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Effect of water stress on dry matter accumulation and partitioning in pot-grown olive trees (cv Leccino and Racioppella)

Claudio Di Vaio[a], Nadia Marallo[a,*], Giulia Marino[b], Tiziano Caruso[b]

[a] Dipartimento di Agraria, Università degli Studi di Napoli Federico II, Italy
[b] Dipartimento Scienze Agrarie e Forestali, Università degli Studi di Palermo, Italy

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ABSTRACT

Three different water regimes were applied on young pot-grown olive trees of the cultivars Leccino and Racioppella, amounting to 100% (treatment T100), 50% (treatment T50) and 25% (treatment T25) of water transpiration as determined by pot weight. During the two-year trial the following parameters were measured: midday stem water potential, shoots growth, total leaf area per tree, dry matter accumulation and partitioning in different parts of the plant (root, wood, leaves and fruits). Dry matter was affected by the water regime and cultivar. The cv Leccino, for T100, displayed a greater accumulation of total dry matter and fruit dry matter, while these two parameters were greatly reduced under the other water regimes (T50 and T25). By contrast, the cv Racioppella always showed a lower accumulation of dry matter and a more balanced canopy/root ratio.

1. Introduction

The olive tree (*Olea europaea* L.) is an evergreen species widely cultivated in the arid and semiarid areas of the Mediterranean basin characterized by prolonged water shortage during the summer months. In similar environmental conditions olive is capable to survive and to produce and, for this reason, this species is well known for being very tolerant to drought (Turner, 1979; Bongi and Palliotti, 1994; Fernandez and Moreno, 1999; Giorio et al., 1999; Tognetti et al., 2004; Connor, 2005; Bacelar et al., 2006).

Different physiological, biochemical and morpho-anatomical mechanisms are involved in olive strategies of drought avoidance and/or drought tolerance (Levitt, 1980) that consist in maintaining, under very drought conditions, the water status of tissues in a level that support the principal vital functions of the plants.

To achieve this, plants, subjected to water shortage, close their stomata, reducing water losses but also transpiration and carbon assimilation (Giorio et al., 1999). Such a limited availability of photoassimilates causes, at whole plant level, a change in the pattern of dry matter distribution: shoot growth is inhibited while a higher quantity of assimilates is transported and accumulated in the root system determining a higher root to shoot ratio in water stressed plants (Xiloyannis et al., 1999).

Anyway, water stress is not the only parameter that affects dry matter distribution in the plant; in particular, many other agronomic and genetic factors, such as rootstock, cultivar, training system, pruning and planting density have been shown to influence growth and to modify the distribution of biomass between roots and canopy (canopy/roots ratio) and between the different plant organs (Caruso et al., 1997, 2001, 2008; Zucconi, 1992; Xiloyannis et al., 2007; Di Vaio et al., 2012; Weibel and Reighard, 2012; Yano et al., 2002).

Different cultivars respond differently to drought showing differences in terms of adaptation, dry matter distribution, production and gas exchange responses to water shortage (Chartzoulakis et al., 1999; Bacelar et al., 2004, 2007; Tognetti et al., 2002).

We studied the effect of water stress on dry matter accumulation and partitioning between the different organs of young olive trees with the aim to elucidate the different response of the two genotypes to drought stress and select a cultivar that is more suitable for arid environments.

2. Materials and methods

In this work we tested the response of Raciopella, a low vigor cultivar native to the province of Benevento (Di Vaio et al., 2013) and Leccino, a vigorous and well productive cultivar from Tuscany, but also grown widely elsewhere in Italy, to different water regimes.

The observations were conducted for two years (2010/2011) on two-year-old rooted plants of the cultivars Leccino and Racioppella. The plants were grown in 50-l pots containing a substrate formed by a mixture of peat, sand and soil (1:1:1 by volume) and regularly watered by means of a drip irrigation system.

* Corresponding author.
E-mail address: nadia.marallo@unina.it (N. Marallo).

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The water regimes are 100 (treatment T100), 50 (T50) and 25% (T25) of water transpired, determined every nine days by weighing the pots. For T100, the losses of transpired water were replenished in full, while for T50 and T25 replenishment was 50% and 25%, respectively, of the consumption of treatment T100. Irrigation was applied throughout the growing season from late March to November. The pots were covered with a plastic film to avoid interference with rain and impede evaporation from the soil. Each irrigation treatment was carried out on 12 plants per cultivar.

During the growing season stem water potential (Ψ_x) was measured with a Scholander pressure chamber (Skye Instruments, UK, model SKPM 1400) on one year in order to obtain water status of the plants. The measurements were done at midday on the 28/6, 27/7 and 13/9 in 2010 and on the 10/7, 28/7, 20/8 and 13/9 in 2011; the leaves were covered at least 1 h before measurement with plastic envelopes and aluminum reflective foils (Begg and Turner, 1970).

Vegetative activity of the trees was estimated by monitoring, at 15 days intervals, the growth of three shoots per plant and determining, at the end of each season, trunk cross section area (TCSA) at 10 cm from the ground.

