Modeling Young Peach Tree Evapotranspiration

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Abstract

A model of young peach tree evapotranspiration (ET) was developed using data from a large weighing lysimeter. Two "Crimson Lady" peach trees were planted in the lysimeter in January 1999. Data from the 1999 season were used to create the model and from the 2000 season to validate it. There are 2 components to the model. First, tree transpiration was modeled as a function of reference ET (ETo) and canopy size, as measured by canopy light interception at solar noon. Estimates of tree transpiration were obtained from lysimeter values on the day before weekly basin irrigation when the soil surface was dry. The equation derived for this relationship agreed very well with values obtained previously with mature trees when the lysimeter surface was covered with a tarp (Johnson et al., 2000). Second, soil evaporation was modeled as a function of ETo, days after irrigation, dimensions of the wetted area, and percent of the wetted area receiving full sun over the course of the day. Overall, the model generally fit the 1999 data from the lysimeter, although it tended to underestimate the peaks associated with irrigation events. It successfully predicted ET during 2000, except for the very end of the season when subsurface irrigation was used. Some additional research may be needed to explain these aberrations, but in general the model was quite accurate in predicting young peach tree water use.

INTRODUCTION

Irrigation management in arid regions of the world is becoming more and more important as competition for scarce water resources increases. Having a dynamic computer model to predict both the tree transpiration and soil evaporation components of young tree ET in an orchard would be particularly useful. With incomplete canopy cover, soil evaporation can be a substantial portion of total ET (Lascano et al., 1987). Different irrigation systems or frequencies could make large differences in the total amount of water used even though tree transpiration and tree growth are essentially unchanged. A model would be useful not only to help determine the appropriate amount of water to apply in a given situation but also to compare different irrigation systems and strategies. The factors controlling tree transpiration and soil evaporation are well established so putting together an interactive computer model should be an achievable goal.

The goal of this project was to develop a model for an orchard manager to use. Therefore it was desirable to keep inputs as simple as possible. Any measurements of soil moisture, stomatal conductance or light interception requiring sophisticated instruments would lessen the chances of the average orchard manager using the model. Therefore, attempts have been made in the development of this model to use simple measurements while maintaining as much accuracy as possible.

MATERIALS AND METHODS

A large weighing lysimeter was built at the Kearney Ag Center near Fresno, California (lat. 36.6° N, long. 119.5° W) in the fall of 1986 (Phene et al., 1991). "O'Henry" peach trees were grown in the lysimeter and surrounding field from 1988 to 1996 and were the basis for developing mature tree crop coefficients (Johnson et al., 2000). In January, 1999 two "Crimson Lady" peach trees were planted in the lysimeter and another 1204 trees in the 1.4 ha surrounding field. Trees were planted 1.8m apart in 4.9m rows and trained to a perpendicular "V" training system (DeJong et al., 1994). A low volume irrigation system was installed in the field with one 20 L/hr emitter per tree. A separate irrigation system was set up in the lysimeter which allowed for either surface irrigation into basins with one 104 L/hr emitter per tree or subsurface irrigation at both 30 cm and 60 cm depths at a delivery rate of 60 L/hr (thirty 2 L/hr emitters) for both trees. Trees grew very well in both 1999 and 2000 reaching heights of 2.6 m and 3.8 m by the end of each year, respectively.

During 1999, the lysimeter was irrigated weekly starting on April 27. Water was applied to a basin 0.85 m in diameter around each tree. With each irrigation, the amount of ET measured by the lysimeter during the previous week was replaced. On August 25, the diameter of the basin was increased to 1.7 m and the frequency of irrigation was increased by several days to make sure the soil surface was dry before the next irrigation. During 2000, the same basin of 1.7 m was used for the first part of the season and irrigations were applied every 3 to 7 days. Starting on August 2, the subsurface irrigation system was set to irrigate automatically every time 1.8 mm ET was lost from the lysimeter. Therefore, on a typical sunny day, the lysimeter trees were generally irrigated 4 or 5 times.

Daily ET values for the peach trees were estimated by summing hourly weight changes measured by the lysimeter. Daily ETo values were determined from the summation of hourly calculations of ETo (modified Penman equation, Snyder and Pruitt, 1992) using weather parameters collected from a nearby weather station. Daily peach tree crop coefficients, Kc, were computed from the ratio of ET/ETo.

Canopy light interception was measured every 2 to 3 weeks during the season with an Accupar Linear PAR Ceptometer (Decagon Devices, Inc., Pullman, WA). Within 15 minutes of solar noon, the Ceptometer was held at ground level under the canopy to take an individual reading. This was repeated at least 70 times to cover the entire ground area assigned to the two trees in the lysimeter. The average of these readings was divided by full sun measurements taken in an open area next to the orchard and subtracted from 1 to give the proportion of light intercepted by the trees. Linear increase was assumed between measurement dates. Values of 0.31 and 0.63 were reached by the end of the season in 1999 and 2000, respectively.

