The reduction of the recommended rate of Triton CS-7 *from 1 quart* per 100 gallons of water to 1 pint per 100 gallons of water did not show the definite enhancement of mite reduction as shown in the 1987 test. However, based on previous results, the addition of CS-7 at its recommended rate of 1 quart per 100 gallons of water could be beneficial in the reduction of citrus red mite populations and an enhancement of the effectiveness of various miticides.

Literature Cited

1. Bourgeois, W. J. 1983. Orange, citrus red mite control. Entomol. Soc. of Amer. Insecticide and Acaricide Test. 9:92.
2. Bourgeois, W. J. 1983. Mandarin, citrus red mite control. Entomol. Soc. of Amer. Insecticide and Acaricide Tests. 9:82.
3. Bourgeois, W. J., R. N. Story, and A. J. Adams. 1984. Evaluation of miticides for the control of citrus red mites *Panonychus citri* (Mc Gregor) on Washington navel oranges in Louisiana. HortScience 19 (2) 202. (Abstr.)
4. Story, R. N. and W. J. Bourgeois. 1984. Orange, red mite control on citrus. Entomol. Soc. of Amer. Insecticide and Acaracide Tests. 10:52.
5. Story, R. N. and W. J. Bourgeois. 1986. Citrus red mite control on 'Washington' navels in Louisiana. Entomol. Soc. of Amer. Insecticide and Acaracide Tests. 12:85.
6. Story, R. N. and W. J. Bourgeois. 1987. Citrus red mite control on 'Owari' satsuma in Louisiana. Entomol. Soc. of Amer. Insecticide and Acaracide Tests. 13:72.

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COMPARISON OF TWO METHODS OF ESTIMATING POTENTIAL CITRUS EVAPOTRANSPIRATION

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Abstract. **Chronic periods of dry weather have lead to irrigation water shortages in southwest Florida. Proper irrigation scheduling of citrus groves, which are major water-users in the region, can decrease water consumption and may delay any mandatory cut-backs in use by regulatory agencies. A major input into water-budget methods of irrigation scheduling is an estimate of potential crop evapotranspiration (ET_p). A comparison of ET_p estimates from weather data using the Penman equation and evaporation pan measurements was made in this study. Linear correlation analysis of average daily, weekly, and monthly ET_p values between the two methods gave correlation coefficients of 0.74, 0.89, and 0.96, respectively, even with the point of weather data acquisition and the evaporation pan separated by approximately 12 km. Daily ET_p calculated from pan evaporation was about 1 mm day^{-1} higher than that calculated with the Penman equation. Either method of estimating ET_p would be suitable for use in current irrigation scheduling models, giving growers a choice in the type of apparatus they might acquire.**

The expansion of irrigated citrus acreage in southwest Florida in combination with chronic periods of dry weather have led to recent irrigation water shortages. This situation is not expected to improve, and will probably worsen with time as competition for limited water resources increases. Current irrigation research and educational programs promote the use of quantitative, water-budget irrigation scheduling techniques as opposed to the more qualitative methods traditionally used by growers. Proper scheduling of irrigations can decrease water consumption and may delay any mandatory cut-backs in use by regulatory agencies.

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A major input into water-budget methods of irrigation scheduling is the estimate of daily crop potential evapotranspiration (ET_p). An accurate value for this parameter is not easily obtainable. The Penman method uses a predictive equation (3, 4) to obtain ET_p. This equation requires the input of daily meteorological parameters usually obtained from electronic weather stations. The Penman method has proven to be accurate under a wide variety of climatic conditions worldwide, however, it requires a substantial initial investment for specialized equipment. Another option to estimate daily ET_p involves the measurement of pan evaporation (3, 6). This usually requires a National Weather Service standard evaporation pan and water level measuring equipment.

Past research has shown good agreement between monthly ET_p values estimated using these two methods in a citrus grove on Florida's east coast (5). The current study was undertaken to: 1) compare daily, weekly, monthly, and annual ET_p values calculated using the Penman equation and pan evaporation in southwest Florida; 2) determine which form of the Penman equation gave ET_p values which correlated best with those calculated using pan evaporation;, and 3) compare 1 yr of ET data from southwest Florida to an 8-yr average measured in a developing citrus grove at Ft. Pierce on the east coast of Florida.

