aerial pathogens.

Management of pruning remains is a far-reaching social practice that it is well regulated; they must be removed and destroyed prior to bark beetle emergence. Furthermore, control of the olive bark beetles *P. scarabaeoides* and *Hylesinus* spp and even the bark mosquito *R. oleisuga* can be accomplished by placing bait trunks that must be destroyed or treated with insecticides prior to adult emergence. Moreover, leaving water sprouts may prevent shoots against *O. cribicollis* attack as far as this species prefers the former.

Harvesting method and time may also influence the activity of certain insects and pathogens. It is known that wounds caused by beating promote *R. oleisuga, E. pinguis* and *P. savastanoi* activity. In general, it is recommended early harvesting to indirectly increase the olive oil quality by reducing olive fly activity and fruit rots caused by *Colletotrichum* spp. and other fruit rot fungi.

The **plantation density** of olive groves is determined by agronomic, climatic and economic criteria, but can have a great impact on the development of pests and diseases, especially in dense plantations, which favor shady areas between trees and therefore increase leaf wetness duration and infections by aerial pathogens (Trapero, 2007). Furthermore, in the current scenario of olive growing in Spain, one wonders whether considered secondary pests and diseases to conventional plantations, with occasional or local economic importance, may be become a problem in the new high density plantations. This kind of plantations possesses in most cases irrigation-related high soil humidity that might create a favorable environment to pests and pathogens due to high soil humidity and large fruits. Likewise, it has been demonstrated that irrespective of the 10 evaluated Spanish oil varieties, olive tree susceptibility to the olive fly *B. oleae* is higher under irrigated conditions that under rainfed conditions where the high relative humidity is favorable for its biology and the large olive fruits seems to be more attractive for oviposition (Santiago-Álvarez *et al.*, 2010). Besides, there are several reports on the need to perform control measures against new pests (i.e. *Margaronia unionalis*) and diseases (i.e. alternaria fruit rot) on such high density olive plantations (León *et al.*, 2007).

Pruning is a key operation in order to control the necessary tree vigor in such high density plantations, particularly in the hedgerow ones. Even if regular pruning following established codes of practice is performed, pruning wounds are targets for olive pyralid moth *E. pinguis* oviposition. Besides, this pyralid is becoming a serious pest of olive crops in Spain, Portugal, etc., and even in many areas it is becoming a key pest. Likewise, olive knot is becoming a key disease in the hedgerow systems that need to increase control measures due to increased wounds caused by harvesting and pruning.

Although there are more than 2000 olive tree varieties around the World, **genetic resistance** has not been used on purpose as a measure for the control of olive pests and diseases, because productivity and environmental adaptation criteria are taken into account when choosing a variety for planting. Now there is a great interest in the search for varieties better adapted for developing high density plantations. The most important criteria in the selections of the olive breeding programs to obtain new cultivars better adapted to such type of plantations are tree size and shape and resistance to *V. dahliae*. For this purpose, susceptibility of such new cultivars to key olive pests and diseases, such *B. oleae, F. oleagineum, Colletotrichum* spp. or *P. savastanoi*, should not be underestimated. Most olive high density plantations are based nowadays on the use of the available cultivars ‘Arbequina’ and ‘Arbosana’, followed by ‘Koroneiki’. Providently, susceptibility of ‘Arbequina’, ‘Arbosana’ and ‘Koroneiki’ to olive fly attack is very low (Quesada-Moraga *et al.*, 2010). However, these cultivars are susceptible to the three pathogens above mentioned with the exception of ‘Koroneiki’ that is moderately resistant to *F. oleagineum* and *Colletotrichum* spp. Because of the relatively high soil moisture, low biodiversity and high productivity, high density olive plantations seem to be very prone to pests and diseases. For this purpose, it is essential to monitor many olive trees that are well distributed through the orchard and to follow the same inspection route throughout the season.

Choosing a tolerant cultivar makes integrated pest management easier and reduces production costs by reducing chemical inputs. On the other hand, a limited number of susceptible trees in the orchard could act as "traps" for monitoring or controlling pests. This practice, however, is not convenient for disease management because it increases inoculum of the pathogens in olive traps.

