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Effect of moderate high temperature on the vegetative growth and potassium allocation in olive plants

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ABSTRACT

There is little information about the prolonged effect of a moderately high temperature on the growth of olive (*Olea europaea* L.). It has been suggested that when the temperature of the air rises above 35 °C the shoot growth of olive is inhibited while there is any reference on how growth is affected when the soil is warmed. In order to examine these effects, mist-cuttings and young plants generated from seeds were grown under moderate high temperature (37 °C) for 64 and 42 days respectively. In our study, plant dry matter accumulation was reduced when the temperature of both the air and the root medium was moderately high. However, when the temperature of the root medium was 25 °C, the inhibitory effect of air high temperature on plant growth was not observed. The exposure of both the aerial part and the root to moderate high temperature also reduced the accumulation of K^+ in the stem and the root, the water use efficiency and leaf relative water content. However, when only the aerial part was exposed to moderate high temperature, the accumulation of K^+ in the stem, the water use efficiency and leaf relative water content were not modified. The results from this study suggest that the olive is very efficient in regulating the water and potassium transport through the plant when only the atmosphere surrounding the aerial part is warmed up. However, an increase in the soil temperature decrease root K^+ uptake and its transport to the aerial parts resulting in a reduction in shoot water status and growth.

1. Introduction

The Mediterranean Basin has been considered as one of the regions of the world to be more affected by climate change in the course of the 21st century (Giorgi, 2006). Climate experts have anticipated an increase in air temperature in the range of 2–5 °C (IPCC, 2007; Giorgi, 2006; Gualdi et al., 2013). Along with an increase in the average temperature (Giannakopoulos et al., 2009), more frequent and extreme events such as droughts and heat-waves will be observed in the near future in this region (Giorgi and Lionello, 2008; Tanasijevic et al., 2014). Temperature is a primary factor affecting plant growth and development. When temperature rises beyond the species optimum level, morphological, physiological and biochemical changes can be induced in plants, leading to adverse effects on growth and productivity, especially if soil moisture is low (Wahid et al., 2007). The olive (*Olea europaea* L.) is the most prominent crop in the Mediterranean Basin having an enormous ecological an economic importance in this region. It is well adapted to the Mediterranean climate characterized by hot and dry summers and mild winters with little rainfall. The optimum temperature for its vegetative development ranges from 10 to 30 °C, but when the temperature rises beyond 35 °C, it seems that the stomata begin to close limiting the exchange of gases for photosynthesis what may affect negatively its growth (Rallo and Cuevas, 2008). The gradual rise in the temperature of the atmosphere could therefore seriously jeopardize olive cultivation.

The olive is well adapted to arid climates and rain fed agricultural ecosystems. However, a syndrome of dehydration is often observed, which, in many cases, has been associated with a poor potassium nutritional status of the plant (Fernández-Escobar et al.,

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1994). Plants need to accumulate large amounts of K^+ in their cells, reaching concentrations in the cytoplasm of between 100 and 200 mM. Most of the K^+ accumulated is involved in cell osmoregulation, favouring a range of physiological processes which are vital for plants, such as water absorption by the cell and cell elongation (Hsiao and Läuchli, 1986; Mengel and Arneke, 1982). At the whole plant level, K^+ plays a key role in the regulation of water movement through the plant: it is directly involved in the osmotic absorption of water by the root (Läuchli, 1984) and in the control of transpiration (Hsiao and Läuchli, 1986). Therefore, it seems that plant's water economy depends on plant K^+ status. In this regard, in olive trees and other crops, it has been observed that K^+ starvation inhibits the effect of water stress on stomatal closure (Arquero et al., 2006; Benlloch-González et al., 2008) and enhances water loss through transpiration (Sudama et al., 1998; Cabañero and Carvajal, 2007). As a result, the plant displays lower water use efficiency and its growth is diminished (Fournier et al., 2005; Arquero et al., 2006). It is therefore not surprising to observe that when a plant is supplied adequately with K^+ its tissues are better hydrated (Mengel and Kirkby, 2001) and is more resistant to drought and other unfavourable environmental conditions such as salinity, waterlogged soils or toxicity caused by other nutrients (Cakmak, 2005; Zörb et al., 2014).

The increase in the temperature of the atmosphere seems to be accompanied by a gradual rise in soil temperature. Soil warming can affect the fertility of soils (St Clair and Lynch, 2010) and the capability of the root system for acquiring water and nutrients (Kramer, 1983; White et al., 2012) what could limit plant growth and development. Roots are able to modulate nutrient acquisition through changes in their physiology, longevity, morphology and architecture (Chapin, 1980; Clarkson, 1985; Lynch, 1995). Changes in the morphology and distribution of the root system through the soil profile have been observed in response to certain abiotic stresses, most likely to enhance nutrient uptake (Smucker and Aiken, 1992; Feddes and Raats, 2004; Benlloch-González et al., 2014). In different olive cultivars, the hydraulic properties of the root system were adjusted differently according to the grade of salt tolerance of the cultivars (Rewald et al., 2011). Therefore, it might seem reasonable to think that in the near future the nutrient status of crops will be determined in part by the root function under warmer conditions. In relation to this, it has been reported that cropís survival under adverse environmental conditions is linked to the nutritional status of plants (Marschner, 1995; Wang et al., 2013). Among the essential mineral nutrients, K^+, as mentioned above, has a key role in this respect (Zörb et al., 2014). Most plants are able to regulate K^+ homeostasis in response to different environmental challenges (Anschütza et al., 2014). This is because plant tissues have very efficient mechanisms for the uptake and redistribution of K^+, in which different families of membrane proteins are involved (Ashley et al., 2006; Nieves-Cordones et al., 2014).

