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Rootstock influences the response of pistachio (*Pistacia vera* L. cv. Kerman) to water stress and rehydration

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ABSTRACT

Pistachio cultivation requires the use of rootstock because grafting is the only form of vegetative propagation. The main commercial rootstocks are *Pistacia integerrima* L., *Pistacia atlantica* Desf., *Pistacia terebinthus* L. and *Pistacia vera* L. Pistachio is considered to be a drought and saline-resistant crop; however, there is little information describing varietal responses of rootstocks to water stress. Some studies have suggested that *P. terebinthus* L. is the most drought and cold resistant rootstock. The effect of the rootstock on the water relations of the grafted plant is crucial for improving crop performance under water stress conditions and for developing the best irrigation strategy. This work studied the physiological response to water stress of pistachio plants (*P. vera* L. cv. Kerman) grafted onto three different rootstocks *P. terebinthus* L., *P. atlantica* Desf. and a hybrid from crossbreeding *P. atlantica* Desf. × *P. vera* L. Plant physiological responses were evaluated during a cycle of drought and subsequent recovery in potted plants. Parameters measured were soil moisture, trunk diameter, leaf area, leaf number, leaf and stem dry weight, stem water potential, leaf stomatal conductance. The results showed different responses of cv. Kerman depending on the rootstock onto which it had been grafted. The hybrid rootstock was associated with a higher degree of stomatal control and reduced leaf senescence compared to *P. atlantica* and *P. terebinthus*, despite being associated with the most vigorous shoot growth. *P. terebinthus* enabled very effective stomatal control but was also associated with the most rapid leaf senescence. *P. atlantica* was associated with less vigorous shoot growth and similar levels of water stress as occurred with the others rootstocks under conditions of high evaporative demand, which was associated with lower stomatal control. The selection of the most effective rootstock choice for different environmental conditions is discussed.

1. Introduction

Pistachio is an important crop in Iran and USA, which are the major world producers, while in other countries it is becoming an interesting alternative to traditional crops. In the Mediterranean region, uncertainty about the future of economic support from the European Union to traditional crops, such as olive and vineyards, and the use of low fertility soils for agriculture has resulted in a large increase in the area planted with pistachio. In Spain, the total planted area was almost negligible in 1990, and currently is about 4000 ha. While the production in Turkey (third world producer) has been steady during the last 15 years, in Greece it has increased from 5000 t in the early 90s to 9000 t at the beginning of the twenty-first (FAOSTAT, 2007).

Pistachio is considered as a drought and saline-resistant crop (Behboudian et al., 1986; Rieger, 1995), and in the Mediterranean basin it is mainly grown under rain fed conditions. However, as with other tree species, irrigation increases yield. In pistachio, irrigation also improves nut quality (higher percentage of splitted nuts) and dampens the alternate bearing pattern (Kanber et al., 1993; Goldhamer, 1995). The benefits of irrigation in this crop may be higher than in others crops; however, there is a requirement properly quantify these responses. The good performance under dryland conditions and the favourable response to irrigation are very important considering that water is a scarce resource and in the future only the most efficient agricultural systems are likely to receive inputs of irrigation water (Fereres et al., 2003).

Pistachio cultivation requires the use of rootstocks, and grafting is the only form of vegetative propagation. The main pistachio rootstocks are *Pistacia integerrima* L., *Pistacia atlantica* Desf., *Pistacia terebinthus* L. and *Pistacia vera* L. The most used rootstock in Iran is *P. vera* L., in the USA is *P. integerrima* L. and a hybrid between *P.*

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integerrima and *P. atlantica* Desf. (UCB), and in the Mediterranean basin is *P. terebinthus* L. Most scientific studies with pistachio trees have been done with varieties grafted onto Californian commercial rootstocks, such as *P. atlantica* Desf., UCB and *P. integerrima* L. There are few reported studies comparing different rootstocks. Ferguson et al. (2005) reported that *P. terebinthus* L. was the most drought and cold resistant rootstock, while *P. integerrima* L. was susceptible to frost but tolerant to verticillium. *P. atlantica*, which was once one of the most popular rootstocks in California, has been discarded in many places because of its high susceptibility to verticillium (Ferguson et al., 2005). Nowadays, UCB is considered the best commercial rootstock under irrigation (Ferguson et al., 2005). Germana (1997) comparing different rootstocks observed that *P. atlantica* has higher transpiration and photosynthetic activity than *P. terebinthus*, particularly in stressed plants, which could make it more susceptible to drought stress. Guerrero et al. (2003) found no rootstock effect on production when comparing *P. terebinthus* L., *P. integerrima* L., *P. atlantica* Desf. and *P. vera* L. under rain fed conditions.

