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Sap flow and evapotranspiration in an irrigated citrus orchard[1]

Fluxo de seiva e evapotranspiração num pequeno pomar de citros irrigado

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Abstract *- Sap flow and water vapor flux over an irrigated "Tahiti" acid lime citrus orchard were measured to determine the relative contribution of the tree transpiration to the overall orchard evapotranspiration (ET). ET was measured by two micrometeorological methods (Bowen ratio and aerodynamic). Sap flowmeters were installed in two trees with very distinctive leaf area in order to check the effect of the crown size on the transpiration. Sap flow (SF) was measured in units of kg tree^{-1} d^{-1} while ET was expressed in kg m^{-2} ground d^{-1}, and the conversion of units for comparisons requires the definition of a ground area "available" to the tree. Choosing the such area as that given by the planting space (56m^2), regardless of the tree size, resulted that a small tree (48m^2 of leaf area) contributed with 20% and a large tree (99m^2 of leaf area) with 33% of ET given by the Bowen ratio method, which is an unrealistic contribution on the face of the trees size, and also because during the dry (winter) period the irrigated trees were the only source of water vapor in the orchard and the relative contribution should be close to 100%. With the aerodynamic method ET underestimated the SF during the dry period and this is also unrealistic; during the wet period the contribution of each tree decreased linearly as ET increased. If the "available" area is chosen as the ground area shaded by the crown when the sun is at the local zenith then the effect of the crown size is taken into account, and ET given by the Bowen ratio method matched the sap flow for both trees, during the two periods, but this is also an unrealistic result since the trees were not the only source of water vapor during the summer. With the aerodynamic method ET grossly underestimated SF all the time. Sap flow per unit leaf area was equivalent in both trees and correlated with the grass net radiation.*

Key words: *transpiration, Bowen ratio, aerodynamic method, acid lime orchard*

RESUMO *- Medições de fluxo de seiva e de fluxo de vapor d'água acima de um pomar irrigado de lima ácida "Tahiti" foram executadas para se determinar a contribuição relativa da transpiração das árvores para a evapotranspiração do pomar (ET). ET foi avaliada por dois métodos micrometeorológicos (razão de Bowen e aerodinâmico). Medidores de fluxo de seiva foram instalados em duas árvores com áreas foliares bem distintas para se avaliar o efeito do tamanho da copa na transpiração. Fluxo de seiva (FS) foi medido em unidades de kg árvore^{-1} d^{-1} enquanto que ET foi expressa em kg m^{-2} de terreno d^{-1}, e a conversão de unidades para comparações exige a definição de uma área de terreno "disponível" para a árvore. Tomando-se a área definida pelo espaçamento (56m^2), para qualquer tamanho de copa, resultou que a árvore menor (48m^2 de área foliar) contribuiu com 20% e a árvore maior (99m^2 de área foliar) com 33% para a ET dada pelo Razão de Bowen, o que não é uma contribuição realista face ao tamanho das árvores, e também porque durante o período seco (inverno) as árvores irrigadas eram as únicas fontes de vapor d'água no pomar, e a contribuição relativa deveria ser próxima de 100%. O método aerodinâmico ET foi menor que o FS durante o período seco e isto também não corresponde à realidade; durante o período úmido (verão) a contribuição relativa de cada árvore decresceu linearmente com o aumento de ET. Se a área "disponível" for adotada como sendo a do terreno sombreado pela copa, quando o sol está no zênite local, o efeito do tamanho da copa é levado em consideração, e ET dada pelo Razão de Bowen foi equivalente ao FS para as duas árvores, nos dois períodos. Contudo, isto também é irreal porque as árvores não eram as únicas fontes de vapor d'água durante o verão. Com o método aerodinâmico, ET foi menor que o FS nos dois períodos. O fluxo de seiva por unidade de área foliar foi equivalente nas duas árvores e se correlacionou com o saldo de radiação medido em gramado.*

Palavras-chave: *transpiração, razão de Bowen, método aerodinâmico, pomar de lima ácida*