At the end of each growth year, 18 randomly selected plants per cultivar, six per water regime, were uprooted and broken down into roots, shoots, leaves, wood and fruits. The total leaf area per plant was measured with a Leaf Area Meter (Li-Cor 3100) and the amount of dry matter in individual organs was determined; to do that, the organs were placed in a ventilated heater at a temperature of 80 °C until they reached constant weight. Canopy to root biomass ratio was calculated.

Statistical analysis was performed using the SPSS statistical package. All data were subjected to factorial analysis and the averages separated by Tukey's test at the 5% level.

3. Results and discussion

3.1. Year 2010

The different water regimes used in this experiment had a significant effect on the midday stem water potential ($m\Psi_x$): for both cultivars, from T100 to T50 and T25 the values of $m\Psi_x$ significantly decreased (from −2.1 to −2.6 and −2.9 MPa for Racioppella and from −1.9 to −2.3 and −2.7 MPa for Leccino) (Fig. 1).

Comparing the water status of the two cultivars, Racioppella showed slightly lower values of $m\Psi_x$ but differences were not statistically significant.

Shoots growth clearly differed in relation to the cultivar and water regime (Fig. 2). Leccino when fully irrigated (T100) showed, at the end of the season, a greater length of shoots (31.12 cm) compared to cv Racioppella (14.37 cm). On the other hand, the relative reduction in irrigation water influenced the vegetative activity of the plants differently in the two genotypes; final length of the shoots at the end of the growing season in Leccino cv decreased by 16.9% in T50 and 45.6% in T25 with respect to T100 while for Racioppella the reduction was less marked (14.3 and 26.8%, respectively). Consequentially, in the less irrigated treatment (T25) the two cultivars showed a similar length of the shoots at the end of the season (8–10 cm).

In terms of accumulation and distribution of dry matter in the different plant organs, the two varieties behaved differently, both in relation to one another and to water treatment (Table 1).

A first aspect to highlight is the different vigor in the two cultivars. On comparing the most irrigated treatments, total dry matter production in the cv Leccino was significantly higher than in Racioppella (1662.08 against 1190.92 g) (Table 1).

However, Leccino was more sensitive to water deficit: from T100 to T50 there was a sharp drop in accumulated dry matter (51%), especially the fraction of dry matter allocated into aerial parts (53%) and particularly to the fruits (79%) (Table 1).

These values diminished further in the least irrigated T25, such that, in this case, total biomass production was reduced by 61% and fruit production was practically zero.

The cv Racioppella showed a significantly lower decrease in total dry matter accumulation (13% of reduction in T50 and 37% in T25) (Table 1), such that the values of the two treatments submitted to water deficit were even higher than those of cv Leccino. The amount of dry matter allocated to the fruits of cv Racioppella was more constant despite the lower amount of water received (from 78.95 g for T100, to 60.36 g for T50 and to 52.83 for T25 g), showing greater rusticity and greater production efficiency in conditions of water shortage.

Such a different behavior of the two cultivars is likely to depend, at least in part, by the different vigor and canopy–root ratio of the two genotype (Table 2).

When fully irrigated the vigorous Leccino, thanks to a higher leaf area (1.28 m^2), maximizes assimilation and hence total biomass and fruit production (Table 1); the higher canopy/roots ratio (5.8) helps this cultivar to show, in non-limiting conditions, higher performances with respect to the cv Racioppella.

On the other hand, under water deficit the reduced root system of Leccino plants may limit water uptake and affect productivity; the strong reduction in canopy growth observed in Leccino plants under water deficit treatment is a defense strategy, common to most species, that allows plants to minimize transpiration and, consequentially water losses, enabling plants to survive in condition of drought stress (Dichio et al., 2002).

Racioppella plants were characterized by a lower canopy–roots ratio (3.6), and hence a more balanced distribution of dry matter between the two portions (Table 2) that allows the plants of this cultivar to maintain a good water status of the leaves under stress, showing greater rusticity and greater production efficiency in conditions of water shortage.

3.2. Year 2011

The $m\Psi_x$, observed in 2011, confirmed the same decreasing trend described for the year 2010 although the stress level was generally lower with respect to the previous year, probably as a consequence of a more developed root system (Fig. 3).

Furthermore differences between the cultivars in this second year of observation became statistically significant, with lower values of $m\Psi_x$ measured in the cv Racioppella, especially for what concern T50 and T25 treatments.

As reported for the previous year, also in the year 2011, as drought stress increased, total dry matter accumulation decreased and the pattern of allocation of assimilates changed, resulting in a different response of the two cultivars to water stress (Table 3).

In particular, in the cv Leccino, the reduction in dry matter accumulation occurred only at the expense of the aerial part of the plant, and especially of the fruits, while dry matter allocated in the root system remained almost unchanged for the three treatments.

Such a greater decrease in canopy growth compared to root growth in water deficit conditions was observed also by Dichio et al. (2002) on Coratina olive cultivar; the same authors described this response as a defense strategy which improves water availability per unit of leaf area, enabling plants to resist long water deficit periods while keeping the leaves photosynthetically active.

Anyway, in this work, such behavior was observed only in the less arid-resistant cultivar Leccino, while in the rustic Racioppella, as the irrigation volumes were reduced from T100 to T25, the accumulated dry matter in the aerial part and in the root system decreased proportionally, determining a constant canopy to root ratio among the different water treatments (Table 4); at the