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Automated ebb-and-flow subirrigation for citrus liners production. II. Pests, diseases and nutrient concentration

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ABSTRACT

Subirrigation has the potential to reduce water and nutrients losses in citrus seedlings production by recirculating fertilizer solution (FS) and eliminating improper disposal of salts into the environment. The objectives of this study were to evaluate the effect of an automated ebb-and-flow system on pest and disease incidence and nutrient concentration of Rangpur lime (*Citrus* × *limonia*) liners. Nutrients were determined on plant tissue (shoot and root), substrate, and recirculated FS collected on 121-L water tanks. The treatments were four volumetric water content (VWC) to trigger subirrigation (0.12, 0.24, 0.36 and 0.48 $m^3\ m^{-3}$), three FS concentrations (25%, 50% and 75% of the fertilizer recommendation) and a control (nursery manual overhead irrigation using breaker nozzles), arranged in a completely randomized 4 × 3 + 1 factorial plus design, with three replications. The system was automated by 39 capacitance sensors connected to a data logger, multiplexer and relay drivers, which controlled submersible pumps inside 121-L tanks with different FS. Subirrigation was turned on when VWC dropped below the set thresholds. There was occasional appearance of leaf miners (*Phyllocnistis citrella*, Lepidoptera: Gracillariidae) and fungus gnats (*Bradysia* sp. nr. *coprophila*, Diptera: Sciaridae), and no diseases (especially *Xanthomonas axonopodis* and *Phytophthora nicotianae*). Different treatments resulted in changes on macro and micronutrients content in shoots and roots, substrate, and FS at 0, 30, 60 and 90 days ($p < 0.0001$). Higher FS concentrations increased the nutrient content over time ($p < 0.0001$). There was a decrease in pH and an increase in electric conductivity on treatments with higher VWC and FS ($p < 0.0001$). The substrate electric conductivity reached 5 $dS\ m^{-1}$ twice, demanding substrate washing by water application on treatments with VWC of 0.36 and 0.48 $m^3\ m^{-3}$ and FS of 75%. Subirrigation is suitable for liner production in 56-cm^3 cone-shaped containers.

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1. Introduction

Overhead systems used at the citrus nursery industry are characterized by minimal control of solution delivery, often leading to excessive or deficient irrigation, reduced irrigation efficiency, and increased production costs (Salvador et al., 2016). Part of the leachate reaches the soil with potential for salinization and environmental contamination due to the high amount of salts dissolved in the solution. Additionally, the "umbrella effect" (i.e., water redirection by leaves) reduces the water and nutrient uptake causing significant losses. Salvador et al. (2016) evaluated the loss of fertilizer solution (FS) in the production of citrus rootstock liners, and estimated an annual solution leaching of 221.8 m^3 with an average environmental release of 158.9 kg of fertilizer in the greenhouse soils for the production of 300,000 liners per year on 20,000 m^2. There is a lack of environmentally-friendly water management strategies on citrus liners production (Salvador et al., 2014).

The limitations present in the manual overhead irrigation demand new techniques for rational use of water and nutrients, maximizing plant growth with reduced irrigation time and frequency to reduce improper discharge of FS into the environment in citrus nurseries. One of the available alternatives is subirrigation, which uses capillary action to move water and nutrients vertically in the substrate (Ferrarezi et al., 2015b). Water is pumped from a reservoir to a bench and applied directly to the bottom of the containers. After irrigation, the pump is turned off and the unused FS returns to the reservoir by gravity for recirculation. This system can be used for citrus, eucalyptus, coffee, ornamental and vegetable

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seedlings production (Ferrarezi et al., 2015b). More details regarding subirrigation is available at Ferrarezi et al. (2015b, 2017) and Ferrarezi and Testezlaf (2017).

One of the potential drawbacks of subirrigation is the transmission of root-infesting pathogens between containers or benches through recirculated irrigation water (Watanabe et al., 2008). *Pythium* (*Pythium* spp.) and *Phytophthora* (*Phytophthora* spp.) are particularly challenging since they produce large numbers of highly mobile aquatic zoospores and seriously impact plant growth and quality (Sanogo and Moorman, 1993; Stanghellini et al., 2000). Bacteria, viruses, and fungal pathogens can also migrate through the recirculating system and infect new hosts (Ferrarezi et al., 2015b). Although the risk of disease spread exists, several studies showed that subirrigation presents lower disease incidence and severity than sprinkler systems. Losses on floricultural and vegetable crops produced in the ebb-and-flow system are similar to those in the overhead irrigation system (Atmatjidou et al., 1991; Stanghellini et al., 2000). The mortality rates of pepper (*Capsicum annuum*) plants due to *Phytophthora capsici* were lower in an ebb-and-flow system compared to a top-irrigated system (Stanghellini et al., 2000). The movement of *Pythium* from infested pots to other pots within the ebb-and-flow system does not appear to pose any greater threat to production than operations in which recirculating systems are not used (Sanogo and Moorman, 1993). Oh and Son (2008) compared ebb-and-flow and wick systems, and observed that ebb-and-flow delayed the transmission of *Phytophthora nicotiana* on kalanchoe (*Kalanchoe blossfeldiana*) compared to the wick system, resulting in lower infection and increased plant growth due to the filtering provided by the potting mix. These results are similar to Strong et al. (1997), which indicated non-pasteurized substrates reduced the transmission of *Phytophthora parasitica* in the presence of other competing fungi, and that reducing the spacing between containers does not increase the disease incidence and severity.