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Introduction

In orchard irrigation management it is a common practice to use the crop coefficient (Kc) to correct the reference evapotranspiration in order to estimate the water used by an “average” tree. Even though the FAO-56 (ALLEN et al., 1998) guidelines for computing crop water requirements uses the percentage of ground cover by the trees to define a Kc value for orchards, such procedure does not take into account the different sizes of the transpiring surface – the leaf area – in each tree. The semi-isolated and somehow discontinuous distribution of the trees in orchards affects substantially the partitioning of the orchard evapotranspiration in its components, namely: the tree transpiration, the transpiration of the inter-rows vegetation, and the soil evaporation. The relative contribution of each component depends on the tree leaf area, on the spacing among the trees, and on the existence of vegetation around the trees. Dimensioning of irrigation schemes for orchards requires reliable estimates of the evapotranspiration components determined by the small scale field variability induced by the spatial arrangement of the orchard components.

The purpose of the present study was to determine the relative contribution of each component of the orchard to the overall orchard evapotranspiration using the sap flow technique to estimate the tree transpiration and micrometeorological methods (Bowen ratio and aerodynamic methods) to estimate evapotranspiration in an irrigated acid lime orchard. This paper reports also the problems encountered with the conversion of units to compare transpiration (sap flow), given in kg $tree^{-1}$ d^{-1}, with orchard evapotranspiration, expressed in kg m^{-2} d^{-1}.

Material and methods

A irrigated 8 years old orchard of acid lime (*Citrus latifolia* Tanaka) with 0.7ha, grafted over lemon (“Cravo”) rootstock with trees planted in a 7m by 8m spacing, in Piracicaba, SP, Brazil (22° 42’S; 47° 30’W; 546m a.m.s.l.) was used as experimental site. The average tree height near the measurements site was 4.5m. Conditions for maximum transpiration were given by frequent irrigations with micro-sprinklers below each tree crown to wet a surface area with 4m in diameter.

Sap flow was measured in two trees with very different crown sizes in order to check the effect of the size of the leaf area on tree maximum transpiration using the heat balance technique (SAKURATANI, 1981; BAKER & Van BAVEL, 1987). Due to the large size of the tree trunk (> 0.2 m) and irregularity of its shape (resulting in poor contact with the sensor) it was necessary to install one sensor in each of the three main branches to determine the whole tree sap flow. Each sensor, built by the authors and composed by a combined heater-flux meter similar to the model described by WEIBEL & BORESMA (1995), was fed by a DC current with dissipating power between 1 W and 3 W, depending on the branch diameter. Temperature gradients just above and below the heated segment of the stem were measured by probes built with copper-constantan thermocouples inside a copper tube (2 mm of internal diameter) inserted radially in the stem in order to monitor heat flux in both up-stream and down-stream directions. Change in heat stored in the branch segment was also measured by inserting a temperature probe in the stem at the central position of the segment (VALANCOGNE et al., 2000). All signals were monitored every 10s by a CR7 datalogger, giving mean values after 15 min. Daily totals resulted from the summation of the 96 intervals from each branch using the procedures described by VALANCOGNE & NASR (1993), starting at sunrise, when the tree was assumed to have its internal water capacity at the maximum, that is, there was no significant change in the tree stored water after 24 hours.

The overall orchard evapotranspiration (ET) was determined by two independent micrometeorological methods. One method was the surface energy balance using the Bowen ratio (β) computed from measurements of vertical differences of air temperature (ΔT, °C) and humidity (Δe, kPa), that is,

$$b = g \frac{\Delta T}{\Delta e} \qquad (1)$$

being γ the psychrometric constant (kPa $°C^{-1}$).

