CLIMATE CHANGE MITIGATION THROUGH A SUSTAINABLE SUPPLY CHAIN FOR THE OLIVE OIL SECTOR

Plant growth, plant production, quality of products, intake/uptake balance at field level, in arid and temperate climatic conditions before and after the implementation actions

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1. Introduction

Olive is extensively grown in the areas characterized by a Mediterranean climate, with cold rainy winters and hot dry summers. However, environmental conditions can sensibly vary also within the Mediterranean basin, mainly due to the current climatic change scenario.

The olive tree (*Olea europaea* L.) has represented an integral component (as a crop plant, fruit and oil) of the Mediterranean diet for millennia to the extent that a coevolution between Mediterranean inhabitants and olive has been proposed (Ortega 2006; Zeng et al. 2015). At present, the recognition of olive products as functional food has renewed interest in their consumption (Shahidi & Kiritsakis, 2017).

The specific drought tolerance mechanisms developed by olive, as a subtropical evergreen tree, have greatly contributed to its longstanding success in dry and warm areas (Dichio et al. 2013). However, olive cultivation in the Mediterranean area is now suffering due to competition with products deriving from super-intensive plantations, with those from new olive-growing areas of South and North America, Australia, South Africa and some Asian areas, and as a consequence of the reduction of the European support to olive oil production. The socio-economic constraints, joined with a continuous seasonal threat to flowering and fruiting and the risk of new pathogen onset, are leading to a serious vast abandonment of the olive groves and their replacement with other more profitable crops (Rodrigo-Comino et al. 2017).

Up to 98% of the global olive growing area (10.2 Mha) is cultivated in the Mediterranean basin (FAOSTAT 2017) under traditional cropping systems (80–100 plants ha^{-1}), while a limited fraction (~1%) has recently shifted toward intensive (200–500 plants ha^{-1}) or even super-intensive (up to 2,500 plants ha^{-1}) cropping systems (Tous et al. 2010). The main reason that fosters the change of grove design is the need to increase crop profitability through the reduction of costs per unit yield. However, the potential for change in that crop design is limited because olive is cultivated mainly in marginal hilly areas (Xiloyannis et al. 2008) unsuitable for high density plantations. Hence, identifying alternative strategies to improve the profitability of olive groves is highly desirable for socio-economic reasons and ecological and landscape conservation. However, there is very little information on the behaviour of the most popular cultivars under different climatic conditions. Even less information is available on the interaction of olive cultivars with environment (León et al., 2016; Rondanini et al., 2014; Sadok et al., 2015). Also, cultivar comparative trials are very scarce in olive. These trials are necessary to evaluate the potential of the different olive cultivars in different growing areas. In order to characterize the potential of a cultivar in a given environment, both vigour and production characters should be taken into account. The most important trait related to vigour is the canopy volume, as it determines the suitability of a cultivar to different growing systems (Díaz-Varela et al., 2015; León et al., 2015). Fruit traits are also crucial to determine the potential for productivity of a cultivar in a given environment in terms of oil quantity and quality (Lavee, 2013; León et al., 2016).

We have performed a network of comparative trials among many olive cultivars distributed in areas with different environmental conditions and here we report the results obtained from these studies.

The olive tree is considered a thermophilic species and its area of natural diffusion includes the coastal strip of the Mediterranean, where it adapts to extreme environmental conditions, such as drought and low temperatures.

The crop is distributed between 25°-40° parallels of north latitude and south and is mainly concentrated in the Mediterranean, with mild, rainy winters and hot, dry summers.

Tolerance to water stress

The annual rainfall of 400-700 mm is suitable for growing olive without irrigation, but supplementary water inputs during the summer can increase the production of fruits by 30-50%, although with a slight reduction in the fruit oil percentage.

The ideal relative humidity (RH) is around 40-65%, while more than 80% RH during flowering can cause the fall of flowers, pollination failure and settlement of fungal diseases.

The olive is a xerophilous plant, able to withstand extreme drought conditions, while maintaining a good balance between intake and water dispersion. Thanks to its xerophitic characters, olive is cultivated in many areas characterized by low rainfall and long periods of summer drought. The available data indicate that over 85% of the olive groves are cultivated under dry conditions and less than 15% benefits from irrigation (mostly relief).