3. Sustainable olive pest control

Current olive pest and disease management strategies are still based on the use of chemical pesticides, either in traditional Mediterranean olive groves or intensively managed olive plantations. However, increasing public sensitivity towards environmental pollution in this key Mediterranean agro-system and problems derived from the side effects of these products has provided the impetus for the development of alternative, benign pesticides. Likewise, Regulation (EC) 848/2008 of the European Commission resulted in a drastic reduction in the number of authorized active ingredients for olive pest control and a more limited reduction in the authorized fungicides for disease control.

Further, the prevailing environmental awareness, and the high prevalence of Sustainable Agriculture as a guiding principle of EU agricultural policies has led to the European Parliament to the establishment of a framework for Community action to achieve a sustainable use of pesticides which under the shelter of the concept of Integrated Pest and Disease Management (IPDM or IPM), prioritize non-chemical methods of pest control. Accordingly, from January 1, 2014 in Europe will only accommodate the olive pest control according to the principles of IPM.

IPM strategy developed in the 1960s and 1970s is based on ecological principles. It encourages reduced reliance on pesticides through the use of a number of control strategies in a harmonious way to keep pests and diseases below the level causing economic injury. It came out of the realization that too heavy a reliance on pesticides (particularly those with broad-spectrum activity) can cause major problems, notably effects on human health and safety, environmental contamination, pesticide resistance in target and non-target organisms, resurgence of secondary pests, plant damage or yield loss (phytotoxicity), residues on fruit and products, with national and international consequences. There is also general community concern about the use of pesticides, particularly on foods.

IPM commonly utilizes or encourages biological control through natural enemies such as predators, parasites, insect pathogens and non-pathogenic antagonistic or competitive microorganisms. It also frequently involves cultural control strategies to minimize pest and disease entry and their spread in space and time. Cultural controls include protocols of entry to farms; manipulation of the field environment to discourage pests and diseases, such as opening crop canopies to increase air movement and reduce humidity; the elimination of alternative hosts for pests; or growing nectar and pollen-producing plants to encourage natural enemies. IPM may also involve the physical destruction of infested and infected materials and the use of tolerant or resistant plant species, where available. Chemical pesticides are used judiciously, and thus play a supportive role.

The major components of IPM systems are: (i) identification of pests, diseases and natural enemies; (ii) monitoring of pests, diseases, damage and natural enemies; (iii) selection of one or more management options on the basis of monitoring results and action thresholds, from a wide range of pesticide and non-pesticide options; and (iv) use of selective pesticides targeted at the pest or disease for instance, pesticides that will interfere least with natural enemies, targeted only at infested trees or parts of trees.

As an example, the Agricultural Entomology group of the University of Cordoba, Spain, has studied the susceptibility of 20 Spanish olive oil cultivars to the olive fly *B. oleae* under rainfed and irrigated conditions. We have found highly significant differences among oil and table varieties in their susceptibility to olive fly attack, with the most susceptible oil varieties being 'Nevadillo Blanco de Jaén', followed by either 'Picudo' and 'Lechin de Sevilla' and the least ones 'Arbequina' followed by 'Empeltre', while the most susceptible table varieties were ‘Ascolana Tenera’ and ‘Gordal Sevillana’ and the least ones ‘Callosina’ and ‘Kalamón‘. On the overall, for each cultivar, susceptibility to *B. oleae* was higher under irrigated conditions than under rainfed ones.

Currently, bioinsecticides are considered the most viable alternative for olive pest control. Nonetheless, not all entomopathogenic microorganisms invade susceptible hosts in the same way. While viruses, bacteria, and protozoa have to be ingested with food, entomopathogenic fungi (EF) enter 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. Besides, EF have a dual role as bioinsecticides as they may used both as microbial control agents and also as an unexplored source of new insecticide molecules of natural origin. Our work has revealed the elevated occurrence of the mitosporic ascomycetes *Beauveria bassiana* and *Metarhizium anisopliae* in the soil of olive crops but also in the olive and olive weeds phylloplane. Besides, it has been found *B. bassiana* as a natural biocontrol agent of the olive moth *Prays oleae* and the olive pyralid moth, *Euzophera pinguis*. It has been shown that these native isolates are in general well matched to the particular olive crop environmental conditions. Among them, there are several isolates that show potential to be used against medfly both in adult sprays and in soil treatments beneath the tree canopy for puparia control, and even one *B. bassiana* isolate obtained from an infected larva of *E. pinguis* with high biocontrol potential against this pyralid in stem and branch (pruning bounds) (Spanish Patent P201030539) (Quesada-Moraga and Santiago-Álvarez, 2008).