The evapotranspiration equivalent to the latent heat is then given by the expression

$$ET = \frac{Rn - G}{l(1+b)} \qquad \beta \neq -1 \qquad (2)$$

being Rn the above orchard net radiation; G the soil heat flux densities; and λ (= 2.45 MJ kg^{-1}) is the latent heat of vaporization. The condition β = -1 occurs when Rn – G = 0, that is, when the energy fluxes are very small and negligible (near sunrise and sunset times). Even though excluding such periods from the daily summation does not affect substantially the results (PIERI & FUCHS, 1990), whenever the condition β < -0.75 occurred the evapotranspiration was computed as ET = Rn – G as suggested by PEREZ et al. (1999), avoiding unrealistic estimates at that time.

A net radiometer (REBS Q7) was placed at 7m above the ground and over the center of a tree crown. To have a spatial description of the soil heat flux three sensors (REBS HTF3.1) were used, being one below a tree crown and the other two at the spacing between adjacents trees, placed at 0.03m depth to minimize heat storage in the soil layer above the sensor. Dry and wet bulb ventilated copper-constantan thermocouple psychrometers (MARIN et al., 2001) were placed at 2.5m and 6.5m above the ground in a row between two trees to give the 15-min temperature and humidity average gradients as determined by PEREIRA et al. (2001). Such equipment setup is similar to that used by BRAUN et al. (2000) in an apple orchard.

The evapotranspiration (ET) was also determined by the aerodynamic approach described by THOM (1975):

$$ET = -r\ k^2 \frac{0.622}{P} (\bar{z} - d)^2 \frac{\Delta u\, \Delta e}{\Delta z^2}\ fe \qquad (3)$$

being ρ the air density (=1.26 kg m^{3}); k the von Karman constant (= 0.4); P the local atmospheric pressure (kPa); (= 4.5m) the average height between the two levels of measurements (Δz = 6.5m – 2.5m); d the zero-plane displacement height (m); Δu the difference in wind speed between the two heights (m s^{-1}); Δe the difference in water vapor pressure at the same two heights (kPa); and *fe* is an empirical correction function for the atmospheric stability (THOM, 1975) determined by the gradient Richardson number (Ri), and described as:

· $fe = (1 - 16\ \mathrm{Ri})^{0.75}$ Ri < -0.01 (unstable) (4)

· $fe = (1 + 16\ \mathrm{Ri})^{-2}$ Ri > 0.01 (stable) (5)

· $fe = 1$ -0.01 ≤ Ri ≤ 0.01 (neutral) (6)

and

$$Ri = g \left(\frac{\Delta T}{\Delta z}\right) \Big/ T \left(\frac{\Delta u}{\Delta z}\right)^2 \qquad (7)$$

being g the gravitational acceleration (=9.8 m s^{-2}); T (K) is the average temperature of the Δz interval of measurements; ΔT is the difference in temperature; and Δu is the difference in wind speed at the same Δz interval (m s^{-1}). Wind speed profiles were measured with Met-One anemometers (model OA14; starting speed = 0.45 m s^{-1}) at the heights: 2.5m, 3.5m, 4.5m, 6.5m, and 8.5m for determining the zero-plane displacement (d). For equations (3) and (7) Δu was determined at the same heights used for ΔT and Δe, that is, the 2.5m and 6.5m anemometers.

For both methods, all electrical signals generated by the sensors were measured by a CR7 datalogger at every 10s, computing automatically 15-min averages. Daily totals were given for the period corresponding to the hours of positive Rn. Rainy days were discarded from the analysis due to operational problems with the instruments. A rain gauge was available at the orchard, and grass net radiation was measured at a nearby weather station. Difficulties with the use of the Bowen ratio and the aerodynamic methods in small orchards are discussed by PEREIRA et al. (2001).