In other woody crops, the use of rootstocks is optional; they may be grown without rootstock, and they are mainly used because of improving some of the cultivar characteristics as tree size, crop yield or yield quality. Different studies on apple (Olien and Lakso, 1986; Cohen and Naor, 2002) and peach (Weibel et al., 2003) showed that specific rootstocks had an important influence on vegetative growth rate. Solari et al. (2006) confirmed in peach that rootstock effects on the tree water relations and vegetative growth are derived, at least partially, from differences in the tree hydraulic conductance associated with specific rootstocks. In addition, several hypothesis reviewed by Rogers and Beakbane (1957), Lockard and Schneider (1981) and Webster (1995) suggest that rootstock can affect vegetative tree growth through hormonal effects (Kamboj et al., 1999), mineral nutrition (Jones, 1971) or water status (Olien and Lakso, 1986).

The pistachio response to water stress has not been adequately characterized. There are few works studying the water relations of this species. Behboudian et al. (1986) subjected potted pistachio plants (*P. vera* L. cv. Kerman grafted on *P. atlantica* Desf.) to water and saline stress and reported some photosynthetic activity even at midday stem water potential (ψ_x) between −5 and −6 MPa. In this work, they concluded that the stress response of pistachio plants was better than some other fruit trees and other typical xerophytes species (Behboudian et al., 1986).

In recent years, a breeding program has been developed to improve pistachio rootstocks at El Chaparrillo Research Station, Ciudad Real, Spain. This program is being conducted using two techniques: first, crossings have been made between traditional rootstocks, and second, germplasm from different areas of Castilla-La Mancha (central Spain) and northern Andalucia (southern Spain) has been collected to be used in the breeding program (Guerrero et al., 2003). At present, the most promising individuals are being tested. One of the best rootstocks obtained in this program is the second generation, open-pollinated seed crossing *Pistacia atlantica* Desf. × *Pistacia vera* L., which shows a high vigour (Guerrero et al., 2007). This is the rootstock referred to as 'hybrid' in current study. Initial assessments of collected germplasm have shown differences depending on the area they come from, the one from Calzada de Calatrava (Ciudad Real, Spain) showing the highest vigour. This germplasm has been used in our previous testing to establish the characteristics of *P. terebinthus* as a rootstock (Guerrero et al., 2007).

As pistachio is planted in Spain mainly in dryland areas, the effect of rootstock in the cultivar response to water stress under these conditions will be of major importance. Rootstock effects are important for both physiological responses of the shoot variety and its productivity. The objective of this work was to study the effect of three different rootstocks (*P. terebinthus* L., *P. atlantica* and a hybrid from the crossbreeding *of P. atlantica* × *P. vera*) on the physiological responses to water stress of pistachio plants (*P. vera* L. cv. Kerman). Plant responses were evaluated during cycle of drought and recovery.

2. Materials and methods

2.1. Site description and experimental design

The experiment was conducted during the summer of 2007 at La Entresierra Research Station, Ciudad Real, Spain (3°56′W–39°0′N; altitude 640 m). One-year old pistachio plants (*P. vera* L. cv. Kerman) grafted onto three different rootstocks, *P. terebinthus* L., *P. atlantica* Desf. and a hybrid from the crossbreeding *of P. atlantica* × *P. vera* (hereafter referred to as 'hybrid') were used. The hybrid was obtained in the breeding program at the El Chaparrillo Research Station. Thirty plants were planted in the spring of 2007 in 50 L pots filled with a mixture of gravel, sand and peat (5, 80 and 15% respectively), and placed outdoors. The experiment took place from "day of the year" (DOY) 190 until DOY 225. Reference evapotranspiration (ETo) was calculated according to Allen et al. (1998), and rainfall data were obtained from a nearby (aproximately 500 m) meteorological station.

