

# Sap Flow, Stem Water Potential and Stomatal Conductance to Water and CO<sub>2</sub> in Mature Olive Trees under Regulated Deficit Irrigation and Partial Root Drying

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## Abstract

**Partial root drying irrigation do not improve the performance of mature olive trees under field conditions, as compared to regulated deficit irrigation.**

## INTRODUCTION

Deficit irrigation (DI) is currently considered by many fruit growers as the most advantageous approach for irrigating the orchards of areas where water is scarce. Among the different DI techniques, regulated deficit irrigation (RDI) and partial root drying (PRD) are the ones that have risen more interest in the last years. Both irrigation techniques have been tested in a variety of species. The irrigation equipment for applying PRD is more expensive –it requires double pipe per tree row- than that for RDI, and its management is more complex, since water must be supplied alternatively to each half of the rizosphere every a certain number of days, usually every two weeks. Despite this, some authors claim that PRD is the most advantageous DI approach, due to a reduction in the water lost by transpiration caused by stomatal closure, which increases the water use efficiency (Dry et al., 1996, 2001; Stikic et al., 2003). Other authors, however, have found no evidence for the use of PRD (dos Santos et al., 2003; de Souza et al., 2003; Goldhamer et al., 2003). PRD has been sometimes compared with a control treatment in which enough water is supplied by irrigation to cover the crop water demand, or to a fixed partial root zone irrigation, but not to a RDI treatment (Dry and Loveys, 1999; Dry et al. 2000; Kang et al., 2002, 2003a,b). In those cases, the observed advantages of the PRD system might be due to the fact that this is a DI treatment, and the doubt remains on whether a similar crop behaviour could have been found if the plants had been under RDI conditions. In addition, the time for alternating irrigation in the PRD system is not clear, at least for field trees growing in soils with a medium to high water retention capacity. In this case, the normally recommended 14 days period (Loveys et al., 2000; Stoll et al., 2000; Dry et al., 2001) could perhaps be too short. Apart from that of Goldhamer et al. (2003) and Kang et al. (2002, 2003a,b), little work has been published on PRD applied to fruit tree species. We know no work made with the olive tree.

The aim of this work was to study the behaviour of mature “Manzanilla de Sevilla” olive trees growing under RDI and PRD, to see whether PRD has any advantage over RDI.

## MATERIALS AND METHODS

The experiments were carried out in a 0.5 ha olive orchard at 15 km from Seville, southwest Spain (37° 17' N, 6° 3' W, elevation 30 m). The trees (*Olea europaea* “Manzanilla de Sevilla”, from now on “Manzanilla”), planted at 7 m × 5 m, were 35 years old in 2003. The soil of the orchard is a sandy loam (Xerochrept) of some 2 m depth in the area of the experimental plots. The texture is quite homogeneous, with average values of 14.8% clay, 7.0% silt, 4.7% fine sand and 73.5% coarse sand. Laboratory measurements showed that the volumetric soil water content ( $\theta$ , m<sup>3</sup> m<sup>-3</sup>) is 0.33 m<sup>3</sup> m<sup>-3</sup> for a soil matric potential ( $h$ , MPa) of 0 MPa, and 0.10 m<sup>3</sup> m<sup>-3</sup> for -1.5 MPa. In the field, however,  $\theta$  measured closed to the drippers a few hours after irrigation was rarely greater than 0.20 m<sup>3</sup> m<sup>-3</sup>. The climate of the area is typically Mediterranean, with average rainfall and evapotranspiration values of 484 mm and 1442 mm, respectively (period 1976-2001).