The experiment was performed during two very distinctive soil moisture conditions. The first part was executed during the rainy season (from 15/01 to 18/02/2000) when the whole region was wetted by frequent rains (235mm in 11 days), with the soil moisture close to the field capacity. During this period, due to unavailability of sensors, the sap flow measurements were limited to one tree at a time (Tree 1, with leaf area of 48m^2; Tree 2, with leaf area of 99m^2). The second part of the experiment was held during the dry season (from 23/06 to 15/07/2000), after 110 days without rain, but the orchard was irrigated frequently (148mm in 8 applications) with micro-sprinklers to supply the trees with enough water to keep maximum transpiration. In this last environmental condition the trees can be considered as the major source of water vapor, and two trees were instrumented simultaneously (Tree 1, with leaf area of 64m^2; Tree 2, with leaf area of 87m^2). Tree leaf area was estimated once for each tree, during each period, using the LI-2000 Canopy Analyser (Li-Cor).

Results and discussion

When integrated during 24 hours the sap flow can be taken as equivalent to the daytime tree transpiration since the sap flow at night means recovering of the internal tree water storage (VALANCOGNE & NARS, 1993; TREJO-CHANDIA et al., 1997). Under identical weather conditions it is expected that a larger tree leaf area should result in a larger sap flow; however, the sap flow per unit leaf area (SF/LA, in kg m^{-2} leaf d^{-1}) should not differ significantly, and this has been the case with apple trees, as shown by BRAUN et al. (2000). Here, with the irrigated acid lime citrus trees it was found that indeed the SF/LA was similar for both trees when two trees were instrumented simultaneously, and it varied between 0.2 and 0.6kg m^{-2} d^{-1} during the dry period (Figure 1). The large spread shown by five points were caused by difficulties with the operation of the sap flow sensors in large trees, but in general the agreement can be considered as good with most of the points falling along the perfect fit line.

During the summer (wet season), under conditions of high evapotranspirative demand, when the SF/LA reached values as large as 1.3kg m^{-2} d^{-1}, the above direct comparison was not possible. One possible indirect comparison is through the relationship between SF/LA with the daytime grass net radiation (Rng), taken as an indicator of the evapotranspirative demand of the environment (Figure 2). The two periods were included in the analysis and two very distinctive situations occurred. One, during the dry (winter) period, when Rng varied between 3 and 10 MJ m^{-2} d^{-1}, resulting in SF/LA = 0.057Rng (r^2 = 0.2566), indicating that the transpiration expressed on a unit leaf area basis was grossly equivalent to 5.7% of Rng for both trees. Another, during the wet (summer) period, when Rng varied from 5 to 18.5MJ m^{-2} d^{-1} and SF/LA = 0.089Rng (r^2 = 0.4561), discarding the 5 points above the 16MJ m^{-2} d^{-1}. This is an indication that the SF/LA was similar for both trees also during the wet period. One possible cause of the separation of the points in two distinctive groups is the temperature regime during each period. The average air temperature was equal to 23.9°C (21.8°C to 26.1°C) during the wet period, while it varied from 10.8°C to 22.1°C, with average of 16.7°C during the dry period. As explained by KRIEDMANN & BARRS (1981), the hydraulic conductivity of citrus roots is to a large extent controlled by the soil temperature, and transpiration is expected to decline sharply as the temperature declines. Consequently, different temperature regime during the two periods induced two different transpiration rates with the same amount of Rn, resulting in smaller transpiration efficiency during the winter than during the summer.

The five discarded points from the summer relationship indicate that as the Rng increased above 16MJ m^{-2} d^{-1} the transpiration by tree 2 declined after reaching the peak value of 1.31kg m^{-2} leaf area d^{-1}. It can be inferred that the large tree crown intercepted a large amount of energy but the root system was not able to get enough water in time to supply the demand, perhaps a restriction imposed by a very shallow root system conditioned by the frequent irrigations. VIEIRA & RIBEIRO (1993) found that over 70% of the “Tahiti” acid lime root system is located in the top 0.3m of the soil, and distributed around the tree trunk covering an area of 2m in radius, in a 5m x 7m irrigated orchard. This findings substantiate the

