CROP COEFFICIENTS FOR MATURE PEACH TREES ARE WELL CORRELATED WITH MIDDAY CANOPY LIGHT INTERCEPTION

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Abstract

Two 'O'Henry' peach trees were planted in a 2x4x2 m weighing lysimeter in the spring of 1988. An additional 1186 trees were planted in the 1.1 ha field surrounding the lysimeter. Row and tree spacing were 4.9 and 1.8 m respectively, and trees were trained to a "V" shape perpendicular to the row. The irrigation system in the field consisted of one 20 L/hr microsprinkler per tree. Within the lysimeter, a circle of ten 2 L/hr drip emitters per tree simulated this same pattern of water distribution. Irrigation was automatically called for when 5.4 mm of ET was lost from the lysimeter trees, which resulted in approximately daily irrigations during the summer. Daily peach ET values (ETc) were recorded during the growing seasons of 1990 to 1994 when the trees were mature. Reference crop values (ETo) were calculated from a nearby weather station using a modified Penman equation. Crop coefficients (Kc) were calculated as the ratio of these two (ETc/ETo). Kc values generally started at about 0.2 early in the season and reached as high as 1.1 to 1.2 by August. The increase in Kc values over the growing season and year-to-year variability was largely accounted for by midday tree canopy light interception. Weather parameters such as vapor pressure deficit, wind speed, temperatures and solar radiation accounted for very little additional variability. Therefore, light interception seems to be the main variable needed to explain changes in Kc due to tree size and leaf area development, and may even apply to young trees and different tree and vine species.

1. Introduction

In arid climates, supplemental irrigation of tree crops is necessary for maximum production and tree survival. There has been considerable research to determine tree water use so the correct amount of water can be applied to orchards. The approach of developing reference evapotranspiration values (ETo) and then adjusting these with specific crop coefficients (Kc) has been widely adopted and is used regularly for irrigation scheduling (Allen *et al.*, 1998). In 1986 we constructed a large weighing lysimeter that was capable of accurately measuring hourly and daily peach tree evapotranspiration (ETc) rates. The objective of this study was to use this lysimeter to measure daily crop coefficients for mature peach trees over several growing seasons and relate these to tree size as measured by canopy light interception. Some researchers have theorized that tree transpiration and grass transpiration should respond differently to certain weather parameters such as humidity and wind speed (Annandale and Stockle, 1994; Jarvis, 1985). This suggests that tree Kc values may not be constant over short periods of time, but instead may vary with changing environmental conditions. Therefore, a second objective of this study was to determine if daily and weekly variations in peach tree Kc values could be explained by environmental conditions.

2. Materials and Methods

A 2x4x2 m weighing lysimeter was constructed at the Kearney Agricultural Center near Fresno, California (lat. 36.6° N, long. 119.5° W) in the fall of 1986 as described by Phene *et al.* (1991). In the spring of 1988, two "O'Henry" peach trees were planted in the lysimeter and an additional 1186 trees were planted in the 1.1 ha surrounding field. Row spacing was 4.9 m and the trees were spaced 1.8 m apart including the two lysimeter trees. Trees were trained to the Kearney "V" system (DeJong *et al.*, 1994) with 2 scaffolds perpendicular to the row. A low volume irrigation system was installed in the field with one 20 L/hr microsprinkler per tree. To keep irrigation water within the surface area of the lysimeter, a different irrigation system was used for the two lysimeter trees. A circle of ten 2 L/hr drip emitters was placed around each tree to simulate the pattern of the microsprinklers. Therefore, these trees received water at the same rate and in about the same pattern as the rest of the field. Two large tanks (300 L each) suspended from the bottom of the lysimeter provided irrigation water for the two trees so there was no net change of weight during an irrigation event. The tanks were automatically refilled at midnight. An irrigation event was automatically called for when the weight of the lysimeter had lost the equivalent of 12 mm of water. This is equal to 5.4 mm of water over the surface area assigned to each tree in the field. When the trees were mature, irrigation events were occurring every 2 to 5 days in the spring but daily and often twice per day in the summer. The lysimeter trees were approximately the same size as surrounding trees during the course of the experiment. Fruit harvest was generally started by about July 25 and completed by August 10 to 15 of each year.

