Improving a Model for Predicting Peach Tree Evapotranspiration

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Abstract

A model of young peach tree evapotranspiration (ET) was reported on previously. It was developed using data from the first two years of growth of "Crimson Lady" peaches planted in a large weighing lysimeter. Tree transpiration and soil evaporation were modeled as separate components. The model predicts daily peach tree ET based on reference crop ET (ETo) and several simple measurements from the orchard. Since then, two more years of data have been collected and several improvements to the model have been made. The model can now be used for mature as well as young trees. Tree transpiration was originally modeled as a function of canopy size as measured by light interception at solar noon. A vapor pressure deficit function was added which explains some of the short-term variation observed in the lysimeter trees. Percent canopy light interception of very small trees can be difficult to estimate accurately. Therefore, equations were derived from measurements of tree height and canopy spread, and were verified in the field. To improve the soil evaporation component of the model, an equation was developed to estimate the percent of the irrigation wetted area in full sun over the course of the day for different irrigation systems and planting configurations. The model can now be applied to peach trees of any age and spacing, and a range of irrigation regimes.

INTRODUCTION

A model of young peach tree evapotranspiration (ET) has been developed using data from the first two years of growth of "Crimson Lady" peaches planted in a large weighing lysimeter (Johnson et al., 2002). The model was originally designed for easy use by peach growers and required a minimum of inputs. Since then, two more years of data have been collected as the trees reached maturity in the high-density configuration to which they were planted. Several modifications were needed in order to apply the model to mature trees and still keep it simple to use. In addition, measurements were made on trees outside the lysimeter, planted in different configurations and with varying simulated wetted patterns, in order to improve the modeling of soil evaporation. With these modifications, the model should now be applicable to peach trees of any age and spacing, and a range of irrigation regimes.

MATERIALS AND METHODS

In the fall of 1986, a large weighing lysimeter was built at the Kearney Ag Center (lat. 36.6° N, long. 119.5° W) near Fresno, California (Phene et al., 1991). From 1988 to 1996, "O'Henry" peach trees were grown in the lysimeter and surrounding field and were the basis for developing mature tree crop coefficients (Ayars et al., 2003, 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 1.8 m apart in 4.9 m rows and trained to a perpendicular "V" training system (DeJong et al., 1994). A low volume irrigations 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. In 1999 the trees grew very well, reaching a height of 2.6 m by the end of the season. In 2000 they grew to 3.8 m and were intercepting 60% of available light at midday by August. Thus, the tree canopies had virtually filled in their allotted space at this high-density spacing and were considered mature for the 2001 and 2002 seasons.

In both 2001 and 2002, the watering system for the lysimeter tank was rotated between basin and subsurface irrigation about every 3 weeks. Irrigations started on March 16, 2001 and April10, 2002 and continued through the middle of October each year. With either system, the lysimeter weight was kept fairly constant by adding the amount of water used since the previous irrigation. For basin irrigation, an area about 1.7 m in diameter around each tree was wetted every 2 to 5 days. The only exception to this was during two periods when three moderate stress cycles were imposed each time. Starting at the end of May to mid June and during most of July 2002, no irrigations were applied for 5 to 6 days in order to achieve this moderate stress (Mata et al., 1999). Upon re-irrigation, enough water was added to restore the original lysimeter weight. The subsurface system was set to irrigate automatically every time 1.8 mm ET was lost from the lysimeter. Thus 1 to 3 irrigations occurred daily in the spring and fall, and 4 to 5 in the summer. There was also one exception to this pattern. In early July of 2001, the emitters at 60 cm depth were inadvertently shut off for about 2 weeks. Therefore, the trees only received 50% ET during that period and experienced some stress.

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 of PAR. 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. Light interception was measured within 48 hours before and after summer pruning events that occurred on May 7 and June 15 in 2001 and August 28, 2002. Fruit were harvested between June 1 and 6, 2001 and May 28 and June 3, 2002.