The demand for natural insecticidal compounds to be incorporated in pest control programs in IPM grows each day as they degrade more quickly and possess excellent ecotoxicological profile. Example of this is inclusion of spinosad, secondary metabolite produced from the fermentation of the actinomycete soil *Saccharopolyspora spinosa* in the regulation of organic farming. Among the microorganisms, entomopathogenic fungi which share the same ecological niche that phytophagous insects, fulfill all criteria of the "intelligent screening" in the search for new insecticidal compounds of natural origin. Secondary metabolites and macromolecules secreted in vitro by several *M. anisopliae* isolates from our strain collection have shown high insecticidal activity against adult tephritids that may be developed as new insecticide molecules of natural origin for medfly control (Quesada-Moraga and Santiago-Álvarez, 2008).

With regard to olive diseases, a big piece of research has been developed in the Department of Agronomy at the University of Córdoba during the last 20 years (Trapero and Blanco, 2010). Results have characterized the epidemics of main diseases, including the complex of fungal aerial diseases (peacock spot, anthracnose and cercosporiose), *Verticillium* wilt, phytophthora root rot and olive knot, as well as the epidemics of new diseases such as alternaria and botryosphaeria fruit rots and a branch canker caused by *Neofusicoccum mediterraneum*. This information together with results of research on different control methods (physical, cultural, biological, genetic resistance and chemical) are serving to define integrated control programs for each disease and implement a comprehensive strategy for integrated management of pests and diseases in commercial groves.

References

AEMO, 2012. Aproximación a los costes del cultivo del olivo. In: *Jornadas técnicas de la Feria del Olivo del Montoro*. Córdoba, Spain.

Bartolini *et al.* Olea databases : http://www.oleadb.it

De la Rosa R., León L., Guerrero N., Rallo L. and Barranco D., 2007. Preliminary results of an olive cultivar trial at high density. In: Aust. J. Agr. Res., 58, p. 392-395.

Dias A.B., Peça, J., Pinheiro A., Santos L., Morais N. and Pereira A.G., 2008. The influence of mechanical pruning on olive production and shaker efficiency. In: *Acta Horticulturae.* 791, pp. 307-313.

EC (2008). Commission Regulation (EC) No 848/2008 of 28 August 2008 amending Regulation (EC) No 2076/2002 and Decision 2003/565/EC as regards the time period provided for in Article 8(2) of Council Directive 91/414/EEC. Official Journal of the European Union, L 231/9.

Fernández-Escobar R. 2007. Fertilization In: *Production techniques in olive growing*. Madrid, Spain: International Olive Council, p. 145-168.

Fernández-Escobar R., 2008. Olive fertilization practices in the Mediterranean region. In: *Olivae,* 109, p. 13-22.

Fernández-Escobar R., 2011. Use and abuse of nitrogen in olive fertilization. In: *Acta Horticulturae,* 888, p. 249-258.

Fontanazza G., Bartolozzi F. and Vergari G., 1998. Fs-17. In: *Riv. Frutticoltura,* 5, p. 61.

Gil Ribes J.A., López Giménez F.J., Blanco Roldán G.L. and Castro García S., 2010. Mecanización. In: *El Cultivo del Olivo.* Madrid, Spain: Mundi-Prensa-Junta de Andalucía, p. 434-506.

Gómez J.A., Giráldez J.V. and Vanwalleghen T., 2008. Comments on "Is soil erosion in olive groves as bad as often claimed?"by L. Fleskens and L. Stroosnijder. In: *Geoderma*, 147, p. 93-95.

Gómez J.A., Llewellyn C., Basch G, Sutton P.B., Dyson J.S. and Jones, C.A., 2011. The effects of cover crops and conventional tillage on soil and runoff loss in vineyards and olive groves in several Mediterranean countries. In: *Soil Use and Management,* 27, p. 502-514.