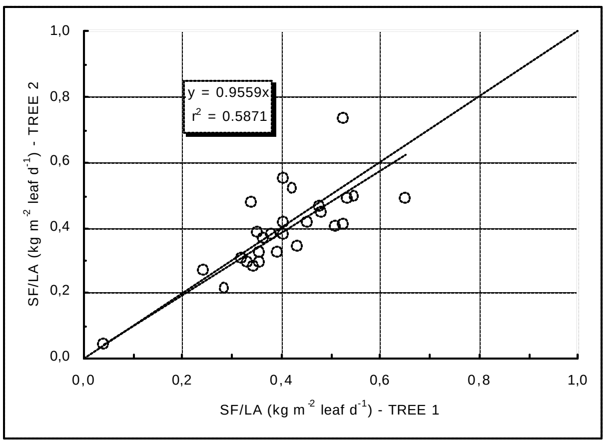

Figure 1. Sap flow per unit leaf area (SP/LA) for two irrigated “Tahiti” acid lime citrus trees, during a dry period (winter) of 2000, in Piracicaba, SP, Brazil.

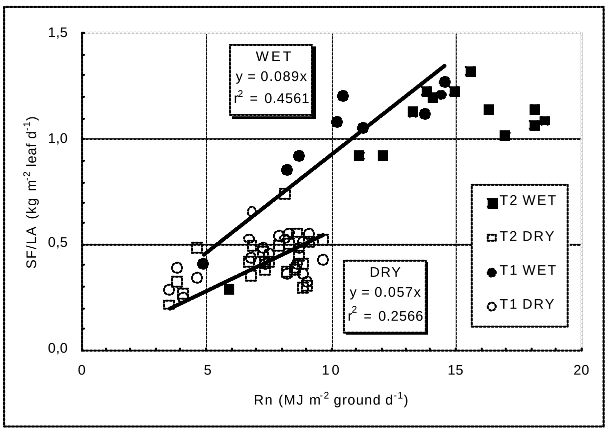

Figure 2. Relationship between sap flow per unit leaf area (SF/LA), for two irrigated “Tahiti” acid lime citrus trees, and grass net radiation in 2000, in Piracicaba, SP, Brazil. (WIN = winter; SUM = summer).

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KRIEDMANN & BARRS (1981) statement that the citrus foliar development is luxurious and the transpirational losses under strong insolation and advection readily exceeds the tree's absorptive capacity.

One way to determine the relative contribution of each tree to the overall orchard evapotranspiration is by comparing the sap flow (SF) with the evapotranspiration (ET) obtained by micrometeorological methods. Such comparison is possible only after both terms are expressed in the same dimensional units. Sap flow is measured in kg tree^{-1} d^{-1} while ET is given in kg m^{-2} of ground d^{-1}. Taking the sap flow per unit leaf area of the tree (SF/LA, kg m^{-2} of leaf d^{-1}) and multiplying it by leaf area index (LAI, m^2 of leaf / m^2 of ground) gives the dimensions of ET (HAM et al., 1990; BRAUN et al., 2000). However, in the case of orchards with trees semi-isolated due to the wide spacing between rows, there are two possible definitions for LAI. One, if the ground area is considered to be that available to the trees, that is, the area imposed by the spacing between the rows and the adjacent trees in the row. Another, if the ground area is taken as that equivalent to the crown area projected horizontally (shaded ground area when the sun is at the local zenith). For the "Tahiti" acid lime tree this second approach considers only the ground area responsible for the supply of soil water to the roots, as shown by VIEIRA et al. (1993). Both alternatives give the same dimensional units of ET, but the numerical results are quite different depending on the spacing, and both approaches will be tested here. Conversely, if ET is multiplied by the corresponding ground area it is also expressed in units of sap flow. This conversion was preferred here since it does not require measurements of leaf area, a very difficult task under field conditions along a season for a large tree (up to 50 000 leaves).

