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Sustainability of pistachio production (*Pistacia vera* L.) under supplemental irrigation in a Mediterranean climate

G. Marino[a,*], S. Di Martino[c], A. Amico Roxas[b], T. Caruso[c], L. Ferguson[b], E. Barone[c], F.P. Marra[c]

[a] Department of Land Air and Water Resources, University of California, Davis, One Shields Ave., 95616 Davis, CA, USA
[b] Department of Plant and Environment Sciences, University of California, Davis, One Shields Ave., 95616 Davis, CA, USA
[c] Department of Agricultural, Food and Forest Sciences, University of Palermo, Viale delle Scienze Ed. 4, 90128 Palermo, Italy

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ABSTRACT

The objective of this study was to examine the effects of supplemental micro-irrigation, in a commercial rainfed orchard, on tree water status, gas exchange and productivity of *Pistacia vera* L. (cv Bianca) grafted on *P. terebinthus*. Irrigating with 10–15% of estimated full evaporative demand significantly increased average annual productivity by increasing yield in the on-crop year of this alternate bearing species. Irrigation increased yield by 30%, resulting in 1600 kg of in-shell product per ha. Irrigation delayed leaf senescence while flower bud abscission was not reduced until the third year of experiment. Irrigation did not improve gas exchange during Stage I (pericarp growth). Both stomatal conductance (g_s) and maximum photosynthesis (A_{max}) increased with irrigation during Stage III (intense embryo growth). Stem water potential appeared less sensitive than gas exchanges in detecting differences in water stress between treatments. The results suggest that the efficiency of irrigation can be improved taking into consideration crop load and tree phenology. The results also demonstrate pistachio production is environmentally and economically sustainable in Mediterranean areas having 500 mm rainfall, with as little as 100 mm of irrigation water.

1. Introduction

Pistachio (*Pistacia vera* L.) is a drought resistant species (Behboudian et al., 1986; Rieger, 1995), native to Western Asia and Asia Minor (Ferguson, 1995). Due to its ability to survive and produce modest crops with little or no irrigation (Goldhamer, 1995) it was traditionally cultivated in arid regions on marginal soils.

Multiple studies have defined the positive effect of irrigation on pistachio yield and quality (Goldhamer et al., 1985; Polito and Pinney, 1999; Goldhamer, 2005; Iniesta et al., 2008). More detailed studies have demonstrated irrigation's effects on photosynthesis (De Palma and Novello, 1998), flower bud retention (Marra et al., 1998, 2009), and therefore the ability of irrigation to affect yield and alternate bearing (Kanber et al., 1993). As a result, if water is available, modern production orchards are irrigated. The most recent orchards developed with more vigorous, highly productive rootstocks and scions are established with the expectation of applying 1150 mm of irrigation per hectare annually and producing an average annual yield of 2500 kg per hectare of dried marketable in-shell split nuts (2015 Pistachio Costs & Returns Study). The studies above also demonstrated irrigated pistachio tree transpiration is much higher than that of other deciduous species. During the summer months, transpiration can peak at 8.1 mm d^{-1} (Iniesta et al., 2008; Goldhamer et al., 1985). The high volume irrigation regimes dictated by this high tree water use is not sustainable in most Mediterranean climates with their low water availability. This situation is particularly important as climate change decreases agricultural water supplies (Kiparsky and Gleick, 2003). Using Iran, formerly the world's largest producer and exporter, now second in both to California, as an example, many pistachio producing regions will either cease production or move due to lack of water (Financial Tribune, 2017).

Pistachio's differential responses to irrigation that suggests high volume irrigation may not be the best strategy for economic sustainability. Several authors reported that irrigation volumes meeting seasonal orchard evapotranspiration can be reduced by 50% in some phenological stages without affecting yield (Phene et al., 1987; Goldhamer and Beede, 2004; Gijón et al., 2009). Multiple studies have demonstrated a high variability of drought resistance (Phene et al., 1987; Goldhamer, 2005), water relations (Gijón et al., 2011) and photosynthetic performance (Marino et al., 2018a) depending on the phenological stage. It has been speculated these responses are a function of tree maturity, variability, and cropping status (Obeso, 2002),

* Corresponding author.
E-mail address: giumarino@ucdavis.edu (G. Marino).

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Table 1
Parameters measured during the experiment, periodicity of data collection and method used to collect data.

Parameters	Periodicity	Method
TCSA	Every year before bud breaks	Circumpherence at 10 cm above graft union
Leaves and bud number	Every 15 days	On 4 fruiting branchelets per tree
Gas exchanges	40, 47, 61, 82, 94 130 DAFB in 2009 29, 44, 65, 86 DAFB in 2010	One leaf per sampled tree
Ψ_{SWP}	61, 82, 94, 100 and 130 DAFB in 2009 29, 44, 65, 86, 103 and 121 DAFB in 2010	One leaf per sampled tree
Yield	130 DAFB in 2009, 127 DAFB in 2010 and 129 DAFB in 2011	Fresh fruit yield (kg)/tree
Shoot and fruit characteristics	At harvest of 2009, 2010 and 2011	In the lab, on preselected branches, split, blank, fruit fresh weight, shoot length

environmental factors (Monselise and Goldschmidt, 1982) and genetic dissimilarity among trees (Wood, 1989; Garner and Lovatt, 2008). Memmi et al. (2016) suggested that the dual response of pistachio to irrigation, a drought tolerant tree consuming high quantities of water, is related to change of stomatal behavior as a function of the phenological stage of nut growth.

