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Transpiration, water extraction, and root distribution of Tahiti lime (*Citrus latifolia* Tanaka) plant under different micro-sprinkler placements

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Measurements of transpiration in cultivated plants are of utmost importance, especially in semi-arid regions where there is low water availability with this, the present work aimed to determine daily transpiration, root distribution, and soil water extraction of 'Tahiti' lime plant under different micro-sprinkler placements in semi-arid conditions of northern Minas Gerais state. We assessed soil water balance, root system and sap flow of plants irrigated by three different micro-sprinklers setups: T1 - a micro sprinkler with 35 L h^{-1} flow rate located between two plants and along the plant row; T2 - a micro sprinkler with 70 L h^{-1} flow rate watering and between two plants, along the plant row; and T3 - a micro sprinkler with 35 L h^{-1} flow rate located 0.3 m from the plant. Treatments changed root distribution, soil water extraction, and transpiration of Tahiti lime. In T2 water loss was lower in upper soil layers than in the remaining treatments. Sap flow in T2 was higher than in T3 and T1, which indicates better water use in T2.

Key words: Sap flow, root, soil moisture.

INTRODUCTION

Transpiration measurements are of utmost importance, especially in semi-arid regions where low water availability is prominent as consequence of lacking and irregular rainfall. Climate change has medium to long-term effects on water resources and reduces water availability or the liability of water supply to numerous areas where water scarcity is already faced (Consoli et al., 2017). Therefore, precision is to be prioritized in irrigation management so as to increase water-use efficiency.

Transpiration rates are directly related to leaf area (Lai, 2015) but canopy geometry and planting can also influence transpiration as these can affect the interaction

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between transpiration and other environment factors, such as relative humidity, temperature, wind, solar radiation, and soil water availability. Soil water content and climate alter water status of plants, gas exchanges, and leaf temperature, influencing growth, development, and overall yield (Santos et al., 2013).

Root-zone drying leads to stomatal closure, even in turgid leaves, to decrease transpiration water loss (Silva et al., 2015; Sampaio et al., 2010; 2014). Stomatal closure is linked to chemical signaling, especially abscisic acid (ABA), and other signals, such as pH and redistribution of inorganic ions from roots to shoot, as a response to water deficit. Lima et al. (2015) reported that water deficit as a result of alternate partial root-zone drying leads to higher ABA production in papaya trees. Santos et al. (2013) reported that either full or partial water deficit reduce photo-synthesis rates, transpiration, and stomatal conductance in 'Tommy Atkins' mangoes.

On the other hand, irrigation setup on the field changes water supply to plants and influences water-saving irrigation strategies, especially in warmer regions. Coelho et al. (2016) observed that using micro-sprinklers with different flow rates and wetting diameters affected leaf area, root distribution, and yield of 'Grand Nain' bananas.

Root distribution directly influences water and nutrient uptake by plants. According to Taiz and Zieger (2013), plants' roots are predominately superficial in well-watered soils; though, superficial roots decrease and deeper roots increase when water is depleted close to soil surface. Deeper roots growing towards soil water can be considered a second line of plant defense from incorrect irrigation management. Accordingly, knowing the root system distribution and its water-extracting patterns allows the use of more adequate crop practices, such as irrigation management and fertigation (Santos et al., 2016), which might provide increases in water-use efficiency and nutrients uptake by plants.

Several methods have been proposed to quantify water demand of plants. Among the alternative methods to determine transpiration of citrus plants, those that are based on heating plant stems (stem heat balance, thermal dissipation, and heat pulse methods) have advanced the knowledge of water relations and provided good transpiration estimates (Boehringer et al., 2013; Pinto Jr et al., 2013; Marin et al., 2008; Coelho Filho et al., 2005). As advantages, these methods are non-destructive (Hernandez-Santana et al., 2016), need no calibration, are easy to install, and allow monitoring numerous plants simultaneously.

A few studies have been done aiming at quantifying the transpiration of 'Tahiti' lime by using stem heat balance method (Vellame et al., 2012; Marin, 2008; Rojas et al., 2007; Coelho Filho et al., 2004). However, these studies have not addressed the relation between sap flow, water extraction by roots, and the irrigation system in place.

Therefore, the objective of this work was to determine daily transpiration, root distribution, and water extraction patterns of 'Tahiti' lime under different micro-sprinkler placements and grown in semi-arid conditions.

MATERIAL AND METHODS

The work was carried out at an Experimental Farm of Mocambinho belonging to the Agricultural Research Enterprise of Minas Gerais (EPAMIG), located at the municipality of Jaíba, Minas Gerais state, at 15º32'S and 43º46'W. Soil at the experimental area is a Typic Quartzipisamment (90% sand, 2% silt, 8% clay, and mean density of 1.62 kg dm^{-3}), in a BSwh climate (savanna hot climate, according to Köppen classification), with rainy summers and dry winters. 'Tahiti' lime, *Citrus latifolia* Tanaka, seedlings were grafted onto four-year old Rangpur lime *Citrus limonia* Osbeck) at a spacing of 5 × 7 m. Plant rows were east-west oriented and plants were irrigated daily.

