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Towards a near-soilless culture for woody perennial crops in open field conditions

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ABSTRACT

Increasing water-use efficiency (WUE) is mandatory for more sustainable agricultural land use. Here we studied during three consecutive years in a nectarine (*Prunus persica* L.) orchard the effects of placing 2 × 40 L coconut fiber substrate (S) bags per tree on the agronomic performance and WUE. Additionally, there were two regimes of watering, control (C), fulfilling 100% of the estimated crop evapotranspiration (ET_c) and a deficit (D) irrigation treatment, replacing the 65% of the ET_c. Root colonization of the substrate, changes in the soil and substrate water content and temperature, tree water status (midday stem water potential), shoot growth (trunk diameter and tree volume), fruit yield and fruit quality compounds, were determined. Coconut substrate was colonized by the roots after two months from its installation, and after three years root dry weight in the substrate averaged 172 and 155 g per tree for the control and deficit irrigation treatments, respectively. During the first year, tree growth was enhanced in the C irrigation, while freezing temperatures during fruit set almost totally removed all fruits. In the second year, probably the abundant rainfall disguised the effect of the substrate on the yield parameters. However, this year and the next, deficit irrigation reduced fruit mean weight and delayed fruit harvest. In the third year, the substrate in the deficit irrigation treatment had a positive effect on fruit yield by increasing the number of fruits per tree in comparisons with deficit irrigation trees without substrate. The combination of deficit irrigation and substrate increased the WUE over the rest of the treatments but with no clear improvements in the tree water status. The results suggest that nectarine trees with deficit irrigation and substrate could be benefiting from a more efficient use of nutrients that further increases fruit set or prevent fruit drop.

1. Introduction

The most immediate agriculture challenge for the 21[st] century is the increasing of yield per surface unit while reducing the consumption of water. Increasing water-use efficiency (WUE) is mandatory in countries where water is limited and irrigation water competes heavily with other more competitive economic activities and human uses. In arboriculture, there have been important advances in fertirrigation strategies and techniques with important impacts in terms of both water and fertilizer saving; e.g. regulated deficit irrigation strategies (De la Rosa et al., 2015; Gonzalez-Dugo et al., 2012; Phogat et al., 2013), fine-tuning of irrigation-fertilization scheduling (Phogat et al., 2014), partial root zone drying (Faber and Lovatt, 2014; Yang et al., 2011) and different irrigation systems (Maris et al., 2015; Panigrahi et al., 2012).

An Open Field Hydroponics (OFH) system has already been developed in citriculture (Martínez-Valero and Fernández, 2004). The successful establishment of OFH relies on the power of the system to both limit root growth within the irrigate zone, and release water and nutrients to supply plant demand in the short-term (Stover et al., 2008). This is achieved through the management of the irrigation system design, usually drip irrigation, the number and lengths of the irrigations events and the management of the nutrient balance in the irrigation solution as well. This framework lets growers use the soil as a medium for delivering water and nutrients to the plant and not as a medium

Abbreviations: WUE, water-use efficiency; $\Psi_{s,\ md}$, mdmidday stem water potential; ET_o, reference evapotranspiration; ET_c, crop evapotranspiration; VWC, volumetric water content; EC, electrical conductivity

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used to store water and nutrient to future plant demand, maximizing external water and nutrient-use efficiency and reducing nutrient leaching (Morgan and Kadyampakemi, 2012). In citrus, OFH has proven to increase productivity, early growth, increase water and nutrient use efficiency, and reduced nutrient leaching (Morgan et al., 2010).

Here, an approach to this system, which uses soilless techniques and could be called Open Field Soilless System (OFSS), is developed for a nectarine orchard. In common with OFH, this system attempts to concentrate some roots, the more the better, in the substrate bags, leaving these active roots in a balanced nutrient mixture after each irrigation event, inducing the tree to use water and nutrients more efficiently. This system relies on the specific characteristics of the coconut fiber (high water holding capacity and high cationic exchange capacity) in terms of water and nutrient holding capacity to attain a high flexibility in the irrigation scheduling (Rubio et al., 2011, 2010). The OFSS should facilitate both the adaptation to conditions where the water for irrigation is uncertain or unreliable throughout the growing season, and the adaptation to tree crops that need more spacing between irrigation events. Also, as much of the root system is in the soil, it serves as an anchor for the tree at the same time that root performance is buffered by the soil water and nutrient content. Compared with other approaches that aim to increase water and nutrient use efficiency (e.g. drippers located only where the trees are, hydrogels, covering drippers with mulch or digging them into the upper soil layer), OFSS may be a powerful system for the establishment of crops where soil chemical or physical properties might hinder plant survival (e.g. high salinity level, heavy metals, etc.). Also, as compared with others substrates such as rock-wool or perlite, coconut fiber is biodegradable and environmentally-friendly.

In the present work, a novel system based on soilless culture techniques is studied for three years in a nectarine orchard in an open field. The system was designed with 2 × 40 L coconut fiber substrate bags laid on the ground below each tree, with drip emitters that supplied water and nutrients both inside the bag and in the upper part of the substrate and in the soil. The aim was to test the feasibility of supplementing a standard irrigation drip design in a nectarine orchard with this system in order to promote root colonization of the substrate and improve water-use efficiency. The final purpose would be to incorporate this design in regions where there is a shortage of water resources for agriculture. This system was tested under two irrigation regimes, 100% and 65% ET_c, and the working hypothesis was that the substrate should favor water-use efficiency, especially under deficit irrigation conditions.

