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Estimation of Peach Tree Water Use Using Infrared Thermometry

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Additional index words. lysimeter, foliage-minus-air temperature, energy balance, irrigation, *Prunus persica*

Abstract. **Infrared (IR) thermometry has not been extensively applied in deciduous tree fruit production to determine water use. The objectives of this study were to a) examine IR measurement techniques for evaluating canopy temperatures in peach [*Prunus persica* (L.) Batsch.] trees; b) evaluate a foliage-minus-air temperature- (Tc − Ta) based diffusion equation for vapor flux used to predict tree water use; and c) measure the Tc − Ta response of irrigated peach trees over a range of air vapor pressure deficits. The mean Tc − Ta for a tree was similar for readings made from the canopy sides (horizontal orientation of the IR thermometer) or canopy tops (vertical orientation). Peach tree water use from weighing lysimeters was predicted within 9.4% ± 3% using the diffusion equation for vapor flux. Tc − Ta for irrigated peach trees was related to the air vapor pressure deficit (VPD). Data are presented to show that stomatal response to VPD does alter the Tc − Ta nonstressed baseline for peach at VPD > 2 kPa.**

Measurement of plant water status can be an effective indicator of drought stress only if the measurement intregrates characteristics of available soil water, potential water use rates, and water flow through the soil–plant system (Chalmers et al., 1983; Jones et al., 1985; Spomer, 1985). In fruit trees, plant resistance to water flow can increase the effect of evaporative demand on leaf water potential, indicating that soil water potential is not always a good measure of plant water status (Campbell and Campbell, 1982; Jones et al., 1985; Syvertsen, 1985). Determination of drought stress is further complicated by soil variability and root distribution, both of which can alter the supply of water, and by variations in the aerial environment that determine plant water requirements.

Evaporation from the leaf surface cools plant tissue relative to air temperature. As water becomes limiting to the plant, transpiration is reduced and leaf temperature rises. Monteith and

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Szeicz (1962) have shown through energy balance analysis that the difference between leaf surface temperature (Tc) and air temperature (Ta), (Tc − Ta), is related to the leaf to air vapor pressure deficit and depends on the aerodynamic resistance to water flow and on net radiation level for a constant Ta. Extensive work has shown that Tc − Ta is inversely related to the air vapor pressure deficit (VPD) (Jackson, 1982; Idso, 1982). Tc − Ta measurements using infrared thermometers allow rapid and accurate readings of large areas of the plant canopy. In field crops research, Tc − Ta measurements have become an effective measurement of plant water status and are used to determine the onset of drought stress related to yield reductions and to schedule irrigation (Jackson, 1982).

Evans et al. (1982) showed that the Tc − Ta of irrigated, shaded apple leaves was inversely related to VPD over a range of 0.2 to 2 kPa. Tormann (1986) found that the nonstressed Tc − Ta of shaded and exposed nectarine leaves was also inversely proportional to the VPD and that the stress index (Idso et al., 1981; Jackson et al., 1981) and the canopy temperature differential between stressed and nonstressed trees were highly correlated with plant water potential. However, Syversten and Albrigo (1980) showed that sun-exposed citrus leaves were as much as 5C above the air during periods of maximum stomatal conductance; shaded leaves did not differ from air by >0.5C for a range of VPD from ≈0.5 to 2.5 kPa.

The purpose of our study was to 1) examine infrared measurement techniques for evaluating canopy temperatures in peach trees, 2) evaluate a foliage-minus-air temperature- (Tc − Ta) based diffusion equation for vapor flux used to predict tree water use, and 3) measure the Tc − Ta response of irrigated peach trees over a range of VPD levels.