The trees grew well in 1988 and 1989, reaching heights of 1.5 and 3.1 m, respectively. By the end of the growing season in 1989, the trees had basically filled their allotted space within the tree row and had grown to the desired height for the orchard. Therefore, the trees were considered mature and daily ETc values were collected over the next five growing seasons (1990-94) from March 1 to October 31. Daily ETo values were calculated for this same time period from weather parameters collected at a weather station about 600 m from the orchard. Hourly ETo values calculated using a modified Penman equation (Snyder and Pruitt, 1992) were summed up over 24 hours to give daily ETo. The ratio of ETc/ETo was computed to produce daily peach Kc values. About 10% of the daily values were eliminated from the data set because of excessive noise in the lysimeter output, continuous rain, instrument failure at the weather station, power outages and sudden weight gains by the lysimeter.

Midday tree canopy light interception was measured within an hour of solar noon on a cloudless day every 3 to 4 weeks using an Accupar Linear PAR Ceptometer (Decagon Devices, Inc., Pullman, WA) from April or May to August or September of each year. The Ceptometer was held at ground level facing straight up to take an individual reading. At least 50 readings were averaged throughout the entire ground area assigned to the tree. This value was divided by a full sun reading taken in an open area next to the orchard and subtracted from 1 to give the proportion of light interception by that tree. Light interception between measurements was linearly interpolated. For this analysis, only the dates between the first and last light interception measurements were used in each year. This gave a total of 574 daily data points.

3. Results and Discussion

The seasonal patterns of peach Kc values were similar for the 5 years of study of this experiment (Fig. 1). 1990 was lower than the other 4 years because the trees had not quite filled their allotted space. In general, Kc values started at about 0.2 early in the season and reached as high as 1.1 to 1.2 by August when fruit harvest occurred. This pattern is quite different from published values for deciduous fruit trees which start at about 0.5 early in the season and peak at about 0.9 to 0.95 (Snyder *et al.*, 1989). The reason for such different patterns is unknown but may be related to differences in canopy light interception as discussed below.

In most years, there appeared to be a slight drop in the Kc values for a short period of time in mid to late August (Fig. 1). This period generally came shortly after fruit harvest. Researchers have reported increased water use with heavy fruit loads (Chalmers *et al.*, 1983) so it would be reasonable to expect a decrease in water use after the fruit are removed. However, the Kc values tended to return to preharvest levels by the end of September so the postharvest dip was only temporary. Also, we generally observed (but did not quantify) some abscission of interior, shaded leaves right after harvest. Again, it might be expected that whole tree transpiration would be decreased by the abscission of these leaves, although the degree would depend on light interception and energy balance factors. More detailed studies are needed to determine the physiological factors that may be affecting tree water use during and shortly after fruit harvest.

Light interception at midday by the canopy was the one parameter that was able to account for the greatest amount of variability in the Kc values (Fig. 2) according the following equation:

$$Kc = 0.082 + 1.59 \cdot (\text{Proportion midday light interception}),\ R^2 = 0.86 \qquad (1)$$

It accounted well for the year-to-year variability (1990 had lower Kc and correspondingly lower light interception values than the other 4 years) and the seasonal variability (increasing Kc values correlated well with increasing light interception). Overall, 86% of the total variability was accounted for by this one factor. Attempts to account for the remaining 14% of the variability, which was mainly due to day-to-day and week-to-week variations, were largely unsuccessful. Using multiple regression, factors such as maximum air temperature (+), vapor pressure deficit (+), wind speed (-) and solar radiation (-) were statistically significant but only accounted for an additional 1 to 2% of the variability and thus are of questionable practical usefulness. It is possible that some random variability associated with the ETo calculations, weather station microclimate (which may be different from the orchard microclimate) and accuracy of the weather station instruments could account for the remaining 14% variability. Also, based on energy balance theory, the effect of individual environmental factors on tree Kc values would not be expected to be linear or independent of other factors (Annandale and Stockle, 1994). Therefore, multiple regression would probably not be a very effective tool for quantifying the significance of these environmental factors. Instead, it would probably be much more useful to model the expected effect of all the environmental factors combined and compare the model results to the actual value.

