Olive responses to different irrigation management in the Mediterranean environment

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Introduction

Olive has long been considered a marginal low-income crop. Only in recent years has there been a widespread renewal of interest, stemming from the increasing trend in oil consumption. Olive oil is beginning to be regularly used also in the diet of many non-Mediterranean countries. Hence the market for oil and table olives shows interesting development potential especially as regards high-quality production. Unlike what has occurred in other agricultural sectors, the model of olive-growing is still being adapted to new market needs.

Today, suitable farming areas have what should be called "income" olive-growing which is based on low-impact agronomic techniques with the aim to shorten the unproductive period, reach high standards in terms of quantity and quality of production, stabilise production in time and contain costs. Moreover, the yield of an orchard depends mainly on environmental resources and the agronomic techniques adopted. In areas characterized by Mediterranean climate, low water availability is generally the major limiting factor which is most capable of compromising yield quantity and quality. In the Mediterranean region water availability is generally limited and the distribution of precipitation is concentrated in winter, while in many areas the almost total absence of summer rainfall exposes the plant to severe and prolonged deficits. This condition causes a reduction of yield potential and vegetative growth both in the year and in the following years.

Positive effects of an adequate water supply during reproductive phases, fruit development and vegetative growth are reported. Fruit size, the pit/flesh ratio and the number of fruits *per* plant are positively affected by irrigation. During the fruit development stages, water stress entails a slow-down in growth which, if it persists throughout the period of cell enlargement growth, results in small fruits and a low pit/flesh ratio. Clearly, the stress level leads to more or less evident effects.

In general a reduction in the percentage of oil on fresh weight basis is observed in irrigated fruit. However, the percentage of oil calculated over the fruit dry weight does not seem closely related with water stress. Studies carried out in environments with a mean annual rainfall higher than 450 mm report that irrigation does not entail substantial variations in oil content over the fruit dry weight. Thus the pattern of oil yield is similar to the enhancement of fruit dry matter production due to the irrigation regime (d'Andria *et al.,* 2004; Michelakis, 1995; Alegre, 2001). This may not be confirmed in environments with more severe water deficit.

However, irrigation does not seem to have an effect on acid composition or on peroxide number (Patumi *et al*., 2002), while the effects of irrigation level on phenolic substances remain unclear. The importance of such substances is known since, besides having anti-oxidative properties, they affect the organoleptic characteristics of bitterness and pungency. Some authors (Inglese *et al.,* 1996; Ismail *et al.,* 1997) report reduction in polyphenols under water deficit conditions, while the results of other field trials (d'Andria *et al.,* 2000; Patumi *et al.,* 1999; Salas *et al.,* 1997; Fernandez et al., 2008; d'Andria et al., 2008) indicate a reduction in phenols under fully irrigated conditions

As regards organoleptic characteristics of the oils, in the literature no cases of defects induced by irrigation are reported, while reduction in the intensity of bitterness and pungency was found. As such sensations are attributed to the content of polyphenolic substances in the oil, the lessened intensity with these attributes perceived in the most irrigated treatments is in line with their lower content (Salas *et a.l,.* 1997, Magliulo *et al.,* 2003). There is evidence that the fruity characteristic underwent no variation with irrigation, nor did the intensity olfactory sensation show the appearance of new sensory attributes (d'Andria *et al.,* 2004).

Moreover, irrigation regime does not affect all phenolic compounds in the same way, which could have a major effect on oil to define typicity and the degree of consumer satisfaction. These aspects require further research.

The possibility of using water for irrigation in olive growing is a tool that farmers could use to improve yield in terms of quality and quantity. This is at odds with the current situation and predicted trends of water availability for agriculture. In the Mediterranean region, water availability for productive purposes has generally declined due to the increase in domestic and industrial use. However, climate change forecasts indicate a rise in global temperature (1-3.5 °C, from now to 2100) and major changes in the distribution of water availability. For some years there has been a general decrease in rainfall in the Mediterranean environment, which is causing considerable problems in the availability of this resource especially for land irrigation. In addition, agriculture will also consider the increase in water costs caused by the increase of energy and distribution rates.

This makes it crucial to optimize the use of irrigation water by avoiding loss of water resources and improving methods that allow reductions in water volumes by adopting appropriate irrigation scheduling. In some environments encouraging results have been obtained by applying the suspension or reduction of water supply during fixed phenological stages (Alegre *et al.,* 2000; Girona, 2001).