The experimental design was a completely randomized split plot design with 5 replicates. The main factor was the rootstock and the secondary factor was irrigation. The irrigation treatments were full irrigation (Control) and no irrigation (Stress). The different combination of the two factors will be named as follows:

- *P. terebinthus*-Control (PTC)
- *P. terebinthus*-Stress (PTS)
- *P. atlantica*-Control (PAC)
- *P. atlantica*-Stress (PAS)
- Hybrid-Control (HC)
- Hybrid-Stress (HS)

From DOY 190, the control and stressed plants were drip irrigated until slight drainage occurred. Each pot had 4 drippers ($4\,\mathrm{L\,h^{-1}}$) and was irrigated every afternoon. To determine pot weight at field capacity, all pots were weighted early in the morning, always at the same time, at least three times per week (Monday, Wednesday and Friday). In plants subjected to water stress, irrigation was withdrawn from DOY 204 until 218 when they were re-watered to study re-hydration. Once the stress period was completed, pots were re-watered up to field capacity. The weight at field capacity at the end of the experiment was different to that at the beginning of the experiment, probably due to the decreasing water retention capacity of the peat as it dried out. Soil moisture measurements were taken at 10, 20 and 30 cm depth with a portable capacitance probe (Diviner, 2000, Sentek Pty. Ltd., Australia) placed approximately 15 cm away from the stem. As the results were similar to those obtained by the weighing method, only the latter will be shown in Section 3.

2.2. Measurements

Trunk diameter was measured in all plants once a week with a digital gauge, 1 cm above the grafting point. Measurements were taken early in the morning, from 183 to 225 DOY. At the end of the experiment, leaf area (LA) data were obtained using a leaf area meter (LI-3100C, Lincoln, Nebraska, USA), and leaf and stem biomass was determined drying the plant organs in an oven at 70 °C until constant weight. Prior to each biomass determination, visual leaf damage caused by water stress was visually evaluated on a scale of 1–5. Value 1 corresponded to leaves without

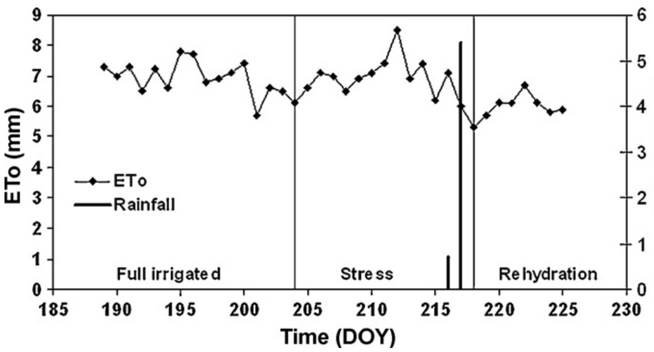

Fig. 1. Rainfall and reference evapotranspiration (ETo) during the experiment. The two vertical lines represent the water stress period.

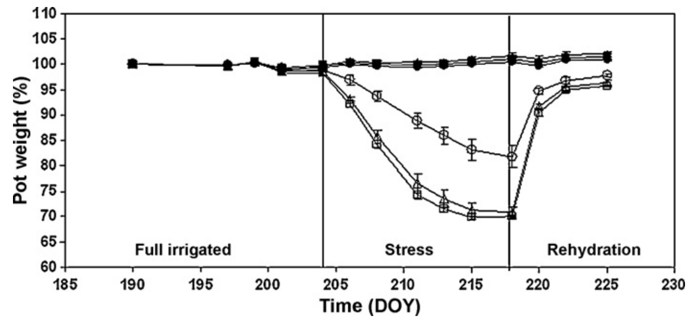

Fig. 2. Pot weight throughout the experiment as a percentage of the weight at field capacity, for all groups. Each point represents the mean of 5 measurements. The two vertical lines represent the water stress period. Bars represent the standard error. (●) PAC; (○) PAS; (■) PTC; (□) PTS; (▲) HC; (△) HS.

wilting symptoms, value 3 to when 50% of leaf surface presented wilting symptoms and value 5 indicated leaves completely wilted.

Stem water potential (Ψ_x) was periodically determined, six measurements were made throughout the experiment to evaluate plant water status. Fully expanded leaves were covered with aluminium foil at least 1 h before measurement, and Ψ_x determined at midday using a pressure chamber (Soil Moisture Equip., Santa Barbara, CA, USA). Each time, one leaf per plant and per replicate was used. Abaxial leaf conductance (g_s) was measured with a steady-state porometer (LICOR-1600, UK) between 12:00 and 14:00 local time, on the central leaflets of the composite leaf. Measurements were taken in all plants (two measurements per plant) on fully expanded leaves receiving direct sunlight, three times a week throughout the experiment.