Four adjacent plots of 27 trees each were chosen for the experiments. Each plot received a different water treatment: (a) Treatment D was dry-farming, with rainfall as the only means of water supply; (b) Treatment FAO was a daily drip irrigation for the whole irrigation season, from May to October. Enough water was supplied to replace the crop evapotranspiration ( $ET_c$ , mm), calculated as described by Palomo et al. (2002), except that the potential evapotranspiration ( $ET_o$ , mm) was determined with the FAO56 Penman-Monteith equation. Gavilán and Berengena (2000) found that this is the most accurate equation for the area. The  $K_c$  values were adjusted accordingly, resulting 0.76 in May, 0.70 in June, 0.63 in July and August, 0.72 in September and 0.77 in October. The weather variables needed for calculating  $ET_o$  were registered with an automatic weather station next to the orchard. Irrigation was made with a single pipe per tree row with five 3 L h<sup>-1</sup> drippers per tree, 1 m apart; (c) Treatment RDI was a regulated deficit irrigation treatment based on Girona (2001); enough water was supplied to replace  $ET_c$  during pit hardening and some two weeks prior to harvest (flowering occurred within the rainy seasons), when the tree is less tolerant to water stress; reduced irrigation amounts were applied the rest of the time (about 50% in 2003 and 30% in 2004); (d) Treatment PRD was a partial root drying treatment; two laterals per tree row were used, each equipped with tree 3 L h<sup>-1</sup> drippers 0.6 m apart, being the one closer to the trunk at 0.8 m from it. This allowed to irrigate each side of the tree independently. In 2003, we supplied 50% of  $ET_c$  to one side of the tree, shifting to the other side every 14 days, all throughout the irrigation season. In 2004, we applied 100% of  $ET_c$  at pit hardening and on the three weeks prior to harvest, with the two laterals irrigating simultaneously, wetting both sides of the trees; for the rest of the irrigation season we supplied 30% of  $ET_c$  to one side of the tree, shifting to the other side every 21 days.

The following variables were monitored on both irrigation seasons (except leaf area, that was estimated in 2004 only), in representative trees of each treatment, to characterise both the crop response to the water status and the tree water consumption: phenological stage, observed every week; leaf area (LA, m<sup>2</sup>) of the three RDI and PRD trees in which sap flow was recorded, estimated every 20-40 days, from the beginning to the end of the growing period; diurnal time courses of stem water potential ( $\Psi$ , MPa; n=6; Scholander chamber), stomatal conductance ( $g_s$ , mol m<sup>-2</sup> s<sup>-1</sup>; n=6; Licor 6400) and net photosynthesis ( $P_N$ ,  $\mu$ mol m<sup>-2</sup> s<sup>-1</sup>; n=6; Licor 6400), registered once per month; sap flow (the compensation heat-pulse method, calibrated for olive by Fernández et al., 2004) recorded in the trunk of three representative RDI trees, and in the main branch, in the trunk and in a main root in each of the two sides affected by irrigation of three PRD trees.

## RESULTS

The  $ET_c$  for the irrigation period of 2003 was calculated to be 383 mm. In the FAO treatment we applied a total of 398 mm, 104% of  $ET_c$ . The irrigation amounts in RDI and PRD were 287 mm (75% of  $ET_c$ ) and 296 mm (77% of  $ET_c$ ), respectively; these amounts were too high, due to problems with the control of the irrigation system. In 2004, however, the irrigation management is going as expected. To date, just two weeks prior to the end of the irrigation season, we have applied 99% of the corresponding  $ET_c$  in the FAO treatment, 46% in RDI and 45% in PRD. Since in the two remaining weeks we will apply 100% of  $ET_c$  in both DI treatments, we expect to end the season having applied some 50% of  $ET_c$ , both in RDI and PRD, as expected.

No differences in phenological stage were observed between treatments, neither in 2003 nor in 2004. Clear differences were observed, however, on LA, estimated in 2004 only. The average values estimated in March 23, at the beginning of the growing season, are 30.96 m<sup>2</sup> for the PRD trees and 25.25 m<sup>2</sup> for the RDI trees. In September 15, at the end of the growing season, we estimated 67.53 m<sup>2</sup> for the PRD trees and 44.42 m<sup>2</sup> only for the RDI trees.

