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Partial Rootzone Drying Irrigation Modulates Transpiration of Olive Trees †

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Abstract: Water scarcity and the increasing water demand for irrigation in olive orchards are leading to adopt deficit irrigation approaches to save water. The partial rootzone drying (PRD) irrigation technique has been proposed for woody crops as an agronomic practice to improve water productivity. This study was conducted to evaluate the effect of this irrigation strategy on water relations and transpiration of olive tree (cv. Cobrançosa) under climate conditions of the Northeast of Portugal, during the season of 2014. To irrigation treatments were used: control (FI), irrigated with 100% of the estimated crop evapotranspiration (ET) and PRD_{50}, irrigated with 50% of the control (FI) on one side switching every two weeks. Whole tree transpiration (T) was quantified by sap flow, that was monitored within the trunk of both the control (FI) and deficit irrigated (PRD_{50}) trees using the compensation heath-pulse technique. Foliage gas exchange and water potentials were determined throughout the experimental period. During summer, daily transpiration reached roughly 27 and 43 L d^{-1} for PRD_{50} and FI olive trees, respectively, with a clear reduction of 37% in PRD_{50} olives trees. PRD_{50} showed statistically comparable values of water potentials to the Control which seemed to prevent an excessive drop in tree water status by modulating stomatal closure.

Keywords: *Olea europaea* L.; deficit irrigation; water relations; sap flow; heat pulse

1. Introduction

The olive tree (*Olea europaea* L.), assumes an important role in the Mediterranean landscape and, the "Vilariça valley", located in the region of Tras-os-Montes of Portugal, is no exception. The region, with 75 266 ha of olive groves, is assumed as the second most important area of the country (22% of the total area). This region, according to Köppen classification, has a Csa climate type, where summer is characterized by scarce rainfall, high temperatures and intense solar radiation, conditions that lead to the development of a high vapour pressure deficit. Olive tree is an evergreen tree, well known to be resistant to drought, however as a consequence of that capacity, the photosynthesis activity decreases, and that, limits the growth rate and yield [1,2]. Thus, irrigation in olive trees has been adopted to overcome theses negative impacts and ensure crop yield. However, increasing irrigated areas is very difficult in the olive industry, due to water scarcity and increased competition with non agricultural uses [3]. Therefore, great emphasis is placed on irrigation management in arid regions with the aim of increasing water use efficiency leading to adopt deficit irrigation approaches to save water. Partial Rootzone Drying (PRD), derived from split-root research, is a well-documented technique of water saving irrigation [4–6]. The technique was developed based on knowledge of the physiological mechanisms controlling plant transpiration and root-shoot signalling under water deficits. It consists in irrigating only one side of the rootzone, so that the plant can be simultaneously exposed to both wet and dry soils. This technique has already been successfully tested on several [7–10]. In olive, different studies have showed that PRD irrigation effects water relations, namely leaf water potential and stomatal conductance [11–13], vegetative growth [14], with minimal impacts in yield and beneficial effects on olive oil quality [15]. Evaluation of olive tree water use can be assessed by sap flow measurements with the heat compensation pulse technique [16–18]. The aim of this studied is to assess the effect of PRD irrigation on water relations, sap flow and transpiration of olive tree (cv. Cobrançosa) under hot and dry climate conditions of the Northeast of Portugal, during the season of 2014.

2. Experiments

2.1. Field Conditions and Plant Material

The field trial was carried out in 2014 in a 12-year old organic commercial olive (cv. 'Cobrançosa') orchard located at "Vilariça" Valley (Trás-os-Montes, Portugal, 41.3° N, 7.0° W, 150 m altitude), a typical olive growing area of Northeast Portugal. The climate in the area is Mediterranean (IPMA, 2015), with an average rainfall of 520 mm concentrated from autumn to spring, and 1130 mm of average ET_0. The soil is classified as Eutric Leptosols developed on metamorphic rocks (schists), of sandy loam texture.Two irrigation treatments were used: fully irrigated (FI) control, for which the water applied equaled the difference between the maximum (estimated) ET and rainfall, and PRD irrigated: partial root drying system applying the same irrigation dose as FI to one half of the root system, with the irrigated and drying halves of the root-zone alternating every two weeks. Watering was done every day from June to October, corresponding to fruit set fruit ripening stages, respectively.The experimental design was a complete randomized block, replicated trees times. Each plot contained four central olive trees surrounded by 14 border trees. All measurements were made on the central trees of each plot.