The olive tree is a species known to be tolerant to water stress due to numerous anatomical adaptations and physiological mechanisms that allow the plant to maintain vital functions even under very severe stress. Among these are:

- the presence of stellar hairs in the underside of leaves;
- the reduced number of stomata (density 200-700 mm^{-2}), inserted in small depressions in the lower surface, with consequent limitation of transpiration;
- the reduced diameter of the xylem vessels;
- the ability of the olive root system to use water from the ground with soil water potential below the commonly reported values, as wilting point for other species;

- the ability to carry out leaf photosynthetic activity and transpiration also at leaf water potential of -6, -7 MPa;
- the effective regulation of stomata that allows to modulate gas exchange according to variations in atmospheric evaporative demand so as to reduce the transpiration rate;
- a photosynthetic capacity by 50% when the availability of soil water is at 40% of field capacity;
- a high capacity of the species to increase the ratio between roots and foliage in water deficit conditions, enabling an increase in the volume of soil explored by the roots.

The olive tree is a plant with long photoperiod and benefits from prolonged sunlight (from 2,400 to 2,700 hours of direct sunlight). It is moderately tolerant to salinity and irrigation with sub-saline waters.

Although irrigated areas will increase for olive cultivation in the near future, water scarcity, in the Mediterranean basin and in the new countries where cultivation is expanding, will limit or restrict the use of fresh water in agriculture, especially in most coastal areas, where olive is mainly cultivated. Furthermore, salinity is becoming a major problem due to the high rates of evaporation, insufficient leaching and a large quantity of saline water used for olive irrigation (Carr et al., 2013).

Considering the knowledge already known available about the olive response to drought stress and the great variability of this character among many varieties, some experiments have been performed in order to evaluate the plant growth, plant production and the quality of production in four different zone, olive irrigated field, rainfed olive field, arid olive cultivation zone and temperate zone.

Tolerance to salt stress

Plant tolerance to salinity stress involves the activation of physiological complexes, metabolic pathways and molecular networks.

A deeper understanding on how olive plants respond to different levels of salinity stress and the development of integrated info on the genetic, epigenetic and physiological changes in plants under stress will represent important pre-requisites for the development of salt-tolerant varieties (Mousavi et al., 2019; Zhang and Shi, 2013).

In fact, there is an increasing requirement to develop varieties with enhanced tolerance to drought and salt stress, to enlarge the area of cultivation towards dry areas or salty soils and to face new climate change scenarios.

Understanding the reprogramming events that plants put in place in response to environment changes is of longstanding interest for plant breeders.

Among defence mechanisms, a number of regulatory and/or protective proteins involved in plant tolerance to different stresses, have been identified. Climate affects practically all physiological processes throughout the life cycle of plants (Osborne et al. 2000). Among all biological phases, flowering is the most critical for every fructiferous plant. Olive floral phenology is characterised by bud formation during summer, dormancy during autumn, budburst in late winter, and flowering in late spring (Fernández-Escobar et al. 1992; Galán et al. 2005).

The fatty acid profile of olive oil is an important quality attribute and is used to verify its genuineness and origin (IOOC, 2001). Variety is the main determinant of fatty acid composition, but environmental factors are strongly linked to variations in quality. Changes in quality between years (Bodoira et al., 2016), or locations (Rondanini et al., 2014) have been attributed to climatic differences. Oleic acid concentration, the main fatty acid of olive fruit and oil, generally decreases as latitude or altitude decreases (Mailer et al., 2010; Ceci and Carelli, 2010; Orlandi et al., 2012).

PLANT GROWTH

Plant growth of olive varieties typical of arid areas (cvs. Chemlali and Chetoui) in comparison to others traditionally grown in temperate regions of Spain and Italy (Arbequina, Coratina and Frantoio) was measured in plants (18-year-old plants) growing in four different environments, including an arid and a temperate area, in irrigated or rainfed fields (4-year-old plants) (Table 1). In order to compare their growth, three main parameters were measured: trunk diameter, plant height and canopy width. All data represent the mean of three plants for each cultivar (Table 2).

The results clearly showed the higher plant growth in arid zone with 197.5 mm of annual precipitation and 224 mm annual irrigation, especially during spring and summer, when temperatures are high, while in temperate zone, with 862 mm annual precipitation, especially during autumn when temperatures are low, without irrigation plant growth was lower. Hot climates, characterized by high temperatures and long vegetative season, can induce a great vegetative growth when very high irrigation levels are applied. Plant growth including shoot elongation, trunk expansion, canopy volume and pruned biomass can be strongly influenced by irrigation levels (Correa-Tedesco et al., 2010).