Preliminary studies by Caruso et al. (1996) suggested 1000–1500 m^3/ha might be sufficient for economic commercial production in Sicilian pistachio orchards. This, and the earlier reports discussed above, suggest supplemental irrigation may have a significant effect on mature pistachio orchard productivity in Mediterranean climates, particularly those grafted onto *P. terebinthus* (Caruso et al., 2008; Barone and Marra, 2004), the most drought tolerant rootstock, for which there is little experimental data (Ferguson et al., 2005). Our hypothesis is that supplemental irrigation, versus a rainfed control, will increase economic sustainability and profitability. Specifically, we investigated the effects of supplemental irrigation on tree water status, gas exchanges and productivity of cv Bianca in a commercial orchard in a Mediterranean climate. The final objective is to optimize irrigation management in arid climates with limited water.

2. Material and methods

The three-year experiment was carried out from 2009 to 2011 in thirty-year-old commercial pistachio orchard (*Pistacia vera* L. cv Bianca on *P. terebinthus* L. rootstock) located in Sicily (37°26′02″ N, 14°03′12″ E, 360 m a.s.l.), on a soil having the following composition: sand 33.8%, silt 15.1% and clay 51.1%. The climate is Mediterranean with 5 dry months and an average annual precipitation of 550 mm (30 year average) concentrated in the winter months (Cartabellotta et al., 1998). Trees were spaced 6.5 × 4.5 m and trained to a vase shape. The treatments were a Rainfed (R), no water applied, as control and an Irrigated (I), 100 mm of water total supplied by 3.0 l h^{-1} emitters spaced 80 cm on a double dripper line. Each irrigation event lasted about 10 h. They started in June and finished in August/September, depending when the water available in the in farm reservoir finished. In 2009, there were 10 irrigations: June 25, July 17, July 22, July 27, August 1, August 7, August 12, August 17, August 21 and September 17. In 2010, there were 9 irrigations: June 8, June 18, June 25, June 30, July 6, July 12, July 27, August 3 and August 16. In 2011 there were 10 irrigations: June 12, June 22, July 1, July 11, July 19, July 27, August 7, August 17, August 25 and September 5. About 10 mm of water were applied per each irrigation treatments. The experimental design was a Complete Block. Three blocks, constituted with three adjacent rows each, were replicated for each irrigation treatment. Three trees for each block were selected for their uniformity in the central row for a total of 9 trees per treatment.

A weather station monitored weather conditions during the experiment. Temperature and relative humidity were measured by an MP100 (Rotronic Instruments Ltd – UK) and a pluviometer (ARG100 Raingauge. Environmental Measurements Limited – U.K.) measured precipitation data. All instruments were connected to a data logger (CR1000, Campbell Scientific Inc. – Utah. USA) that recorded data every 5 min. Trunk cross sectional area (TCSA) of selected trees was measured at 10 cm above the graft union at the beginning of each year. Four randomly selected branches (combined one-year-old and current year's growth shoot growth) per tree were labelled and the number of buds, leaves and inflorescences were monitored every 15 days. Full bloom was the 26 of April in 2009, 26 of April in 2010 and 24 of April in 2011. Midday stem water potential (Ψ_{SWP}) was determined with a pressure chamber (PMS Instrument Co. Corvallis, Oregon, USA) on one leaf per tree, (9 leaves for treatment), selected from a bearing branch located in the central part of the canopy. Measurements were taken at 61, 82, 94, 100 and 130 DAFB in 2009 and 29, 44, 65, 86, 103 and 121 DAFB in 2010. The selected leaves were covered with a plastic bag and aluminium foil for at least 1 h before the measurement to reduce leaf transpiration (Begg and Turner, 1970) and equilibrate Ψ_{SWP} with branch water potential. A piece of absorbing paper was used to distinguish the xylem water from the resinous exudates. Maximum net assimilation rate (A_{max}) and stomatal conductance (g_s) were determined on one leaf selected from a bearing branch located in the central part of the canopy using a portable infrared gas analyser (CIRAS-2 PP Systems. Amesbury – Massachusetts, USA) connected to an automatic leaf cuvette (PLC6 (U) PP Systems). Gas exchanges were measured at 40, 47, 61, 82, 94 and 130 days after full bloom (DAFB) in 2009 and at 29, 44, 65 and 86 DAFB in 2010.

At harvest, 130 DAFB in 2009, 127 DAFB in 2010 and 129 DAFB in 2011, fresh in-shell yield per tree by weight was measured. Prior to harvest, the pre-selected sampling branches were collected and examined for: fresh and dry fruit weight (50 °C until constant weight), shoot length and percentage of blank and splitting fruits. The number of fruits per tree was also calculated using fresh yield per tree and average fresh weight of the single fruits (average of all the fruits from the 4 branches per tree). This data was used to calculate crop efficiency (CE, yield/TCSA) and crop density (CD, number of fruits/TCSA) (Table 1).

The effects of irrigation were analyzed as a two-way analysis of variance (ANOVA) using Systat package (SYSTAT Software Inc., Chicago, IL). Treatment means were separated using Tukey's HDS test ($P < 0.05$).

3. Results

In all the three years the dry season started between the end of May and mid-June, depending on the year, and in 2009 ended the 21 of August, when a heavy rain (27 mm) was recorded. No rain fell before the beginning of September in 2010 and half of September in 2011. August was the hottest month, 18–35 °C, and January and February the coldest months, 4 − 15 °C (Fig. 1).

The trunk cross sectional area (TCSA) was not significantly different between treatments and increased from 238 to 250 cm^2 from the first to the third year (Table 2). Yield per tree was highly and significantly affected by the irrigation treatment (Table 2). Higher yield was observed in the on-years 2009 and 2011, averaging 8.6 kg/tree versus the off-year 2010 with 2.8 kg/tree. The irrigation treatments significantly increased tree productivity by 30%. This effect was significant only in the on-years (Table 3). Similar behavior was observed for crop