Vapour pressure deficit (VPD) was calculated from data of a meteorological station around 500 m from the place where the experiment was performed.

2.3. Statistical analysis

The main effects of the two factors were examined by ANOVA and means were compared using the test of Tukey, with a significance $P < 0.05$. Significant differences are identified with different letters. The Statistix 8.0 (Analytical Software, USA) was used for the statistical analysis.

3. Results

3.1. Evapotranspiration and plant water requirements

During the experimental period (DOY 190–225), ETo ranged from 5.3 to 8.5 mm d^{-1}. During the water stress period (DOY 204–218), except on day 212, ETo was more steady, with values around 7 mm d^{-1} (Fig. 1). Precipitation was low, just two events were recorded on day 216 (0.7 mm) and day 217 (5 mm) at the end of the stress period (Fig. 1). The pots had an initial mean weight of 58 kg (100% in Fig. 2) when the soil was at field capacity, and those of the stressed plants lost on average 17.8, 17.0 and 10.5 kg (PTS, HS and PAS, respectively) from the beginning of the experiment to the time of maximum stress (DOY 218; Fig. 2). The recovery of the soil water content was very fast. Two days after the beginning of the rehydration, PAS pots recovered 94.7% of their initial weight, followed by the HS (91.6%) and PTS (90.4%) (Fig. 2). After a week, the 3 rootstocks had recovered almost their initial weight: 97.7, 96.3 and 95.7% (PAS, HS and PTS, respectively) (Fig. 2).

3.2. Plant biomass and trunk and leaf growth

Trunk diameter increased with time in all water treatments and rootstocks. Fig. 3 shows the values of the trunk diameter as a fraction of the diameter at the beginning (TD/TDi) of the experiment for each treatment and rootstock. When plants were well irrigated, there was no effect of the rootstock on the diameter trunk growth. Although *P. atlantica* and the hybrid showed higher final values (1.40) than *P. terebinthus* (1.25), differences were not significant.

Water stress affected trunk diameter earlier in PTS and HS than in PAS, showing a decrease in the slope of TD/TDi with time in relation to well-watered plants with the same rootstock. However, it was only at the end of the stress period (218 DOY) when signifi-

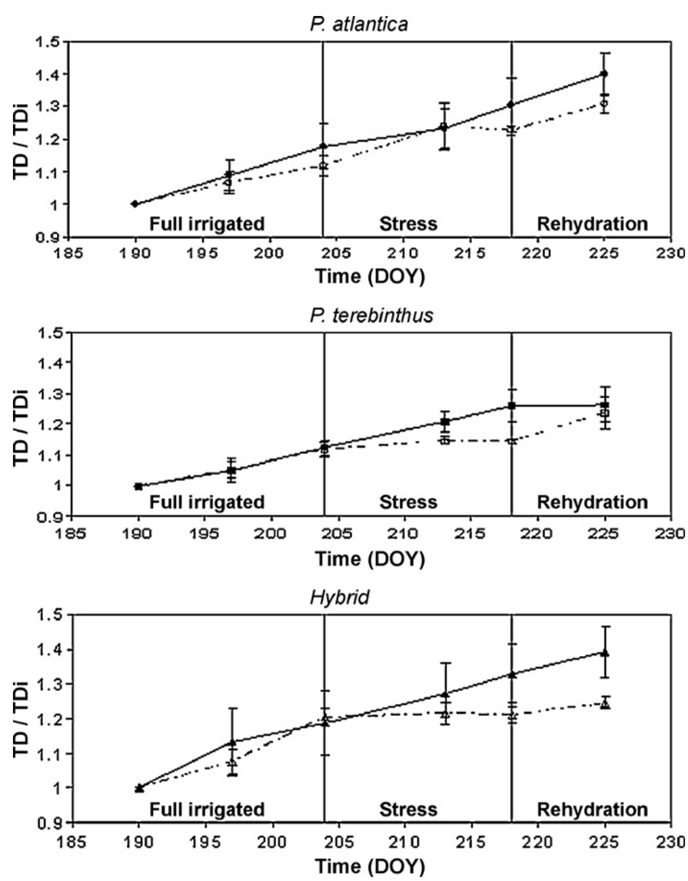

Fig. 3. Seasonal pattern of the trunk diameter as a fraction of the initial value (TD/TDi), for the three rootstocks and two water treatments. Each point is the average of 5 measurements. Bars represent the standard error. (●) PAC; (○) PAS; (■) PTC; (□) PTS; (▲) HC; (△) HS.