The experimental design was randomized blocks in which each experimental unit consisted of three measurement plants. We assessed three micro sprinkler setups: T1 - a micro sprinkler with 35 L h^{-1} flow rate located 2.5 m from the plant and along the plant row, following a plant-emitter-plant setup; T2 - a micro sprinkler with 70 L h^{-1} flow rate watering two plants, located 2.5 m from one another, along the plant row, following a plant-emitter-plant-plant-emitter-plant setup; and T3 - a micro sprinkler with 35 L h^{-1} flow rate located 0.3 m from the plant, along the plant row. Pressure-compensating micro sprinklers were used to avoid fluctuations in rate flows.

Crop practices for citrus were used when carrying out the experiment as recommended by Coelho et al. (2004). Irrigation scheduling was based on reference evapotranspiration (ETo), computed by Penman-Monteith method using daily data of a weather station near the experiment site and crop coefficients to determine crop evapotranspiration (ETc) (Doorenbos and Pruitt, 1977). Therefore, each tree was given the same amount of water, but it was applied differently. Cumulative rainfall over the study, from May to December, was 23.5 mm. Mean ETo was 4.4 mm day^{-1} and its lowest and highest measurements were 2.1 and 7.0 mm day^{-1}, respectively. Mean solar radiation was 19.4 MJ m^{-2} day^{-1} and its lowest and highest measurements were 9.0 and 26.4 MJ m^{-2} day^{-1}, respectively.

Water movement within the plant was measured by calculating sap flow using the stem heat balance approach, as recommended by Baker and Van Bavel (1987). The heat supplied at a constant rate (Pin) to sampled volume can be split into different heat fluxes (Equation 1).

$$P_{in} = Q_r + Q_v + Q_s + Q_f \quad (1)$$

where, Q_r is the radial heat loss from the sensor, Q_v is the heat transported axially by the stem both above and below the control volume, Q_s is the stored heat by unit time at heated section, and Q_f is the heat transported by convection through plant sap. Potency applied to the heating element was measured following Equation 2.

$$Pin = \frac{V^2}{R} \quad (2)$$

where, V is the voltage (volt) and R is the resistance (ohm) of heating elements. 111.9, 111.6, 90.8, and 60.6Ω corresponded to models SGB9, SGB13, SGB16, and SGB19, respectively. Radial outward flux (Q_r) was calculated from the thermal conductivity of a cork ($K_{sh)}$, which consisted of a radial flow gauge, from the

difference in temperature (ΔT) adjacent to the heating element, and from the outer surface of the cork, calculated by a thermopile with alternate joints (flow gauge) attached to the heater (Equation 3).

$$Q_r = K_{sh}\Delta T \quad (3)$$

K_{sh} was calculated at dawn (4 to 5 a.m.) when sap flow was zero or close to zero. Axial fluxes (*Qv*) were calculated with Equation 4.

$$Qv = AKst\frac{(\Delta Tc - \Delta Tb)}{\Delta z} \quad (4)$$

where, *A* is the cross-sectional area of heated section of the stem and K_{st} is the thermal conductivity of the stem, which is considered 0.42 $Wm^{-1}K^{-1}$ according to Steinberg et al., (1989), Δ*Tc* and Δ*Tb* are related to upstream and downstream temperature gradient from heated section of the stem, and Δz is the distance between two thermocouple junctions attached above and below the thermal sheath. According to Weibel and Vos (1994) and Trejo-Chandia et al. (1997) *Qs* has little contribution to sap flow estimates of 'Tahiti' lime seedlings, so it can be disregarded without affecting estimates; therefore, flow rate of sap (SF) was calculated by Equation 5.

$$SF = \frac{Pin - Qv - Qr}{cp.dT} \quad (5)$$

where, cp is the specific heat capacity of sap (cp = 4.186 kJ kg^{-1} K^{-1}) and *dT* is the difference in sap temperature between the upper and lower limits of the heated section.

Sensors were installed in four branches of four measurement plants of each treatment, in the north, south, east, and west quadrants, at an approximate height of 1.5 m from the canopy, as recommended by Mars et al. (1994), to measure physiological parameters. Daily transpiration was calculated by dividing total sap flow by total leaf area of each plant. Total leaf area was estimated by multiplying the total number of leaves of each measurement plant by the mean leaf surface area. The latter was estimated by measuring the length and width of 10% of all leaves (Coelho Filho et al., 2005).