The intensification of olive orchards, in terms of water and fertilizer supply, may lead to excessive plant growth that could be controlled by decreasing irrigation levels without compromising yield (Girona et al., 2002; Lavee et al., 2007; Pastoret al., 2007).

The comparison of plant growth in two fields, respectively under irrigated and rainfed conditions, showed approximately the same growth in three cultivars. Observations on plants flowering, showed that for almost all analysed cultivars, the flowering index was higher in irrigated field than in the rainfed one. These results suggest the importance of the natural raining period or irrigation supply to better manage plant growth and flowering (Table 3).

In a study on plant growth and yield response under different irrigation levels, it has been shownthat when the highest annual rainfall (i.e., 100–400 mm) occurs during the summer, in contrast to the winter rainfall of the Mediterranean, and temperatures are high for much of the year, the timing of phenological events may be modified, affecting flowering time, vegetative growth patterns, oil quality, and yield potential (Correa-Tedesco et al., 2010).

Monitoring plant growth of cultivars originating from arid areas

The plant growth of cultivars originating from arid regions was monitored in an irrigated field and all cultivars growed approximately with the same rate, excepting for the cultivar Chemlal de Kabylie from Algeria that resulted the more vigorous respect to all other cultivars (Table 4), meanwhile in the rainfed field, the cultivar Chetoui from Tunisia was the most vigorous one. It is important to note that from three plant replicates per cultivar, the cvs. Khalkali, Chemlali and Kadesh resulted less adapted than other cultivars to this environment, and at least one of the three plants died. Under non irrigated conditions, the Spanish cultivar Picual was the most vigorous one, while the cultivar Souri from Lebanon grew more than others in a temperate zone.

PLANT PRODUCTION

Fruits were harvested from each of the three trees, randomly chosen around the canopy and promptly transferred to the laboratory. From each sample, 25 g of fruits were weighted before and after fruit drying for fresh weight (FrFW) and fruit moisture (FrM), all others were conserved at −20°C. The harvesting time in the Mediterranean countries was set in November, as the usual harvesting time, regardless of the maturation phase.

FrFW among two environments had the highest differences for Picual cultivar, while for other cultivars, no big differences were observed. Cultivars Chetoui, Chemlali and Picual showed high differences in fruit moisture comparing two environments, while Coratina and Meski had approximately the same values. The highest difference in fruit production was related to cv. Coratina in the temperate area, while Chetoui had the same amount of production in both environments.

QUALITY OF PRODUCTS

Oil content and fatty acids profile

After measuring FrFW, the three fruit sub-samples were dried in a forced-air oven at 105°C for 42 h to ensure complete dehydration and FrM was determined. Oil content was measured using an NMR Fat Analyzer Bruker Series NMS 100 Minispec (Bruker Optik GmbH, Ettlingen, Germany) and expressed as oil content on dry fruit weight (OCFrDW). FrFW, FrM and OCFrDW values were independently determined in the laboratories of each environment, by applying the same methodology (Figure 1).

FA composition was analyzed directly on dry fruits by FA methylation of fruit flesh (fruit epicarp and mesocarp). Separation of fatty acid methyl esters was carried out by Gas–Liquid Chromatography (GLC) with Split injector and flame ionization detector, using similar equipments and conditions for samples of different origin. Fatty acids monitored in this study include palmitic acid (C16:0), oleic acid (C18:1) and linoleic acid (C18:2), expressed as percentage of total FAs and oleic/(linoleic + palmitic) acids ratio (OLP) (Figure 2).

The highest variation of oil content among two environments was related to Picual and Chemlali cultivars, while Coratina and Meski cultivars showed the lowest variations, with the highest oil content in Chemlali cultivar in arid zone.

For what concerns the fatty acid composition, all cultivars showed the highest level of oleic acid in the temperate region and the cvs. Picual and Coratina had the maximum level. The highest variation among two environments for the main olive fatty acid was related to Meski cultivar, in the arid region, followed by cv. Arbequina, that showed a high value of the saturated palmitic acid in the same environment, meanwhile cv. Meski was low also for this component.

The linolenic acid variation was not high among two environments and the cultivar Chemlali had the highest variation for this fatty acid.

CONCLUDINGS REMARKS

Variation among fruit yield and fruit composition may be due to heritable differences among cultivars or it may be the result of phenotypic plasticity across varying environmental conditions (Weber et al., 2014).