Materials and Methods

This study covered a period of 12 months from April 1988 through March 1989 in which climatic conditions were much drier than normal. Meteorological data were obtained from an electronic weather station of a LaBelle, FL citrus grower located approximately 12 km north of the Southwest Florida Research and Education Center (SWFREC) at Immokalee. The weather station was situated within a mature citrus grove, surrounded immediately by weeds and grass of varying height. The data recording equipment was an Omnidata Easylogger system, which scanned its climatic sensors every 3 min. At 2400 hours (midnight) each day, maximum and minimum air temperature, total daily solar radiation, and average daily wind speed were recorded. Penman daily ET_p was calculated using four variations of the equation. Two expressions for net outgoing thermal radiation were used: that originally proposed by Penman (4), and that suggested by Doorenbos and Pruitt (1). ET_p was then either calculated directly using an albedo value of 0.23, or indirectly using an albedo value of 0.05. (The latter method calculates ET_p by first estimating evaporation from a free water surface, then converting to the potential ET value by multiplying by a coefficient $k_1 = 0.70$). Detailed information on the Penman equation as used above and associated methods can be found in the Appendix and in IFAS Bulletin 840 by Jones et al. (3).

Daily pan evaporation was measured at the SWFREC at approximately 0800 hr, Monday through Friday using a standard National Weather Service Class A pan (unscreened). The pan was situated on a wood pallet over low-cut grass vegetation. ET_p was calculated by multiplying the daily pan evaporation by a pan coefficient of 0.75 as suggested by previous research (3,6). Daily ET_p values for Friday, Saturday, and Sunday of each week were estimated by dividing the value obtained from the Monday reading by 3.

Linear regression equations were calculated and degree of correlation was examined for the relationships between the ET_p values estimated using each method on a daily, weekly, and monthly basis. Monthly and total ET_p for the 12-month period was compared to that measured by Rogers et al. (5) at Ft. Pierce for the period 1973-1980.

Results and Discussion

Resulting regression equations and associated correlation coefficients (r) for the simple linear correlation analysis of pan evaporation ET_p and Penman ET_p are shown in Table 1. The correlation of daily values was good, considering that the pan evaporation ET_p values for three out of seven days of each week were estimated by averaging. This source of error was eliminated when weekly values were considered, and the correlation coefficients increased substantially. Highest correlation was seen with monthly values, as expected.

Figs. 1-3 show daily Penman ET_p values (calculated using the Doorenbos and Pruitt expression for net outgoing thermal radiation and albedo = 0.05) plotted against those calculated from pan evaporation. These graphs illustrate what is normally seen when averaging ET data over variable time periods, i.e., the scatter of points around the regression line is reduced when increasing the time interval over which ET_p is estimated.

Regression coefficients in Table 1 varied between 0.90 and 1.06 where Penman ET_p was calculated indirectly by first estimating the evaporation from a free water surface (albedo = 0.05). This is the recommended method to estimate daily ET_p in Florida due to the difficulty in estimating seasonal changes in surface albedo (3). Although the slope indicated a relationship between the two methods close to 1:1, the intercept term varied between 0.77 and 1.38 mm day^{-1}, indicating that higher ET_p was estimated with pan evaporation as compared to the Penman equation. The 0.75 pan coefficient was recommended for Florida's average climatic conditions (3, 6). Irrigation scheduled using this coefficient would have resulted in approximately 10% greater application of water than what would have been applied using the Penman method.

A lower pan coefficient may have been justified given the extreme drought conditions that prevailed during the observation period. Pan coefficients of 0.50 to 0.70 are often used in arid regions. Local exposure conditions of the evaporation pan can also affect evaporation measurements (1,). Thus, these initial data suggest the possibility of a flexible pan coefficient. A wet season and dry season pan coefficient may also be justified for inland areas re-

Table 1. Linear regression equations and associated correlation coefficients determined from the relationship between ET_p calculated from pan evaporation (Y) and ET_p calculated from four different forms of the Penman equation (X).