Water extraction by crops and percolation were measured at each treatment by soil water balance. Soil content was measured with time-domain reflectometry-TDR 100 (Campbell Scientifics) operating six multiplexers allowing the reading of 48 sensors simultaneously. TDR probes were installed in two trenches two months prior to readings. One trench was dug along the plant row and the other perpendicular to the row, with a plant in the center. Probes were positioned in these trenches so as to form a 0.25 × 0.25 m grid (profile) reaching radially a maximum distance of 2.5 and 2.0 m from the plant, longitudinal and perpendicular to plant row directions, respectively and at a maximum depth of 1.0 m. Data were collected every 10 min. The area occupied by the plant with the two trenches was covered with white plastic material to avoid soil evaporation.

Differences between water contents in the profiles one hour after irrigation and immediately before the next irrigation event were used to calculate, according to Coelho and Or (1996), the extracted water in the soil profile. Deep percolated water contents in the deepest monitored soil layer below 0.75 m were obtained every hour after irrigation up to right before the next irrigation event. Since intervals between measurements were the same, deep percolation occurring in the two profiles from one hour after irrigation up to right before the start of the next irrigation was measured by integrating numerically percolated water contents (Equation 6) during the time between two irrigation events.

$$P = \int_{t_1}^{t_2} q dt \quad (6)$$

where, q is the flow rate (m^3 m^{-3} h^{-1}); t_1 is the time immediately after irrigation and t_2 is the time before the next irrigation event. The flow rate q was determined by TDR redings in the deepest layer during time t, one-hour period (θ_{j-1} and θ_j), where θ is given in m^3 m^{-3} (Equation 7).

$$q = \frac{\theta_j - \theta_{j-1}}{t} \quad (7)$$

Soil samples were collected to assess roots with a soil auger made of galvanized iron measuring 0.1 m in diameter and 1.30 m in length. Sampling was done where TDR probes were installed in three plants at each treatment. Soil was rinsed off the sample with the aid of 0.5 and 1.0 mm sieves mesh, so that only roots remained. Then, roots were scanned at a resolution of 600 dpi, 100% scale, and intensity of 100 to 130% for thicker roots; and 43 to 62% for finer roots. These files were processed with the software Rootedge (Kaspar and Ewing, 1997) to determine root lengths and diameters. Roots were sorted in six diameter groups as described by Santos et al. (2014). Root lengths were added up to obtain total root length in the different soil layers. To do so, we used the average of three plants per treatments.

RESULTS AND DISCUSSION

Figure 1_{T1a} shows that in treatment T1 the highest percentage of water extraction by crop (WEC) was within the layer 0 - 0.375 m, with more than 70% of the total WEC. By adding up the percentage of WEC, we can observe that up to 0.625 m, more than 90% of water was extracted, both longitudinally (Figure 1_{T1a}) and transversally (Figure 1_{T1b}). The larger extraction of water in the shallower layer was due mainly because of soil water availability that was near 100% within the layer 0 to 0.375 m and reduced to 80% up to 0.60 m depth. Also 64% of very fine and fine roots (diamaeter smaller than 2 mm) were within the same soil layer and 82% within the layer 0 to 0.625 m. Figure 1_{T2b} shows that in treatment T2 the highest percentage of WEC, both longitudinally and transversally, was within the layer 0.125 to 0.375 m, extracting about 40% of the total. As for the total percentage of WEC in relation to depth, we can see that more than 85% of water was extracted up to 0.625 m deep. In treatment T2, the increase in the percentage of WEC in greater depths, compared to the remaining treatments, might be related to the distribution of total available water for this treatment in these deep layers. Soil water availability was about 100% within the layer 0.125 to 0.375 m and about 90% at 0.625 m depth. Most of roots, particularly, very fine and fine (81%) were within the layer 0 to 0.625 m. Both Figures 1_{T3a} and 1_{T3b} show that plants of treatment T3 exhibit higher WEC in longitudinal and transversal profiles, in 0 to 0.375 m, in which 70% of the total is extracted. Adding up the percentages of WEC in relation to depth, 90% of water

