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Water stress thresholds for regulated deficit irrigation in pistachio trees: Rootstock influence and effects on yield quality

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ABSTRACT

The response of "Kerman" pistachio trees budded on three different rootstocks (*Pistacia terebinthus*, *Pistacia atlantica* and *Pistacia integerrima*) to regulated deficit irrigation (RDI) in shallow soils was studied for 3 years. The trees were either fully irrigated (C treatment) or subjected to deficit irrigation during Stage II of fruit growth with two water stress thresholds (T1 and T2). The irrigation scheduling for fully-irrigated trees and water-stressed trees was managed by means of midday stem water potential (Ψ_{stem}) measurements. The use of direct measurements of the water status allowed estimating accurately the irrigation requirements for pistachio trees, with water reductions ranging from 46 to 205 mm in fully-irrigated trees. The combination of the Ψ_{stem} use and the RDI regime saved 43–70% in T1 and 48–73% in T2 of water compared to the calculated crop evapotranspiration (ET_c) for fully irrigated treatment (C).

Deficit irrigation during Stage II significantly reduced the vegetative growth of the trees. Yield and fruit quality were not affected by any irrigation regime, except during the first year of the study. Thus, the results indicate that full irrigation scheduling and RDI can be achieved successfully using Ψ_{stem} tool on pistachio trees growing in shallow soils. A Ψ_{stem} threshold of −1.5 MPa during stage II (T1) was suggested for RDI scheduling, as it did not reduce the yield or the production value. However a Ψ_{stem} threshold of −2.0 MPa (T2) resulted in a significant reduction and an extensive delay in the recovery of stomatal conductance (gl), with negative effects on long-term pistachio production.

P. integerrima showed a weaker capacity of adaptation to the study conditions compared to *P. atlantica* and *P. terebinthus*, having a tendency to get more stressed and to produce a lower quality crop.

1. Introduction

The pistachio tree (*Pistacia vera*) is native from western Asia and Asia minor, where it can still be found growing wild (Crane and Iwakiri, 1981). It has been traditionally cultivated in semi-arid areas of the Middle East and the Mediterranean basin.

The increase in pistachio consumption due to its high nutritious value and favourable taste has led to an intensification and expansion of its cultivation. Thus, planting pistachio trees outside its autochthone area of cultivation has become more common and now it can be found in places such as the USA since 1960 and, more recently, Spain. In 2012, the total pistachio area harvested was 494,000 hectares, including 258,000 hectares in Iran and 70,000 hectares in the USA (FAOSTAT, 2012). In Spain, the areas used for growing pistachio trees nowadays is estimated at about 5000 hectares, whereas it was negligible in the 90s (Ministerio de Agricultura, Alimentación y Medio Ambiente, 2014). The expansion of pistachio trees cultivation in countries like the USA has been linked to a change in the type of orchard management, with the aim of increasing yield mainly by transforming pistachio from a traditionally rainfed cultivated crop to an irrigated crop. Bilgen (1982) indicated that irrigation should be considered among the most important cultural practices to sustain high yields in pistachio orchards.

Cultivated for a long time in semi-arid areas, the pistachio tree has been considered as a drought-tolerant species (Spiegel-Roy et al., 1977; Behboudian et al., 1986; Rieger, 1995) mainly for its ability to survive under extreme conditions of water stress (Kanber et al., 1990; Goldhamer, 1995). At the same time, the pistachio tree water demand is not known to be particularly low (Goldhamer et al., 1985) and the potential evapotranspiration rate at the max-

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imum seasonal evaporative demand is equal or exceeds that of many other deciduous species (Goldhamer et al., 1983). The relation between Crop Evapotranspiration (ET_c) and Reference Evapotranspiration (ET_o) is named Crop coefficient (K_c) and represent the needs of water for each crop. Kanber et al. (1993) estimated a K_c for pistachio between 0.49 and 0.80 from May to August, but suspected that these values underestimated the real water consumption of pistachio trees. Goldhamer (1995) presented a K_c much higher, estimating a maximum of 1.19 from the first fortnight of July to the first fortnight of August. The elevated pistachio water needs became a concern, since the majority of pistachio producing regions were suffering an alarming continuous depletion of their water reserves and could not always sustain the tree water requirements due to the scarcity of rain and the increasing competition for fresh water. This situation led to the need of improving the efficiency of water use. Deficit irrigation is proposed as a tool for this purpose and it consists on imposing a continuous water deficit during the season (sustained deficit irrigation) (Goldhamer et al., 1987) or during specific phenological stages (regulated deficit irrigation). Regulated deficit irrigation (RDI) has been a common research line for most fruit trees (Behboudian and Mills, 1997). The concept of RDI was first suggested by Chalmers et al. (1981) and Mitchell and Chalmers (1982) to control vegetative growth in peach orchards, and they found that savings in irrigation water could be realized without reducing the yield. In order to determine the response of pistachio trees to sub-optimal water application at several periods of growth, Goldhamer (1995) divided the pistachio fruit growth cycle into four phenological stages (stage I, II, III and postharvest). Stage I covers the whole period of shell expansion, stage II the period of shell hardening, and stage III the embryo growth. He observed that stage II and postharvest are the most tolerant stages to water stress. Gijón et al. (2011) ascribed this tolerance during stage II to changes in water relations. In contrast, stage III was reported to be the most sensitive stage to water deficit that can have a dramatically negative impact on all pistachio yield components. Goldhamer and Beede (2004) observed that the water stress during stage I increases shell splitting; however it could affect the final fruit size and increase undesirable premature shell splitting. Gijón et al. (2008) imposed a water stress during stage I and II (50% of ET_c) and observed no differences on yield, but no positive effects were reported either with regards to an increase of nuts splitting. The early nut splitting was more closely associated to a roof temperature than to the water status during stage I.