The proportion of the irrigation basin exposed to the sun over the course of the day was estimated on 4 dates: April 26, May 31, July 26 of 2000 and May 8, 2001. Percent shade was measured using a tarp cut to the shape of the basin and covered with a grid of 10x10 cm squares. Each hour, the number of squares in the sun was counted and divided by the total number of squares. These hourly proportions were then weighted by the hourly ETo to obtain an average daily value.

RESULTS AND DISCUSSSION

Daily crop coefficients were obtained from April 14 until October 7 in 1999 and from March 1 until September 24 in 2000. The data from 1999 were used to develop the model and from 2000 to validate it. The model is basically separated into a tree transpiration component and a soil evaporation component.

The tree transpiration component of the model was estimated from lysimeter measurements taken the day before irrigation. On these dates, the soil surface appeared dry. However, the literature indicates soil evaporation continues at a decreasing rate for several weeks after an irrigation event. Ritchie and Johnson (1990), in reviewing the literature on soil evaporation, concluded that a diversity of soils all show a similar rate of cumulative evaporation equal to a constant times the square root of time, with the constant consistently equal to about 3.5 mm $d^{-1/2}$. Therefore, using this equation, we estimated the soil evaporation occurring on the day before irrigation and subtracted this value from the lysimeter measurement. Early in the season, this had very little effect, but the last two measurements of the season were reduced by about 10% because of the expanded area of the irrigation basin.

The peach tree Kc values showed an excellent linear correlation (r=.99) with canopy light interception (LI) taken on the same dates (Fig. 1). Therefore, the first component of the model, Kcb or tree transpiration, was modeled solely as a function of canopy light interception measured at solar noon according to the following equation:

$$Kcb = 0.0046 + 1.501*LI \qquad (1)$$

The equation of the regression line was almost identical to that obtained with mature peach trees (0.007 + 1.48*LI) with the lysimeter surface area covered by a tarp to eliminate soil evaporation (Johnson et al., 2000) and a similar study with grape vines (L. E. Williams, personal communication). This suggests the equation may be universal among tree ages and even different species of trees and vines.

The second component of the model is soil evaporation. Numerous mechanistic models have been developed to simulate water loss from a bare soil, many of them requiring multiple inputs (Ritchie and Johnson, 1990). For the purposes of a useful field model, we need a simple functional model with a minimum of inputs. The approach of Ritchie (1972) only requires a few inputs but has been shown to predict evaporation reasonably well (Ritchie and Johnson, 1990). This model is based on the assumption that soil evaporation occurs in 2 stages. Stage 1 lasts for one to several days after irrigation and is largely a function of the energy available for evaporation. Thus, it is set equal to ETo until a certain threshold, U, is reached. U has been shown to range from 5 mm for sand to 14 mm for clay loams. The soil in the lysimeter is a fine sandy loam, so a value half way between these 2 extremes (9.5 mm) was selected.

The other factor needed for stage 1 evaporation is the proportion of the wetted area exposed to the sun over the day (WS). This was measured under the trees on 4 dates and regressed against canopy light interception to obtain the following equation:

$$WS = 0.84 - 1.07*LI \qquad (2)$$

Measurements taken in 2001 suggested the wetted area in the shade was still evaporating at a rate about 35% of the sunlit wetted area under orchard trees. Therefore, stage 1 soil evaporation (Es1), until 9.5 mm was lost, was modeled as follows:

$$Es1 = (ETo*(WA/TS)*WS)+(0.35*(ETo*(WA/TS)*(1-WS))) \qquad (3)$$

where WA is the area wetted by irrigation in m^2, and TS is the spacing of trees in the orchard in m^2.

Stage 2 evaporation occurred from this point until the next irrigation and was much more a function of soil properties than available energy. As mentioned above Ritchie and Johnson (1990) concluded from several studies that the following equation would describe cumulative soil evaporation (ΣEs) for many different soil types:

$$\Sigma Es = at^{1/2} \qquad (4)$$

where a is a constant equal to 3.5 mm $d^{-1/2}$ and t is the time in days. For an individual day the equation for Es would be:

$$Es = at_n^{1/2} - at_{n-1}^{1/2} \qquad (5)$$

Since stage 2 evaporation is more a function of soil hydraulic properties than available energy, it was assumed that evaporation would occur over the whole wetted area whether in sun or shade (Ritchie and Johnson, 1990). Therefore, to model stage 2 evaporation (Es2) for the lysimeter trees, only the area wetted by irrigation was needed as follows:

$$Es2 = Es^{*}(WA/TS) \quad (6)$$

Stage 2 evaporation was modeled to proceed according to this equation unless the value exceeded the energy available for evaporation, in which case Es1 was used instead (Black et al., 1970). Once the Es values were estimated for both stages 1 and 2, they were then converted to crop coefficients for soil evaporation (Ks) as follows:

$$Ks = (\text{Lesser of } Es1 \text{ or } Es2)/ETo \quad (7)$$

These two components combined (Kcb + Ks) were able to predict the crop coefficients obtained from the lysimeter reasonably well (Fig. 2). However, the beginning of each irrigation event was generally underestimated. There could be several possible explanations for this. First, advective energy transferred from nearby bare, sun-exposed soil might be expected to substantially increase soil evaporation under the trees. This would be particularly significant with a newly planted orchard where there is a large proportion of the orchard floor not irrigated or shaded from the sun. Increases of 30% in the evaporative demand have been shown at the edges of field crops planted downwind from uncropped dry fallow areas (Davenport and Hudson, 1967).

Second, it is possible that irrigation stimulated an increase in transpiration due to more available water in the soil. For example, on two different occasions when the lysimeter was irrigated and the surface was covered with a tarp at the same time, there was a small increase in the crop coefficient for several days. Also, plotting daily model deviations from actual Kc values (from Fig. 2) vs soil water content showed a tendency for the model to underestimate Kc on days of high water content (data not shown). However, regression analysis of the data yielded an R2 value of only 0.17 so the relationship is not very strong. Stomatal conductance measurements should be taken in the future to test the validity of this relationship. Finally, the trees may have been moderately stressed by the end of each irrigation cycle, thus decreasing transpiration just before each irrigation. Past experiments with the lysimeter have shown a tendency for the trees to experience stress more quickly than similar trees in the field, presumably because of a more restricted root zone (Mata et al., 1999). Unfortunately, no measurements were taken of water potential or stomatal conductance to test this possibility.

For 2000, the same equations were applied as a validation of the model. In general the model predicted peach tree crop coefficients reasonably well except at the very end of the season, especially after August 1 (Fig. 3). The measured crop coefficients of 1.4 to 1.8 during September are much higher than have generally been reported for any crop (Allen et al., 1998) and are therefore questionable. ETo values from the weather station were consistently less than a similar nearby station by 15 to 25% during September and are thus a likely source of this error. If these values were substituted in the calculation of Kc, the average for September would be 1.26 which is closer to the model.

Although there was general agreement between the model and the measured Kc values, there were individual days that differed substantially (Fig. 3). Recent measurements of the lysimeter trees suggest this may be due to a strong response of peach trees to vapor pressure deficit (VPD) where increased Kc values are associated with high VPD measurements (data not shown). This could account for some of the day-to-day variability and also account for the underestimation of Kc values in July through September when VPD levels tend to be high.

In summary, the model presented in this paper should be a very useful tool for predicting water use of young peach trees in the orchard. The required inputs are simple enough for an orchard manager to measure and yet the accuracy appears to be reasonably good. However, improvements can always be made, so research to refine the model should continue, especially to better characterize the increased transpiration or evaporation associated with an irrigation event and to evaluate the response of peach trees to VPD.

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Figures

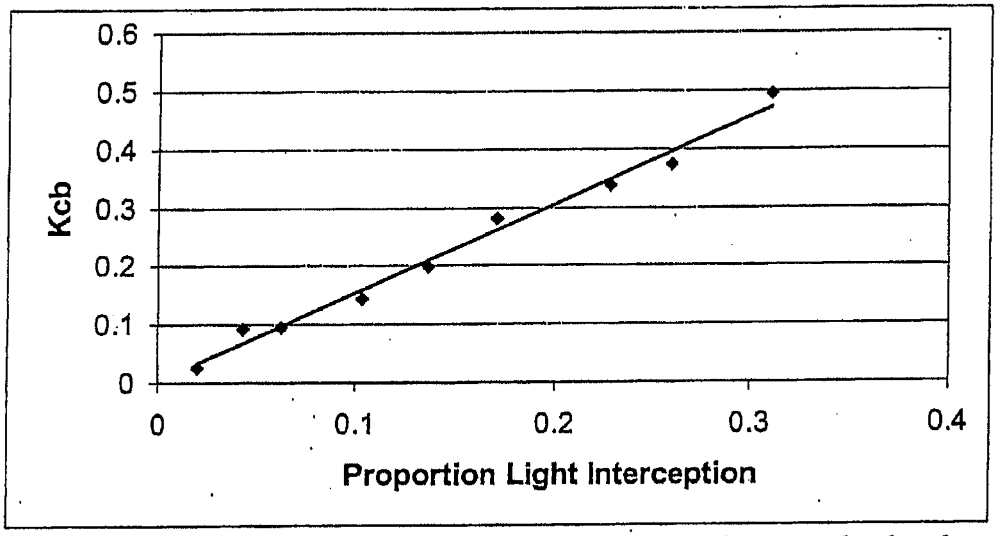

Fig. 1. The crop coefficients representing transpiration alone or the basal crop coefficient (Kcb) of a one-year-old peach tree as predicted by the proportion light interception of the canopy at solar noon. R^2 of the regression line is 0.987.