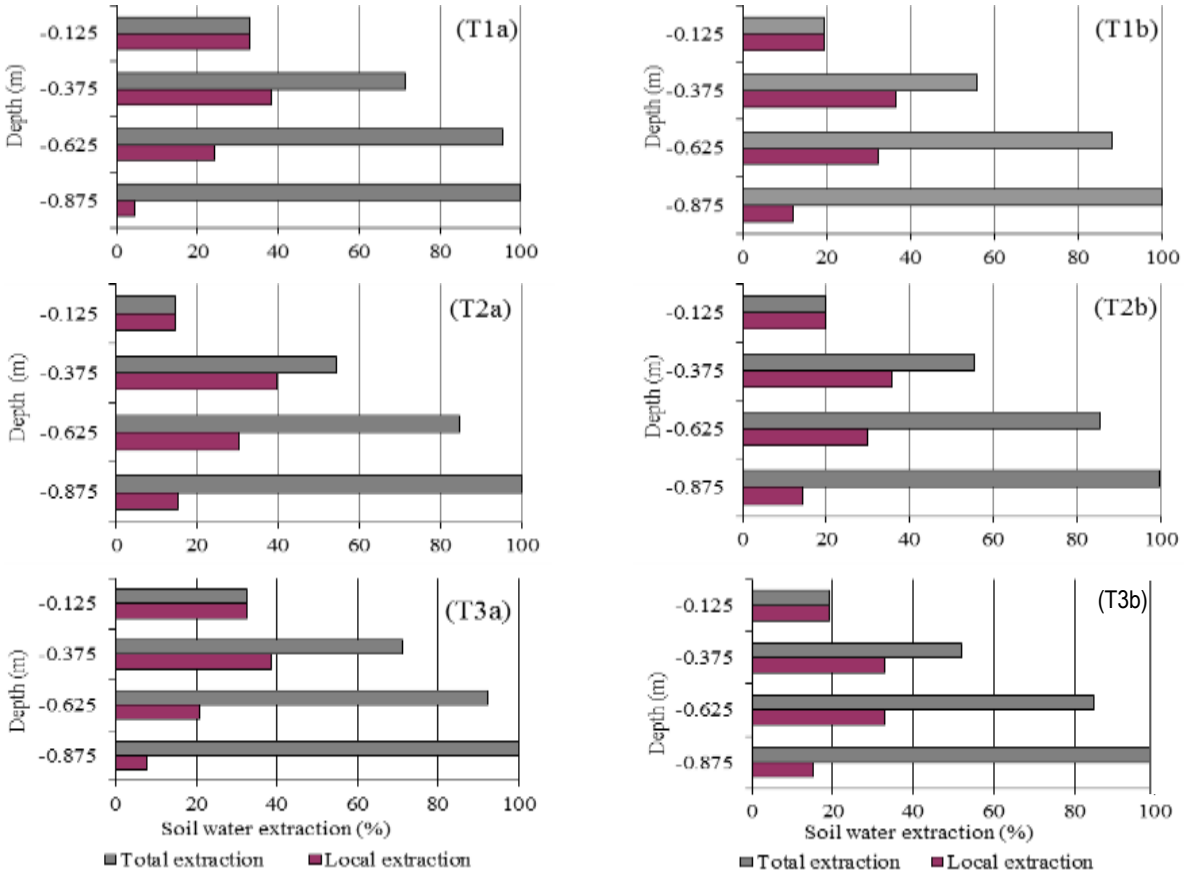

Figure 1. Total water loss in the profile, longitudinally (a) and transversally (b) to the plant row, in treatments T1, T2, and T3, as a function of depth.

was extracted up to 0.625 m, in longitudinal and transversal profiles. Results of this treatment did not differ from those of T1 and T2, mainly because of the root distribution, in which very fine and fine roots (80 %) were more concentrated within 0 - 0.625 m layer. Soil water availability was about 90% up to 0.375 m, but smaller than 80% below 0.625 m depth. Irrigation water depths were applied in order to minimize deep percolation and to keep soil water availability at levels above 70% in the 0 - 0.60 m layer. Santos et al. (2004) working with Tahiti lemon over a five year-old citrumelo swingle rootstock obtained most of the water extraction by roots at depths close to 0.25 m, that is, smaller depth than the ones in this work.

In treatment T1, the amount of percolated water was low both within and between plant rows, which was determined by integrating percolation measured hourly over the day (Figure 2a). Percolation peaked close to the plant and to the micro sprinkler within the row (2.5 m) and at 2.0 m from the plant in between plant rows. Figure 2b shows that as for T2, the amount of percolated water was somewhat higher than that of T1, both within and between plant rows. Percolation peaked at 0.25 and 1.0 m from the stem, within and between plant rows, which is possibly due to the higher moisture found in these places after irrigation event. The amount of percolated water in T3 was also low (Figure 2c), both within and between plant rows, peaking close to the stem (0.25 m) as well as between 1.25 and 2.0 m from the plant, longitudinally and transversally to the plant. In general, these results were slightly higher than those found in treatment T1 and slightly lower than those of treatment T2, which supports the little difference in water distribution between treatments. The emitter flow rate of treatment T2 was double of the flow rates of other treatments and this favored percolation in this treatment mainly longitudinally between two plants wher the emitter was located.

The percentage of roots graded as to diameter (Tables 1 and 2) in the treatment T1 revealed that very fine roots represented 14.77% of root total. The highest percentages were in the upper layers of soil: 4.41% at0.375 to 0.625 m. At a distance from the stem of 0 to 0.25 and 2.25 to 2.5 m, 4.78 and 2.55% of roots were observed, respectively, as the latter region corresponds to the area right below the emitter. Roots with diameter of 0.05 to 0.2 cm represented the majority of sampled roots, that is, 81.15% of the total. They were more prominent at