2.2. Sap Flow Measurements

To evaluate sap flow rates and transpiration, a representative trees in each irrigated treatment were selected and a set of heat – pulse probres (ref das sondas) were installed into a parallel holes drilled in radial position (north and south side) into the semi-trunk of each tree, at a height of about 50 cm of each tree. The heat pulse gauge consists of a heater of diameter 1.8 mm and two temperature-probes of the same diameter (one at 15 mm down-stream and the other at 5 mm up-stream of the heater). Each temperature probe has four (copper-constantan) thermocouple junctions spaced along the radius of the cross section. Using the compensation heal pulse technique [18] sap flow was taken from 30 min intervals and tree transpiration of each tree was estimated as the average of the two set of probes per tree.

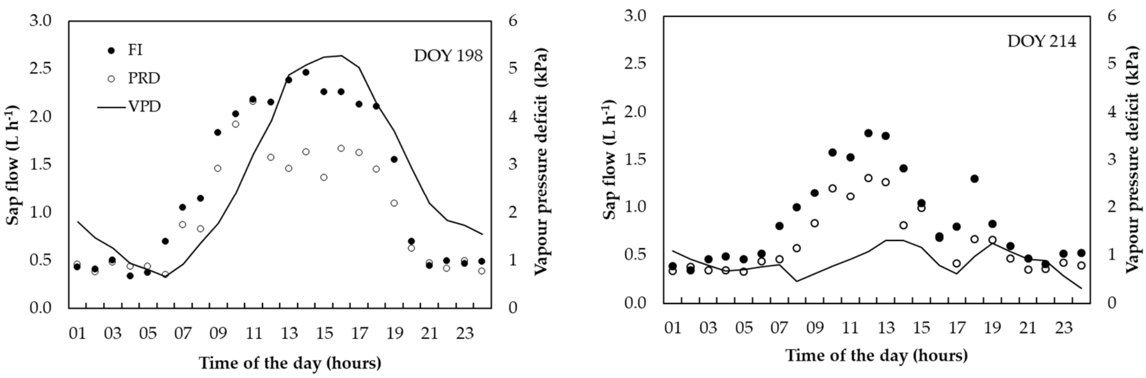
2.3. Tree Water Status and Stomatal Conductance

The plant water status (predawn and midday stem water potential) was measured periodically during 2014 cropping season using a Scholander pressure chamber (Soil Moisture Equipment Pressure Chamber, PMS-1000, Corvallis, OR, USA). Predawn leaf potential (Ψ_{PD}) measurements were carried out early (at≈4:30 a.m.) before sunrise while midday measurements of stem water potential (Ψ_{stem}) were taken between 12h00 and 13h00 on a small leafy shoot near the trunk that had been covered with aluminium foil at least 1 h before the measurement. Measurements of water potential were taken on six plants in each irrigated treatment.

Leaf stomatal conductance (gs) was measured at midday with a portable porometer (Delta-T AP4, Delta-T Devices, Cambridge, UK). The device was calibrated before use on every occasion using the supplied calibration plate. The terminal part of the main leaf lobe was placed into the cup on the head unit which was positioned normal to the sun. Measurements were conducted during cloudless periods on six exposed leaves/treatment around noon.

3. Results

Figure 1 shows the diurnal pattern of sap flow in condition of high and low evaporative demand. Sap flow diurnal patterns showed, for both treatments, a steep morning increase leading to the maximum rates achieved at about midday, when vapour pressure deficit (VPD) was at its maximum, followed by a sustained gradual decrease until late in the afternoon (Figure 1). However, in conditions of high evaporative demand (ETo = 7.0 mm d^{-1}) sap flow values of FI and PRD trees are similar in the first hours of the morning until 11:0 am afterward it start to fall in PRD trees reaching a high rate of decrease at midday, being 37% lower than those of FI trees.