For the estimation of light interception by small trees, 10 peach trees trained to different shapes and from different orchards near the Kearney Ag Center were selected in 2002. Trees ranged in age from 1 to 3-years-old and none had overlapping shadows with neighboring trees at solar noon. Two to three measurement dates for each tree, together with nine measurement dates for the lysimeter trees in 1999, gave a total of 37 data points. At each date the following data were recorded: tree and row spacing, tree height, N-S canopy spread, E-W canopy spread and canopy light interception at solar noon measured with a Ceptometer as described above.

For estimating the proportion of the irrigation wetted area exposed to the sun over the course of the day, 9 trees (including the lysimeter trees) from different orchards were selected. Simulated wetted areas corresponding to different micro sprinklers or drippers were established under each tree for a total of 19 data points. On the day of measurement, every one to two hours during daylight hours, wetted area in the sun was visually estimated. These hourly proportions were then weighted by hourly ETo to obtain an average daily value. On the same day, canopy light interception at solar noon was measured with a Ceptometer as described above. Measurements of wetted area, tree spacing and row spacing were also recorded.

RESULTS AND DISCUSSION

The original model developed for young peach tree ET (Johnson et al., 2002) was separated into a tree transpiration component and a soil evaporation component. The tree transpiration component was shown to correlate very well with canopy light interception with a slope of 1.5. Therefore, a tree with canopy light interception of 0.6 (60% of available light) would have a crop coefficient (due to transpiration alone) of 0.9. This relationship should hold true for trees of all ages since the same correlation (slope = 1.48) was shown for mature peach trees in the lysimeter when the soil surface was covered to prevent soil evaporation (Johnson et al., 2000). The only difficulty lies in determining the upper limit of this relationship. It seems unreasonable that the same linear relationship would extend to 100% light interception since the predicted Kc of 1.5 would be greater than has been reported for any crop (Allen et al., 1998). Fereres et al., (1982) reported a leveling off of this relationship above 50 to 60% light interception for young almond trees. Data from the lysimeter supports a continued linear relationship up to 70% light interception (Johnson et al., 2000) but there is little data above this level. Therefore, until more information can be collected, the model uses a slope of 1.5 between 0 and 70% light interception. It then sets an upper limit, with a predicted Kc value of 1.05 for basal tree transpiration between 70 and 100% light interception.

In an attempt to keep this model simple for orchard growers to use, difficulties sometimes arise in estimating light interception. Most growers do not own a Ceptometer or other light measuring devise and counting shaded squares in a grid under the tree can be very time consuming. Experience has shown that estimating light interception of mature orchards (between 35 and 70%) can be done visually with a fair degree of accuracy. However, young trees that are only intercepting a small proportion of available light are much more difficult to estimate. Therefore, an improvement was added to the model that estimates canopy light interception from a few simple tree dimension measurements. The estimate is based on geometric assumptions and relationships and only applies to the situation where there is no overlapping of shadows from adjacent trees at solar noon. Assuming the canopy to be elliptical in shape, light interception is equal to the projected area (PA) of the tree shadow on the ground as follows:

$$PA = (EW/2) * ((\text{Greater of NS or PH})/2) * PI \qquad (1)$$

where EW is the East-West canopy diameter in meters, NS is the North-South canopy diameter in meters, PI is 3.14159 and PH is the height of the tree (H in m) projected on the ground according to the following equation:

$$PH = H * \text{Tan (Angle of the sun from the horizon)} \qquad (2)$$

The projected area (PA) of the tree shadow is then converted to proportion light interception (LI) by dividing by tree area (TA in m^2) as follows:

$$LI = PA/TA \qquad (3)$$

Using 37 data points collected from 11 young trees from different orchards on several dates, these equations were tested against measured light interception. The resulting regression equation had a slope of 0.99 and R^2 value of 0.87, suggesting an excellent fit.