Both in 2003 and 2004, the greater differences in  $\Psi_{stem}$ ,  $g_s$  and  $P_N$  were found in September, at the end of the deficit irrigation periods (Fig. 1). Clear differences in  $\Psi_{stem}$  were observed, in both years, between the treatments D and FAO. The differences between RDI and PRD were, in general, not significant, being the  $\Psi_{stem}$  values of both treatments closer to those of the FAO treatment than to those of the D treatment. The same was observed for  $g_s$ , except in the evening of September 2, 2004, when the  $g_s$  values of the DI treatments were similar to those of the D treatment. The values of  $P_N$  registered in 2003 were lower in D than in FAO, being the values of both DI treatments in between. No significant differences in  $P_N$  were found among treatments in September 2, 2004, but this was a cloudy day in which the incoming radiation was low.

No differences in the sap flows of the PRD trees were observed when shifting irrigation from one side to the other, neither in 2003 nor in 2004. This accounts for the sap flows recorded in the main roots (Fig. 2), in the base of the trunk and in the main branches of each side. The daily records of the sap flows echoed those of the  $ET_o$ , for the three conductive organs. Figure 2 shows records taken at the end of the irrigation seasons; the same conclusions were drawn from the sap flows recorded earlier in the irrigation seasons (data not shown).

Figure 3 shows the values of the daily transpirations calculated from the sap flow records in a representative PRD and RDI tree, on four periods from the beginning to the end of the irrigation season of 2004. Irrigation began on DOY 150, and the two DI treatments were irrigated with 100% of  $ET_c$  from DOY 258. The LA values estimated on each period allowed us to calculate the water transpired per square meter of leaves, for each DI treatment. These values were similar for both treatments, on the four studied periods. They decreased from the beginning to the end of the irrigation season, mainly due to the decrease in  $\theta$  (values shown in the figure). On the last period, in which the  $\theta$  values were close to field capacity due to the irrigation of both DI treatments with enough water to replace 100% of  $ET_c$ , the water consumed per square meter of leaves was still low, due to the decrease in the atmospheric demand.

## DISCUSSION

We feel it is too risky to conclude from our LA results that PRD enhanced growth, because LA estimations were made in three trees per treatment only. We can say,

however, that we found no reduction in the growth of the olive trees caused by PRD, contrary to what it has been observed in tomato (Stikic et al., 2003) and grapevine plants (dos Santos et al., 2003), among other species.

No evidences supporting the use of PRD can be obtained from our results on the trees water status and gas exchange. The performance of the PRD and RDI trees did not decrease too much, as compared to that of the FAO trees, despite of the marked reduction in the irrigation amounts. These results are not surprising, since it is well known that the olive is able to keep a high performance with reduced water supplies (see the review by Fernández and Moreno, 1999).

The sap flow records indicated no differences between both DI treatments. We expected differences in the sap flows in main roots as affected by the shifting on irrigation, because it is known that the olive roots growing in dry soil respond immediately to an increase in soil humidity (Fernández et al., 2001). It seems that the decrease in  $\theta$  in the non irrigated half of the rizosphere of the PRD trees was not enough to cause a decrease in the amount of water taken up by the roots growing in that side. In 2003, when the irrigated side changed every 14 days,  $\theta$  decreased to an average minimum of  $0.17 \text{ m}^3 \text{ m}^{-3}$ ; in 2004, when we shifted irrigation every 21 days, the average minimum of  $\theta$  in the non irrigated side was  $0.14 \text{ m}^3 \text{ m}^{-3}$ . Both values are still far from the  $0.10 \text{ m}^3 \text{ m}^{-3}$  corresponding to  $h = -1.5 \text{ MPa}$ . Despite the lack of differences in the water taken up by the roots of each side, the decrease in  $\theta$  in the non irrigated side could have been enough to generate the signals that cause the stomatal closure described by other authors in PRD plants of other species (Augé and Moore, 2002; de Souza et al., 2003). However, our results, both on the water transpired per square meter of leaf (Fig. 3), and on  $g_s$  (Fig. 1) show that the stomatal conductance was similar in both DI treatments.

