Deficit irrigation of peach trees to reduce water consumption

D. Wang
USDA-ARS, Water Management Research Unit Parlier, California, USA

Abstract

Lack of water is a major limiting factor for production tree fruits such as peaches in the San Joaquin Valley of California and many other arid- or semi-arid regions in the world. Deficit irrigation can be used in some cropping systems as a water resource management strategy to reduce non-productive water consumption. A difficulty in using deficit irrigation is the lack of techniques for quickly and accurately measuring plant water status so as not to cause irreversible damage on the plants, especially in perennial species such as vine and tree crops. Field measurements and analyses were carried out in a multi-year experiment to evaluate deficit irrigation strategies for managing postharvest reduced water application of peach trees. Micrometeorological variables were collected near the center of the orchard for energy balance computations and infrared temperature sensors were installed in different field areas which received full or deficit irrigation treatments. Results indicated that with approximately 30-40% of the full seasonal water use, deficit irrigation with furrows produced peach yield similar to full irrigation. With subsurface drip irrigation, deficit water application at 25-30% of the full rate reduced the yield in the first year but not the second year. Smaller fruit sizes were found under the severe deficit treatment in the subsurface drip irrigation method. Measured midday canopy to air temperature differences in the water-stressed postharvest deficit irrigation treatments were consistently higher than that in the full irrigation control treatments. Crop water stress index was estimated and consistently higher values were found in the deficit irrigation than in the full irrigation control treatments. The study clearly showed that with carefully measured water stress levels, deficit irrigation is a potential management strategy for reducing water consumption in growing peaches.
Keywords: crop water use, water management, canopy temperature, evapotranspiration, water productivity.

WIT Transactions on Ecology and the Environment, Vol 145, © 2011 WIT Press
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/WRM110431

1 Introduction

Fresh water is becoming less available to agriculture with increasing demands from urban, industrial, and environmental or recreational needs. In addition, a generally accepted weather pattern in recent decades is the reduced total annual precipitation such as in a pre-longed drought or increased frequency in extreme precipitation events that exceeds the surface water storage capacities resulting in loss of water for agriculture use during peak water demand period of the growing season. For perennial crops, a controlled plant water stress could be used to improve carbohydrate partitioning from the non-reproductive parts to reproductive parts such as fruits or berries thus increasing the yield or used as a strategy to control excessive canopy growth [1] or used as a technique to manipulate crop quality such as in wine grapes [2, 3]. Deficit irrigation has been studied as a means of reducing total crop water consumption for fruit trees because fruit yield and quality at harvest may not be sensitive to water stress at some developmental stages such as during non-fruit bearing postharvest season [4].

Although the concept and methods have been developed, deficit irrigation is not widely used due partially to the lack of effective and fast methods for measuring plant water stress and determining associated risks of applying deficit irrigation. When crops are managed under deficit irrigation, the margin of error in timing and amount of water application becomes smaller before causing yield losses. Monitoring the soil and plant water status is more critical for reducing risks for causing a crop failure or permanent damage to the trees. However, current established techniques of monitoring the soil and plant water status such as neutron probe readings of soil water profile, stem water potential measurements, or trunk diameter shrinkage measurements are labor intensive, and lack the timeliness needed for day-to-day irrigation decisions [5].

Using a canopy-temperature based approach, the crop water stress index (CWSI) was developed by Jackson et al. [6] and Jackson [7] for annual crops that may be used to quantify water stress in managing deficit irrigation of perennial agricultural crops. A key component in applying CWSI is the measurement of canopy temperature. Sometimes the relative degree of canopy to air temperature difference may be used as an indirect measure of crop water stress. Using canopy temperature measurements, the canopy and air temperature difference was related to the air vapor pressure deficit in peach trees [8] and also reflected in stomatal responses to water stress. Water stress in wine grapes was estimated using CWSI when both thermal and visible images of the vine canopy were measured [9]. In short-seasoned annual crops the canopy temperature based water stress method was applied to measure irrigation uniformity [10] and extended to create water management strategies such as scheduling irrigation for cotton [11].