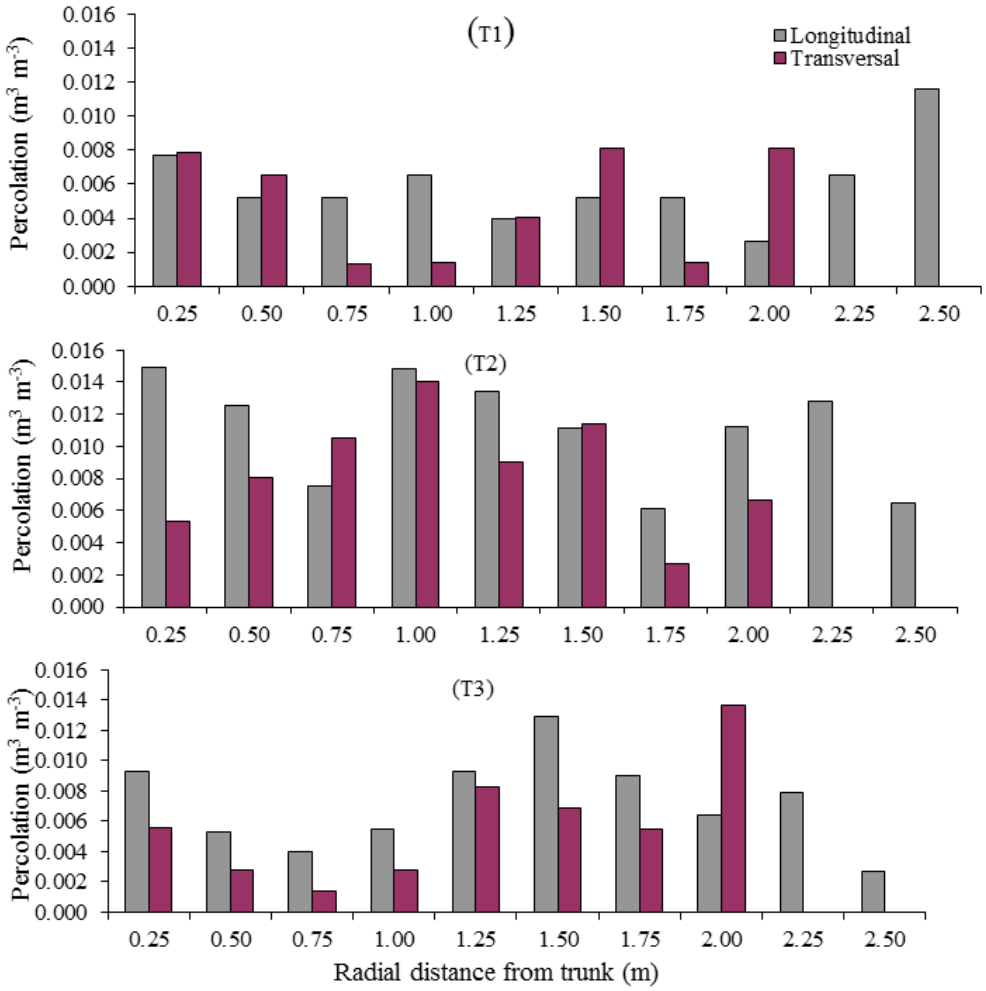

Figure 2. Daily mean water percolation in the soil profile, longitudinally and transversally to the plant row, in treatments T1, T2 and T3.

0.125 to 0.375 m deep (30.54%) and at 2.25 m from the stem (14.81%). Roots with diameter of 0.2 to 0.5 cm represented 3.6% of the total, concentrating at 0.375 - 0.625 m deep and at the distances of 1.0 and 2.5 m from the stem. The thickest roots (diameter > 0.5 cm) represented only 0.48% of the total, which were more abundant at 0.125 to 0.375 m and at a distance of 0.5 m away from the stem. In this regard, we observed that roots with a diameter below or equal to 0.2 cm were mainly found in upper layers of soil. As the diameter increases, so does root distribution at the depth to which roots can reach, which is evidence of root's function in anchoring and supporting the plant.

Roots with diameter lower than 0.05 cm represent 12.94% of root total found in treatment T2 (Table 1 and 2), concentrating in 0.375 to 0.625 m (7.83%) and at a distance of 1.50 m (4.21%) from the stem.

Roots with diameter of 0.05 - 0.2 cm were found at a depth of 0.375 to 0.625 m (7.83%) and at a distance of 1.50 m (4.21%) from the stem. Roots with 0.05 to 0.2 cm in diameter were the most abundant (83.42% of the total) and they were mostly found at a depth of 0 to 0.125 m (31.46%) and at a distance of 1.5 m from the plant (10.53%). Roots with 0.2 to 0.5 cm in diameter represented 3.12% of the total and were more prominent in the 0.875 to 1.125 m depth and at a distance of 0.25 m away from the stem. Thicker roots (diameter > 0.5 cm) represented only 0.53% of root total and were mostly found in the 0.125 to 0.375 m depth and 1.25 m away from the stem.