We conclude that PRD is not advantageous, as compared to RDI, for irrigating olive tree orchards.

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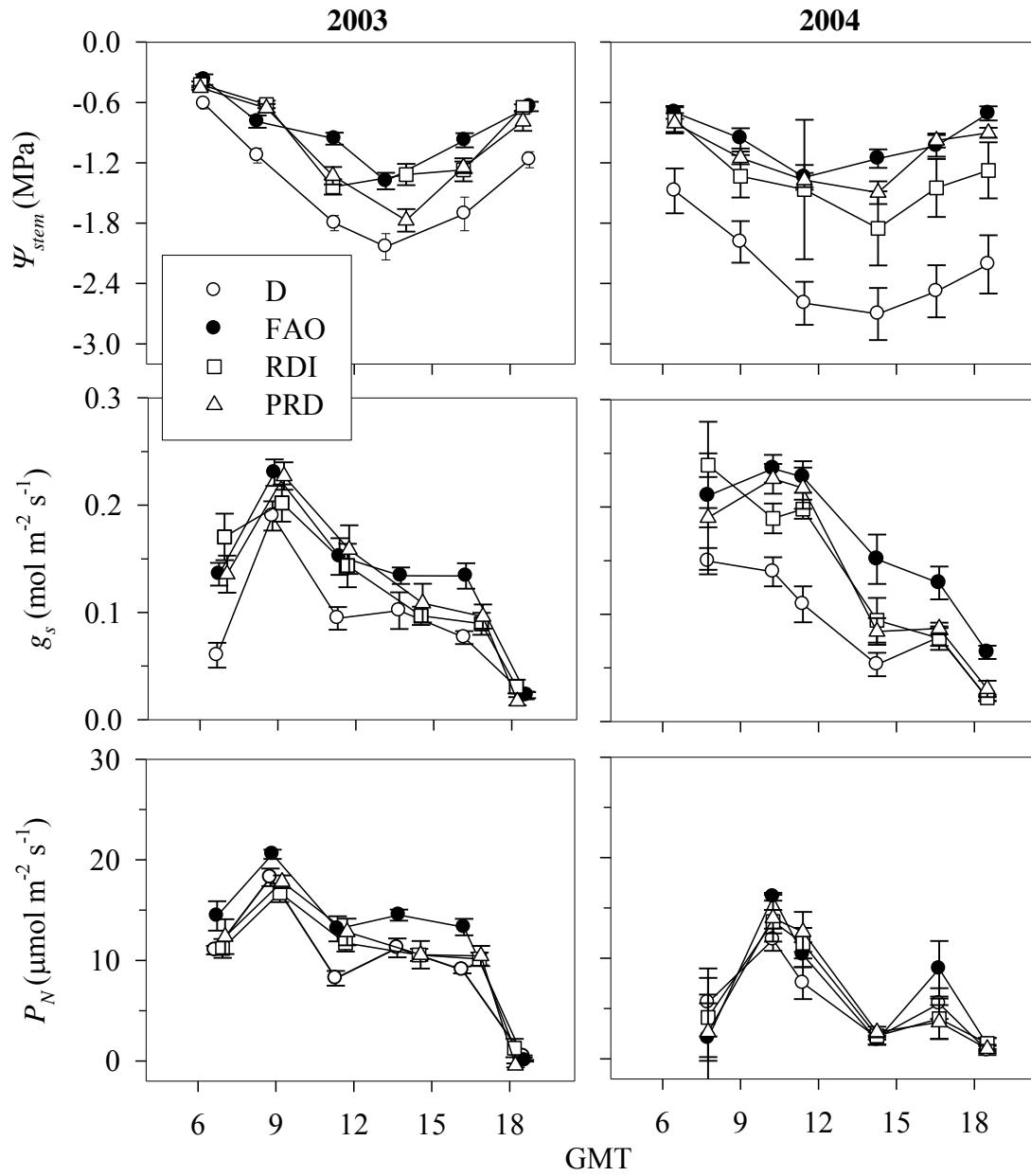


Fig. 1. Diurnal time course of stem water potential ( $\Psi_{stem}$ ), stomatal conductance ( $g_s$ ) and net photosynthesis ( $P_N$ ) measured in September 2 in trees of the four treatments, in the two experimental years. Each point represents the average of six values. Vertical bars indicate twice the standard error. See text for definitions of treatments. GMT = Greenwich mean time.

