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An approach to global warming effects on flowering and fruit set of olive trees growing under field conditions

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ABSTRACT

The increase in air temperature associated to climate change is expected to affect olive (*Olea europaea* L.) tree fructification. To determine the potential effects of global warming on floral phenology and fruit set under field conditions, olive trees growing in a Mediterranean climate type area were subjected to warmer temperature than ambient by the use of temperature controlled Open-top-Chambers (OTCs). Each OTC, equipped with heating and ventilation devices, was able to maintain a day/night temperature gradient between the tree and the surrounding environment of 4 °C throughout the complete reproductive cycle of this species. After three years of study, the results obtained have shown that increasing temperature 4 °C above the actual ambient temperature may led to an advance of the date of flowering in the olive, an extent of the flowering period, an increase of pistil abortion, and a reduction in fruit set, conditions which may reduce yield.

1. Introduction

The Mediterranean Basin has been considered as one of the most vulnerable regions to climatic changes in the near future (Giorgi, 2006; Lionello, 2012). Climate experts have anticipated an increase in air temperature in the range of 2–5 °C (Giorgi, 2006; Giannakopoulos et al., 2009; Gualdi et al., 2013; IPCC, 2014). In addition, more frequent and extreme events such as drought periods and heat-waves will be observed in this region (Giorgi and Lionello, 2008; Tanasijevic et al., 2014). Temperature is a primary environmental factor controlling plant growth and development, so changes in seasonal temperatures can affect the biological processes of the reproductive cycle of Mediterranean crops, affecting crop production. The olive (*Olea europaea* L.) is one of the most emblematic crops in the Mediterranean Basin having a great economic, social and cultural impact. This species is widely spread and well adapted to the rustic conditions of the Mediterranean region, but a constant increase in ambient temperature may affect the phenology of this crop and, consequently, may reduce yield.

Floral phenology is a critical process in determining final yield. Olives flower on one-year-old wood and display two inflorescences per node or, exceptionally, directly at the shoot apex. The inflorescences contain a mixture of perfect (hermaphroditic) and imperfect (staminate) flowers. The former group contains well-developed stamens and pistil while in the latter a residual atrophied pistil is often visible in the center as a consequence of varying degrees of pistil abortion (Cuevas and Polito, 2004; Reale et al., 2006). Flower bud induction is manifested by July in the northern hemisphere (Fernández-Escobar et al., 1992), and floral differentiation is evident by March (Hartmann, 1951). Anthesis occurs by May. Shortly after anthesis, massive abscission of flowers and fruits occurs (Rallo and Fernández-Escobar, 1985). The remaining fruits usually persist on the tree until harvest, which takes place during the fall and winter (October-February) depending on the year and the cultivar. The olive tree exhibits a strong alternate bearing phenomenon.

Olive produces an abundant number of flowers but only a small percent (1–2%) of them set normal fruits that reach maturity (Martin, 1990; Lavee et al., 1996). This phenomenon is partly influenced by flower quality. It is not clear if warmer temperatures during pre-flowering and flowering phenophases could modify any morphological or developmental characteristics of the flower affecting its ability to set and form a fruit. Although it has been informed that environmental factors and cultural practices have a significant effect on floral quality (Hartmann, 1950; Uriu, 1953, 1960), there are not references related to temperature effect. Some studies have reported that poor N nutritional

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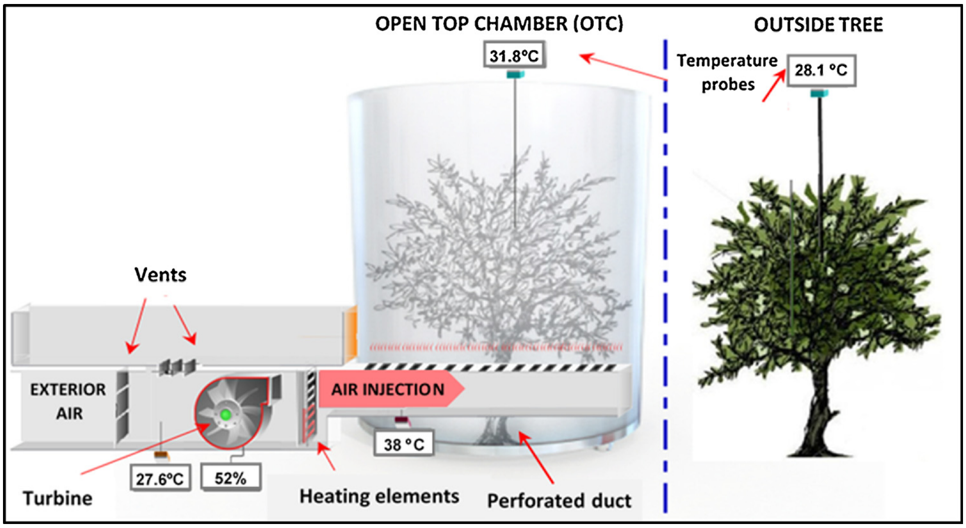