In the treatment T3 (Table 1 and 2), very fine roots (<0.05 cm) accounted for 14.70 % of root total. These roots were predominately found in the 0.375 to 0.625 m soil layer (4.23%) and distributed evenly in the 2.5-m range from the stem (1.88%). Roots with 0.05 to 0.2 cm diameter composed 81.32 % of root total and were predominantly found in 0 to 0.125 depth and at a distance of 0.75 m away from the stem. Roots with 0.2 to 0.5 cm

Table 1. Percentage of total root length (TRL) as to four diameter groups (< 0.5; 0.5- to -2.0; 2.0- to -5.0; and > 5.0 mm), at different depths, in the treatments T1, T2 and T3.

Treat	Depth (m)	Diameter (mm)			
		< 0.5	**0.5 – 2.0**	**2.0 – 5.0**	**> 5.0**
T1	0 – 0.125	4.03	25.56	0.14	0.04
	0.125 – 0.375	3.95	30.54	0.61	0.26
	0.375 – 0.625	4.41	14.09	1.20	0.03
	0.625 – 0.875	2.06	7.63	0.93	0.06
	0.875 – 1.125	0.32	3.32	0.72	0.09
	Total	14.77	81.15	3.60	0.48
T2	0 – 0.125	0.16	31.46	0.66	0.01
	0.125 – 0.375	1.16	27.38	0.70	0.34
	0.375 – 0.625	7.83	12.86	0.27	0.03
	0.625 – 0.875	1.92	7.94	0.66	0.08
	0.875 – 1.125	1.86	3.78	0.86	0.08
	Total	12.94	83.42	3.15	0.53
T3	0 – 0.125	1.57	35.75	0.41	0.01
	0.125 – 0.375	3.47	25.27	1.06	0.13
	0.375 – 0.625	4.23	9.73	1.09	0.12
	0.625 – 0.875	3.69	6.01	0.60	0.12
	0.875 – 1.125	1.74	4.55	0.33	0.10
	Total	14.70	81.32	3.49	0.48

diameter accounted for 3.49% of root total and concentrated in 0.375 to 0.625 m depth (1.09%) and at a distance of 0.5 m away from the stem (0.59%). Roots with diameter larger than 0.5 m constitute only 0.48% of root total and were mostly found in 0.125 to 0.375 m (0.13%) and at a distance of 0.5 m away from the stem (0.08%).

Roots with diameter between 0.05 and 0.2 cm, in the three treatments, accounted for more than 81% of the total and exhibited higher distribution in 0 to 0.625 m depth. There was a trend of a higher length density and root redistribution in treatments T2 and T3 possibly due to soil water distribution in these treatments. These results are consistent with Taiz and Zeiger (2013) who reported that lower soil water content in topsoil reduces superficial root development and increases the number of deep roots due to the higher water availability in deeper soil layers in treatment T2 in which the micro sprinkler close to the stem provided higher water percolation. It is worth noting that root growth into deeper soil layers towards wet soil can be considered a line of defense against drying topsoil. Results regarding root system's depth are consistent with those reported by Alves Junior et al (2011) who observed an effective rooting depth of 0.6 m in 30 and 48-month-old drip-irrigated 'Tahiti' lime grafted onto rootstock 'Swingle' citrumelo in Piracicaba, SP.

Average leaf areas of plants were: 184.62 m^2 (T1), 182.85 m^2 (T2) and 185.12 m^2 (T3). ETo and sap flow measurements recorded over the day are in Figure 3. Sap flow measurements were consistent over the three days on which evaluations took place; nonetheless, there is a difference between treatments as to the time at which sap flow reduced during the day. In T2, sap flow reduces in average after the most water-demanding time of the day, followed by a decrease during the afternoon. As for T3 and T1, sap flow decreases earlier as a result of low water availability in these treatments leading to premature stomatal closure, thereby decreasing plant transpiration.

Average sap flow measurements varied between branches with similar results reported by Oliveira et al. (2009) in mangoes, and the highest measurement was 0.686 L m^{-2} day^{-1} (Table 3). These are considered a low sap flow rate in comparison with studies carried out with lemons by Marin et al. (2008) and Rojas et al. (2007) reporting measurements varying from 1.00 to 1.83 L m^2 day^{-1} in young plants or plants having less leaf area than the plants used in this study. Cotrim et al. (2019) observed estimated values of sap flow ranging from 0.697 to 1.255 L m^{-2} day-1, under conditions that did not suffer water deficit during the three phases of development of 'Tommy Atkins' mango fruits. A more active plant metabolism might explain this lower rate at this early stage, as well as other factors mentioned by

Table 2. Percentage of total root length (TRL) as to four diameter groups (< 0.5; 0.5- to -2.0; 2.0- to -5.0; and > 5.0 mm), in different radial distance from the stem, in the treatments T1, T2 and T3.

