IRRIGATION REQUIREMENTS AND TRANSPIRATION COUPLING TO THE ATMOSPHERE OF A CITRUS ORCHARD

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ABSTRACT

Crop evapotranspiration (ETc) was measured as evaporative heat flux from an irrigated acid lime orchard (*Citrus latifolia* Tanaka) using the aerodynamic method. Crop transpiration (T) was determined by a stem heat balance method. The irrigation requirements were determined by comparing the orchard evapotranspiration (ETc) and T with the reference evapotranspiration (ETo) derived from the Penman-Monteith equation, and the irrigation requirements were expressed as ETc/ETo (Kc) and T/ETo (Kcb) ratios. The influence of inter-row vegetation on the ETc was analyzed because the measurements were taken during the summer and winter, which are periods with different regional soil water content. In this study, the average Kc values obtained were 0.65 and 0.24 for the summer and winter, respectively. The strong coupling of citrus trees to the atmosphere and the strong coupling of the sensitivity of citrus plants to large vapor pressure deficits and air/leaf temperatures caused variations in the Kcb in relation to the ETo ranges. During the summer, the Kcb value ranged from 0.34 when the ETo exceeded 5 mm d^{-1} to 0.46 when the ETo was less than 3 mm d^{-1}.

Keywords: micrometeorology, plant-atmosphere coupling; leaf conductance, micro-sprinkler

INTRODUCTION

Brazil is the greatest citrus producer in the world. In the state of São Paulo in Southern Brazil, has more than 80% of national area occupied with citrus. Approximately 15% of the citrus-cultivated area is under irrigation (Alves Jr. et al., 2007), whereas the remaining areas are subject to weather variability and its effects on fruit yield and quality.

Despite the advancement of technologies for water supply and the economic importance of citrus, irrigation management remains inadequate in most areas. The lack of basic information on crop water needs is one of the causes of inadequate irrigation management.

Good irrigation practices lead to higher yields and incomes for producers, but also increase the demand for water. Although water resources are reasonably available in southeast Brazil, water use for irrigation has become a major issue in this region during the winter and spring seasons when rainfall is scarce.

The crop coefficient (Kc) approach (Allen et al., 1998) for determining evapotranspiration makes it possible to consider the independent contributions of the soil evaporation and crop transpiration by splitting Kc into two separate coefficients as follows. This approach can be adopted as the procedure for scheduling and quantifying the water amount to be applied. However, few experiments have been carried out to determine the evapotranspiration for citrus orchards (van Bavel et al., 1967; Kalma and Stanhill, 1969, Alves et al., 2007). Orchards have discontinuous soil cover and, when the plants are fully developed, they are normally tall, allowing intense air mixing in the environment. These features should be taken into account in the determination of Kc values.

In this study, we determined the values of Kc and Kcb for an acid lime orchard. We also discussed the paradigm involving the crop water requirements approach for orchard crops considering the orchard-atmosphere coupling effect on crop water requirements.

MATERIALS AND METHODS

The study was carried out in an orchard in the experimental area of the College of Agriculture “Luiz de Queiroz” at the University of São Paulo, Piracicaba, São Paulo State, from January 1998 to August 2000. The micrometeorological measurements were carried out during two seasons of 2000: the wet, hot summer (January) and the dry, cold winter (July).

The diurnal course of leaf diffusive resistance (r_s) was determined at least once a month throughout 1998 using a steady state pre-calibrated porometer (LI 1600; Li-Cor, Inc.). The mean values were used to compute the decoupling factor (Ω) for a hypostomatous leaf, which was defined by Jarvis (1985). Conceptually, the extreme values for the decoupling factor are as follows: a) $\Omega \rightarrow 1$ as $r_s/r_a \rightarrow 0$, implying that the net radiation is the only contributor to the evapotranspiration process and that vegetation is completely decoupled from the atmospheric conditions; b) $\Omega \rightarrow 0$ as $r_s/r_a \rightarrow \infty$, indicating complete coupling of vegetation with atmospheric vapor pressure deficit and wind speed.

In 1999, micrometeorological and sap flow measurements were taken on a 10-m-tall tower was positioned in the middle of the field (50 m from the crop edge in the predominant wind direction). Net radiation (Rn) was measured with a net radiometer (NR Lite; Kipp and Zonen, Inc.) and soil heat flux (G) at the surface was measured using three heat flux plates (HTF3, REBS). The overall crop evapotranspiration (ETc) was determined by the aerodynamic method (Thom et al., 1975) during the summer and winter of 1999. To measure the vapor concentration, we used four aspirated copper-constantan thermocouple psychrometer (Marin et al., 2001) mounted at 2.5 m, 3.5 m, 4.5 m and 6.5 m above the ground in a row between two trees. The wind speed was measured with Met-One anemometers (model OA14; 0.45 m s^{-1} starting speed) at the same heights with an extra sensor at 8.5 m above the ground.