The olive is well known to be resistant to water stress due to a series of anatomic adaptations and physiological mechanisms which allow the plant to maintain its vital functions even under very severe conditions. The main adaptations are the tomentum of the leaf and the high capacitance of the tissues, the small number of stomata and their position, the structure of the xylematic vessels (Fernandez and Moreno, 1999); the capacity of the plant to use soil water at potentials lower than the value commonly reported as the wilting point; the high functionality of the leaves that show a certain photosynthetic and transpiration activity with leaf water potentials of - 6, -7 MPa (Xiloyannis *et al.,* 2003); the highly efficient mechanism regulating stomatal activity that enables the leaf water potential to be modulated according to variations in the evaporative demand (Orgaz and Fereres, 1997); the high capacity to increase the ratio between the roots and canopy under conditions of water deficit that allows an increase in the soil volume explored by the root system.

However, such drought tolerance mechanisms are activated with considerable energy expenditure on the part of the plant to the detriment of yield quality and quantity, the formation of reproductive organs and the development of new shoots. Hence not only may the season's production be compromised, but also that of future years.

Water requirements

Plants produce new biomass with the photosynthesis process when carbon dioxide is absorbed and water in its vapour state is delivered via stomata aperture. To avoid water stress, with irrigation practice we should maintain soil humidity conditions that allow plants to satisfy the evaporative demand of the atmosphere. This water consumption of the plants together with water loss by soil surface represents, deducting useful precipitation, the theoretical amount of water that must be supplied by watering, net of possible losses from runoff and/or deep percolation.

To estimate water consumption, different methods may be adopted that are based on the knowledge of the soil water budget, the energy budget, plant water status (leaf water potential, stomatal conductance, sap flow and dendrometric measurements). The methods listed above are generally applied in scientific research and, with their advantages and disadvantages, constitute reference points on which to validate simplified approaches.

We may transfer to farmers and technical assistance centres the FAO ‘two steps’ method (Doorenbos and Pruitt, 1977) according to which maximum crop evapotranspiration is given by the well-known relation: ETc = ETo kc, where ETo is the reference evapotranspiration, and kc is the crop coefficient.

It should be noted that kc also depends on the phenological phase and is not constant all year round. The maximum values are in the period of vegetative recovery in spring and early summer, as well as the phase of rapid drupe expansion up to ripening.

Analysis of the literature shows that detailed information is not always available as regards kc values under different environmental conditions.

To calculate the ETo, empirical models based on the knowledge of one or more climatic parameters are normally used. Of the more commonly used methods, we recall the model of Penman-Monteith, Hargreaves-Samani, the modified atmometer and the class A evaporimeter. The choice of method to be applied must be made on the basis of available equipment, the environment in question and the frequency of readings.

For a correct estimation of ETc also a reduction coefficient (kr) must be considered since plants do not cover the entire soil surface, which takes into account the percentage of the soil covered by the canopy. The kr varies according to plant development and, in the absence of specific data for olive trees, good results are obtained by applying the relation proposed by Fereres (1981) for the almond: kr = 2 Sc/100, where Sc is the percentage of soil covered by the plant canopy. Sc is determined by the following equation: $Sc = \pi D^2$ N/400, where D is the average canopy diameter expressed in metres and N is the number of plants *per* hectare.

Furthermore, in calculating the irrigation volume it is effective to adopt an irrigation strategy that does not maintain 100% of field water capacity, supplying rates below ETc. In this case, we need to estimate the contribution of the water reserves available in the soil so that they do not fall below 70% of water available. At the end of the irrigation season, groundwater resources will be partly or totally used and will then be recharged during rainy periods.

For this purpose, knowledge of texture characteristics of soil profile explored by the root system will indicate the water storage capacity. Different types of soil have well-defined hydrological characteristics on which the capacity to release water to the root system depends.

To maintain the crop in optimal conditions of water supply we must know the soil moisture content at which the crop begins to undergo water stress: the difference between the water content at field capacity and that found at the beginning of stress conditions is the fraction of readily available water. It is generally considered that the olive undergoes no damage from water stress until 70-75% of available water has been used (Orgaz and Fereres 1997) even if it must be consider that the fraction may differ according to environmental, crop and agronomic variables.

To briefly report the various situations most commonly occurring in olive-growing areas, for the sake of simplicity we may distinguish environments in which water is available throughout the irrigation season and environments where water is available only at certain times.