In order to exploit the olive adaptation to drought and salinity areas, the selection of genotypes/varieties showing high stability among different environments may represent the most fruitful strategy for developing new sustainable cultivation systems. The selection of varieties able to maintain high production performance in the face of low water availability and fertilizers is mandatory. To improve crop management practices, it will also be vital a better understanding of the stress effects on plants.

Several researches have demonstrated that cultivars growing in areas with low water availability, may be more tolerant to drought and salt than others selected under more suitable environments. In the studies conducted within this project, a big variation was observed among cultivars originating from arid and temperate regions when grown under different environmental conditions and under irrigation or rainfed fields. A strong genotype by environment interaction was observed on three studied growth parameters. New studies are needed to better identify the effect of genotype and environment separately.

The highest variation of fruit fresh weight among the seven cultivars, was related to Picual, while fruit moisture had the highest variability for all seven cultivars in two different environments, confirming the environment effect on this trait, that exceeds the genetic one.

In olive, fruit oil content and composition are the result of a complex interaction between genotypic, environmental and agronomical factors (Esmaeili et al., 2014; Zaied and Zouabi, 2016). Among the oil quality traits, the oil content of fresh fruits and the percentage of oleic acid (C18:1) were the most variable traits in two different environments for seven cultivars. Several works have evaluated the effect of climate conditions on drupe maturation and oil composition in restricted sets of cultivars and locations (García-González et al., 2010; Di Vaio et al., 2013; Borges et al., 2017), nevertheless, it has been observed that olive cultivars may have different responses to temperature regimes during the oil synthesis period in terms of FA composition (Orlandi et al., 2012; Di Vaio et al., 2013; Bodoira et al., 2016).

In summary, all agronomic parameters under evaluation were highly influenced by genotype or environment or by their interaction. This implies that the agronomic behaviour of a given cultivar in a given environment is very difficult to predict. Therefore, in olive, more local experimentation on the basis of cultivar trials is needed to really determine the best cultivars suitable for each environment. These trials would be very important to really promote the use of the wide diversity existing in the olive germplasm.

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Table 1. Climatic data related to two different environments.

Climate data	Env1 (temperate, rainfed)	Env2 (dry subtropical, irrigated)
Average annual Tmax (°C)	21.6	27.4
Average annual Tmin (°C)	6.8	12.0
Rainfall (mm/year)	864	198
Rainfed / Irrigated (mm/year)	Rainfed	224

Table 2. Plant growth of a set of cultivars under arid and temperate conditions. All measures are expressed in centimeters.

	Arid irrigated zone			Temperate zone		
Cultivar	Trunk diameter	Plant height	Canopy width	Trunk diameter	Plant height	Canopy width
Arbequina	30	280	245	16	190	77
Chemlali	34	280	250	18	212	103
Chetoui	30	260	180	20	225	112
Coratina	30.5	265	265	16	250	180
Frantoio	53.5	310	275	21	134	108

Table 3. Plant growth of a set of cultivars under irrigated and rainfed conditions. All measures are expressed in centimeters.

	Irrigated (Boneggio)			Rainfed (Lugnano)		
Cultivar	Trunk diameter	Plant height	Canopy width	Trunk diameter	Plant height	Canopy width
Arbequina	5.75	143	60	4.61	151	54.67
Barnea	5.23	120	45	10.26	167	70.33
Frantoio	6.28	167	77	6.28	177	93.67
Picual	5.76	127	55	7.85	181	75.67

Table 4. Cultivars mostly originated from arid zones and cultivated in different environmental conditions. They were included in the analysis together with reference international cultivars.

Cultivar	Country of origin	Cultivation site
Abbadi abou gabra	Syria	Env2
Abou kanania	Syria	
Abou satl mohazama	Syria	
Barri	Syria	
Chemlal de kabylie	Algeria	
Jabali	Syria	
Maarri	Syria	
Majhol-1013	Syria	
Majhol-152	Syria	
Chemlali	Tunisia	Env1
Chetoui	Tunisia	
Coratina	Italia	
Khalkali	Syria	
Kadesh	Israel	
Massahabi	Syria	
Meski	Tunisia	
Sari Hasebi	Turkey	
Sigoise	Algeria	
Sourani	Syria	
Zaituna	Italy	
Berri meslal	Morocco	Env3
Menara	Morocco	
Meski	Tunisia	
Picual	Spain	
Barnea	Israel	Env4
Kadesh	Israel	
Massahabi	Syria	
Shatqui	Syria	
Sourani	Syria	
Souri	Israel	