Treat	Distance (m)	Diameter (mm)			
		< 0.5	0.5 – 2.0	2.0 – 5.0	> 5.0
	0.25	4.78	8.16	0.28	0.10
	0.50	1.89	5.55	0.30	0.13
	0.75	2.29	3.62	0.54	0.03
	1.00	0.37	7.06	0.65	0.03
	1.25	0.08	7.21	0.38	0.06
T1	1.50	0.09	8.35	0.15	0.03
	1.75	0.10	8.85	0.26	0.01
	2.00	0.57	12.25	0.10	0.01
	2.25	2.06	14.81	0.25	0.03
	2.50	2.55	5.28	0.70	0.05
	Total	14.77	81.15	3.60	0.48
	0.25	1.28	9.23	0.65	0.01
	0.50	1.13	6.17	0.51	0.01
	0.75	1.79	5.00	0.22	0.05
	1.00	0.35	9.77	0.54	0.11
	1.25	1.22	6.31	0.12	0.13
T2	1.50	4.21	10.53	0.09	0.05
	1.75	1.08	8.79	0.17	0.12
	2.00	0.35	10.08	0.44	0.01
	2.25	0.60	8.39	0.23	0.01
	2.50	0.93	9.16	0.18	0.01
	Total	12.94	83.42	3.15	0.53
	0.25	1.80	10.00	0.63	0.05
	0.50	2.20	7.80	0.67	0.10
	0.75	0.77	9.04	0.40	0.09
	1.00	1.90	7.59	0.30	0.05
	1.25	0.73	7.33	0.22	0.01
T3	1.50	1.41	7.71	0.21	0.01
	1.75	1.60	7.87	0.25	0.05
	2.00	1.28	8.50	0.45	0.08
	2.25	1.95	7.78	0.18	0.03
	2.50	1.07	7.70	0.18	0.01
	Total	14.70	81.32	3.49	0.48

Syvertsen (1982), such as lower water loss regulation than mature leaves since young leaves lack structural rigidity and have lower deposition of cuticular wax than mature leaves. Regarding plant size, according to Rojas et al. (2007), increasing leaf area may interfere with canopy net and lead to a decrease in mean net radiation per unit leaf area due to increasing leaf density and self-shading inside the canopy. When assessing the treatments as to averages of either sap flow/solar radiation (SF/SR) or SF/ETo, we can observe that treatment T2 exhibited the highest values followed by T3 and T1. This demonstrates that plants of treatment T2 are transpiring more than those of T3 and T1 in relation to incident radiation (MJ m^{-2} day).

The above-mentioned difference can also be seen only when evaluating sap flow rates on days with similar ETo (4.27, 4.21, and 4.25). The same behavior is observed in analyses done using the proposed ratios (SF/ETo and SF/SR), that is, transpiration of plants in T2 is the highest, followed by T3 and T1.

If we consider the amount of water applied to the three treatments the same, then the water condition found in