One final change has been added to the transpiration component of the model that explains some of the short-term variability observed in the lysimeter trees. During the 3-

week periods of subsurface irrigation in 2001, there were often substantial fluctuations in Kc values within just a few days. For instance, in early June Kc dropped from 1.1 to 0.8 in less than a week (Fig. 1). Since the trees were irrigated several times per day and the soil surface was practically dry, one would not expect such changes to be due to water stress or soil evaporation. Instead, one weather factor explained a lot of this variability. Midday vapor pressure deficit (VPD) closely followed the daily changes in Kc values (Fig. 1). This same correlation was observed during the other periods of subsurface irrigation as well (except for the accidental dry down in July). From these data, an empirical formula to adjust Kc has been derived as follows:

$$\text{Adjusted Kc} = (\text{VPD} * 0.102) + 0.821 \quad (4)$$

Therefore, with a VPD of 2 kPa there is virtually no adjustment in the Kc, but at 4 kPa it is increased by 22%. No data exists for VPD values greater than about 4, so this is set as the upper limit for the model.

The soil evaporation component of the model has been slightly modified to make it more applicable to various irrigation systems and wetted patterns. The equations modeling the two-stage process proposed by Ritchie (1972) are still used (Johnson et al., 2002). In the original model, an equation was developed to predict the proportion of the wetted area in the sun (WS) over the course of the day. It was based on basin irrigation of the lysimeter trees and thus would not apply to other wetted areas and tree spacings. Therefore, in 2001, another equation was derived from orchards representing a range of tree shapes, spacings and wetted patterns. A total of 19 different scenarios were used. The empirical formula derived is a function of canopy light interception (LI) and wetted area (WA in m^2) as follows:

$$\text{WS} = ((-0.946 * (\text{LI})) + 0.730)/(0.744 * (e^{(0.196 * (\text{LI}/(\text{WA}/\text{TA})))})) \quad (5)$$

At light interception values greater than 0.77 (77%), the equation predicts negative values. Therefore, an upper limit of 0.77 for LI is used in the model.

The modified model was used to predict peach tree crop coefficients from the lysimeter in 2001 (Fig. 2) and 2002 (Fig. 3). In general, there was good agreement except for the accidental stress period in 2001 and the 6 stress cycles imposed in 2002. Efforts are being made to quantify the effects of water stress on tree water use so a stress component can be added to the model in the future. The model also tends to underestimate tree water use late in the season, particularly after August 1. The same trend was observed in the original young tree model (Johnson et al., 2002). The explanation for this is still unknown. Perhaps there is extra advective energy entering the orchard from surrounding dry fields late in the season. Overall, the model appears to be quite accurate for predicting water use of unstressed peach trees during the majority of the season. It can now be applied to trees of any age and spacing, and a range of irrigation regimes.

The next goal for this project is to make the model available on a website. The user would need to identify a weather station for ETo and VPD data and enter some basic orchard (tree spacing, soil type etc.) and irrigation (wetted area, irrigation frequency, emitter output etc.) information. They would also need to estimate the percent light interception of a mature orchard or the tree dimensions of a young orchard. Thus, inputs would be quite simple and the original goal of creating an easy-to-use, yet accurate model of peach tree water use would be achieved.