2. Material and methods

2.1. Experimental site and growth conditions

The trial was carried out over three consecutive years (2012, 2013 and 2014) in a commercial orchard located in Carlet (39° 13′ 59″ N; 0° 31′ 27″ W), Valencia, Spain. The experimental plot (0.3 ha) consisted of 4-year-old early nectarine trees (*Prunus persicae* L. *Batsch* cv Viowhite 15) grafted onto GF-677 rootstock at a spacing of 5 m × 3 m. The soil had a loam-clay texture, an average depth of 1.2 m, and 0.85% of organic matter. The electrical conductivity (EC) of the irrigation water was 0.85 dS m^{-1}. Cumulative rainfall per year until harvest (beginning of June) was 115, 318 and 54 mm in 2012, 2013 and 2014, respectively, while total rainfall was 333, 401 and 147 mm in 2012, 2013 and 2014, respectively (Fig. 1). Total ET_o was 1022, 1094 and 1104 mm, in 2012, 2013 and 2014, respectively. Normal cultivation practices (e.g. weed control, fertilization, pruning, fruit thinning and banding) were performed by the technical department of the commercial orchard. A drip irrigation system was installed, with two pipes per tree row, and each pipe had pressure-compensated emitters inserted, placed every 75 cm. Irrigation was scheduled weekly and the dose per tree was provided as a function of the reference evapotranspiration (ET_o) and crop coefficient (Allen et al., 1998), and corrected for percent shade area (Fereres and Goldhamer, 1990). After harvest, water applications were in general reduced for all treatments, as post-harvest deficit irrigation is a standard practice for early maturing stone fruit trees in this field of study (Intrigliolo and Castel, 2005). The amount of N, P_2O_5 and K_2O applied to fulfil the estimated crop nutrient demand were 110, 50, and 120 kg per ha and year, which were applied through the irrigation system. Several commercial soluble fertilizers (%); potassium nitrate (13-0-46), calcium nitrate [15.5 (14.4 N-NO_3^- + 1.1N-NH_4^+)-0-0-26 CaO], magnesium nitrate (10.5-0-0-15.5 MgO), Sequestrene (7% Fe), and monopotassium phosphate (0-52-34) were used throughout the growth cycle.

2.2. Treatments and experimental design

There were four treatments that combined the irrigation dosage with the presence or not of coconut fiber substrate bags; 100% of ET_c with not substrate bags (C), 100% of ET_c with substrate bags (CS), 65% of ET_c with not substrate bags (D), and 65% of ET_c with substrate bags (DS). As the fertilizers were applied with the irrigation water, the dose of N, P_2O_5 and K in the D treatments were reduced in the same proportion as the irrigation dose (65%). The total amounts of nutrients supplied were calculated to meet the requirements of the trees in the C treatment. The irrigation dose was set using drip emitters with a flow rate of 4 L h^{-1} for the control treatments and 2.6 L h^{-1} for the deficit treatments. The coconut fiber bags (Projar Golden Grow Standard), after saturation, had a volume of 40 L, were 1.2 m in length, 22 cm wide, and 15 cm high. The volume of the bag was distributed in 2 L of solid material, 15.9 L of air, and 22.1 L of water at field capacity (Verdonck, 1984). From this volume of water, 6.22 L was easily available water, and 1.83 L stands for the water buffering capacity (Wallach, 2008). Bags were laid on the soil surface after flattening the soil for proper contact between the soil surface and the coconut fiber. There were two bags per tree and each bag was placed on each side of the tree, closest to the two drip emitters. Then, in the treatments with the substrate, each tree has the closest 4 drip emitters inside the bags (two per bag) and the 4 most distant drip emitters outside the bag, which poured water directly to the soil. The bags were hydrated through the irrigation system and after bags were fully hydrated, three windows, 100 cm^2 each, were made on the bottom of the bags. Irrigation treatments started March, 21th 2012 and ended Sep, 4th 2014.

The irrigation schedule changed during the crop season from zero per week during winter to two irrigation events per day during the rapid growth phase of the fruit. The irrigation schedule was managed following the standard practices of irrigation in the nectarine orchard, with the only requirement being that the irrigation dose was enough to replenish the volume of available water for the plant, as able to be stored in the substrate bag. To replenish the nutrient solution into the bag in each irrigation event and to be sure that the substrate returned to uniform conditions in terms of water and nutrients, the irrigations events were scheduled to last at least 2 h. The maximum time per irrigation event was no more than 4 h. If the time needed to fulfil tree water requirements was more than 4 h, there were two irrigation events per day. This is the time it takes to pour 10.4 L and 16 L inside the bag in the deficit and control irrigation treatments, respectively. The experimental plot design was comprised by three blocks, each block had three tree lines and 8 trees per line. The measurements were done in the 6 central trees, and the others were left to avoid border effects. The treatments were randomly allocated to each block. The rows of trees on the boundaries of the plot were discarded.

2.3. Substrate colonization by roots and root biomass inside the bag

Substrate colonization by the roots was evaluated two months after treatments started by visual exploration of 10 bags per treatment. Bags