The conversion factor, taking the available area (first approach for defining LAI), is equal to 56m^2 tree^{-1} (7m x 8m spacing) for both trees, regardless of its crown size. Comparing the converted orchard ET given by the Bowen ratio method with the SF it became evident the different contribution of each tree (Figure 3). Results from tree 2 (LA = 99m^2), obtained during the wet period, were representative of days with high evapotranspirative demand, with only one day of low demand (cloudy). Such restriction was imposed by the instruments that gives unreliable results under rainy conditions. For tree 1 (LA = 48m^2) the points were more evenly distributed representing a much wider evapotranspiration conditions. Grouping the data for the wet (summer) and the dry (winter) periods, transpiration from tree 2 was responsible, on average, for 33% of the orchard ET (SF = 0.331 ET; r^2 = 0.7618), while tree 1 contributed with about 20% (SF = 0.2049 ET; r^2 = 0.5632). The linear equations constrained to pass through the origin did not differ significantly from the complete equations. It is interesting to note that the ratio SF/ET found in the above relationships grossly represent the ratio between the area of the zenith crown shade (Tree 1, wet = 10.7m^2, dry = 11.4m^2; Tree 2, wet = 18m^2, dry = 16m^2) and the plant spacing area (56m^2).

Considering the soil moisture conditions during the two periods it is very difficult to accept that the tree transpiration represented such small fraction of the orchard ET, mainly during the dry period when they were the main source of water vapor to the atmosphere. Such results are an evidence that the conversion factor (available area to each tree) was not adequate in this situation. In fact, the LAI defined by the available area was very small; and for tree 1 it varied from 0.86m^2 m^{-2} (wet) to 1.14m^2 m^{-2} (dry), while for tree 2 the variation was between 1.8m^2 m^{-2} (wet) and 1.6m^2 m^{-2} (dry), resulting in exaggerated ET estimatives by the Bowen ratio method when compared to the sap flow. During the summer, for ET estimates between 230 and 370kg tree^{-1} d^{-1} (4.1 to 6.6mm d^{-1}) the SF for tree 2 (LA = 99m^2) varied only from 90 to 130kg tree^{-1} d^{-1}, with average around 110kg tree^{-1} d^{-1}. For tree 1 (LA = 48m^2) this condition became evident when ET exceeded 200 kg tree^{-1} d^{-1} (3.6mm

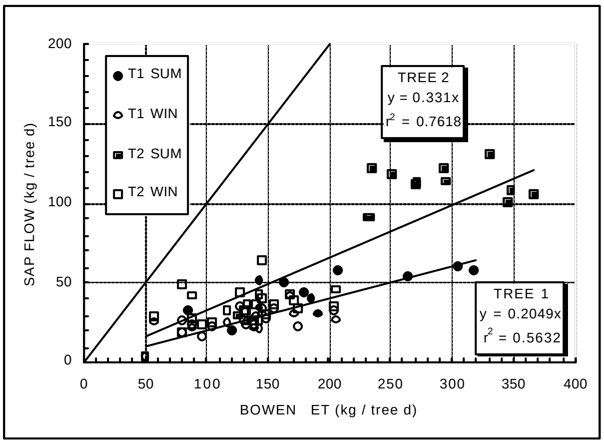

Figure 3. Sap flow versus orchard Bowen ratio evapotranspiration, converted by the available area for each tree, in an irrigated "Tahiti" acid lime citrus orchard in 2000, in Piracicaba, SP, Brazil. (WIN = winter; SUM =summer).

d^{-1}) and the SF stayed around 60kg $tree^{-1}$ d^{-1}. As mentioned before, this indicates that the trees had reached their maximum transpirative capacity, restricted by the roots uptake, even under irrigation.