Most of the studies reported in the literature highlight the effects of different irrigation levels supplied constantly throughout the period of drought. However, it must be remembered that the results obtained by adopting this method of irrigation management are only applicable in areas where water resources are not subject to particular limitations.

Recent experiments have shown that, for various cultivars (for table olives, oil and double aptitude), complete satisfaction of the crop water requirement throughout the irrigation season did not result in a significant increase in yield compared with treatments that had received a 33% reduction in the maximum rate. Moreover, also the treatments irrigated with only 33% ETc proved more productive than rain-fed crops. Yield increases in both cases were caused both by a larger number of fruits per plant and by the higher fruit mean weight (Patumi *et al.,* 1999; d'Andria *et al.*, 2000).

These results agree with those of other trials held in different environments and with different cultivars (Italy, Greece, Spain). Hence the choice of an irrigation rate between 33 or 66% of ETc depends on economic considerations, while from an agronomic standpoint irrigation volumes amounting to 100% of ETc appear excessive, if not even negative. The latter consideration results from the strong vegetative vigour of the treatment irrigated with the maximum rate which caused an increase in the pruning cost and the onset of diseases stemming from the lack of air circulating within the canopy.

In many olive-growing situations, water for irrigation is not always available in sufficient volumes to completely satisfy crop requirements. Moreover, there are ever-increasing cases in which there are regulations restricting the use of public water (Pastor, 2001).

The above situation has given rise to trials to study irrigation strategies aiming to ascertain the possibility of irrigating the olive with deficit volumes during some specific phenological phases, and has generated methods based on recharging the land's water endowment during periods of water availability.

In California (USA) reductions in water applications (50% of ETc) in the period from mid June-July or June-mid August allowed a respective 16 and 25% reduction in the seasonal irrigation volume compared with the fully irrigated control without a yield reduction of cv. Manzanilla. Moreover, the same trial showed that with deficit irrigation from May to September, a 45% water saving was achieved, with a 10% loss of yield compared with the fully irrigated control (Goldhamer, 1999).

These irrigation strategies may be adopted in deep soils with a good water retention. Under such conditions, the plant may develop a root system that explores a large soil volume and there are no percolation losses.

From the results available in the literature, it thus seems possible to apply an irrigation strategy that allows considerable water savings with the application of reduced irrigation volumes in fixed phenological stages. This approach still requires validation before it can be recommended in pedo-climatic environments which are very different from those where trials were conducted.

In areas where water for irrigation is very limited in quantity there is no other solution but to carry out complementary irrigation. In such conditions, when possible, it is necessary to supply the crop with watering in the phenological phases that are most sensitive to water stress for yield. However, the most sensitive phases are fruit set, fruit development during cell division and rapid growth.

Conclusions

Irrigation management in olive-growing is specific to the various growing areas, although in all situations only slight reductions in volumes per hectare may often make available considerable quantities of water which may be used for other purposes or to increase the irrigable area.

It is clear that in most producer countries irrigation in olive-growing is essentially based on empiricism and direct producer experience. To modernise the sector, the strategy of irrigation management must be based on two fundamental aspects: irrigation scheduling and use of high-efficiency water distribution methods.

Improving irrigation efficiency also means equipping producers with suitable irrigation methods. The most efficient water distribution methods are the localised ones, of which the drip irrigation method permits the greatest saving in the irrigation volume. Recently sub-irrigation has become fairly widespread: besides the advantages of localised distribution, it ensures a further water saving (about 20% compared with drip irrigation systems), reduces losses due to soil evaporation, facilitates the control of pests and gives greater guarantees for the operator and the product when urban wastewater is used, although some aspects regarding the control of distribution systems in different soil types require further examination.

References

Alegre Castellvì S., (2001) – *Efecto de diferentes estrategias de riego deficitario controlado durante la época estival sobre la produccion del olivo (Olea europea L.) cv. Arbequina*. PhD Thesis Univ. of Lleida, Spain.