(**a**) (**b**)

Figure 1. Diurnal pattern of sap flow an vapour pressure deficit (VPD) for full irrigated (FI) and partial rootzone drying olive trees. (**a**) A day for a high evaporative demand (ETo = 7.0 mm d^{-1}); (**b**) A day for a low evaporative demand (ETo = 3.3 mm d^{-1}).

Seasonal evolution of daily transpiration (T) is presented in Figure 2. Averaged daily transpiration showed a progressive reduction along the season with maximum values at the end of July for both irrigated treatments, when daily reference evapotranspiration was as it maximum. Such reduction is quite similar between treatments. However, partial rootzone drying irrigated plants showed invariably lower daytime sap flow rates than full irrigated plants. Values of transpiration in FI plants ranged from 16 to 39.9 L d^{-1} respectively at DOY 265 (ETo = 1.9 mm d^{-1}) and 209 (ETo = 7.6 mm d^{-1}), while in PRD plants a minimum of 13.1 L d^{-1} and a maximum of 27.3 L d^{-1} was attained in the same dates. A good agreement between measures daily water use and daily reference evapotranspiration was observed for both treatments ($p < 0.05$) with a coefficient of determination (r^2) of 0.74 for FI and 0.68 for PRD, thought the slope of the regression was significantly higher in FI plants compared to PRD trees.

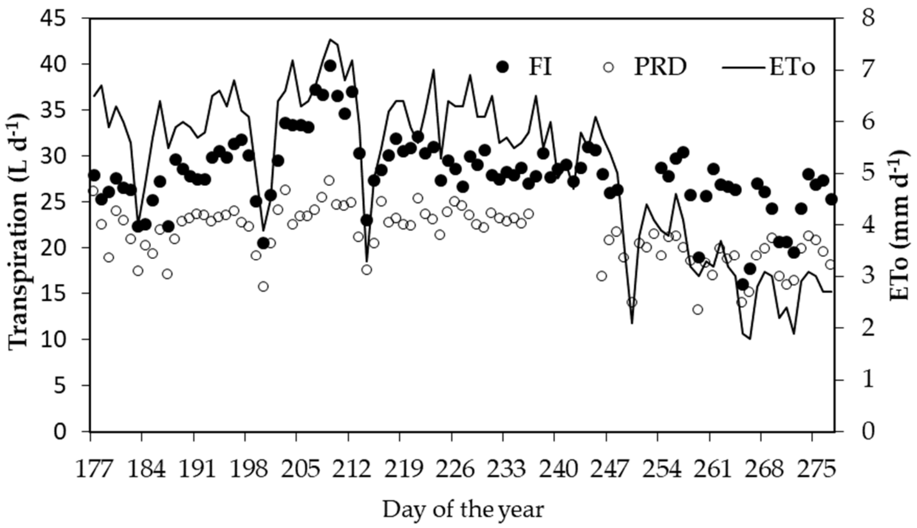


Figure 2. Seasonal evolution of daily reference evapotranspiration(ETo) and daily sap flux from June 26th until October 4th, for full irrigated (FI) and partial rootzone drying (PRD) olive trees.

Predawn values of water potential showed slight differences between FI and PRD treatments only in DOY 231 in which Ψ_{PD} of PRDI plants attained a minimum of −1.16 MPa (Figure 3). For FI trees values were higher of −0.65 MPa whereas for PRD plants they were usually higher than −0.80 MPa. Stem water potential was not significantly affected by PRD that had values similar to FI plants, in general higher than −2.0 MPa.