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Tables

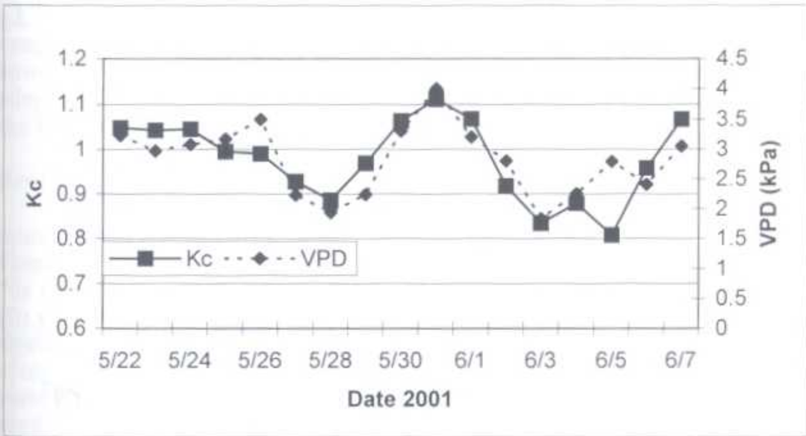

Fig. 1. Peach tree crop coefficients (Kc) derived from the lysimeter during the period of May 22 to June 7, 2001. The lysimeter was automatically irrigated several times per day through subsurface emitters during this period. Midday vapor pressure deficit (VPD) calculated from a nearby weather station is also shown for the same dates.

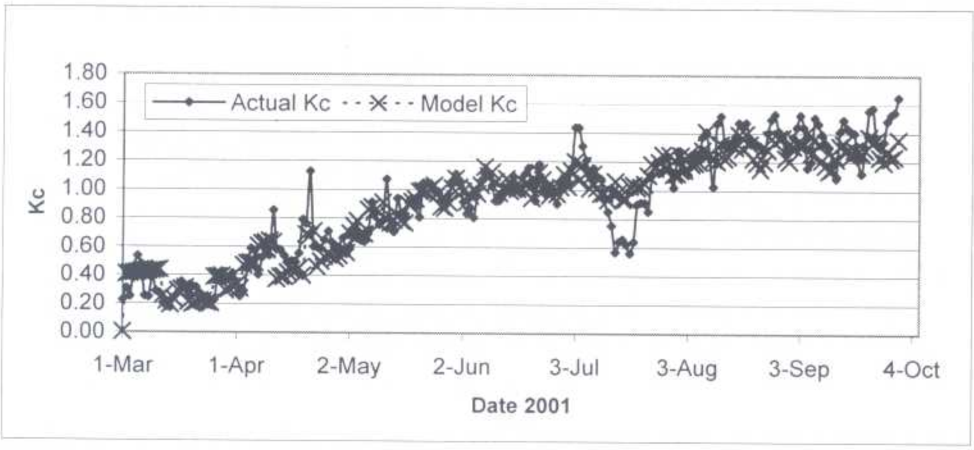

Fig. 2. 2001 crop coefficients (Kc) for "Crimson Lady" peach trees predicted by the model as compared to values derived from a weighing lysimeter.

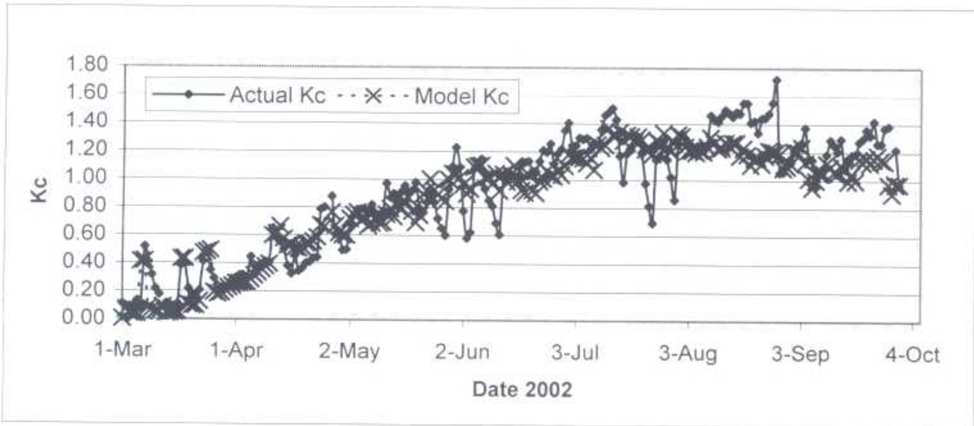

Fig. 3. 2002 crop coefficients (Kc) for "Crimson Lady" peach trees predicted by the model as compared to values derived from a weighing lysimeter.