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Water relations and yield of olive tree (cv. Chemlali) in response to partial root-zone drying (PRD) irrigation technique and salinity under arid climate

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ABSTRACT

Water scarcity and the increasing water demand for irrigation in olive orchards are leading to adopt deficit irrigation approaches and the use of saline water. Field experiment was conducted on nine-year-old olive trees (*Olea europaea* L. cv. Chemlali) grown on sandy deep soil and drip irrigated with saline water (EC 6.7 ms cm^{-1}) under arid Mediterranean climate in southern Tunisia during 2003–2006. Three irrigation treatments (i) Control: full irrigated, (ii) DRY: rain-fed and (iii) PRD: partial root-zone drying were applied. PRD_{30} and PRD_{15} supplied 50% of the Control with an alternate irrigation switched every 30 and 15 days, respectively. PRD achieved significantly better soil water status in comparison to DRY and less than 30% of soil moisture level under the Control. Soil salinity levels were significantly lower during wet season than that of the summer period. PRD reduced the quantity of salt incorporated in the root-zone. Predawn (Ψ_{PD}) and stem (Ψ_{stem}) water potentials across all irrigation treatments diverged progressively from one another throughout summer season. Minimum values of −0.9, −1.3, −1.2 and −1.3 MPa for Ψ_{PD} and −2.2, −2.4, −2.4 and −2.9 MPa for Ψ_{stem} were measured during the summer for the Control, PRD_{30}, PRD_{15} and DRY, respectively. PRD 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. High correlations of Ψ_{stem} with Ψ_{PD} and soil water potential indicated that Ψ_{stem} could be used for the control of water supply in olive orchards. An improvement of olive yield was achieved by irrigation with saline water. PRD_{30} achieved a slight cumulative yield reduction (11%) compared to the Control while applying half of irrigation quantity. The oil content showed an improvement with increasing deficits. PRD_{30} seems to realize a good compromise between yield, quality and environmental impact and could be recommended for irrigation of olive trees under similar situations of water quality, soil and precipitation regimes.

1. Introduction

The olive tree (*Olea europaea* L.) is considered as one of the best adapted species to the Mediterranean climate and is traditionally cultivated under rain-fed conditions. In recent years, the olive industry is attracting considerable interest due to the growing perception of olive oil which induced an intensive wave of olive planting. The environmental adaptability of the olive tree and its tolerance to drought and salinity (Gucci and Tattini, 1997; Melgar et al., 2009; Wiesman et al., 2004) permitted to these new plantations to be established in arid and marginal areas. New orchards are drip irrigated and planted at higher densities as compared to traditional systems, achieving higher yields with reduced alternate bearing behavior (Beede and Goldhamer, 1994). However, increasing irrigated areas is very difficult in the olive industry, due to water scarcity and increased competition with non agricultural uses (Fereres et al., 2003). Nevertheless, the use of irrigation is expanding in both traditional and modern olive orchards and irrigation management must be optimized to ensure efficient water use (Fereres and Evans, 2006).

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Water demand for irrigation is increasing in olive orchards because of enhanced yields and profits, leading to the use of low quality water resources. Olive is considered moderately tolerant species to salinity (FAO, 1985; Maas and Hoffman, 1977). Due to scarce fresh water resources in the Mediterranean basin, irrigation with saline water (EC 5–10 mS cm^{-1}) is often practiced (Bouaziz, 1990; FAO, 1985; Melgar et al., 2009). However, early rainfalls allow the accumulated salinity to be annually removed from the root zone and plant produce new growth at considerable rates (Melgar et al., 2009; Tattini et al., 2008; Shalhevet, 1994). Olive tree response to salinity stress is a cultivar dependent characteristic (Chartzoulakis et al., 2002; Chartzoulakis, 2005; Marin et al., 1995; Therios and Misopolinos, 1988). Many cultivars under semi arid and transient state salinity conditions may grow well with no significant reduction of yield with EC ranged between 3 and 6 mS cm^{-1} (Aragüés et al., 2005; FAO, 1985; Maas and Hoffman, 1977). Salt tolerant cultivars seem to be more able to exclude toxic ions then sensitive ones (Chartzoulakis et al., 2002; Gucci and Tattini, 1997). Salinity affects shoot growth and number of flowers and fruits (Cresti et al., 1994; Klein et al., 1994), while the effects on yield depend on the salt concentration (Melgar et al., 2009; Wiesman et al., 2004).

Due to the scarce water resources in Mediterranean areas, drip irrigation is widely used for applying water to olive orchards. However, in order to increase irrigation efficiency, best agronomic and irrigation practices must be implemented in order to reduce water losses and increase crop water productivity (Chalmers et al., 1981). Furthermore, irrigation strategies not based on full crop water requirements should be adopted for more effective and rational use of water. Deficit irrigation is an optimizing strategy under which crops are allowed to sustain some degree of water deficit and yield reduction (d'Andria et al., 2004; Fernandez et al., 1997; Goldhamer, 1999; Moriana et al., 2003; Tognetti et al., 2005). Such strategies practiced in horticultural crops are the partial root-zone drying (PRD) and the regulated deficit irrigation (RDI), which reduced tree vigor and increased fruit quality with less impact on yield (Centritto et al., 2005; Gowing et al., 1990; Kang et al., 2002; Wahbi et al., 2005).