Taking the conversion factor area as that defined by the sun shaded ground area at the local zenith the LAI was equivalent to 4.5m^2 m^{-2} for tree 1 (10.7m^2 of shaded area), and 5.5m^2 m^{-2} for tree 2 (18m^2 of shade) during the summer (wet) period; during the dry period, LAI was equal to 5.6m^2 m^{-2}, for tree 1 (11.4m^2 of shade), and 5.4m^2 m^{-2}, for tree 2 (16m^2 of shade). Such figures are more compatible with those displayed by agricultural crops. Converting the Bowen ratio ET estimatives with these equivalent shaded areas the effect of the different crown sizes were taken into account and the comparison with the sap flow shows that a single relationship (SF = 1.07 ET; r^2 = 0.8181) fitted adequately the data from both trees (Figure 4). This was expected from the analysis of the equations parameters discussed before. Again, the data from tree 2 during the wet season shows that as the Bowen ET increased above 70kg $tree^{-1}$ d^{-1} (3.9mm d^{1}) the sap flow did not show much of a variation. Even though the winter data for tree 2 and all the data for tree 1 spread around the perfect fit line (1:1) it is more important to verify that such conversion resulted unreliable because during the wet period the trees were not the only source of water vapor to the atmosphere.

In regard to the aerodynamic method, taking the available area as the conversion factor, Figure 5 shows the contribution of each tree to the overall orchard evapotranspiration. For days when the ET estimatives were less that 40 kg $tree^{-1}$ d^{-1} (< 0.7mm d^{-1}) they had a tendency to be smaller than the sap flow, which is an unrealistic situation. But, as the ET estimatives increased during the summer they became larger than the sap flow. The empirical relationships found, which could not be forced to pass through the origin, indicate that as the ET increased the relative contribution of each tree decreased. For instance, the SF/ET ratio varied from 0.52 at 80kg $tree^{-1}$ d^{-1} (1.4mm d^{-1}) to 0.37 at 160kg $tree^{-1}$ d^{-1} (2.9mm d^{1}), for tree 1; and from 0.69 at 120kg $tree^{-1}$ d^{-1} (2.1mm d^{-1}) to 0.6 at 200 kg $tree^{-1}$ d^{-1} (3.6mm d^{1}), for tree 2. This substantiates the idea that the tree transpiration tends to a plateau as the environmental demand for water vapor increases.

Similarly, taking the ground shaded area as the conversion factor, it can be seen that the aerodynamic method grossly underestimated the sap flow (Figure 6). Even though the data from both trees could be fitted by a single equation it is an unrealistic relationship and will not be discussed.

It is obvious that errors are associated with all field measurements. In regard to the major problems of the application of micrometeorological methods in orchards they were dealt with in detail by PEREIRA et al. (2001). Briefly, one possible source of significant error in the Bowen ratio method is the fact that the orchard net radiation was measured above a single tree and not high enough to view the surrounding ground vegetation. A single point measurement was

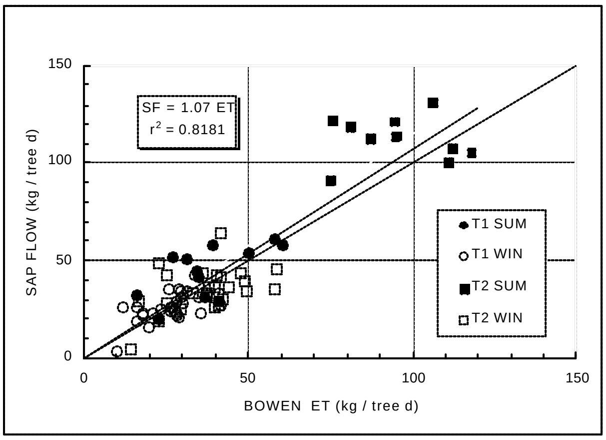

Figure 4. Sap flow versus orchard Bowen ratio evapotranspiration, converted by the ground shaded area by each tree, in an irrigated "Tahiti" acid lime citrus orchard in 2000, in Piracicaba, SP, Brazil. (WIN = winter; SUM = summer).