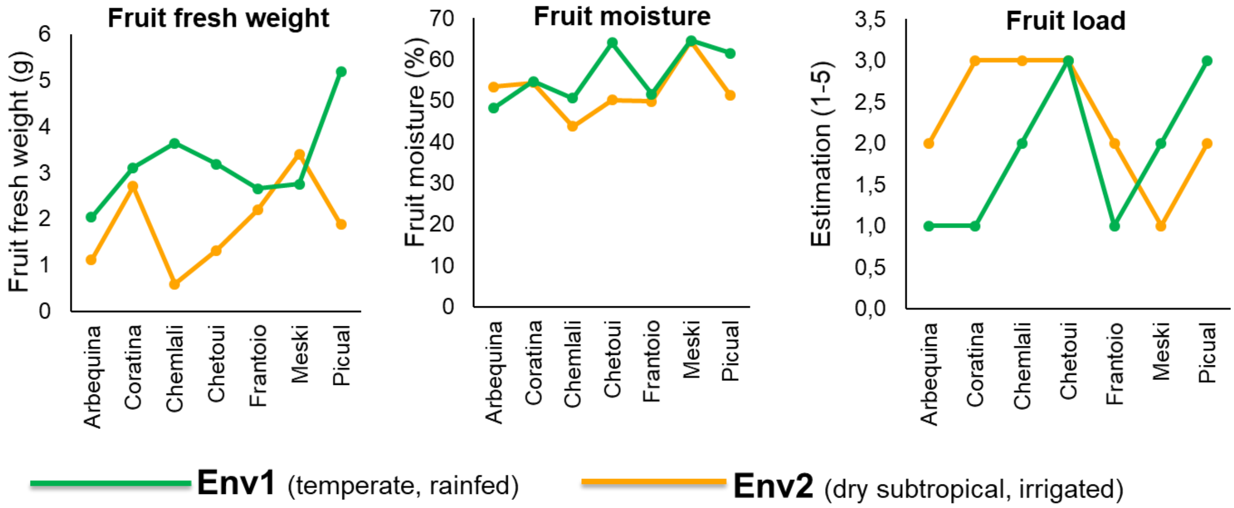

Figure 1. Fruit traits and estimated fruit load in two environments.

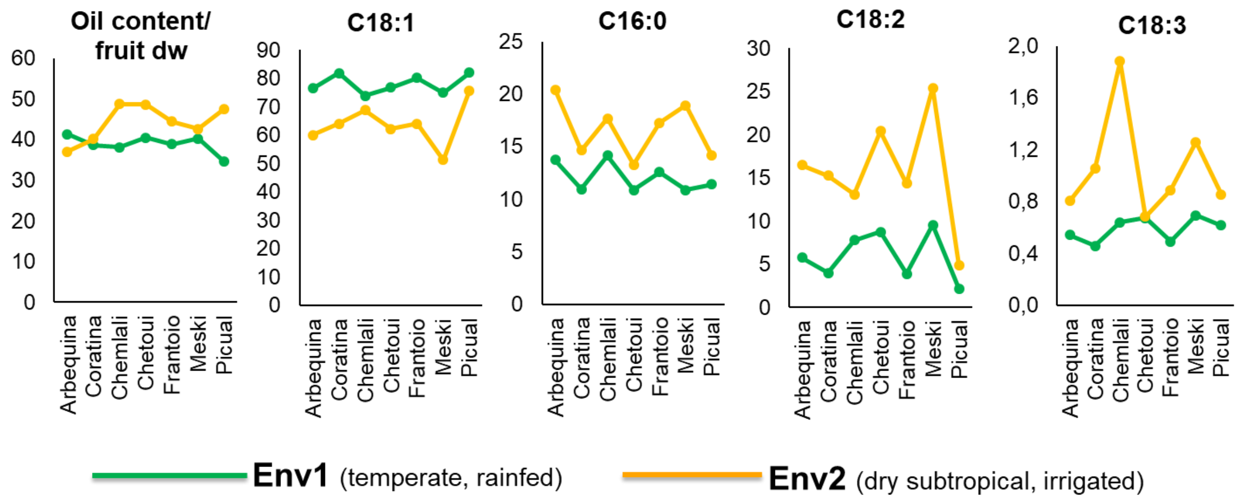

Figure 2. Fruit oil content and fatty acid composition in two environments.

plant (third algorithm