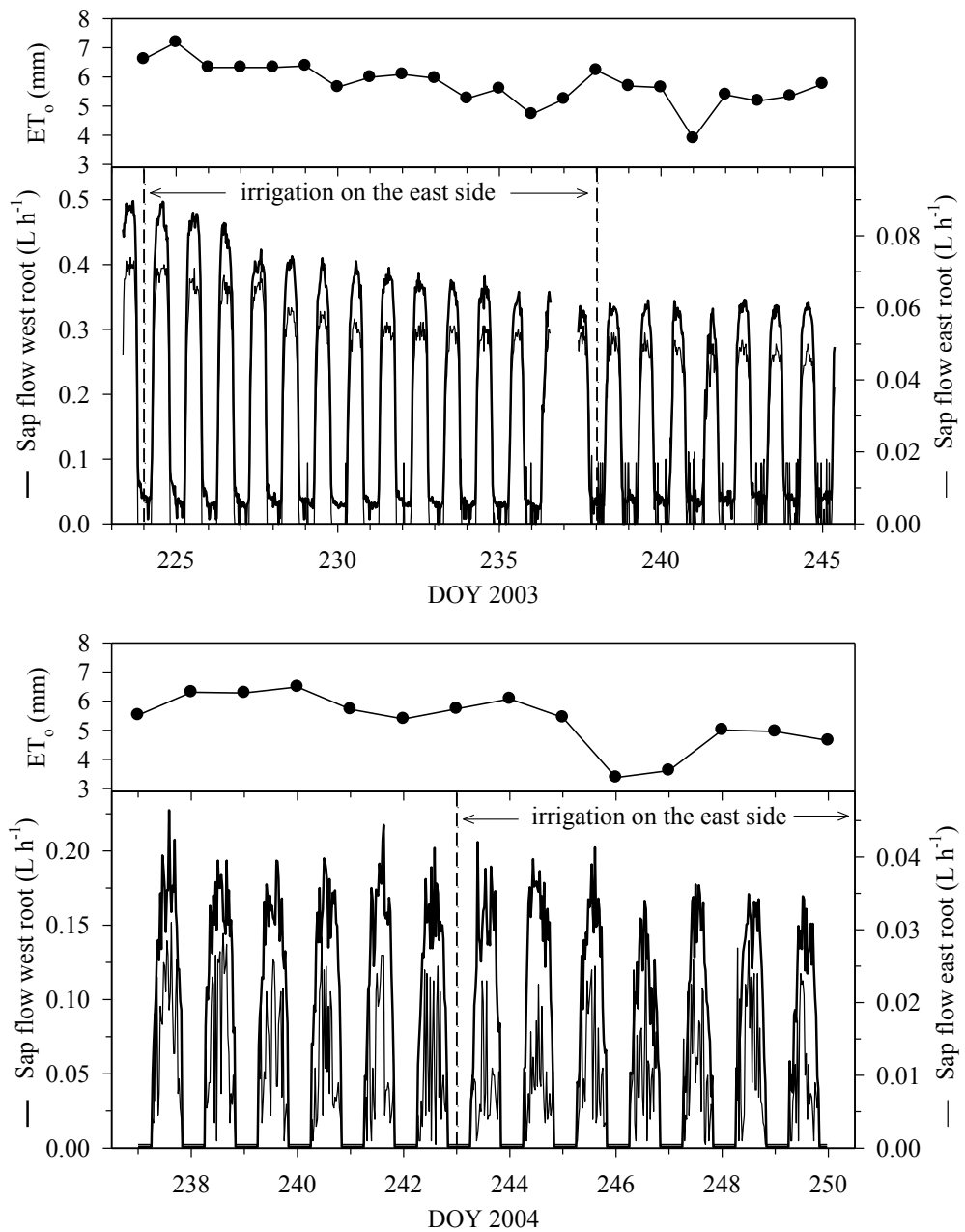


Fig. 2. Sap flows monitored in a main root of the west side and east side of an olive tree of the PRD treatment. See text for definition of the treatment. Records were taken in periods of the two experimental years in which the irrigated side changed. Also shown are the values of the potential evapotranspiration ( $ET_0$ ) estimated from the weather records. DOY = day of year.