From a practical perspective, irrigation scheduling of peach trees based on regional weather station generated ETo and a simple canopy light interception model will usually be adequate. However, from an academic perspective it would be useful to test whether the predicted effects of environmental factors on tree crop coefficients could be validated. To do this would require placing well calibrated weather instruments in the same orchard as the lysimeter and using detailed energy balance computer models.

Several sources of data suggest the relationship between crop coefficients and canopy light interception obtained in this experiment might be fairly universal for different species and tree ages. For example, a similar weighing lysimeter at the Kearney Agricultural Center but planted to grapes generated an almost identical relationship (L. E. Williams, unpublished data). Also, Fereres *et al.* (1982) used percent shaded area under the tree (which is essentially the same as percent light interception by the canopy) to predict young almond tree water use as a proportion of mature tree Kc. Using a peak Kc of 0.92 from their early studies (Snyder *et al.*, 1989), this relationship is again almost identical to the one we obtained with the peach lysimeter.

The differences in the seasonal peach tree Kc pattern from this experiment and the pattern published for deciduous fruit trees (Snyder *et al.*, 1989) may be due to canopy light interception. The published Kc values were developed using mainly almond as the tree species. Almond has a spur type growth habit and therefore develops a canopy much more quickly than peach trees in the spring. This may be why it initially has greater Kc values than peach trees. Once the spur canopy is developed, almond trees don't tend to produce much vigorous shoot growth, while peach trees continue to grow vigorously into the summer. Therefore, by mid season, one might expect peach trees of a given size to have greater light interception than almond trees of the same dimension. Again, the Kc values reflect these expected differences. The experiments discussed here were all conducted within the same climatic zone of California. It would be valuable to test this relationship in other climatic zones to see if it can be universally applied.

Evapotranspiration includes both tree transpiration and soil evaporation. The amount of soil evaporation depends on the type and frequency of irrigation especially for young trees or in early spring when canopy light interception is low. For our experiment, irrigation events occurred frequently but only wet about 20 to 25% of the soil area assigned to the tree. In an attempt to separate the two components of ET, the surface area of the lysimeter was covered with a plastic tarp one or two days per month during the growing season. On these days, it was presumed the lysimeter was measuring only tree transpiration. The regression of Kc vs canopy light interception on these dates produces a line parallel to equation (1) discussed above (Fig. 3):

$$Kc = 0.007 + 1.48 \cdot (\text{Proportion midday light interception}),\ R^2 = 0.93 \qquad (2)$$

This suggests soil evaporation under the irrigation regime of this experiment was a fairly constant amount no matter what the proportion of light interception by the tree canopy. One might expect this evaporation to be larger under conditions of low light interception by the canopy since more radiation would reach the soil. However, under these conditions, irrigation events were less frequent, thus allowing the soil to dry out somewhat between irrigations. Also, the soil area wetted by the irrigation system was directly under the tree which was often in shade even when canopy light interception was low in the early spring. It would be useful to separate out the soil evaporation component of ET, to enable predicting ET with different irrigation systems. Tree transpiration would primarily be a function of canopy light interception and soil evaporation could be reasonably predicted from information on size of the wetted area and frequency of irrigation (Ritchie and Johnson, 1990).

In summary, the relationship between canopy light interception and Kc values seems to be quite universal and accounts for much of the variability in mature tree water use. It appears to account for differences in tree size and the development of the canopy over the season. It might also be useful for trees of varying ages, tree structure, and spacing, and may even apply across different species of trees and vines. Since it is quite an easy parameter to measure, this could simplify the prediction of ET for fruit trees. Rather than having tables with different leaf out dates, different ages, different leaffall dates etc., one would only need a single equation converting light interception readings into Kc values.

References

Allen R.G., Pereira L.S., Raes D., and Smith M. 1998. Crop evapotranspiration. Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56. 300 pgs.

Annandale J.G., and Stockle C.O. 1994. Fluctuation of crop evapotranspiration coefficients with weather: a sensitivity analysis. Irrig. Sci. 15: 1-7.