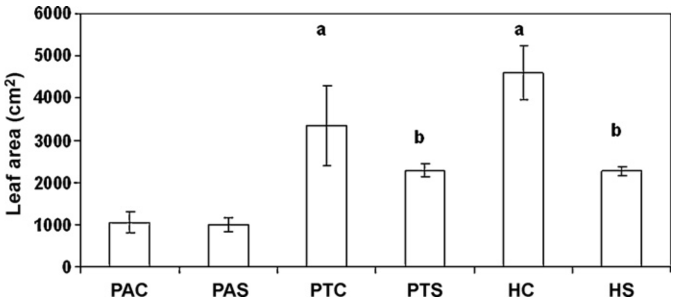

Fig. 4. Leaf area for all the rootstock and water treatments at the end of the experiment (DOY 225). Data are the averages of 5 replicates. Bars represent the standard error. Different letters indicated significant differences between control and stress treatment in each rootstock ($P < 0.05$; Tukey test).

cant differences were found among rootstocks, with smaller TD/TDi values in PTS than in PAS and HS.

The response of plants to re-watering on DOY 218 was faster in PAS and PTS than in HS, although all the rootstocks showed no significant differences between control and stressed plants at the end of the rehydration period.

Another parameter that characterises growth is leaf area. In control conditions, PTC and HC showed a significantly higher leaf area than PAC. Differences between PTC and HC, even though the hybrid was approximately 30% higher, were not statistically significant (Fig. 4). Water stress mainly affected leaf area development of PTS and HS, producing significant reductions in leaf area of both these treatments. The largest leaf area decrease occurred in the HS, being about 50%, while in PTS it was 32%. On the contrary, there was no significant effect on leaf area development in PAS, with differences between the control and stress treatments being only 6%.

Fig. 5 shows the final leaf number as a fraction of that at the beginning of the experiment (LN/LNi, Fig. 5a) and the leaf dry weight and stem dry weight (Fig. 5b) at the end of the experiment for all the rootstocks and water treatments. LN/LNi was calculated in order to avoid the effect of the variability in leaf number among plants at the beginning of the experiment on the possible differences between water treatments at the end of the stress period. It was not possible to use the same approach for leaf and stem dry weight as it involved destructive measurements. As it was observed in leaf area, in the control treatment, HC and PTC showed significantly higher leaf and stem dry weight than PAC (Fig. 5b), while the ratio LN/LNi was similar for all the rootstocks. Water stress resulted in a significant reduction in LN/LNi in PTS and HS, but not in PAS (Fig. 5a). PAS also showed similar values of final leaf and stem dry weight than PAC. However, although leaf and stem DW of stressed plants of the hybrid were lower than those of control plants, the differences were not statistically significant, which was probably due to the initial variability of this parameter among plants. The response of PTS plants to water stress was intermediate, with leaf DW being affected but not stem DW, although once again the differences were not statistically significant (Fig. 5b).