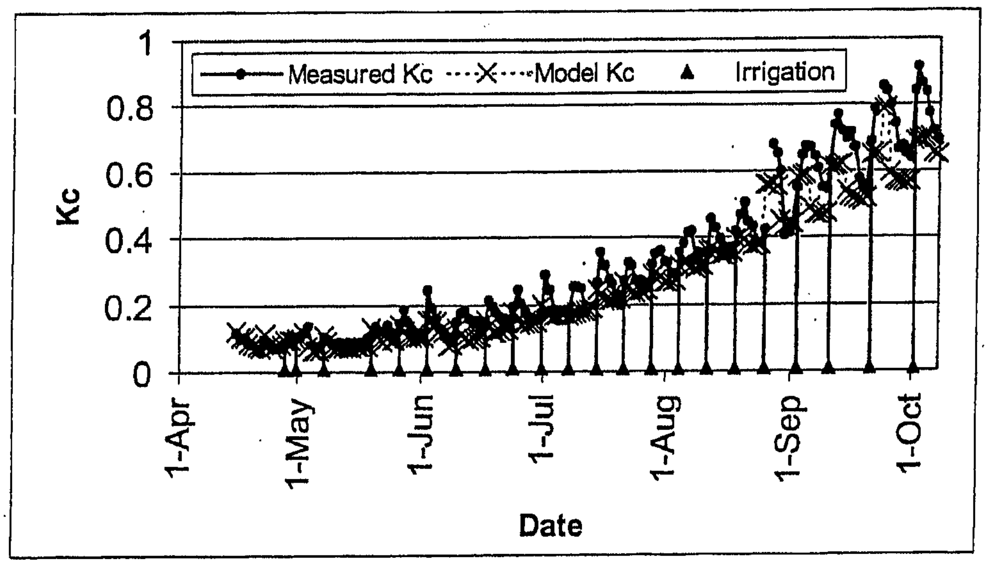

Fig. 2. 1999 peach tree crop coefficients predicted by the transpiration and soil evaporation components of the model as compared to values measured by a weighing lysimeter and a nearby weather station. Vertical lines represent irrigation dates.

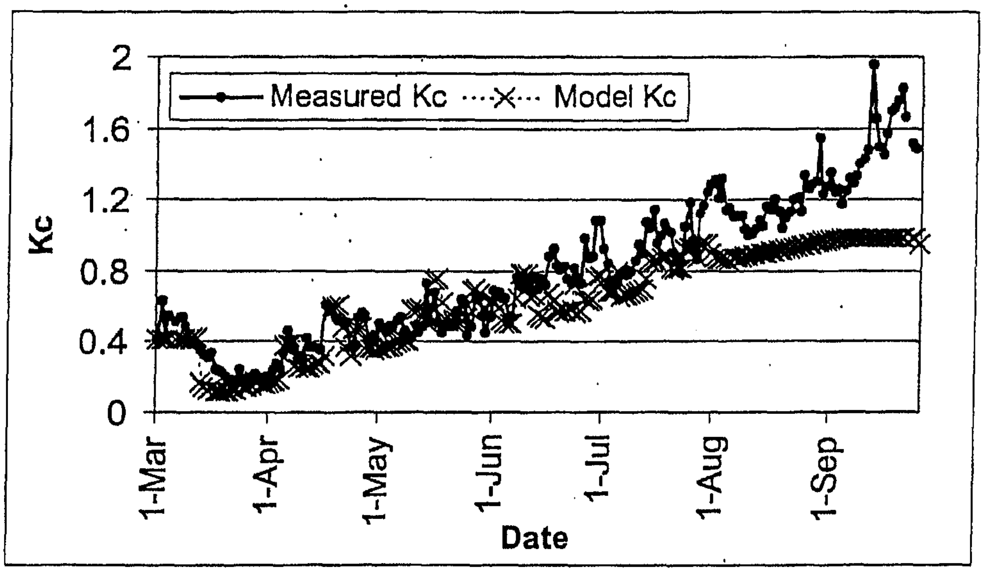

Fig. 3. 2000 peach tree crop coefficients for two-year-old trees predicted by the model as compared to values derived from a weighing lysimeter.