Tunisia is among countries with limited water resources. Therefore, an irrigation experiment started in Sfax region (central Tunisia) to evaluate the long term combined effect of irrigation with saline water and partial root zone drying (PRD) as a deficit irrigation management on olive trees (Ghrab et al., 2006, 2007). The aim of the present work was to test how the PRD treatments affected soil water status and salinity distribution in root zone in sandy deep soil, typical soil of the main olive production zone in central Tunisia in comparison to full irrigated and rain-fed treatments. A second objective was to assess the implication of this irrigation management on tree water status and yield of mature olive trees drip irrigated with saline water under arid Mediterranean climate.

2. Material and methods

2.1. Orchard site and irrigation treatments

The experiment was carried out in an olive orchard of the Olive Tree Institute in Sfax (34°43′ N, 10°41′ E) in central Tunisia. The region is characterized by an arid climate of Mediterranean type with mean annual precipitation and reference evapotranspiration ET_o of 220 and 1390 mm respectively and marked summer drought. The experimental orchard consisted of nine-year-old olive trees, cv. Chemlali planted at a distance of 4 m apart (625 trees ha^{-1}) and drip irrigated. Trees were planted on deep sandy soil (89.9% sand, 5% clay, 5.1% silt) with field capacity and wilting point of 12% and 6% respectively and irrigated with saline water (EC 6.73 mS cm^{-1}) from ground water source. Saline water composition was 600 mg/l Na^+, 1491 mg/l Cl^-, 21 mg/l K^+, 5.6 mg/l NH_4^+, and 84 mg/l NO_3^- and pH of 7.29. The groundwater table depth is stated below 2.5 m. Water was delivered using two dripper lines located at 0.5 m from the trunk with a dripper of 2.3 l h^{-1} m^{-1}. Four irrigation treatments were applied for four growing seasons (2003–2006):

- *Control*: Fully irrigated that applied daily the necessary water to match crop evapotranspiration ET_c.
- *PRD_{15}*: Alternate irrigation switched every 15 days, that supplied 50% of the irrigation water applied in the control.
- *PRD_{30}*: Alternate irrigation switched every 30 days, that supplied 50% of the irrigation water applied in the control.
- *Dry (rain-fed)*: Olive trees were grown under rain-fed conditions without irrigation supply.

Each experimental plot consisted of 10 trees from two adjacent rows, selected to be similar in potential yield and canopy and to be used for the agronomic measurements. In PRD treatments, a micro valve was installed on each drip line for switching irrigation every 15 and 30 days. The PRD_{15} treatment was applied only during the first two years 2003 and 2004.

Crop evapotraspiration (ET_c) of the olive trees was calculated with the formula $ET_c = K_c \times ET_o$, where ET_o is the reference evapotranspiration calculated with the Penman–Monteith equation (Allen et al., 1998), and K_c is the crop factor with monthly values of 0.6 during June–September and 0.65 during October–November (Pastor, 2003). Daily weather data, recorded at the weather station of the National Institute of Meteorology (INM), located about 5 km from the experimental site, were used to estimate ET_o.

2.2. Soil water and salinity measurements

The soil water content (SWC) was determined monthly by a gravimetric method. Samples were taken using soil auger up to 0.8 m in depth. For each sampling point four sub-samples were obtained at 0.2 m intervals. Three replications were taken per treatment during 2003, 2004 and 2005 cropping seasons. Three tensiometers (SMS 2500S electronic pressure meter; measuring range 0 to −99 kPa) per treatment were installed at the beginning of the dry season of 2003, in the wetted zone (50 cm from the trunk and from the drippers) at three soil depths of 40, 65 and 100 cm and used to monitor soil water tension during 2003 and 2004. This system consists in measuring the vacuum created in an airtight system filled with water which equilibrates with the soil through the porous ceramic after 3–4 days.

Soil samples taken from tree root zone during the periods of low (winter) and high (summer) evaporative demand were also used to determine the electrical conductivity (EC) of the soil solution extracted from saturated paste. Salinity distribution through the 2 m soil depth was characterized in relation to irrigation treatments.

2.3. Plant water status measurements

The plant water status (predawn and midday stem water potential) was measured periodically during 2004 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 ≈3:30 a.m.) before sunrise while midday measurements of stem water potential (Ψ_{stem}) were taken between 12h00 and 13h00. Ψ_{PD} and Ψ_{stem} were measured on three mature, fully expanded and sun exposed leaves per tree, with three trees per treatment for the irrigation regimes Control, PRD_{30} and Dry. Stem water potential Ψ_{stem} was determined on leaves enclosed in a black plastic sachet covered with aluminum foil more than 2 h before taking measurements.