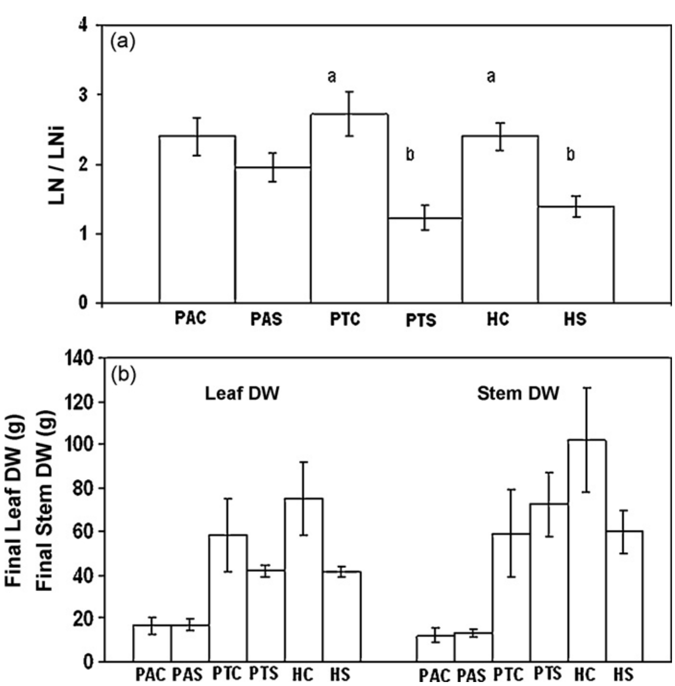

Fig. 5. (a) Leaf number as a fraction of the value at the beginning of the experiment (LN/LNi) and (b) leaf and stem dry weight (final leaf DW and final stem DW, g/plant) at the end of the experiment for all the rootstock and water treatments. Data are the average of 5 replicates. Bars represent the standard error. Symbols are indicated in the figure. Different letters indicated significant differences between control and stress treatment in each rootstock ($P < 0.05$; Tukey test).

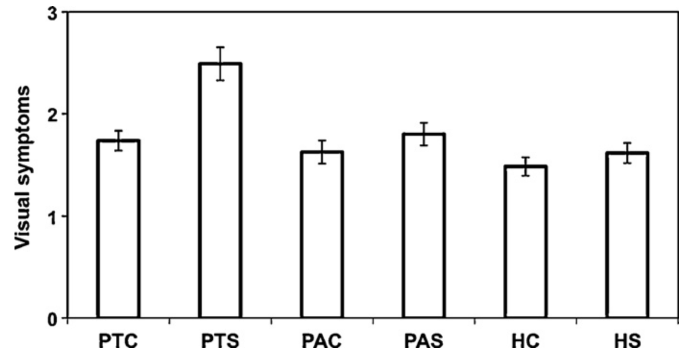

Fig. 6. Values of the visual symptoms of water stress (1 = no symptoms; 5 = 100% wilting surface) for all rootstocks and water treatments. Data are the average of 5 replicates. Bars represent the standard error.

There were no significant differences among rootstocks in visual wilting symptoms of stressed plants, although it seemed that PTS was more affected than PAS and HS, with mean values of 2.5, 1.8 and 1.6 respectively (Fig. 6). Surprisingly, for each rootstock, although stressed plants showed higher wilting damage values than control plants, differences were not significant according to the scale chosen, as high variability was found among plants of the same treatment.

3.3. Water relations

Fig. 7 shows the time course of Ψ_x throughout the experiment for all the rootstocks. Ψ_x ranged from −0.6 to −1.45 MPa in control plants, and from −0.87 to −3.8 MPa in stressed plants. The effect of water stress on Ψ_x was not detected until DOY 211 as significant differences were not found neither between water treatments nor rootstocks on day 208, 4 days after the beginning of the drying cycle. However, water treatment–rootstock interaction was significant on day 208 showing lower Ψ_x values for HS and PTS than for PAS. The minimum values of Ψ_x were reached on DOY 218 (10 days after the onset of water stress), PTS and HS rootstocks showing significantly lower Ψ_x than PAS, being respectively −3.35 and −3.04 MPa, and following the same pattern as in previous dates. Following, the final measurements on DOY 218, plants were fully irrigated and the recovery began. Only 2 days later (DOY 220) PAS was fully recovered from the stress, while PTS and HS had recovered 90% and 81% of the Ψ_x measured in the respective control plants that day. At the end of the experiment (DOY 225), Ψ_x values in PTS and HS were 93% and 91% of that of their controls, respectively. These differences between values of recovered and stressed plants were not statistically significant.

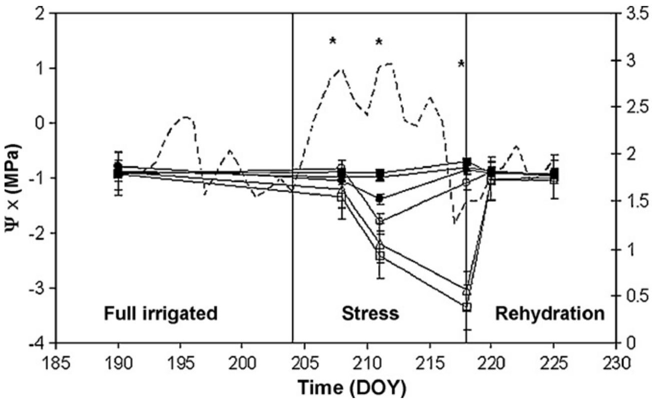

Fig. 7. Seasonal pattern of the stem water potential (Ψ_x) and VPD (dotted line) during the experiment. Each point is the mean of 5 measurements. The two vertical lines represent the water stress period. Bars denote the standard error. Asteriks "*" represent significant differences between rootstock in the stress treatment ($P < 0.05$; Tukey test). (●) PAC; (○) PAS; (■) PTC; (□) PTS; (▲) HC; (△) HS.