The evolution of leaf gs measured throughout the olive growing season (Table 1) showed that control plants had significantly higher gs values compared to the plants exposed to PRD with a reduction of 33–45%

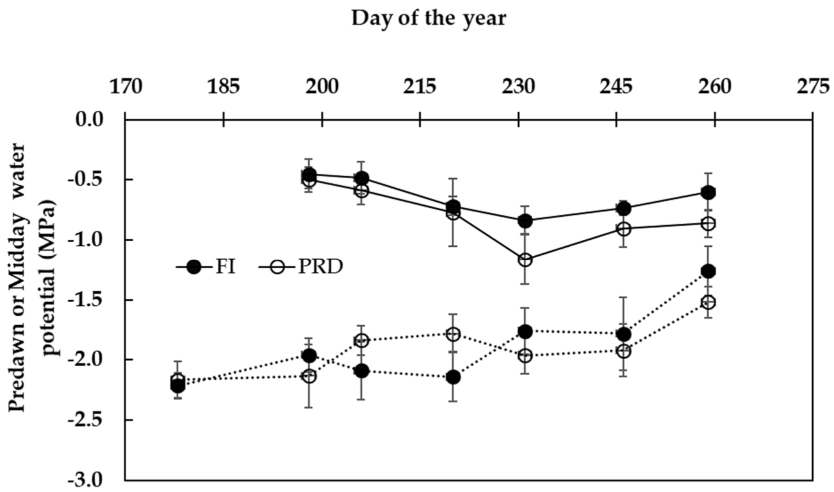


Figure 3. Time course of predawn (solid line) and stem midday (dashed line) water potential for full irrigated (FI, ●) and partial rootzone drying (PRD, ○) olive trees. Values are means (±SE) of six replicates.

Table 1. Midday values of leaf stomatal conductance (gs, mm s[1]) for the two irrigation treatments, on three representative days of the season. Values are means (±SE) of six replicates.

Irrigation Treatment	July 24th	August 18th	September 15th
FI [1]	6.1 ± 0.17	6.5 ± 0.13	7.2 ± 0.12
PRD [1]	4.1 ± 0.32	3.6 ± 0.19	4.7 ± 0.74

[1] FI—full irrigated; PRD—partial rootzone drying.

4. Discussion

The values of Ψ_{PD} for FI plants are in accordance with those observed for others environmental conditions and cultivares in conditions of absence os water stress. The minimum Ψ_{PD} of −1.16 MPa indicated that plants didn't full recovery hidratation during night indicanting a mild water stress. The absence of differences in midday values of Ψ_{stem} between FI e PRD treatments associated with lower values of gs in PRD plants indicated a more conservative use of water than FI olive trees to prevent excessive water loss and avoid leaf dehydration. Similar gs response were observed for others cultivars in field growing conditions and that this decrease did not limited the overall photosynthesis process [11–13]. Some studies described a clear decrease in PRD olive trees water status (Ψ_{stem} and relative water content) and others reported no differences [19], which seemed to prevent an excessive drop in tree water status by modulating stomatal closure. In our previous studies in this cultivar [20], we observed a large fluctuations in midday gs with midday leaf water potential quite stable and higher than −3 MPa, and a near-isohydric hehavior is identified for Cv. Cobrançosa. The behavior of PRD plants, could be explained by the roots of the well-watered side that would keep up the plant water status, while dehydrating roots would be responsible of inducing stomatal closure, may be by sending chemical signals to the shoots throught the xylem [21]. The PRD irrigated olive trees exhibited daily sap flow and transpiration consistently lower that FI plants thought the season, which is an another evidence of that these plants have an effective regulation of water lost by stomatal closure, showing a more conservative water use strategy.

5. Conclusions

Preliminary results of this study done in fieldgrown olive trees showed that partial rootzone drying irrigation did no affect plant water relations, as expressed by bulk leaf water potential, when the total amount of water supplied to these adult olive trees was 50% of to that supplied to Control plants. Stomatal closure observed in PRD plants effects water use in PRD_{50} plants showed by a clear reduction of sap flow and transpiration of mature olive trees. The coordinated adjustment in stomatal responses may represent an adaptive advantage in conditions of water deficit induced by PRD irrigation. Further research is need to understand the long term yield and water use efficiency response of Cv. Cobrançosa to this irrigation strategy.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used: A.A.F.-S. wrote the paper, conceived, designed and perfomed the experiment, analyzed the data; A.E. perfomed the experiment, analyzed the data; M.C. analyzed the data; F.L.S. analyzed the data. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

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