Equation type	Albedo	Regression equation	r
		Daily values (n = 368)	
D & P[z]	0.05	Y = 0.93 X + 0.77	0.74**
D & P	0.23	Y = 0.80 X + 0.78	0.74**
Penman[y]	0.05	Y = 0.90 X + 1.06	0.73**
Penman	0.23	Y = 0.62 X + 1.08	0.73**
		Weekly values (n = 52)	
D & P	0.05	Y = 1.06 X + 0.85	0.89**
D & P	0.23	Y = 0.90 X + 0.94	0.89**
Penman	0.05	Y = 0.98 X + 1.32	0.87**
Penman	0.23	Y = 0.68 X + 1.32	0.87**
		Monthly values (n = 12)	
D & P	0.05	Y = 1.05 X + 0.87	0.96**
D & P	0.23	Y = 0.89 X + 0.98	0.96**
Penman	0.05	Y = 0.96 X + 1.38	0.94**
Penman	0.23	Y = 0.67 X + 1.38	0.94**

[z]Expression for net outgoing thermal radiation in Penman equation from Doorenbos and Pruitt (1).
[y]Expression for net outgoing thermal radiation in Penman equation from Penman (4).
** indicates significance at the 0.01 level.

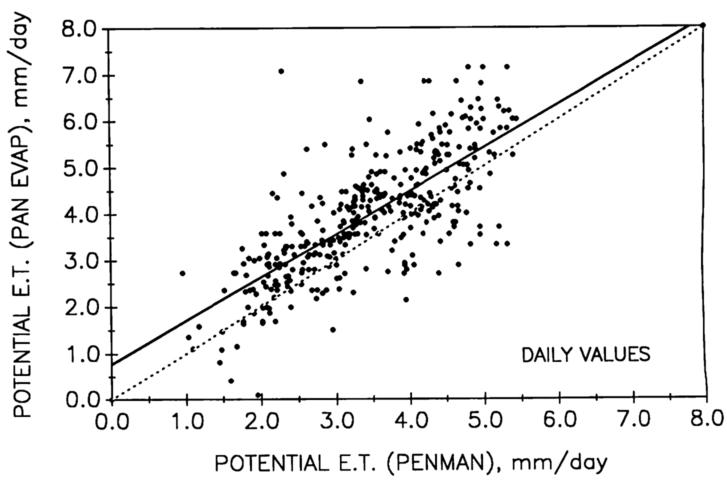

Fig. 1. Relationship between daily ET_p calculated from pan evaporation (Y) and Penman ET_p (X) (Calculated using Doorenbos and Pruitt expression for net outgoing thermal radiation and albedo = 0.05). Regression equation is Y = 0.93 X + 0.77, r = 0.74. Dashed line indicates perfect 1:1 relationship with Y-intercept = 0.

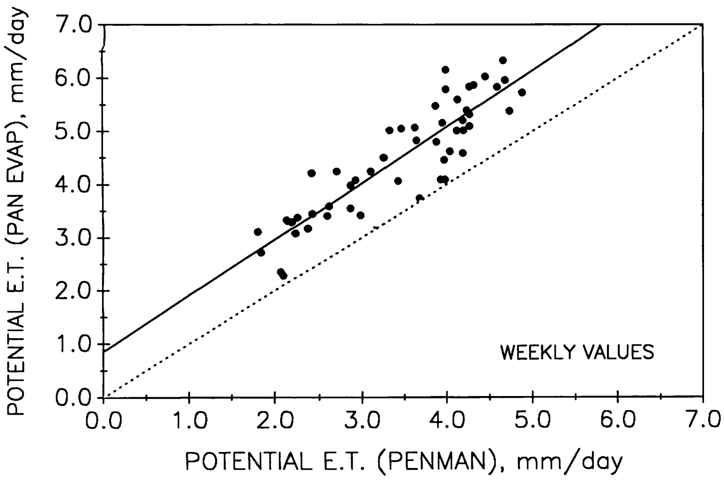

Fig. 2. Relationship between weekly ET_p calculated from pan evaporation (Y) and Penman ET_p (X) (calculated using Doorenbos and Pruitt expression for net outgoing thermal radiation and albedo = 0.05). Regression equation is Y = 1.06 X + 0.85, r = 0.89. Dashed line indicates perfect 1:1 relationship with Y-intercept = 0.

Table 2. Average monthly ET_p for southwest Florida (Apr 1988-Mar 1989) compared to an 8-yr average for Ft. Pierce, FL.