Approximately 10,000 ha of commercially-grown peach trees in central California depend on irrigation as the primary source of water in the peak summer growing season. A potential solution for managing water shortage is to use deficit irrigation in growth stages not sensitive to some degree of water stress. However, there is limited information available in the literature on managing deficit irrigation in Prunus crops such as peaches. The objective of this study was to evaluate effect of deficit irrigation on yield and quality of early-ripening peaches. CWSI was determined to evaluate the degree of water stress of the deficit irrigation treatments used in the study.

2 Experiment

2.1 Field description

A multi-year field experiment was carried out to evaluate deficit irrigation strategies for managing postharvest reduced water application in peach trees. The deficit irrigation treatments included furrow irrigation and subsurface drip irrigation to replace a portion of the crop evapotranspiration (ETc). For the furrow deficit irrigation treatment, a watering event was initiated when stem water potential approached -2 MPa. For the subsurface drip deficit irrigation treatment, one fourth of the full amount of ETc was applied during each irrigation event. A non deficit control was used for both the furrow and the subsurface drip treatments where 100% ET was applied for the experiment. The values of ETc were determined by multiplying the potential evapotranspiration (ETp) with crop coefficients for the same variety of peach crop developed from a nearby weighing lysimeter measurements.

The study was conducted during 2007-2009 in a 1.6 ha peach orchard located near Parlier, California, USA. The trees were early-ripening “Crimson Lady” (*Prunus persica (L.)* Batsch) peach trees on “Nemaguard” rootstock planted in April 1999. The trees were spaced 1.8 m apart within rows and 4.9 m between rows. Each treatment plot consisted of three rows with eight trees per row. The middle six trees in the center row were used for measurements, including yield and fruit quality assessments. A total of six replications were used, with each replication including the four irrigation treatments or a total of 24 treatment plots for the study. The soil at the study site is a Hanford sandy loam soil (coarse-loamy, mixed, thermic Typic Xerorthents).

To facilitate water stress assessment, canopy temperature was measured from 12 of the 24 treatment plots (or three replications per irrigation treatment) using infrared thermometers. These temperature sensors were installed in each plot by mounting them on galvanized metal pipes extending above the orchard canopy. The center of field of view for each sensor was aimed at the middle three trees of the center row for each measurement plot. The aiming was achieved by mounting a webcam camera in parallel with the infrared sensors. A datalogger system was used to record temperature readings.

2.2 Evapotranspiration and CWSI calculations

To compute ET_p for irrigation scheduling and CWSI for water stress, air temperature and other meteorological parameters were obtained from a weather station installed near the center of the orchard. Estimation of ET_p was carried out with the modified Penman-Monteith equation [12]:

$$ET_p = \frac{s(R_n - G) + \gamma^* \lambda\, g_v D_v / p_a}{s + \gamma^*} \tag{1}$$

where s = slope of the saturation model fraction at apparent atmospheric pressure (p_a), R_n=net radiation, G=soil heat flux, γ^* = apparent psychrometer constant, λ = latent heat of vaporization of water, g_v = vapor conductance of the canopy, and D_v = vapor pressure deficit. Parameters s and D_v are determined using measurements of air temperature (T_a) and relative humidity (h_r) and the Tetens formula for saturation vapor pressure:

$$s = \frac{abc}{p_a(c + T_a)^2} \exp\left(\frac{bT_a}{c + T_a}\right) \tag{2}$$

$$D_v = a\,(1 - h_r)\exp\left(\frac{bT_a}{c + T_a}\right) \tag{3}$$

where coefficients a = 0.611 kPa, b = 17.502, and c = 240.97 °C.

Vapor conductance of the canopy (g_v) was computed from stomatal conductance (g_s) and boundary layer aerodynamic conductance (g_a):

$$g_v = \frac{1}{\frac{1}{g_s} + \frac{1}{g_a}} \tag{4}$$

The aerodynamic conductance was calculated using

$$g_a = \frac{k^2 \hat{\rho}\, u(z)}{\left[\ln\left(\frac{z-d}{z_M}\right) + \Psi_M\right]\left[\ln\left(\frac{z-d}{z_H}\right) + \Psi_H\right]} \tag{5}$$

where k = von Karman constant (0.4), $\hat{\rho}$ = molar density of air, u=wind speed, z = height of wind measurement, d = zero-plane displacement height, $z_{M,H}$ and $\Psi_{M,H}$ are roughness lengths and profile diabatic correction factors for momentum and heat, respectively.