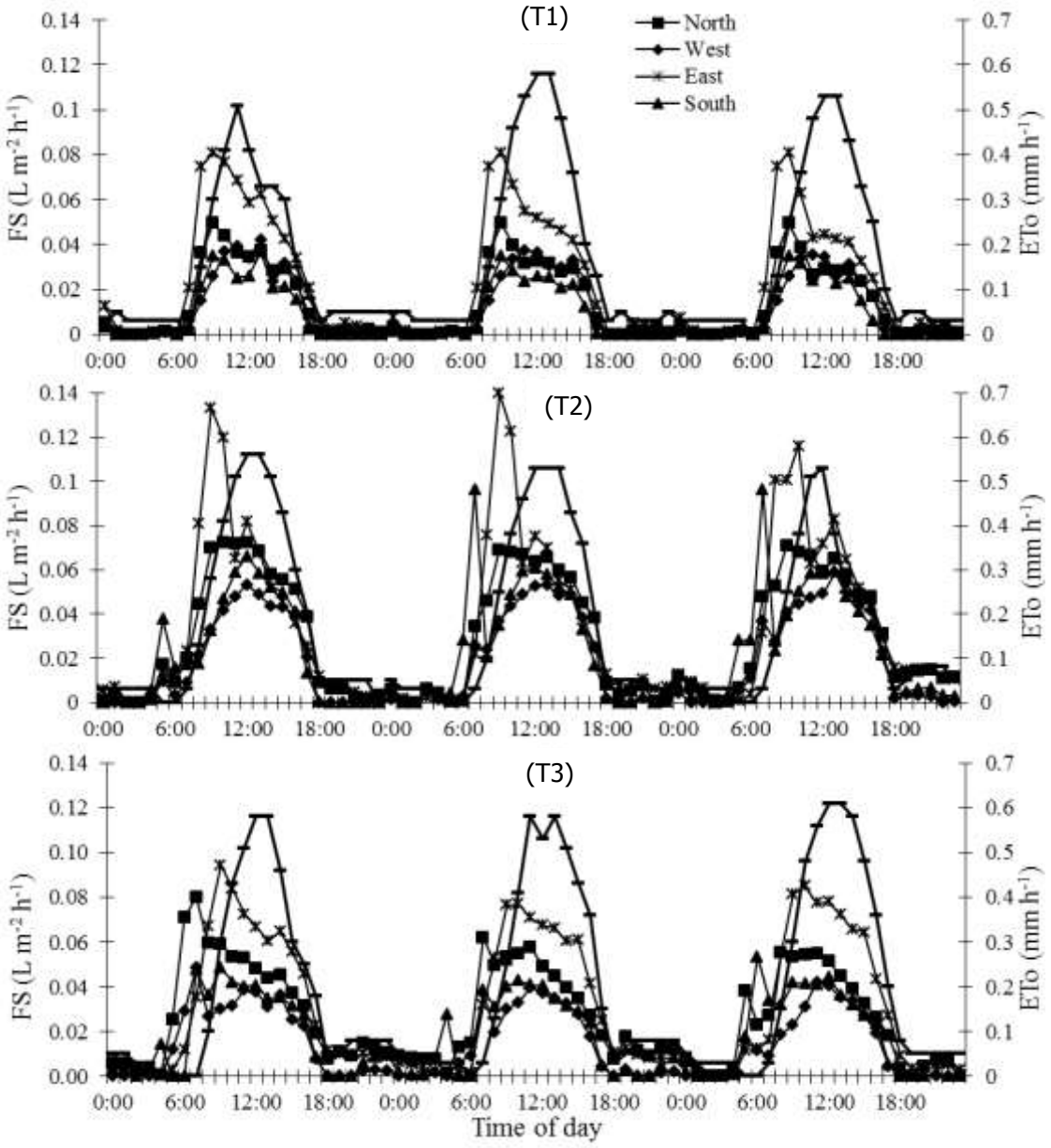

Figure 3. Daily variation of sap flow (FS) of 'Tahiti" lime tree and reference evapotranspiration (ETo) determined by Penman Monteith method, of treatment T1, T2, and T3 during the flowering stage.

treatment T2 resulted, possibly, in a system in which water is better stored and used.

Conclusion

Micro-sprinkler placements affected root distribution, water extraction, and transpiration of 'Tahiti' lime. Transpiration was higher using one micro-sprinkler of 70 L h^{-1} flow rate irrigating two plants, located at 2.5 m away from the stem, than using one micro-sprinkler per plant, either located at 0.3 or 2.5 m away from the stem, along the plant row.

Water extraction by lemon plants were more significant within the layer 0 to 0.375 m, but most of it, that is, about 85 to 90% occurred up to 0.625 m depth. The use of one microsprinkler per two plants instead of one plant is feasible concerning root water extraction, root development and plant transpiration as long as water supply be applied according to plant needs.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interest.

Table 3. Sap flow in each plant (FSp) determined by heat balance method, sap flow in branches (FSb) measured per quadrant, reference evapotranspiration (ETo) and solar radiation (RS) and ratio between sap flow and these factors, during flowering stage of 'Tahiti' lime.

Treatments		T1			T2			T3		
ETo	mm day^{-1}	3.48	4.27	3.82	4.32	4.21	3.6	4.25	4.58	4.36
SR	MJ m^{-2} day^{-1}	14.97	19.01	17.95	18.94	18.79	15.20	17.395	19.07	19.85
	North branch	0.350	0.328	0.307	0.684	0.658	0.738	0.712	0.625	0.552
	West branch	0.284	0.275	0.252	0.417	0.462	0.501	0.389	0.341	0.314
FSb (L m^{-2} day^{1})	East branch	0.627	0.556	0.506	0.808	0.799	0.874	0.762	0.711	0.734
	South branch	0.245	0.221	0.215	0.514	0.577	0.630	0.473	0.415	0.436
	Mean	0.377	0.345	0.320	0.606	0.624	0.686	0.584	0.523	0.509
	North branch	0.023	0.017	0.017	0.036	0.035	0.048	0.040	0.0327	0.027
	West branch	0.018	0.014	0.014	0.022	0.024	0.032	0.022	0.017	0.015
Ratio (FSb/SR)	East branch	0.041	0.029	0.028	0.042	0.042	0.057	0.043	0.037	0.036
	South branch	0.016	0.011	0.011	0.027	0.030	0.041	0.027	0.021	0.021
	Mean	0.025	0.018	0.017	0.031	0.033	0.045	0.033	0.027	0.025
	North branch	0.100	0.076	0.080	0.158	0.156	0.205	0.167	0.136	0.113
	West branch	0.081	0.064	0.065	0.096	0.109	0.139	0.091	0.074	0.064
Ratio (FSb/ETo)	East branch	0.180	0.130	0.132	0.187	0.189	0.242	0.179	0.155	0.151
	South branch	0.070	0.051	0.056	0.118	0.137	0.175	0.111	0.090	0.089
	Mean	0.108	0.080	0.083	0.140	0.148	0.190	0.137	0.114	0.104
FSp	L day^{-1}	76.39	70.42	65.95	110.75	114.12	125.3	110.10	99.01	97.43

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