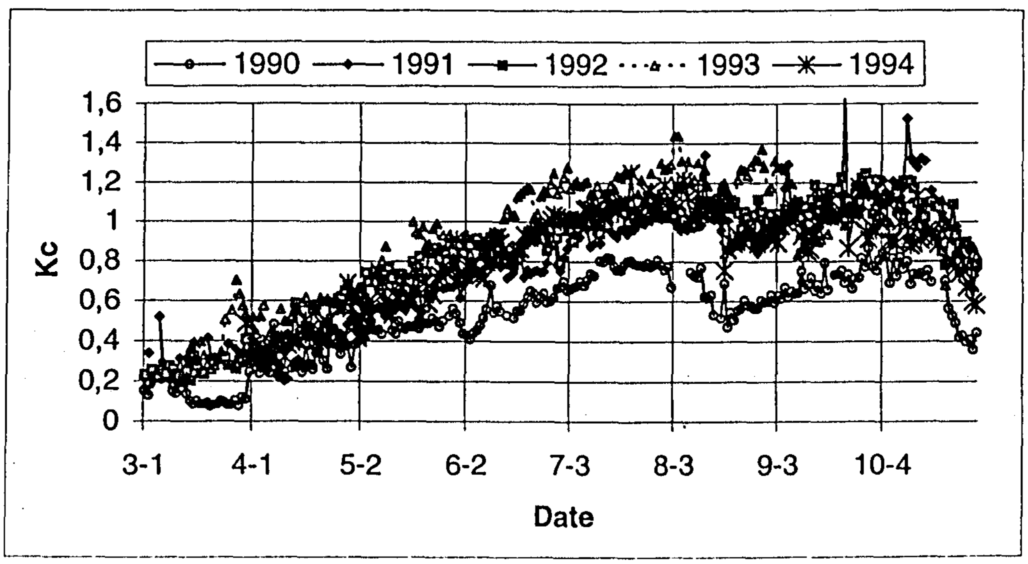
Chalmers D.J., Olsson K.A., and Jones T.R. 1983. Water relations of peach trees and orchards. In: Water Deficits and Plant Growth. Vol. VII. T. T. Kozlowski (ed.). Acad. Press.

DeJong T.M., Day K.R., Doyle J.F., and Johnson R.S. 1994. The Kearney Agricultural Center perpendicular "V" (KAC-V) orchard system for peaches and nectarines. HortTech. 4(4):362-366.

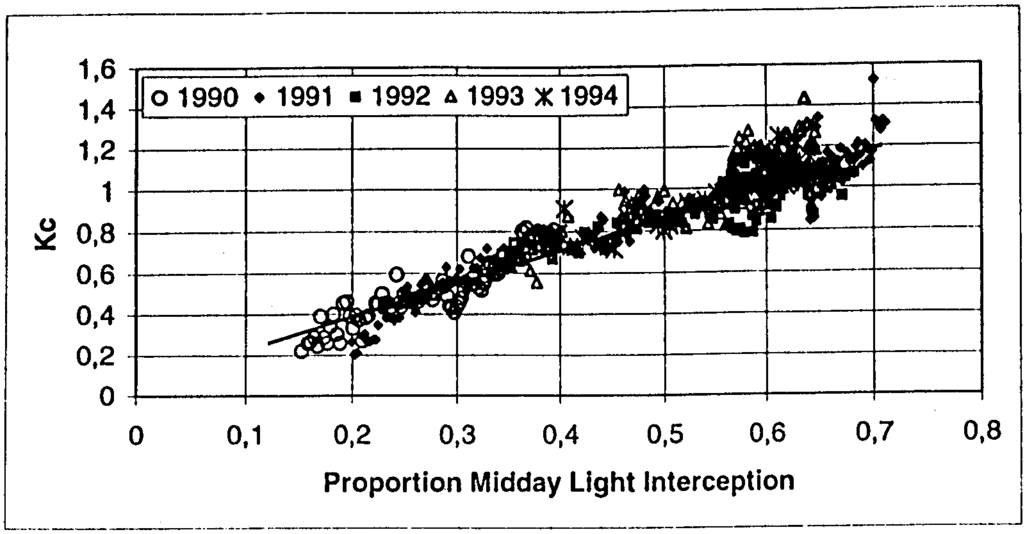
Fereres E., Martinich D.A., Aldrich T.M., Castel J.R., Holzapfel E., and Schulbach H.