RDI works in pistachio trees were generally scheduled imposing a water stress that was quantified as a fraction of ET_c during a specific stage. However, the different agronomical conditions (mainly soil characteristics), when different locations are used for experimentation, produce a lack of similarity between results and make them little transferable. To overcome this inconvenience, several authors suggested using plant water status measurements as an efficient tool for irrigation scheduling (Turner, 1990; Fereres and Goldhamer, 1990) rather than indirect estimations. Shackel et al. (1997) carried out probably the first study that suggested using plant water status measurements (leaf water potential) as a tool for irrigation scheduling.

For pistachio trees, Goldhamer et al. (2005) suggested an initial approach based on shaded leaf water potential measurements for a fully irrigated mature orchard, recommending an range from −0.7 MPa to −1.2 MPa in which the shaded leaf water potential decreases gradually from stage I to postharvest, founding also a good correlation between midday shaded leaf water potential and stem water potential (R^2 = 0.948). In other deciduous tree crops, such as prunes, almonds or grapevines, the behaviour of the stem water potential was found to be more closely linked to vapour pressure deficit (VPD) variations than to the growth stage (McCutchan and Shackel, 1992; Shackel, 2011; Williams and Baeza, 2007).

A possible cause for the response variations of pistachio to water stress could be the influence of the rootstock used. *Pistacia integerrima* L., *Pistacia atlantica* Desf., *Pistacia terebinthus* L. and UCB-I (a cross between *Pistacia integerrima* L. and *Pistacia atlantica* Desf.) are currently the most widely used rootstocks for pistachio cultivation. *P. integerrima* is recognized as the most vigorous rootstock, *P. atlantica* as having medium vigour, and *P. terebinthus* as the weakest one (Ferguson et al., 2005). There are few studies comparing the water relation responses between pistachio rootstocks. Germana (1997) mentioned that potted *P. atlantica* induced a more intense transpiration and net photosynthetic activity when it was compared to *P. terebinthus*, and this may limit its use in water-deficient areas. Ferguson et al. (2005) considered UCB as the most preferable commercial rootstock under irrigated conditions, and *P. terebinthus* in rainfed conditions.

Thus, the aims of this work were: to test the viability of using stem water potential measurements as a tool for irrigation scheduling, to study the effects of a water stress levels between -1.5 MPa and -2.0 MPa during stage II on the pistachio-water relations, growth, production and yield quality and to compare the behaviour of different rootstocks when subjected to the imposed water stress.

2. Materials and methods

2.1. Experimental site and plant material

The study was conducted for three years, from 2012 to 2014, in an orchard of trees grafted in 2000 and located in "La Entresierra" research station, Ciudad Real (Centre of Spain) (L 3°56′W; L 39°0′N; altitude 640 m). *P. vera* L. cv. Kerman was budded on three different rootstocks: *P. terebinthus* L., *P. atlantica* Desf. and *P. integerrima* L. Tree spacing was set at 7 × 6 m (238 trees ha^{-1}). Peter cv. was used as male tree and was distributed evenly throughout the field, in a proportion of 10%.

Irrigation was performed daily using a drip irrigation system with twelve self-compensating emitters (each delivering 4 L h^{-1}) per tree and irrigation water with an electrical conductivity of 2.6–2.9 dS cm^{-1}. Irrigation lines were separated 1 meter from the tree line and the distance between drippers was also 1 m (Fig. 1).

The soil at the experimental site is an alkaline (pH 8.1) shallow soil with a discontinuous petrocalcic horizon located at 0.50 m (Petrocalcic Palexeralfs), with a clay loam texture, low electrical conductivity (0.2 dS m^{-1}), 1.05% of organic matter, 0.12% of nitrogen, 17×10^{-4} mol kg^{-1} potassium levels and high cationic exchange capacity (0.186 mol kg^{-1}). The volumetric water content of the soil for the first 0.3 m of depth was 22.8% at field capacity (soil matric potential −0.03 MPa) and 12.1% at permanent wilting point (soil matric potential -1.5 MPa); from 0.3 m to 0.5 m it is 43.0% and 21.1%, respectively.

The climate is Mediterranean with an average annual rainfall of 397 mm, mostly distributed outside a four-month summer drought period.

The orchard was managed under no tillage conditions; weeds were controlled with post-emergence herbicides. Pest control and fertilization practices were those usually followed by local growers.

2.2. Rootstocks and irrigation regimes

The experimental design was factorial and completely randomized. Two factors were considered: rootstocks and irrigation; with three levels for each factor.

The three rootstocks used were *P. terebinthus* L., *P. atlantica* Desf. and *P. integerrima* L., while the three irrigation levels were a Control, without water stress, and two RDI treatments.