Fig. 1. Scheme of functioning of the Open Top Chamber.

status, low leaf-to-bud ratio and water deficit (Fernández-Escobar et al., 2008; Uriu, 1956, 1960; Cuevas and Polito, 2004; Reale et al., 2006; Rapoport et al., 2012) favor pistil abortion. There is also a cultivar-related tendency for producing imperfect flowers (Campbell, 1911; Morettini, 1950; Lavee et al., 1996; Rosati et al., 2011). On the other hand, the success of a flower to become a fruit not only depends on its quality but also on the pollination and fertilization processes. Studies that have analyzed the effect of temperature on pollen germination and pollen tube growth have reported that both are sensitive to elevated temperatures (Fernández-Escobar et al., 1983; Vuletin Selak et al., 2013). Constant temperatures above 33 °C after fertilization may affect fruit setting (Graniti et al., 2011) and subsequent fruit development (De Andrés Cantero, 2001).

Regional Climate Models and olive-pollen capture tramps have been used for long to predict olive floral timing in the Mediterranean region in the future. It seems that olive flowering date will be modified by the increase in air temperature (García-Mozo et al., 2010; Oteros et al., 2013): the development of floral structures will be completed faster leading to earlier flowering dates (Osborne et al., 2000; Giannakopoulos et al., 2009; Orlandi et al., 2010; Aguilera et al., 2015). However, long-term temperature field experiments are necessary to verify these results. Open top chambers (OTCs) are very useful tools for the simulation of global change under field conditions (Allen et al., 1992; Ceulemans and Mousseau, 1994; Norby et al., 1997). These systems are able to simulate real conditions of global warming including daily and seasonal fluctuations in weather. They allow trees to grow in the ground for several growing seasons avoiding the potential negative effects of container artefacts: root mechanic stress or the increase in soil temperature above ambient temperature due to containers overheating.

There is an actual tendency to compare floral phenology in olive orchards located in geographical regions differing in annual mean temperatures. But considering that floral events not only are governed by mean temperature but also by seasonal temperature fluctuations and the photoperiod along the different annual seasons, the results from these studies may lead to misunderstandings. These variables are difficult to be the same in different geographical regions because they partly depend on latitude and altitude.

The aim of this study was to determine under field conditions, in a Mediterranean climate area in which temperature and photoperiod fluctuations occur along the year, the effect of 4 °C increase in air temperature on olive floral phenology and fruit set. To reach this goal temperature controlled Open-Top-Chambers were used. This study is an approach to global warming effects on olive inflorescences characteristics, timing of the different events during flowering and fruit setting in the near future.

2. Material and methods

2.1. Plant material and growth conditions

'Picual' olive trees (*Olea europaea* L.) growing in a experimental farm of Campus de Rabanales, University of Córdoba, Spain (37°55′N 4°43′W) were used for the experiment. The orchard soil is classified as Calcic Luvisols with a clay-loam to clay texture, pH moderately alkaline (7–8), organic matter around 2%, and moderate to high cation exchange capacity (Del Campillo et al., 1993). The trees were planted in autumn 2009 spaced 8 x 6 m apart, with a drip irrigation system. Depending on the season, water was applied over five to six months during the dry season. The experiment was conducted from 2014 to 2017.

2.2. Experimental design and treatments

To perform this study sixteen trees were selected from the experimental farm. Trees were subjected to two temperature treatments, ambient temperature (AT) and 4 °C above ambient temperature (AT + 4 °C), along three consecutive years. The experimental plot was divided into four blocks containing each one two trees (replicates) per temperature treatments (AT vs. AT + 4 °C) which were randomly distributed. To maintain trees at 4 °C above ambient temperature, eight temperature-controlled Open Top Chambers (OTC), specifically designed for this study, were constructed around the trees (Fig. 1). Each OTC (hexagonal prism-shape), consisting of a steel frame covered by panels (panel size: 1.80 cm width x 3.60 cm height) of plastic film of high transparency (transmission: 90–85% of the solar photosynthetically active radiation), was equipped with heating and ventilation devices regulated by an automaton. In this way, a constant day/night temperature gradient between the tree and the surrounding environment of 4 °C was maintained throughout the complete reproductive cycle of this species.

The 4 °C thermal gradient was maintained by two mechanisms that operated independently. 1) A close circuit came into operation at night or under low solar radiation conditions to inject heat to the chamber. This circuit recirculates the air from the chamber through a turbined equipped with electric heating elements (Fig. 1). An automaton regulates the warm air flow by controlling the turbine speed and the number of electric heating elements which comes into operation. 2) During the day, under high solar radiation conditions, the excess of heat