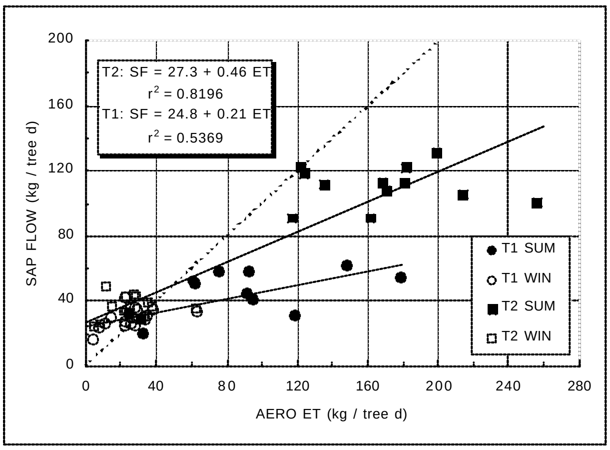

Figure 5. Sap flow versus orchard aerodynamic evapotranspiration, converted by the available area for each tree, in an irrigated "Tahiti" acid lime citrus orchard, in Piracicaba in 2000, SP, Brazil. (WIN = winter; SUM = summer).

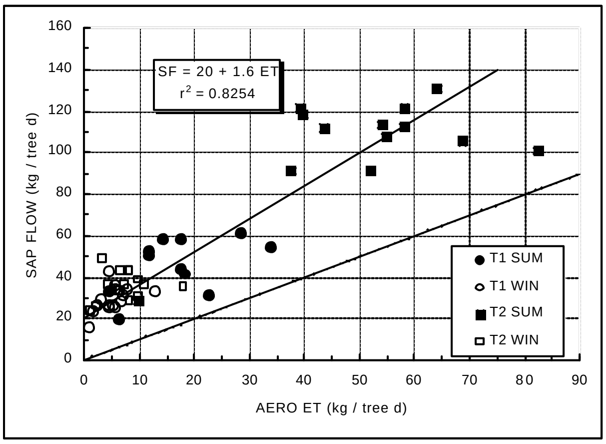

Figure 6. Sap flow versus orchard aerodynamic evapotranspiration, converted by the ground shaded area by each tree, in an irrigated “Tahiti” acid lime citrus orchard in 2000, in Piracicaba, SP, Brazil. (WIN = winter; SUM = summer).

taken as representative of the whole orchard. Such difficulty was only detected during the analysis of the results. With the aerodynamic method one problem was with the determination of the zero-plane displacement height because a logarithmic wind speed profile seldom occurred above the orchard and a fixed value had to be used for the whole period. A more serious problem occurred with the gradient Richardson number when the difference in wind speed between the two heights ($\Delta u/\Delta z$) were very small resulting in erroneous stability corrections (*fe*). To minimize this last problem only the extremes heights of the profiles were used here.

The sap flow is also subjected to experimental errors, but three sensors were used in each tree and comparisons among them were used to detect possible unreliable measurement. Days with large discrepancies among the three sensors were discarded; however, this does not mean that they are free of errors.

Conclusions

The option to take the area defined by the orchard spacing does not take into consideration the effect of the difference in crown size, and it resulted in unreliable relative contribution of the trees as source of water vapor when ET was given by the Bowen ratio method. On average, the small tree would contribute with 20% and the large tree with 33% of ET, and these figures are too small for the size of the tree leaf area. With the aerodynamic method the sap flow was larger than ET, during the dry period, and this is also unrealistic; but during the wet period the relative contribution of each tree varied in a linear way, decreasing as the orchard ET increased. Also against this option of taking the spacing area for conversion of units is the fact that the corresponding leaf area index was too small for both trees (i.e., 0.86 to 1.8m^2 m^{-2}) being smaller than that of a grass field.

The other option is to take the ground area shaded by the tree crown when the sun is at the local zenith, and it resulted in LAI closer to the values of agricultural crops (i.e., 4.5to 5.5m^2 m^{-2}). This option accounts for the difference in crown size but it reversed the sap flow – Bowen ratio ET relationship since sap flow had the tendency to be larger than ET, also an unrealistic condition. For the aerodynamic method this conversion was even worse with ET grossly smaller than the sap flow.

The sap flow per unit leaf area was independent of the tree size up to 1.3kg m^{-2} leaf area d^{-1}, and was correlated with the grass net radiation in a linear way, but with two different relationships, one for each period, determined by two temperature regimes.

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