1982. Drip irrigation saves money in young almond orchards. Cal. Ag. 36: 12-13.
Jarvis P.G. 1985. Coupling of transpiration to the atmosphere in horticultural crops: the omega factor. Acta Hort. 171: 187-205.
Phene C.J., Hoffman G.J., Howell T.A., Clark D.A., Mead R.M., Johnson R.S., and Williams L.E. 1991. Automated lysimeter for irrigation and drainage control. Lysimeters for Evapotranspiration and Environmental Measurements, IR Div. ASCE, Honolulu, HI. July 23-25.
Ritchie J.T., and Johnson B.S. 1990. Soil and plant factors affecting evaporation. In: Irrigation of Agricultural Crops. B.A. Stewart and D.R. Nielsen (eds.). ASA, CSSA, SSSA Publishers, Madison, WI.
Snyder R.L., and Pruitt W.O. 1992. Evapotranspiration data management in California. In: Irrigation & Drainage Session Proceedings/Water Forum '92. Baltimore, MD. Aug. 2-6.
Snyder R.L., Lanini B.J., Shaw D.A., and Pruitt W.O. 1989. Using reference evapotranspiration (ETo) and crop coefficients to estimate crop evapotranspiration (ETc) for trees and vines. Cooperative Extension University of California, Div. of Agriculture and Natural Resources, Leaflet 21428.

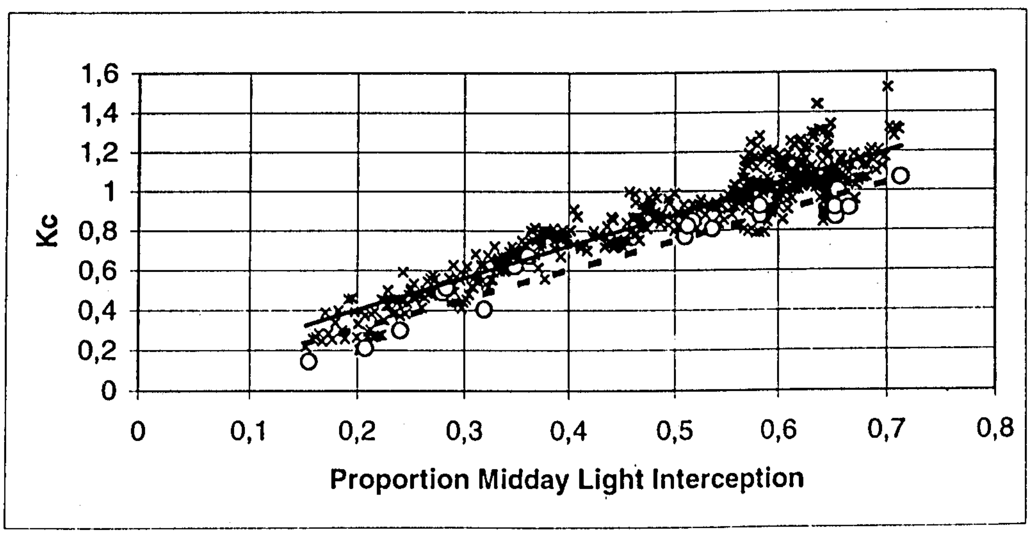
Figures



1. The pattern of crop coefficients (Kc) for mature O'Henry peach trees as measured by a weighing lysimeter from 1990 to 1994.



2. The relationship between mature peach tree crop coefficients (Kc) and the proportion of available light intercepted by the canopy at midday. Equation of the regression line is $y = 1.59x + 0.082$, $R^2 = 0.86$.



3. Mature peach tree crop coefficients (Kc) measured when the lysimeter surface was covered (o) or uncovered (x), plotted against the proportion of available light intercepted by the canopy at midday. Equation of the regression line with the lysimeter covered (- -) is: $y = 1.48x + 0.007$, $R^2 = 0.93$. Equation of the regression line with lysimeter uncovered (–) is given in Figure 2.