The crop water stress index (CWSI) was computed using the energy balance method of Jackson [7]:

$$CWSI = \frac{\gamma\left(1 + \frac{g_a}{g_c}\right) - \gamma^*}{\Delta + \gamma\left(1 + \frac{g_a}{g_c}\right)} \tag{6}$$

$$\frac{g_a}{g_c} = \frac{\frac{\gamma}{g_a}\left(\frac{R_n}{\rho c_p}\right) - (T_c - T_a)(\Delta + \gamma) - D_v}{\gamma\left[(T_c - T_a) - \frac{1}{g_a}\left(\frac{R_n}{\rho c_p}\right)\right]} \tag{7}$$

$$\Delta = \frac{bc\, e_s\left(\overline{T}\right)}{\left(c + \overline{T}\right)^2} \tag{8}$$

where γ is psychrometric constant (0.0652 kPa $^{o}C^{-1}$), e_s = saturation vapor pressure at $\overline{T}$ = $(T_c + T_a)/2$, and T_c and T_a are canopy and air temperature, respectively.

2.3 Peach harvest measurements

Peach fruit yield was measured in 2008 and 2009 from the center six trees of the 24 treatment plots. Fruits were picked by a local commercial harvesting crew following typical farming procedures. A total of three picks, about three days apart, were used during each season. The total number of peaches per tree and weight per tree were measured for each treatment plot. Average weight per fruit or fruit size was obtained by dividing the weight per tree with number peaches per tree. Statistical comparisons were made for weight per tree and fruit size between different irrigation methods and deficit treatments for each year.

3 Results and discussion

Because each year peach harvest was completed near the end of May, therefore the deficit irrigation treatments were initiated near the beginning of June and lasted until about November when irrigation was no longer needed. The cumulative irrigation applied for the 2007 and 2008 postharvest season (June – November) is summarized in Table 1. As shown in the table, under furrow irrigation the 100% ET treatment required more than 1000 mm of water during this period. The deficit furrow treatment received 39% and 33% of the full irrigation in 2007 and 2008, respectively. Under subsurface drip irrigation, the 100% ET treatment required approximately 900 mm of water. The deficit subsurface drip treatment received only 25% and 30% of the full irrigation amount in 2007 and 2008, respectively. The imposed deficit irrigation treatments clearly received a significantly reduced amount of irrigation water than the full irrigation control treatments.

To delineate the seasonal changes in irrigation water application with respect to the crop water needs or ET, the cumulative ET and irrigation in 2008 was compared in Figure 1 for the duration of 1 March to 30 September 2008. The figure clearly shows the initiation of deficit irrigation after 30 May where the cumulative amount of irrigation in furrow and subsurface drip deficit treatments started to fall behind the full irrigation (100% ET) treatments. Also seen

Table 1: Cumulative irrigation applications during June-November.

Treatment	2007 (mm)	2007 (%)	2008 (mm)	2008 (%)
Furrow, 100% ET	1030	100	1111	100
Furrow, deficit	405	39	366	33
Subsurface drip,100% ET	977	100	870	100
Subsurface drip, deficit	241	25	259	30

from the figure is that the furrow and subsurface drip deficit treatments tracked well on the graph and the final total amounts were 366 and 259 mm, respectively. The furrow full irrigation treatment appeared to follow the ETp while the subsurface drip full irrigation matched the ETc curve. This discrepancy is likely attributed to differences in methods of irrigation, e.g. furrow vs. subsurface drip, and the actual operation of the irrigation management during the experiment.