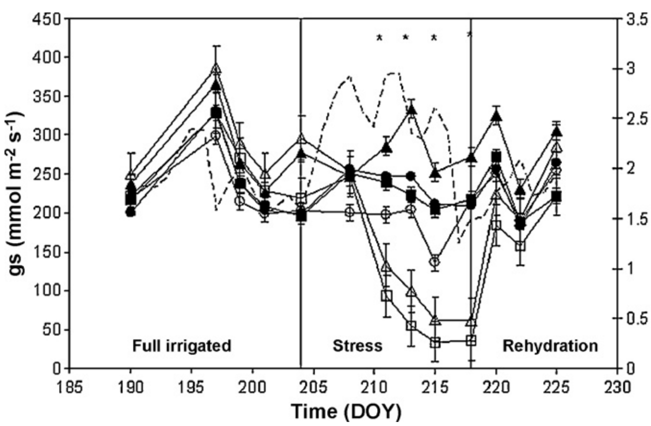

Fig. 8. Seasonal pattern of the stomatal conductance and VPD (dotted line) during the experiment. Each point is the mean of 10 measurements. The two vertical lines represent the water stress period. Bars denote the standard error. Asteriks "*" represent significant differences between rootstock in the stress treatment ($P < 0.05$; Tukey test). (●) PAC; (○) PAS; (■) PTC; (□) PTS; (▲) HC; (△) HS.

Stomatal conductance (g_s) in control plants ranged from 149 to 326 mmol m^{-2} s^{-1}, showing no differences between rootstocks for each date of measurement (Fig. 8). Water stress affected g_s in all rootstocks, with PAS once again being the rootstock less affected, followed by HS and finally PTS. Differences in g_s were significant on days 211, 213 and 215, with values for PAS being higher than those of PTS and HS. The minimum g_s values during the stress period were observed on DOY 215, 7 days after the beginning of the drying cycle, being 136.8, 33.9 and 62.8 mmol m^{-2} s^{-1} in PAS, PTS and HS, respectively. Two days after rehydration (DOY 220), stomatal conductance was fully recovered in PAS at levels even higher than the control plants in some cases. However, g_s in PTS and HS was only 67.7% and 68.6% of that in control plants. On DOY 225, 1 week after the beginning of the recovery, g_s in PTS and HS was already 96% and 93.5% of the values measured in control plants.

4. Discussion

The three different rootstocks studied in this work induced a differential response of growth and water relations in the cultivar Kerman, both under well watered (control) and water stressed conditions. In the absence of water stress, the hybrid rootstock promoted higher vegetative growth in the shoot variety than the other two rootstocks, especially *P. atlantica*, with a larger leaf area and total biomass (Figs. 4 and 5). This greater growth during the initial stages, which was most marked with the hybrid, resulted in different plant size at the beginning of the stress period for the three rootstocks studied. Fig. 2 characterizes these differences very well, showing a much higher water use during the drying cycle for both *P. terebinthus* and the hybrid compared to *P. atlantica*. These results are the opposite of those obtained by Ferguson et al. (2005), who suggested that *P. terebinthus* is the least vigorous of all the rootstocks used in California. Guerrero et al. (2007) have shown significant differences in vigour among different but near populations of *P. terebinthus*. In our study, we could have used a particularly vigorous population of *P. terebinthus*, since *P. atlantica* is usually considered to be a rootstock of moderate vigour (Ferguson et al., 2005; Spann et al., 2007). The vigour of fruit trees may be important because it is likely to be related to yield. In pistachio, Spann et al. (2007) suggested that more vigorous rootstocks can also involve higher pruning costs because they promote more vegetative growth in the shoot cultivar. These authors also suggested that a more moderate vigour could be compensated by a higher plant density. Vigour has been also related to successful field grafting. Guerrero et al. (2007) found that under field conditions, grafting success in pistachio is closely related to the trunk diameter, and therefore greater vigour would probably reduce grafting failures.