From this information it can be deduced that the adaptation of Mediterranean climate crops to future climate conditions may be influenced by the capability of the root system to acquire enough amounts of K^+ from the soil to maintain a relatively high concentration of this ion in cells to be able to fulfil vital functions. Despite the importance of this matter, little is known about how the efficiency of the K^+ uptake systems will be affected by the increase in the air temperature. For olive trees and other species the information on this respect is scarce. The movement of ions through cell membranes seems to be very sensitive to changes in soil or root temperature (Chapin, 1974; BassiriRad et al., 1993). In sunflower plants, the effects of root temperature on the absorption of potassium (Rb^+) have been studied, and 33 °C was observed to be the breaking point: at higher temperatures, the absorption of Rb^+ was inhibited (Benlloch et al., 1989). This phenomenon was observed when the potassium concentration in the external medium was within both the μM and the mM ranges and helped to show the presence of two different potassium absorption systems dependent on the concentration of this element in the external medium. In corn, in isolated roots, it has also been shown that temperatures above 30 °C inhibit potassium absorption (Bravo-F and Uribe, 1981). More recently, in tomatoes grown in hydroponic medium using nutrient technique film (NFT), it has been observed that when the temperature of the nutrient solution reaches 35 °C, potassium uptake was inhibited, which lead to a decrease in potassium concentration in the xylem sap (Falah et al., 2010).

In conclusion, there is little information about the prolonged effect of a moderately high temperature on the growth of olive. It has been suggested that shoot growth is limited when the air temperature rises above 35 °C but there is any reference on how growth is affected when soil is warmed. On the other hand, it seems that K^+ is a key nutrient for plant's resistance to several environmental stresses (Kant and Kafkafi, 2002; Cakmak, 2005; Wang et al., 2013). In addition it is well known that this ion is directly implied on cell expansion and water relations (Hsiao and Läuchli, 1986; Mengel and Arneke, 1982; Mengel and Kirkby, 2001). Considering all these, the aim of this study was to examine in olive the prolonged effect of a moderately high temperature on K^+ accumulation and distribution through the plant and consequently on growth and water relations. To reach this goal, different olive plant material, mist-rooted cuttings and young plants generated from seeds, were grown under moderate high temperature (37 °C) for 64 and 42 days respectively. Finding out more about this subject would contribute to assess the adaptability of this crop to global warming.

2. Material and methods

2.1. Plant material and growth conditions

2.1.1. Experiment 1

Rooting cuttings of olive (*Olea europaea* L.) 'Picual' were used. Previously, March 20-cm length semi-hardwood cuttings, with two pairs of leaves, were propagated. The basal end of cuttings was treated with IBA (indole-3-butyric acid) (3000 ppm) applied for 10 s, and placed in a mist bend with basal temperature control (22 °C).

After 40 days, 20 rooting cuttings were individually transferred to 3.5-L cylindrical plastic pots (11-cm diameter, 37-cm deep) filled up with a sand/peat mixture (2:1v/v). Below the soil substrate a 6–7-cm layer of gravel was placed to facilitate drainage of excess water. To this end, a drainage tube was also connected to the bottom of every container. After transplantation, each plant was watered in excess causing the drainage of water. Olive plants were placed in a controlled growth chamber with a relative humidity between 60 and 80%, a constant temperature of 25 °C (day/night), a photoperiod of 14 h of light and a photosynthetic photon flux density of 350 $\mu mol\ m^{-2}\ s^{-1}$ (fluorescent tubes, Sylvania cool-white VHO). Every week, the plants were irrigated and fertilized. To fertilize the plants 2 $g\ L^{-1}$ of Hakaphos® Verde fertilizer 15-10-15 (Compo) containing 15% N, 4.4% P, 12.4% K, 1.2% Mg, 12% S, 0.01% B, 0.05% Fe, 0.05% Mn, 0.02% Zn, 0.02% Cu and 0.001% Mo was used.

After three weeks of acclimation, half of the plants were transferred to another controlled growth chamber with the same characteristics described above except that the temperature was set at 37 °C. In this way, the plants were exposed to two air temperature regimes: 25 °C (control) and 37 °C (high temperature) for 64 days. While the former were irrigated every week, plants exposed to 37 °C were irrigated every 3-4 days. The volume of water drained was individually collected after each irrigation. Weekly, both types of plants were fertilized as described above.