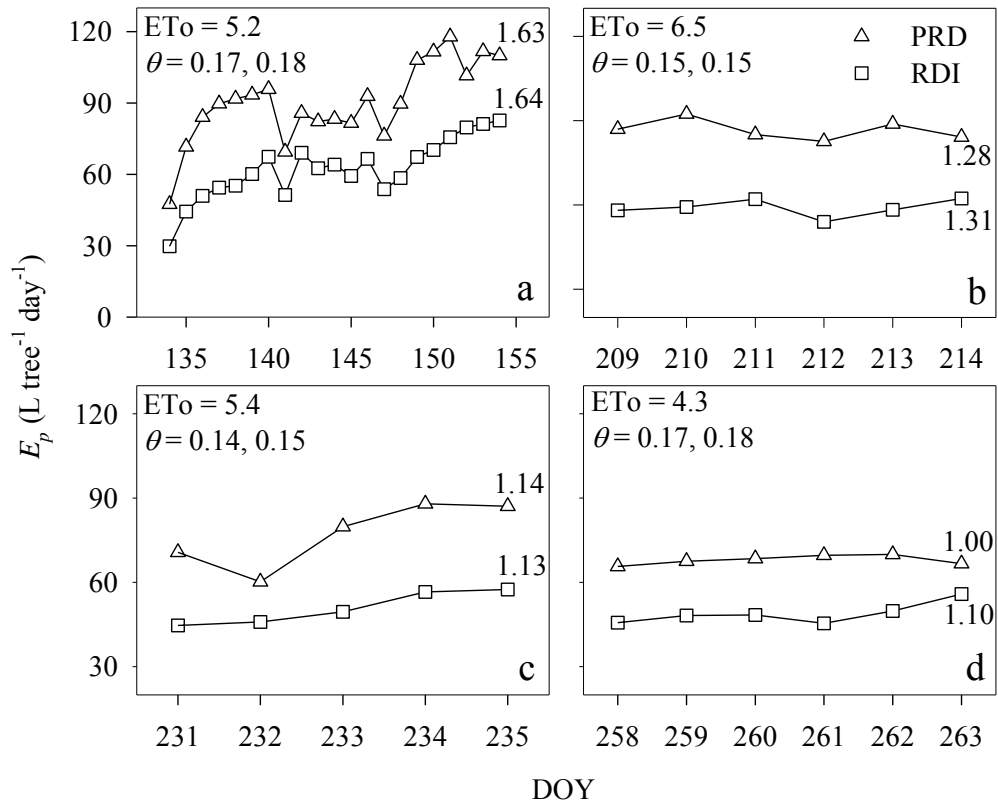


Fig. 3. Total daily transpiration ( $E_p$ ) calculated from the sap flow records in a representative tree of both the PRD and the RDI treatments, at mid May (a), end of July (b), end of August (c) and mid September (d) of 2004. See text for definition of the treatments. The shown potential evapotranspiration ( $ET_o$ ,  $mm \text{ d}^{-1}$ ) values are the daily average for each period. The volumetric soil water content values are also shown ( $\theta$ ,  $m^3 \text{ m}^{-3}$ , averages for the period); the value of the left corresponds to PRD, and that on the right to RDI. The numbers at the end of each curve are the daily average value of  $E_p$  for the period, divided by the average leaf area of the tree trees of each treatment, estimated on the same period ( $L \text{ m}^{-2} \text{ d}^{-1}$ ).