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Effects of photoselective netting on root growth and development of young grafted orange trees under semi-arid climate

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A B S T R A C T

Photoselective netting is well-known for filtering the intercepted solar radiation, therefore affecting light quality. While its effects on above-ground of plants have been well investigated, the root system was neglected. Here, we evaluated the effects of photoselective netting on root growth and plant development. Minirhizotron and in-growth cores were applied in a field experiment, performed in a 4-year-old orange orchard grown under three different photoselective net treatments (red, pearl, yellow) and an unnetted control treatment. Our observations confirmed the significant positive effect of photoselective nets on tree physiological performance, by increases of photosynthesis rate and vegetative growth. Trees grown in the pearl plot developed evenly distributed root system along the observation tubes while trees in control, red and yellow plots had a major part of roots concentrated at different depth ranges of 60–80, 100–120, and 120–140 cm, respectively. Photoselective nets showed a strong impact on shoot-root interaction and proved equally successful in promoting rapid establishment of young citrus trees. However, at long-term effect, yellow net might outperform because it could enable plants to develop deeper root systems, which will uptake water and nutrients more efficiently in semi-arid areas with sandy soil.

1. Introduction

Citrus is one of the main fruit trees of great economic importance worldwide, and countries such as Brazil, China, USA, Mexico and the Mediterranean countries, such as Spain, Italy and Turkey are some of the main producers and exporters (Food and Agriculture Organization of the United Nations, 2013). In the Mediterranean, some of the main producing areas are located in arid or semi-arid areas such as Israel, where the majority of citrus orchards are subject to high solar radiation and scarce water resources (Cohen et al., 2005, Romero-Conde et al., 2014). Thus, the extreme environment conditions lead to a higher transpiration rate, often exceeding root water uptake rate even in well-irrigated soils (Cohen and Fuchs, 1987; Cohen et al., 1997), resulting in reduced photosynthetic activity and adverse effects on plant growth (Kriedemann and Barrs, 1981, Medina et al., 2002; Nicolas et al., 2008). Therefore, the shading practice has been used as an efficient solution to mitigate extreme climatic fluctuation in the orchards in semi-arid and arid areas, and increase the plant water use efficiency by reducing transpiration while maintaining photosynthesis rate (Alarcon et al., 2006; Jifon and Syvertsen, 2003; Nicolas et al., 2008). Among the shading nets, the so-called photoselective netting refers to the use of special netting products into which chromatic elements are incorporated during manufacturing (Shahak et al., 2006). Thus, the photoselective netting is unique since it combines functions of both crop protection and light-quality manipulation in one approach, bringing multiple benefits for plants (Shahak et al., 2004a). Each specific photoselective net could differentially absorb ultraviolet, blue, green, red, radio frequency or infrared spectral regions, and at the same time enrich the scattered and diffused light, which would improve light penetration into the inner canopy, thus increasing radiation use efficiency of plants (Shahak et al., 2004b). Therefore, this method is capable of specifically promoting desired physiological responses by manipulating light spectral composition and increasing scattered light (Healey et al., 1998; Shahak et al., 2008).

Extensive experiments have been conducted to test effects of photoselective nets on agricultural plants including ornamentals (Leite

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et al., 2008; Oren-Shamir et al., 2001), vegetables (Ilić et al., 2012; Lopez et al., 2007; Yan et al., 2011) and fruit crops (Bastías et al., 2011; Blanke, 2009; Schettini et al., 2011; Stamps, 2009). In general, the studies focus mainly at the above-ground parts of the plant, showing that photoselective nets could differentially affect plant vegetative growth, flowering, harvest time (early or late maturation), fruit quality, and yield (Shahak et al., 2004a; Shahak et al., 2008). For example, in a study conducted in a mandarin orchard using four types of photoselective nets (red, yellow, white and transparent), the results showed that a significant increase in the yield (up to 2 fold) occurred under white and transparent nets (Wachsmann et al., 2013). In addition, better external fruit quality was induced by all types of nets, demonstrating the promising potential of using photoselective nets in citrus orchards (Wachsmann et al., 2013). Moreover, the photoselective nets also revealed pronounced benefits in pest and fungi control in vegetable crops (Ben-Yakir et al., 2014; Elad et al., 2007); maintenance of postharvest fruit quality (Goren et al., 2010; Kong et al., 2013); and, reduction of decay incidence (Shahak, 2014).

At below-ground, it is well-known the key role of roots to respond and avoid different types of stresses and control water availability mainly due to preferential growth and control of hydraulic properties (Alsina et al., 2011; Couvreur et al., 2014; De Jong van Lier et al., 2006; Gardner, 1960; Jerszurki et al., 2017; Rewald et al., 2010; Rewald et al., 2012). However, less effort has been made to improve the understanding of how photoselective nets can affect the plant root system development. Nissim-Levi et al. (2014) reported increased root length of ornamental plants grown under yellow shade nets. For peach rootstocks, red radiation supplied by fluorescent tubes caused reduction in root growth, white radiation was the most effective radiation source for adventitious root formation, and green radiation significantly increased iron concentration in roots (Antonopoulou et al., 2004). As it stands, the results are not conclusive, while are influenced by plant species and stage of development. Although those studies have contributed for the evaluation of performance of the photoselective nets on a wide range of crop plants in the field, and studies have been conducted on citrus performance under different light regimes (Cohen et al., 1997; Jifon and Syvertsen, 2003; Raveh et al., 2003; Wachsmann et al., 2013), often overlooked the root properties. Therefore, it is still unknown the effects of light on shoot to root relationship of citrus trees. Accordingly, here we identify the optimal photoselective net that can significantly increase root growth and development of grafted young orange trees, therefore reducing the juvenile phase and fasten the root establishment.