Materials and Methods

Measurement techniques of Tc − Ta were evaluated in 1986 on open-center-trained, fruiting, nonirrigated peach trees planted on a 6 × 4.5-m spacing at the Appalachian Fruit Research Station, Kearneysville, W.Va., with 3-m grassed driveway between tree rows. Two measurement methods were compared: a) Horizontal Tc − Ta; Tc − Ta of the canopy sides was measured for the four cardinal compass directions with an IR thermometer (Everest Scientific, Tustin, Calif., Model 110). The instrument was held horizontally ≈1.5 m above ground level 2 to 3 m from the tree. The Tc − Ta value from the display window was recorded within 5 sec after the instrument reading had stabilized. The four readings per tree were averaged for a tree mean. b) Vertical Tc − Ta. Simultaneous to method a, a second IR thermometer was elevated to 3 m and aimed at a 30° angle below the horizontal. This orientation measured Tc − Ta of the canopy top interior. Readings from this IR thermometer were processed through a Polycorder (Omnidata Corp., Logan, Utah) that collected and averaged Tc − Ta for 250 msec and then repeated the measurement 10 times for a total sampling time of 2.5 sec at each cardinal direction. The four values were averaged for a tree mean. Forty trees were sampled near solar noon on 16 and 21 July 1986. Uniform overcast existed on 16 July with wind speeds ≤1 $m{\cdot}s^{-1}$. The sky was uniformly clear on 21 July, with wind speeds ≤2 $m{\cdot}s^{-1}$. The two measurement techniques were compared using a *t* test of slope and intercept being different from 1 and 0, respectively ($\alpha = 0.05$).

Horizontal Tc − Ta was measured shortly after solar noon on 10 and 12 dates in July and Aug. 1987 and 1988, respectively, on irrigated, 5-year-old fruiting peach trees with a ground-projected canopy area of ≈20 m^2. The Tc − Ta measurements also were processed through a Polycorder. VPD was determined from wet and dry bulb readings preceding data collection. Wind speeds were ≤2 $m{\cdot}s^{-1}$. These trees received 410 liters of water/week in addition to 95 mm of rainfall in July and Aug. 1987, and 816 liters/week in addition to 191 mm in July and Aug. 1988. These irrigation levels were equivalent to 52% and 102% of 90% pan evaporation in 1987 and 1988, respectively (Worthington et al., 1984). Six single-tree replications were sampled from a larger irrigation study established in a randomized complete block design.

The weighing lysimeter facility at the Univ. of Texas Agricultural Experiment Station, Stephenville, was used to validate estimated peach tree water use rates using the diffusion equation for vapor flux. Two weighing lysimeters (McFarland et al., 1983), designated east and west, were monitored hourly from 0800 to 2000 HR for three consecutive days in June 1987 (Julian days 167, 168, 169). The load cell measuring system was capable of resolving a 3.6-kg weight difference. Each lysimeter contained a single 5-year-old nonfruiting peach tree trained to an open-center form. Meteorological data collected hourly included: lysimeter weight, wind speed at 3 m above ground, and wet and dry bulb temperatures using an aspirated psychrometer. Tree measurements collected hourly included: horizontal Tc − Ta from the four cardinal compass directions and stomatal resistance measured on one mid-shoot leaf from each compass direction. Stomatal resistance was measured with a LI-COR 1600 steady-state porometer. Tree leaf area was determined in the fall by collecting all the leaves from each tree and then calculating the total leaf weight using the leaf weight : leaf area ratio.

Results and Discussion

We found the Tc − Ta value at any one compass direction to differ when measured horizontally or vertically (data not presented). However, the mean Tc − Ta (N = 4) for the tree was not significantly different in slope or intercept ($R^2 = 0.81$) whether readings were made vertically or horizontally (Fig. 1). It is more convenient to measure Tc − Ta horizontally; we therefore adopted this technique for our studies.