In 1999, the measurements started during the summer season (wet period) with high regional soil moisture and full inter-row ground cover by small grass vegetation. The winter period was characterized by the decrease of regional soil moisture and by inter-row grass drying, when citrus leaves and wet soil bulbs were the main water vapor sources in the area.

The meteorological data were collected from an automatic standard weather station (CR10X; Campbell Scientific, Inc.), which was located over grass 2 km from the experimental field. They were used to compute daily values of reference evapotranspiration (ETo) based on the Penman-Monteith method, as parameterized by the FAO-56 Bulletin (Allen *et al*., 1998).

In parallel with the micrometeorological measurements, sap flow was measured in two trees with different crown sizes. These measurements were used to observe the effect of the size of the leaf area on tree transpiration using the stem heat balance technique (Sakuratani, 1981; Baker and van Bavel, 1987).

The crop transpiration was scaled up to a ground area unit basis by multiplying the average transpiration rate of the four plants by the average leaf area index (LAI) determined with a LAI-2000 Canopy Analyzer (Li-Cor, Inc.) in the two seasons.

RESULTS AND DISCUSSION

The ETo was consistently higher than the ETc in both seasons, and the T was lower than the ETc in the summer. During the winter, the ETc and T were similar for the season (Figure 1). Gaps in Figure 1 were due to failures in the measurement system. The contribution of the active inter-row vegetation for the overall orchard evapotranspiration may explain why Etc values were higher than T values during the summer. Because the inter-row vegetation was dehydrated and apparently without transpiration activity during the winter, the acid lime trees became the main source of water vapor, leading to the similar values of ETc and T. In both seasons, values for ETo were higher than those for ETc and T.

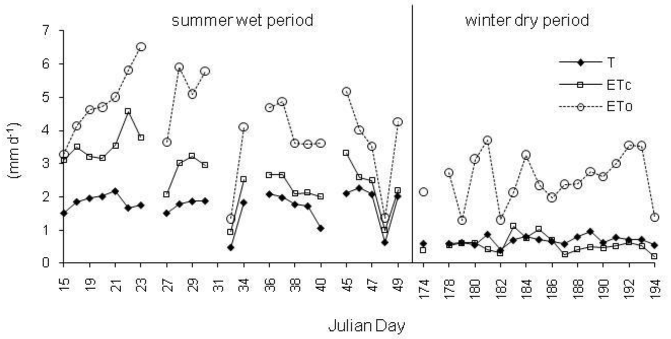

Figure 1. Daily variation of acid lime plant transpiration (T), orchard evapotranspiration (ETc) and reference evapotranspiration (ETo) throughout the experimental period of 1999.

As the evaporation of the inter-row surface was computed by the difference between T and ETc, the role of the inter-row vegetation was inferred by comparing these variables. Except for a few days, T did not follow ETo and ETc for the whole range of values, but rather that T stabilized when ETo reached 4 mm d^{-1}. For the winter, this relationship was not as clear as it was in the summer, as ETo and ETc were lower than in summer. Despite the poor linear relation between the T and ETc, the inter-row evapotranspiration (ETg) represented nearly 35% of the overall evapotranspiration during the summer, which become almost negligible during the winter. The difference of 8% between the T and ETc may be attributed to measurement errors rather than any ecophysiological effect.

The ratio of the overall orchard area occupied by acid lime crowns to the overall orchard area ranged between 0.35 and 0.40, which was a similar value to the T:ETc ratio observed during the summer. Based on this observation, the inter-row vegetation and trees showed similar daily transpiration rates.

The mean daily Kc values during the summer was 0.65 ± 0.11, ranging from 0.51 to 0.94. In the winter, the mean Kc value ranged from 0.10 to 0.52 with a mean value of 0.24 ± 0.12. The summer Kc value compared well with other Kc values reported for humid climates (Rogers et al. 1983; Boman 1994; Doorembos and Pruitt 1977; Castel et al. 1987; Allen et al., 1998), but the winter Kc values were nearly half of the Kc values reported by Allen et al. (1998) for non-ground covered orchards. The winter Kc values were also lower than those observed by Alves et al. (2007) under the same climate and soil conditions.