Several alternatives are available to reduce the pathogen load of recirculated systems such as cultural, physical, chemical, biological and integrated methods. Infectious propagules can easily enter the reservoir with plant debris, and removal of dead material helps minimize disease spread (Atmatjidou et al., 1991; Bauerle, 1990). Physical barriers, sedimentation and FS filtration using membrane, disc filters, and sand slow media can also prevent contamination, removing dormant microbes and preventing infections (Garibaldi et al., 2003; Martínez et al., 2010; Stewart-Wade, 2011). Recirculated FS can also be treated using heat, pressure, ultrasound, and ultraviolet radiation to eliminate pathogens (Martínez et al., 2010; Stewart-Wade, 2011). Biological agents, biofiltration and bioreactors are potential alternatives as well. Finally, chemical treatment using chlorine, ozone, iodine, hydrogen peroxide, surfactants, and antimicrobial compounds such as peracetic acid and fungicides are widely used (Martínez et al., 2010; Stewart-Wade, 2011).

Subirrigation is typically controlled using timers according to a pre-determined schedule, usually designed to meet operational needs. Sensors can be used to monitor substrate moisture and control subirrigation based on plant water demand (Ferrarezi et al., 2014, 2015a,b, 2016). Triggering subirrigation based on specific substrate moisture levels can reduce water use and control plant vigor, potentially decreasing the use of plant growth regulators (Ferrarezi et al., 2015a,b). Inexpensive open-source microcontrollers are available to build low-cost automated irrigation controllers (Ferrarezi et al., 2015c).

Subirrigation use still reduced, especially due to the lack of proper nutrient guidelines for different crops. The recommendations used in other irrigation systems are not suitable for subirrigation (James and van Iersel, 2001a). The FS concentration in subirrigation should be lower than in sprinkler irrigation because the salts are not leached and can accumulate in the root zone (Ferrarezi et al., 2015b). Several studies were performed to stablish the guidelines for ornamental plants production using subirrigation (James and van Iersel, 2001b; Kang and van Iersel, 2002; Kang and van Iersel, 2004; Lumis et al., 2000; Montesano et al., 2010; Pennisi et al., 2005; Zheng et al., 2004). Current management practices are based on the reduction of the FS concentration for other systems. This strategy of reducing FS concentration changes plant tissue nutrient composition, demanding chemical analysis to stablish fertilizer guidelines. There is a lack of nutritional guidelines to produce perennial plants, specifically citrus. The establishment of specific nutrient recommendations for citrus rootstocks production using subirrigation is important for proper nutritional management, maximizing plant growth and reducing the amount of fertilizer used for seedlings production.

The objectives of this study were to evaluate the effects of an automated ebb-and-flow system on pest and disease incidence and nutrient concentration of Rangpur lime (*Citrus* × *limonia*) liners. Nutrients were determined on plant tissue (shoot and root), substrate, and recirculated FS collected on 121-L water tanks.

2. Material and methods

2.1. Location, plant material and substrate, ebb-and-flow benches, 121-L fertilizer solution tanks and submersible pumps, automation, substrate-specific calibration, fertilization and cultural practices

Same as indicated by Ferrarezi and Testezlaf (2017).

2.2. Treatments

We tested four VWC to trigger subirrigation (0.12, 0.24, 0.36, and 0.48 $m^3\,m^{-3}$, which correspond respectively to the water potential of 100, 18, 10, and 3 kPa), three FS nutrient concentrations (25%, 50%, and 75% of the fertilization guidelines for citrus roostock liners established by Bataglia et al., 2008) and an additional control treatment (nursery system with manual overhead irrigation using breaker nozzles and FS with 100% nutrient concentration) with three replications. VWC treatments were based on previous studies to validate the use of capacitance sensors in subirrigation (Ferrarezi et al., 2014, 2015a,b, 2016). The manual treatment with FS 100% was tested since it was the reference available for overhead and drip irrigation; however, this concentration was not included in the factorial because several authors indicate the need to reduce the FS concentration on subirrigation due to salt build up (Ferrarezi et al., 2015b). Each experimental unit was formed by one tray with 187 plants for one individual subirrigation equipment. Plants from the outer row were left as an edge; plant measurements were taken on the 136 central plants.

2.3. Measurements

Pest and disease incidence (especially *Xanthomonas axonopodis*) were visually monitored by scouting plants weekly. *Phytophthora nicotianae* presence was determined in the laboratory on substrate and FS in the 121-L tanks at the end of the study following the procedures from Grimm and Alexander (1973).

Plant specimen samples were collected monthly (at 0, 30, 60 and 90 days) on 20 randomly-chosen plants per treatment to determine N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn concentration in shoot (leaves and stems) and root. N was determined by distillation; P, S, and B by optical emission spectroscopy (OES); and K, Ca, Mg, Cu, Fe, Mn, and Zn by atomic absorption spectrometry (Bataglia et al., 1983).

Substrate samples were taken monthly (at 0, 30, 60 and 90 days) on 20 randomly-chosen cone-shaped containers per treatment to determine pH and EC, and N, P, K, Ca, Mg, S, B, Cl, Cu, Fe, Mn, Na, and Zn concentration. The substrate solution was extracted by the 1:1.5