Peach tree water use at the Stephenville, Texas, lysimeter

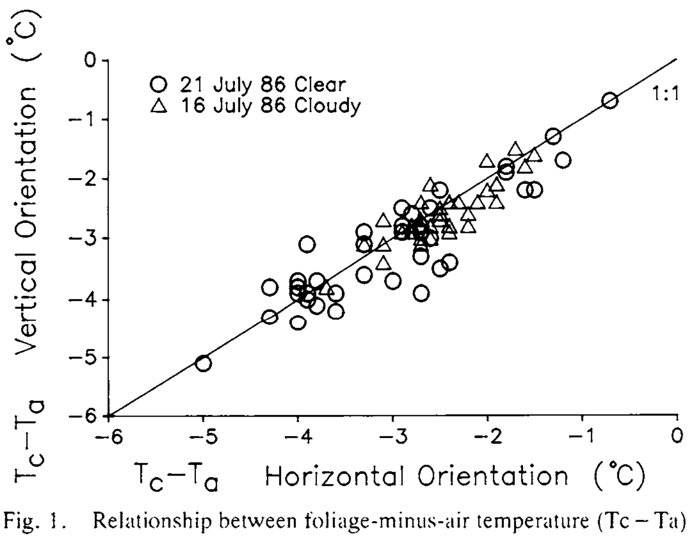

Fig. 1. Relationship between foliage-minus-air temperature (Tc − Ta) and the orientation of the infrared thermometer for peach trees (N = 4).

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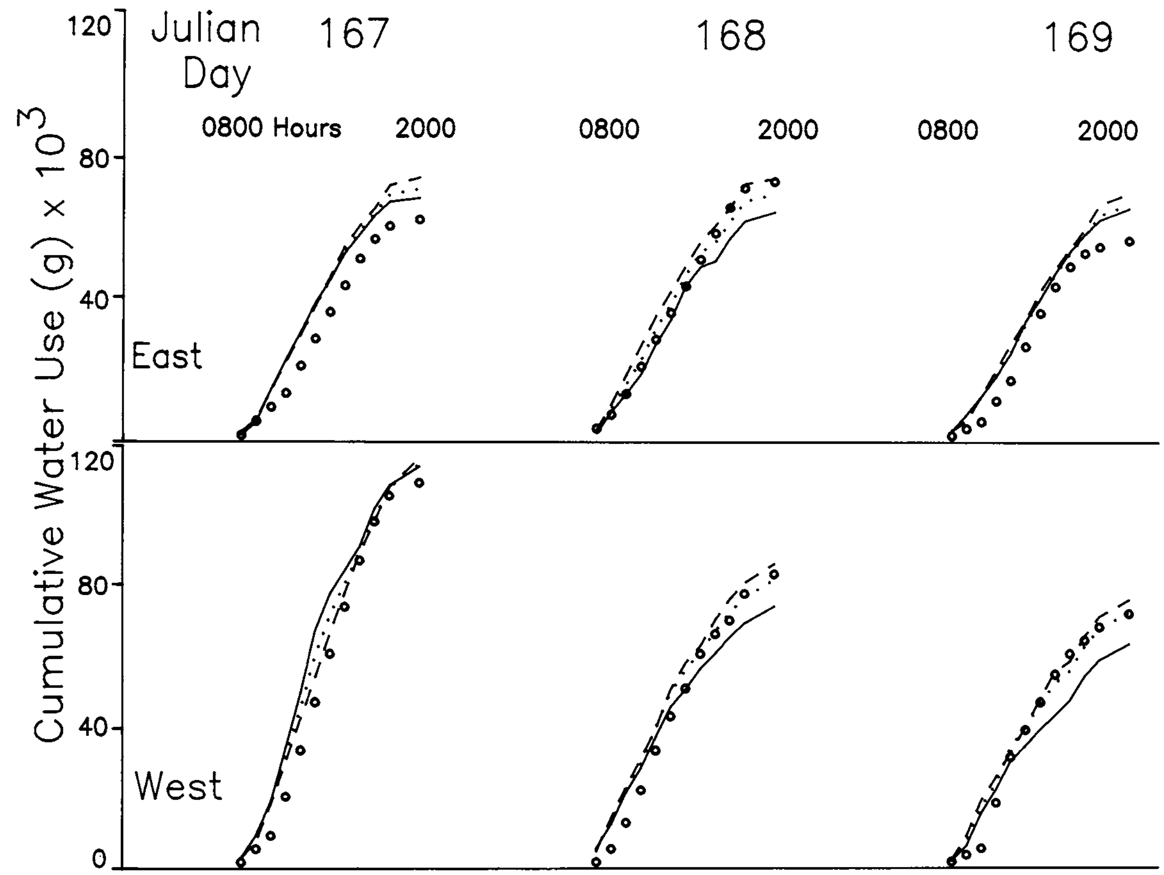