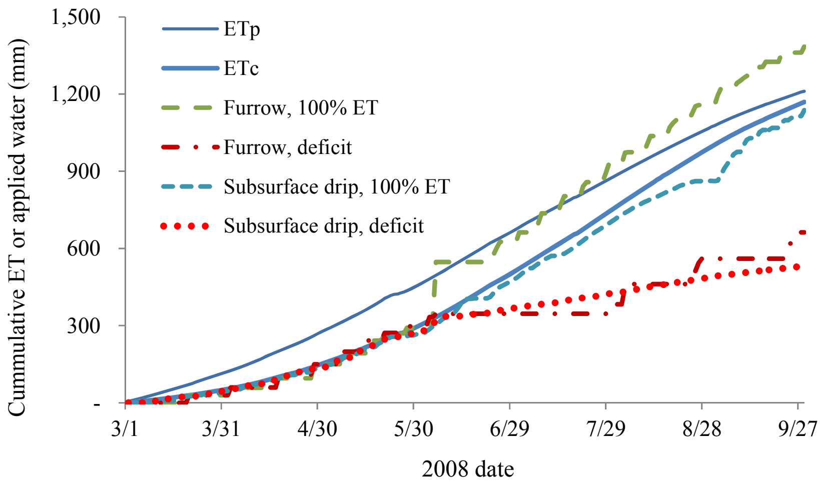

Figure 1: Cumulative potential evapotranspiration (ETp), crop ET (ETc), and applied irrigation water for the 100% ET (non-deficit) and deficit treatments by furrow and subsurface drip irrigation methods.

No statistical difference was found in fruit weight per tree between the deficit irrigation and 100% ET treatments with furrows in either 2008 or 2009 (Table 2). With subsurface drip irrigation, the deficit irrigation treatment reduced peach yield in 2008 but not significantly different from the 100% ET treatment in 2009. The weight per fruit was not different between the deficit irrigation and 100% ET treatments with furrows in 2008 but smaller fruits were found in 2009. With subsurface drip irrigation, the deficit irrigation treatment reduced peach fruit size in both 2008 and 2009. These results indicate that deficit irrigation with furrow application triggered at -2 MPa stem water potential did not cause yield losses (weight per tree or per area basis). Deficit irrigation by subsurface drip at 25% ETc could lead to yield losses (significantly reduced yield for one year but not the second year). The different response to deficit irrigation between furrow and drip irrigation may be attributed to the numeric differences in cumulative amount of irrigation water applied: 405 mm vs. 241 mm in 2008 and 366 mm vs. 259 mm in 2009 (Table 1). The severe deficit likely exceeded the stress threshold in the drip treatments whereas the furrow deficit irrigation was on the bounder before causing yield losses. The other possibility that led to different response to deficit irrigation between furrow and drip irrigation may be reduced wetting in the root zone when water was applied more frequently and delivered via point-source emitters compared to furrows that applied water less frequently that would generate deeper penetration or infiltration of irrigation water so less prone to water stress.

Table 2: Fruit yield after deficit irrigation. Different letters indicate statistical significance at P = 0.05 using the Tukey's studentized range (HSD) test.

Treatment	2008 weight (kg/tree)	2008 size (g/fruit)	2009 weight (kg/tree)	2009 size (g/fruit)
Furrow, 100% ET	22a	123a	12a	128a
Furrow, deficit	22a	121ab	11a	120bc
Subsurface drip,100% ET	21a	124a	11a	126ab
Subsurface drip, deficit	18b	115b	10a	118c

Deficit irrigation treatments clearly increased peach canopy water stress shown as higher CWSI values than in the non-water stressed 100% ET treatments with both furrow and subsurface drip irrigation. For example, in 2008 similar CWSI values (0.5-1.5) were found among all irrigation treatments at the beginning of the postharvest season (i.e., 1 June, Figure 2). Whereas the CWSI values remained about 0-0.1 from 1 June to 15 August 2008 in the 100$ ET control treatments, the stress index increased to approximately 0.4 for furrow deficit and 0.3 for drip deficit in July 2008. The comparison showed that CWSI may be used as an indicator to monitor water stress when applying deficit irrigation in peaches.