Alegre S., Marsal J., Mata M., Arbones A., Girona J., Tovar M. J., (2000) – *Regulated deficit irrigation in olive trees (Olea Europaea L. cv. Arbequina) for oil production.* Acta Horticulturae, 586:259-262.

d'Andria R, Morelli G., Patumi M., Fontanazza G. (2000). *Irrigation regime affects yield and oil quality of olive trees.* Acta Horticulturae 586:273-276.

d'Andria R. Lavini A., Morelli G., Patumi M., Terenziani S., Calandrelli D., Fragnito F. (2004). *Effect of water regime on five pickling and double aptitude olive cultivars (Olea europaea L.)*. Journal of Horticultural Science & Biotechnology, 78(1) 15-23.

d'Andria R., Lavini A., Morelli G., Sebastiani L., Tognetti R. 2008 Changes of physiological and productive responses of Olea europaea L. (cultivars Frantoio and Leccino) to deficit irrigation regime. Plant Biosystem, in press.

Doorenbos J., Pruit W.O. (1977). *Crop water requirements. Irrigation and Drainage*, handbook n. 24 FAO - Roma pp. 144.

Fernandez J.E., Mreno F. (1999). *Water use by olive tree*. Journal of crop production. p. 101-162.

Fernández J.E., Díaz-Espejo A., Tognetti R., d'Andria R., Sebastiani L. 2008 Potential and limitation of improving olive orchard design and management through modeling. Plant Biosystem, 142:129-136.

Fereres E., Pruitt W.O., Beutel J.A. Henderson D.W., Holzapfel E., Shulbach H., Uriu K. (1981) – *ET and drip irrigation scheduling*. In Fereres E., Drip irrigation management. Univ. Of California. Div of agric. Sci. n° 21259, pp. 8-13.

Girona J. (2001). *Strategie di deficit controllato nell'olivo*. Proceeding of International olive course "Gestione dell'acqua e del territorio per un'olivicoltura sostenibile", Naples, Italy, September 24-28 pp. 138-48.

Goldhamer D.A., (1999). *Regulated Deficit Irrigation for California Canning Olives*. Acta Horticulturae, 474:369-372.

Gucci R., Tattini M., (1997). *Salinity tolerance in olive*. Horticultural reviews, 21:177-214.

Inglese P. Barone E., Gullo G., (1996). *The effect of complementary irrigation on fruit growth ripening pattern and oil characteristics of olive (Olea europaea L. cv Carolea)* Journal of Horticultural Science, 71(2):257-263.

Ismail A. S., Stavroulakis G., Metzidakis J., (1997). *Effect of irrigation on the quality characteristics of organic olive oil*. Acta Horticulturae, 474:687-690.

Magliulo V., d'Andria R., Lavini A., Morelli G., Patumi M. (2003) - *Yield and quality of two rainfed olive cultivars following shifting to irrigation*. Journal of Horticultural Science & Biotechnology, 78(1) 15-23.

Michelakis N., Vouyoukalou E., Clapaki G. (1995). *Plant growth and yield response of olive tree cv. Kalamon, for different levels of soil water potential and methods of irrigation*. Adv. Hort. Sci. 9:136-139.

Orgaz F., Fereres E. (1997). *Riego*. In Barranco D., Fernandez-Escobar R., Rallo L. (ed): El cultivo del olivo 261-280.

Orgaz Rosúa, F. and Pastor Muñoz-Cobo, M., 2005. *Fertirrigación del olivo. Programación de riegos.* En: C. Cadahía, C. "Fertirrigación. Cultivos Hortícolas, Frutales y Ornamentales". Ed. Mundi-Prensa, S.A. Madrid. 496-533.

Pastor Munoz-Cobo M. (2001). *Avances en la tecnologia de la programation de riegos en situaciones de baja disponibilitad de agua en el olivar de la provincia de Jaen*. Expoliva 2001.

Patumi M., d'Andria R., Fontanazza G., Morelli G., Giorio P., Sorrentino G., (1999). *Yield and quality traits of three intensively trained olive trees cv. under different irrigation regimes*. Journal of Horticultural Science & Biotechnology, 74:729-737.

Patumi M, d'Andria R., Marsilio V., Fontanazza G., Morelli G., Lanza B. (2002). *Olive and Olive oil quality after intensive monocone olive growing (Olea europaea L., cv. Kalamata) in different irrigation regimes*. Food Chemistry, 77, 27-34.

Salas J., Pastor M., Castro J., Vega V., (1997). *Influencia del riego sobre la composicion y caracteristicas organolepticas del aceite de oliva*. Grasas y Aceitas, 48(2), 74-82.

Xiloyannis C., Gucci R., Dichio B., (2003). *Irrigazione*. In Olea, Trattato di Olivicoltura, a cura di P. Fiorino, by Ed agricole.