Fig. 2. Cumulative water use of peach trees in two lysimeters at Stephenville, Texas, in 1986. (O) = actual water use. (-----) = data (two cardinal directions) from the directly illuminated canopy surface were used to compute water use; (———) = data (two cardinal directions) from the shaded canopy surface were used to compute water use; (···) = data from the average of four cardinal directions were used to compute water use.

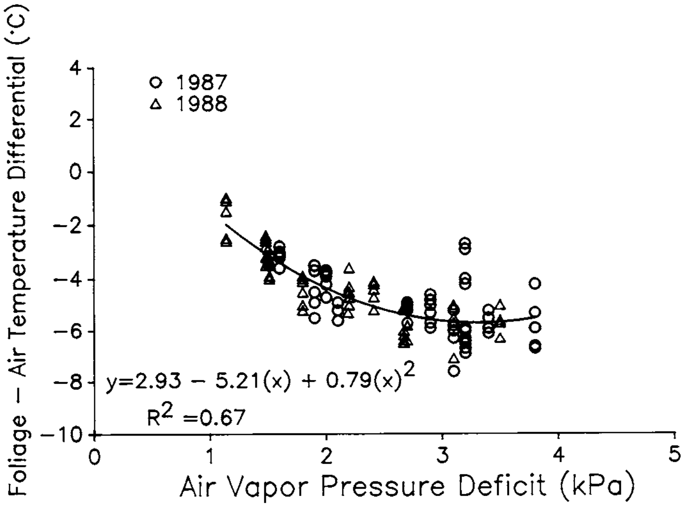

Fig. 3. Relationship between the air vapor pressure deficit and foliage-minus-air temperature for irrigated peach trees. Data represent individual trees sampled 1 to 2 hr after solar noon.

was estimated using the diffusion equation for vapor flux (Smith et al., 1985):

$$T = \rho\, CpS/[L\gamma(r_a + r_c)] \quad [1]$$

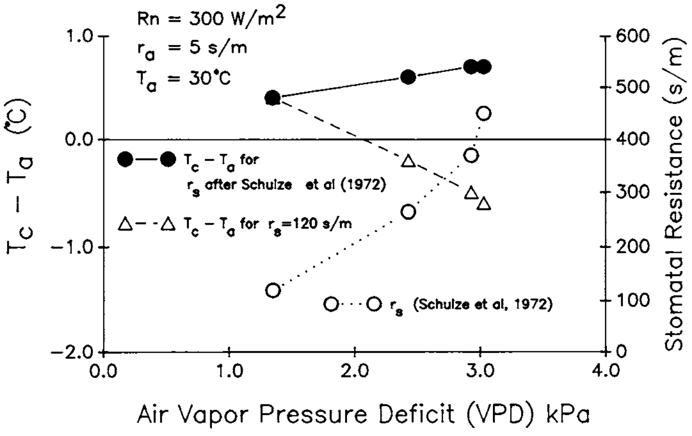

Fig. 4. Relationship between foliage-minus-air temperature (Tc – Ta), stomatal resistance, and the air vapor pressure deficit for irrigated apricot trees (after Schulze et al., 1972). Tc – Ta values are predicted according to Jackson et al. (1981).

where: T = Transpiration rate $g\cdot s^{-1}\cdot m^{-2}$); ρ = density of air ($g\cdot m^{-3}$); Cp = specific heat of air ($J\cdot g^{-1}\cdot {}^{\circ}K^{-1}$); S = leaf-air vapor pressure deficit (Pa); L = latent heat of vaporization ($J\cdot g^{-1}$); γ = psychrometric constant ($Pa\cdot {}^{\circ}K^{-1}$); r_a = resistance to sensible heat flux ($s\cdot m^{-1}$); r_c = canopy stomatal resistance ($s\cdot m^{-1}$) = leaf stomatal resistance.