The study showed that deficit irrigation is a potential management technique for reducing crop water use at non critical stages of growth. The questions remain in the determination of optimum amount of deficit without causing yield losses or losses in product quality, such as fruit size. There is likely a crop specific effect on the tolerable deficit but fundamental physiological principles may be applied to extrapolate to different crop types. The other question is the

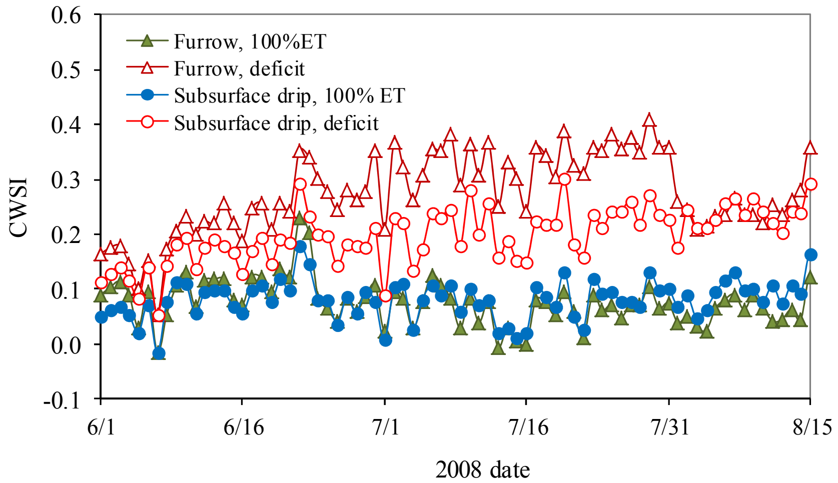

Figure 2: Daily crop water stress index (CWSI) calculated for 1300 hour pacific standard time in 2008 of both non-deficit and deficit irrigation treatments.

timing for applying deficit irrigation. For some crops the timing could be critical in minimizing risks in yield and quality losses. A basic assumption for any deficit irrigation is that soil water will be replenished some time during a hydrologic cycle such as through large precipitation or man-made infiltration events.

References

[1] Chalmers, D.J., Mitchell, P.D. & van Heek, L., Control of peach tree growth and productivity by regulated water supply, tree density and summer pruning. *Journal of American Society of Horticultural Science,* **106,** pp. 307-312, 1981.

[2] Williams, L.E., Dokoozlian, N.K. & Wample, R., Grape. *Handbook of Environmental Physiology of Fruit Crops,* eds. B. Schaffer & P.C. Andersen, CRC Press, Inc., Baco Raton, FL, 1994.

[3] Bravdo, B. & Naor, A., Effect of water regime on productivity and quality of fruit and wine. *Acta Hort,* **27,** pp. 15-26, 1996.

[4] Johnson, S.R. & Handley, D.F., Using water stress to control vegetative growth and productivity of temperate fruit trees. *HortScience,* **35,** pp. 1048-1050, 2000.

[5] Goldhamer, D.A., Fereres, E., Mata, M., Girona, J. & Cohen, M., Sensitivity of continuous and discrete plant and soil water status monitoring in peach trees subjected to deficit irrigation. *Journal of American Society of Horticultural Science,* **124,** pp. 437-444, 1999.

[6] Jackson, R.D., Idso, S.B., Reginato, R.J. & Pinter, Jr., P.J., Canopy temperature as a crop water stress indicator. *Water Resource Research,* **17,** pp. 1133-1138, 1981.
[7] Jackson, R.D., Canopy temperature and crop water stress. *Advances in Irrigation*, **1,** pp. 43-85, 1982.
[8] Glenn, D.M., Worthington, J.W., Welker, W.V. & McFarland, M.J., Estimation of peach tree water use using infrared thermometry. *Journal of American Society of Horticultural Science,* **114,** pp. 737-741, 1989.
[9] Moller, M., Alchanatis, V., Cohen, Y., Meron, M., Tsipris, J., Naor, A., Ostrovsky, V., Sprintsin, M. & Cohen, S., Use of thermal and visible imagery for estimating crop water status of irrigated grapevine. *Journal of Experimental Botany,* **58,** pp. 827-838, 2007.
[10] Sadler, E.J., Camp, C.R., Evans, D.E. & Millen, J.A., Corn canopy temperature measured with moving infrared thermometer array. *Transactions of American Society of Agricultural Engineers,* **45,** pp. 581-591, 2002.
[11] Wanjura, D.F. & Upchurch, D.R., Accounting for humidity in canopy-temperature-controlled irrigation scheduling. *Agricultural Water Management,* **34,** pp. 217-231, 1997.
[12] Campbell, G.S. & Norman, J.M., *An Introduction to Environmental Biophysics*. 2nd Edition. Springer, New York, NY, 1998.