Green P.S., 2002. A revision of Olea L. In: *Kew Bull.*, 57, p. 91-140.

Gucci R. and Caruso G., 2011. Environmental stresses and sustainable olive growing. In: *Acta Horticulturae,* 924, p. 19-30.

Lavee S., Haskal A. and Wodner M., 1986. 'Barnea' a new olive cultivar from first breeding generation. In: *Olea,* 17, p. 95-99.

León L., De la Rosa R., Rallo L., Guerrero N. and Barranco D., 2007. Influence of spacing on the initial productivity of hedgerow 'Arbequina' olive orchards. In: *Spanish Journal of Agricultural Research,* 5, p. 554-558.

Melgar J.C., Mohamed Y., Serrano N., García-Galavís P.A., Navarro C., Parra M.A., Benlloch M. and Fernández-Escobar R., **2009.** Long term responses of olive trees to salinity. In: *Agricultural Water Management*, 96, p. 1105-1113.

Moriana A., Orgaz F., Pastor M. and Fereres E., 2003. Yield responses of a mature olive orchard to water deficits. In: *Journal of the American Society for Horticultural Science,* 128, p. 425-431.

Orgaz F., Testi L., Villalobos F.J. and Fereres E., 2006. Water requirements of olive orchards - II: determination of crop coefficients for irrigation scheduling. In: *Irrigation Science*, 24, p. 77-84.

Pérez-Ruiz M., Carballido J., Agüera J. and Gil J. A., 2011. Assessing GNSS correction signals for assisted guidance systems in agricultural vehicles. In: *Precision Agriculture,* 12, p. 639-652.

Quesada-Moraga E. and Santiago-Álvarez C., 2008. Hongos Entomopatógenos. In: *Control biológico de plagas.* Navarra, Spain: Phytoma Publicaciones de la Universidad Pública de Navarra, p. 98-120.

Quesada-Moraga E., Santiago-Álvarez C., Casado G., Campos C., Rallo L., Caballero J.M. and del Rio C., 2010. Evaluation of susceptibility to olive fly *Bactrocera oleae* (Gmelin) attack in the olive world germplasm bank of Córdoba. In: *IOBC/wprs Bull* , 59, p. 126.

Rallo L., Barranco D., De la Rosa R. and León L., 2008. 'Chiquitita' olive. In: *HortScience,* 43, p. 529-531.
Ravetti L. and Robb S., 2010. Continuous mechanical olive harvesting in modern Australian Growing systems. In: *Adv. Hort. Sci.,* 24, p. 71-77.
Santiago-Álvarez C., Del Rio C., Casado G., Campos C. and Quesada-Moraga E., 2010. Variation of susceptibility to olive fly *Bactrocera oleae* (Gmelin) attack in ten olive Spanish commercial oil cultivars under dry and irrigated conditions. In: *IOBC/wprs Bull* , 59, p. 104.
Taguas E.V., Burguet M., Pérez R., Ayuso J.L. and Gómez J.A., 2012. Interpretation of the impact of different managements and the rainfall variability on the soil erosion in a Mediterranean olive orchard microcatchment. In: *Annual meeting of the European Geosciences Union*. Vienna, Austria.
Testi L., Villalobos F., Orgaz F. and Fereres E., 2006. Water requirements of olive orchards: I simulation of daily evapotranspiration for scenario analysis. In: *Irrigation Science*, 24, p. 69-76
Tous J., 2011. Olive Production Systems and Mechanization. In: *Acta Hort.,* 924, p. 169-184.
Trapero A. and Blanco-López M.A., 2010. Diseases. In: *Olive growing.* Junta de Andalucía/Mundi-Prensa/RIRDC /AOA, Australia. p. 521-578.
Trapero A., 2007. Densidad de plantación y enfermedades del olivar. In: *Mercacei*, 51, p. 210-213.
Van Walleghem T., Infante J., González de Molina M., Soto D. and Gómez J.A., 2011. Quantifying the effect of historical soil management on soil erosion rates in Mediterranean olive orchards. In: *Agriculture Ecosystems and Environment*, 142, p. 341-352.