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We estimated (r_a) by Eq. [2] (Hatfield et al., 1983; Monteith, 1973) in which the transpiring canopy is coupled to the aerial environment by Z_0 and D. Orchard systems are strongly coupled to the aerial environment indicating that the control of transpiration (T) is strongly dependent on S and/or r_c (Jarvis, 1984)

$$r_a = \frac{[\ln [(Z - D)/Z_0]]^2}{K^2 \mu} * \left[1 - \frac{n (Z - D) g (T_c - T_a)}{T_0 \mu^2} \right] \quad [2]$$

where: Z = reference height of wind measurement (3 m); Z_0 = surface roughness height (0.18 m) (0.075 × tree height) (Jarvis et al., 1976); D = zero plane displacement (1.72 m) (Stanhill, 1969); K = Von Karman's constant (0.38); μ = windspeed at reference height ($\mathrm{m \cdot s^{-1}}$); n = constant of 5 (Monteith, 1973) g = acceleration due to gravity ($9.8\ \mathrm{m \cdot s^{-2}}$); T_0 = air temperature (°K); $T_c - T_a$ = foliage-minus-air temperature differential (°K).

Water use was estimated from Eq. [1] using a) data from the illuminated canopy (sunny) surface, b) data from the shaded canopy surface, and c) the mean of the four sides (Fig. 2). The cardinal directions measured for (a) and (b) varied with the time of day. For example, from 0800 to 1200 HR the north and east directions were the illuminated surface and from 1300 to 2000 HR north and west were the illuminated surfaces. The mean hourly deviation from actual lysimeter weight change was 666 ± 319 g ($\bar{x} \pm$ SE) for (a), 40 ± 339 g for (b), and 395 ± 298 g for (c). These results indicate that there was no significant bias using (b) or (c), however, using only data from the illuminated side of the tree (a) did significantly over-estimate hourly water use. For the three dates and two lysimeters, daily consumptive water use was estimated within 9.4% ± 3% of the actual value using (b) or (c). Others have demonstrated in field crops that the Tc – Ta-based energy balance and vapor flux approach is a reliable estimate of crop water use (Choudhury et al., 1986; Hatfield et al., 1983; Jackson et al., 1981; Smith et al., 1985). Our data confirm this approach for peach.

Since this approach has validity with tree crops having a more complex canopy structure and greater coupling between the canopy and aerial environment than agronomic crops, it was our objective to determine how the Tc – Ta from irrigated peach trees responded to changes in VPD. We found that there was no difference in the Tc – Ta vs. VPD relationship between years based on a *t* test of slope (linear and quadratic) and intercept (α = 0.05), despite the fact that trees received 52% and 102% of 90% pan evaporation in 1987 and 1988, respectively (Fig. 3). A doubling of applied water in 1988 did not alter the relationship, and we concluded that these peach trees were well-watered in both years and were able to use soil water reserves at a 52% supplemental irrigation level effectively. Tc – Ta was related to the VPD, but was significantly curvilinear, based on a *t* test of the linear and quadratic terms (α = 0.05) compared to the linear relationship in other plants (Idso, 1982). Jackson et al. (1981) have shown from an energy balance analysis that the generalized Tc – Ta vs. VPD relationship is somewhat curvilinear when r_c is constant. But, for the range of VPD of 1 to 4 kPa, this slight curvilinear character is often obscured by experimental variability. In fruit trees, stomates respond to humidity and temperature via feedback and feedforward mechanisms (Schulze et al., 1972, 1974; Farquhar, 1978; Jones et al., 1985). However, this characteristic nature of stomatal response to VPD is contrary to the concept of the nonwater-stress baseline (Idso, 1982) and the plant water stress index (Jackson et al., 1981) that has been validated in numerous agronomic field studies (Jackson, 1982, Idso et al., 1986) and in fruit crops (Evans et al., 1982; Tormann, 1986). Using the stomatal resistance response of (r_s), Schulze et al. (1972), in equations developed by Jackson et al. (1981), found that the Tc – Ta vs. VPD relationship has a positive slope (Fig. 4). However, if r_s is held constant at $120\ \mathrm{m \cdot s^{-1}}$, then the Tc – Ta vs. VPD relationship resembles the typical inverse relationship demonstrated by others. Idso et al. (1986) state that, in none of the studies in which a nonstressed baseline has been developed, has there ever been "even the slightest indication that stomatal conductance decreases in response to increasing air VPD, as long as root zone moisture remains adequate".