Assuming a measurement error of about 8%, as discussed previously (Figure 1, winter period), we increased the ETc and found average Kc values of 0.70 and 0.26 for the summer and winter, respectively. These corrected Kc values were still slightly lower than those observed by Alves et al. (2007), but were within a similar range reported by others (Rogers et al. 1983; Boman 1994; Doorembos and Pruitt 1977; Castel et al. 1987; Allen et al., 1998).

The Kcb value was 0.41 ± 0.08 for the wet period and 0.28 ± 0.07 for the dry period, and these Kcb values were comparable to previously reported values (Castel, 1994; Boman, 1994; Allen et al., 1998; Alves et al., 2007).

The variety, root-stock, plant age and management practices are responsible for differences in the Kc and Kcb values, but the differences in micrometeorological conditions have an important role, especially regarding the atmospheric water demand (Marin et al., 2005). As mentioned before, there is evidence that Kcb values may decrease under high ETo values, even under high soil water content. Furthermore, papers concerning the relationship between leaf diffusive conductance and environmental variables have demonstrated that citrus leaves restrict water loss under high atmospheric water demand. Several papers have noticed dependence of stomatal conductance on air temperature and VPD with stomatal closure in response to an increase of weather variables (Hall et al., 1975; Khairi and Hall, 1976; Cohen and Cohen 1983; Angelocci et al., 2004).

The non-linear relationship between T and ETo may be due to an increase of inner resistances to water transport of acid lime trees when subjected to conditions of high atmospheric water demand, as verified for other horticultural species (Syvertsen and Lloyd, 1994; Tardieu and Simonneau, 1998) due to an opposite tendency of transpiration and stomatal movement in relation to increased air vapor pressure deficit (McNaughton and Jarvis, 1983).

The decoupling factor, Ω, (Jarvis, 1985a) was calculated using aerodynamic and canopy resistance data collected during 1998. Low values of Ω were found demonstrating the influence of wind speed and VPD on ETc and T, i.e., the crop transpiration was conditioned by aerodynamic conditions rather than radiation conditions, which imposed a tendency of larger crop evapotranspiration rates. As Jarvis (1985b) postulated, Ω tends to gradually lessen in tall horticultural crops with discontinuous ground cover, due to a reduction of aerodynamic resistances of the canopy caused by a vigorous air mixing and a high crop roughness.

Allen et al. (1998) claimed that Kc values must be used under standard climatic conditions (sub-humid climate, minimum relative humidity of 45% and wind speeds averaging 2 m s^{-1}) and that variations in wind speed may alter aerodynamic resistance and, hence, crop coefficients mainly for tall crops. However, some aspects we observed for the lime acid orchard were different from the aspects postulated by Allen et al. (1998). First, we observed high wind speed and low air relative humidity affecting acid lime transpiration and changing Kcb as the ETo varied. Second, we observed that T did not linearly follow ETo, which resulted in a decrease in Kcb values as ETo increased. Thirdly, the Kc values did not show the same pattern during the summer due the inter-row role, compensating the citrus transpiration when there was enough soil water (Table 1).

Table 1. The values of Kc and Kcb for different ETo ranges; the standard deviation is found in the brackets.

	Wet Summer				Dry Winter			
Range	Kc		Kcb		Kc		Kcb	
1.3 < ETo =< 3	0.72	[0.13]	0.46	[0.09]	0.32	[0.15]	0.38	[0.08]
3 < ETo =< 5	0.69	[0.12]	0.44	[0.02]	0.28	[0.15]	0.29	[0.05]
5 < ETo =< 6.6	0.67	[0.11]	0.34	[0.06]	0.19	[0.05]	0.22	[0.03]

Therefore, for tall and sparse citrus orchards using localized irrigation, such as drip and micro-sprinkler systems, it is inadequate to adopt unique values of Kcb and Kc. Finally, it should be noted that Kc has a small variation as the ETo ranges from 1.3 mm d^{-1} to 6.5 mm d^{-1}, which is mainly due to the role of inter-row vegetation. In spite of the sparse field data available in this study, Marin et al. (2005) demonstrated the same trend in coffee in southern Brazil, and this trend may be generalized for other tall sparse horticultural crops with low Ω values after further experiments.

CONCLUSIONS

The mean Kc value during the summer was 0.65 and during the winter 0.24. The average Kcb values ranged from 0.41 to 0.28 for the summer and winter, respectively. The transpiration represented 35% of overall orchard evapotranspiration, a value close to the orchard area occupied by acid lime trees. It was proposed that the Kcb recommendation for practical purposes might be variable in function of ETo. In this study, the Kcb values decreased nearly 40% when the ETo increased from 3 mm d^{-1} to 5 mm d^{-1}.

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