2. Materials and methods

2.1. Study site and design

This research was conducted from July 2015 to December 2016 in a 4-year-old orange orchard (scions of sweet orange (*Citrus sinensis* Osb. var *Valencia*) grafted onto rootstocks of bitter orange (*Citrus aurantium*)) located at Beror Hayil (Fig. 1a), south of Israel (31°55′ N, 34°64′ E). The climate type in Beror Hayil is semi-arid *Bsh* (Monthly Climate Average, 2017), with average annual air temperature and precipitation of 20 °C and 363 mm, respectively (Fig. 1b and c).

The soil type is dark brown sandy clay loam (70% sand, 23% clay, 7% silt) and soil water content at field capacity is approximately 28% (Saxton and Rawl, 2006). Orange trees were transplanted in September 2014 (2-years old) and were surface drip-irrigated with emitters located at 10 cm from the trunk. Photoselective nets were made by polypropylene with a mesh size of 7.3 mm and placed horizontally above the trees, 3.5 m above the ground and 2.0 m above the canopy, totaling 66 m^2 area (Fig. 1a). The experimental design was a randomized complete block design with four net treatments including three types of photoselective nets (20% of shading): pearl, red and yellow, and an unnetted control treatment. Each net treatment consisted of three blocks, with the trees planted at a 4.5 m × 7.5 m spacing, totaling 25 trees per block. To avoid border-row effects due to mixed light, only the data from the trees located at the central part of the block were sampled.

2.2. Physiological traits

Physiological traits were measured with an infrared gas analyzer (CIRAS-2, PP Systems, USA) every 6 or 8 weeks from August 2015 to December 2016, over six replicates for each treatment. These traits included photosynthetically active radiation (PAR – $\mu mol\ m^{-2} s^{-1}$), net photosynthesis rate (Pn – $\mu mol\ CO_2\ m^{-2} s^{-1}$) and stomatal conductance (gs – $mmol\ H_2O\ m^{-2} s^{-1}$). The youngest fully mature leaf of each replicate was measured around midday. During the measurements, carbon dioxide concentration was set at 400 mmol mol^{-1}. Leaves were exposed to the light which was modified by the photoselective nets instead of the artificial light supplied by the infrared gas analyzer because we were interested in how do plants respond to modified light under different types of photoselective nets.

Considering that the plants were exposed to open field conditions, thermal images were obtained only in the summer (August 2016) at noontime to monitor the actual canopy temperature under the color nets. We used a thermal camera (T460, FLIR Systems, USA) with a sensitivity of 0.08 °C and accuracy of ± 2 °C. Images were taken at 2 m height above the ground and 3.5 m distance from the tree. For each treatment, nine trees were selected to be measured. Thermal images were processed by using a thermal image analyze software ThermaCAM Researcher (FLIR systems, USA). Light measurement was also carried out under the nets and in the open field to monitor the actual light conditions to which plants were exposed. Spectra of the total solar light, consisting of both direct and indirect light, were measured at noontime by a field spectrometer (FieldSpec Pro, Analytical Spectral Devices Inc., Boulder, CO, USA) in May 2017. To start with, the white reference was recorded as the reflected spectrum of the sunlight. A tripod with white reflective material on top was leveled in 1.5 m height and the sensor of the field spectrometer oriented in such a way that the reflected light beam of the sun would hit the sensor at the right angle. Six replicates were performed due to the heterogeneous nature of the system.

Tree height was measured with a measuring tape on 24 trees per net treatment from September 2014 until July 2016.

2.3. Root growth

The non-destructive minirhizotron technique (Levan and Ycas, 1987) was used in this experiment to study root dynamics. In May of 2014, 24 transparent observation tubes were installed vertically at a distance of 50 cm from the trunk of the trees. Each tube was 200 cm long, 6 cm outer diameter and 5.15 cm inner diameter. We analyzed two trees per treatment, totaling 24 trees. Trees were planted five months after the observation tubes were installed to avoid the disturbance on the root formation process (Rewald and Ephrath, 2013). Since light and heat can negatively affect root development, the above-ground part of each tube (around 10 cm) was painted black and then white after the installation to prevent light penetration and radiant heating. Both the bottom and top openings of each tube were sealed by rubber stoppers. Root images were taken with a BTC minirhizotron digital image capture system (Bartz Technology Co., Carpinteria, CA, USA) at: 312 days after planting (DAP) (July 2015), 448 DAP (Dec 2015), 504 DAP (Jan 2016), 575 DAP (April 2016), 621 DAP (May 2016), 647 DAP (June 2016), 672 DAP (July 2016), 690 DAP (July 2016), 709 DAP (Aug 2016), 737 DAP (Sep 2016), 760 DAP (Oct 2016), and 825 DAP (Dec 2016). Each observation consisted of systematically taking pictures at 1.35 cm intervals from the bottom to the top of the tube. The Rootfly software (Rootfly, Source Forge) was used to analyze root length and diameter semi-automatically.

In addition, we used 35 cm-deep ingrowth cores to analyze the horizontally distribution of roots at 25 and 50 cm from the trunk of 30