Rootstock changes the response of the pistachio tree to water stress conditions. *P. atlantica* showed slight but not significant reductions in leaf number. In constrast, in *P. terebinthus* and the hybrid, growth was most affected by water stress conditions (Figs. 4 and 5). This response is generally found in all species, since expansive growth is the most sensitive process to water stress in plants and is affected even at relatively high leaf water potentials (Hsiao, 1973). Trunk diameter data showed that growth did not stop absolutely under water stress but that it slowed down (Fig. 3). This agrees with the data shown by Behboudian et al. (1986) in which slight turgor loss under severe stress still allows some tree growth. In our study, the reduction of trunk diameter in response to water stress took place earlier in the variety grafted onto the hybrid and *P. terebinthus* than on *P. atlantica*. This response to water stress seems in accordance to the response measures in other parameters such as Ψ_x and g_s which will be discussed later. In contrast, the recovery of growth was slower in the hybrid than in the other two rootstocks (Fig. 3). Visual symptoms of water stress in leaves and the decrease of green leaf area are indicators of leaf senescence caused by water stress. Apparently, *P. terebinthus* induced a stress avoidance response in Kerman variety with a greater leaf area reduction (lower number and higher damage) than the other two rootstocks. Unless the leaf area can be increased after the stress period, this response is considered as an undesirable feature if it reduces crop yield through a lower assimilation capacity.

Water stress, characterises by stem water potential measurements, was more severe in plants grafted on *P. terebinthus* than the hybrid (Fig. 7). The level of induced water stress was not as great as described in other studies in which minimum Ψ_x values of −5 MPa have been reported (Behboudian et al., 1986). The higher Ψ_x values in *P. atlantica* were likely related to the smaller transpiring plant leaf area and biomass (Figs. 4 and 5). In relation to these leaf area values, differences in stem water potential between rootstocks (Fig. 7) were smaller than expected in the drought stress. In addition, *P. atlantica* also showed very little stomatal control of transpiration (Fig. 8), which could have contributed to reduced Ψ_x differences between this rootstock and *P. terebinthus* and the hybrid. These results are in agreement with the delayed response of trunk diameter to water stress in *P. atlantica* compared to *P. terebinthus* and the hybrid (Fig. 3). Considering the smaller leaf area of *P. atlantica*, the degree of water stress imposed in this experiment may not have not been strong enough to affect parameters such as Ψ_x and g_s, in this rootstock, as quickly as occurred in *P. terebinthus* and the hybrid.

Leaf conductance of well-watered control plants was higher in the hybrid than in the other two rootstocks, especially during the water stress period (Fig. 8). Therefore, the hybrid induced in the shoot variety the highest degree of stomatal control in response to water stress, maintaining also the highest g_s under irrigation. This high g_s of control plants in the hybrid could have contributed to their higher growth through higher assimilation rates. This behaviour is characteristic of drought resistant species (Loomis and Connor, 1992).

5. Conclusions

The behaviour of the Kerman variety in terms of growth and water relations, under irrigated and water stress conditions, depended on the rootstock it was grafted onto. The rootstock that induced a higher sensitivity to water stress was *Pistacia atlantica* Desf., with low stomatal control of transpiration, although these results should be taken with caution as the degree of water stress imposed to that variety was milder as result of its low leaf area development. By contrast, the rootstock *P. terebinthus* L. showed a better stomatal control, and slightly higher levels of water stress than the hybrid which resulted in smaller reductions of leaf area but not in leaf number, probably due to differences in leaf size. Finally, the hybrid rootstock showed slightly less stomatal control under stress conditions than *P. terebinthus* and, even though it was the most vigorous, it lost more leaf area through senescence. Although the reduction in leaf area allowed a quicker recovery of some parameters after water stress was over, it could result in a reduction in the assimilation capacity of the tree under field conditions, which could affect crop yield. This hypothesis should be checked in field experiments. The responses found in this work should be taken into account when selecting the rootstock for the establishment of a new orchard, knowing the irrigation management that will be used. Under irrigation, the hybrid may be the best rootstock since it induces the biggest leaf conductance and vigour, which will be likely to be accompanied by a more productive response. In the case of dryland conditions or regulated deficit irrigation in which water stress periods are induced, *P. terebinthus* might be a good choice for their drought tolerance, as it is able to maintain greater leaf area relative to that of non-stressed plants with lower Ψ_x and g_s values.

All these results suggest the need to evaluate the effect of these rootstocks on the productive response of this variety under variable water stress conditions in the field.

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