In peach, we find evidence for both of these viewpoints. The curvilinear component of Fig. 3 is not significant (α = 0.05) until VPD values > 2.1 kPa are considered. There is a linear relationship between Tc – Ta and VPD up to 2.1 kPa [Tc – Ta = 1.48 – 3.04 (VPD); R^2 = 0.67]. The curvilinear response of Tc – Ta for VPDs > 2.1 kPa suggests that stomatal resistance increases with VPD at values ≥ 2.1 kPa. The mechanism inducing stomatal response is related to plant and soil resistance to water flow at these higher transpiration rates. Peach trees have a root density 10 to 1000 times less than corn and wheat (Atkinson, 1980; Newman, 1974), which maintain a linear Tc-Ta vs. VPD relationship (Idso, 1982). The reduced root density in peach can limit water uptake at high potential transpiration rates due to the greater distance soil water must move to reach roots and the larger potential water gradients created to drive this water movement from the water films to the root surface (Newman, 1974, de Roo, 1969). Apparently, some aspect of water movement to the root system and stomates becomes a limiting factor at transpiration rates driven by VPD > 2 kPa. Through feedback mechanisms, a potential water deficit in the leaf would initiate stomatal closure, maintaining transpiration and Tc – Ta at a constant or reduced level.

Infrared thermometry has potential application to monitor water use and schedule irrigation in peach orchard systems similar to other agronomic crops. However, certain modifications may be required for peach trees, particularly at high VPDs. We found that Tc – Ta measurements made from a horizontal orientation are related to tree water use and that the Tc – Ta of a peach tree responds to the air VPD. At air VPD > 2 kPa it appears that stomatal response to the VPD introduces a curvilinear component to the nonstressed baseline. Further work in varying environments will be necessary to determine if stomatal action is an integral part of the nonstressed baseline in peach.

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Plant Analysis for Nitrogen Fertilization of Asparagus

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Additional index words. *Asparagus officinalis*, total N, critical N levels

Abstract. **This study was initiated to establish critical N plant tissue levels for asparagus (*Asparagus officinalis* L.) during the fern growing season. Tissue samples for chemical analysis were taken from asparagus plants over three growing seasons. The experiment consisted of nine treatments with five levels of water ranging from 750 to 4200 mm·ha^{-1} and five levels of N fertilizer ranging from 100 to 655 kg N/ha. Only the cladophylls were sampled during the fern growing season beginning in mid-April and monthly through mid-September. Total N concentration at various sampling dates and spear yield were highly correlated. Total N concentration indicated the N status of the asparagus plant. Minimum or critical levels of total N were established for the fern growing season in the desert regions of Arizona.**

Plant analysis has been used to evaluate the nutritional needs of many crops (Geraldson et al., 1973). Brasher (1959) reported that total N levels in asparagus fern could be used as an aid in making more accurate N fertilizer recommendations for this crop. He suggested the use of the tissue values to make corrective treatments the following crop year. A critical level of 3% total N was reported for asparagus by Marlow (1986). Researchers in Chile showed that 2.5% to 4.0% total N in asparagus fern tips gave the best yields (Tapia, 1987).

The concentration of nutrients in plant tissues often varies with stage of growth and plant maturity. If plant analysis is to be used as an aid for recommending fertilizer applications during the current crop year as well as making corrective treatments the following year, critical plant tissue concentrations need to be established for the early stages of plant growth as well as later in the season (Tucker, 1984).

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