	S. W. Florida 1988			Ft. Pierce[z] 1973-80	
Month	Penman	Penman	Pan Evap	Penman	Pan Evap
albedo	0.05	0.23	——	0.23	——
k_l	0.70	——	——	——	——
k_p	——	——	0.75	——	0.80
	------------ ET_p, mm day^{-1} ------------				
Jan	2.2	2.5	3.2	2.2	2.2
Feb	2.9	3.3	4.0	2.9	2.9
Mar	3.3	3.7	4.6	3.7	3.9
Apr	4.3	4.9	5.5	4.8	4.8
May	4.4	5.1	5.9	4.5	4.4
Jun	4.5	5.2	5.5	4.5	4.3
July	4.1	4.7	4.8	4.3	4.2
Aug	3.9	4.5	4.7	4.1	4.1
Sep	4.0	4.6	4.9	3.7	3.5
Oct	3.3	3.7	4.7	3.2	3.5
Nov	2.4	2.8	3.2	2.4	2.4
Dec	2.1	2.3	3.0	1.9	2.0
Annual, mm	1255	1441	1639	1270	1280

[z]From Rogers et al. (5).

moved from the moderating influences of large water bodies.

A comparison of average monthly ET_p values from this study and 8-yr averages from Ft. Pierce, FL are shown in Table 2. At Ft. Pierce, Penman ET_p was calculated directly using an albedo of 0.23, and the evaporation pan coefficient used was 0.80. Penman ET_p from the single year of southwest Florida data was 13% higher than the 8-yr Ft. Pierce average when the same type of equation was used. When southwest Florida Penman ET_p was calculated indirectly (i.e. albedo = 0.05 and k_l = 0.70), there was essentially no difference in the annual comparison.

Pan annual ET_p from southwest Florida in 1988 was 28% higher than that measured at Ft. Pierce from 1973-80. Weather conditions typically differ between coastal and interior areas which can lead to higher ET_p inland (2). However, other factors such as evaporation pan exposure and temporal deviation may have caused the observed difference. Thus, there are limitations to the comparison made here, but these will be eliminated over time as the collection of pan evaporation and climatic data in southwest Florida continues.

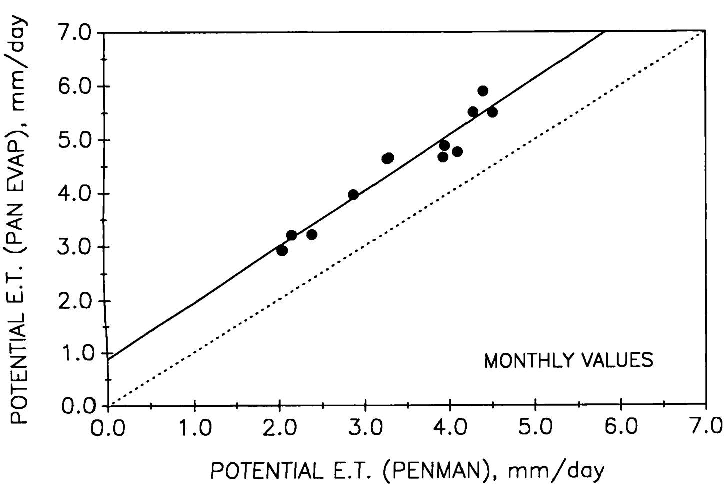

Fig. 3. Relationship between monthly ET_p calculated from pan evaporation (Y) and Penman ET_p (X) (calculated using Doorenbos and Pruitt expression for net outgoing thermal radiation and albedo = 0.05). Regression equation is Y = 1.05 X + 0.87, r = 0.96. Dashed line indicates perfect 1:1 relationship with Y-intercept = 0.

Summary

Potential evapotranspiration calculated based on evaporation pan measurements was significantly correlated with ET_p calculated from weather data under southwest Florida conditions. The correlation improved substantially as the time interval for the calculation of mean values increased.

Pan evaporation ET_p was consistently higher than Penman ET_p (calculated using albedo = 0.05 and k_l = 0.70) by about 1 mm day^{-1}. Normally these two methods estimate ET_p to about the same magnitude, but the distance between the data acquisition sites or dissimilarity in surrounding vegetation and the abnormally low rainfall may have contributed to the difference observed.

Southwest Florida ET_p calculated by either method was higher for the 1-yr period studied than ET_p calculated at Ft. Pierce over an 8-yr period. Coastal ET_p is generally lower than that measured in the interior portions of the state. Future research in southwest Florida should help quantify this difference.

Both methods examined in this study will provide sufficiently accurate data for calculation of daily ET_p, thus citrus growers using water balance irrigation scheduling models have a choice as to which apparatus they might acquire. A weather station, while more expensive, can provide additional climatic data which the grower may find useful for pest management or other purposes. For irrigation scheduling needs only, however, the evaporation pan would probably be the instrument of choice due to its lower cost.

Literature Cited

1. Doorenbos, J., and W. O. Pruitt. 1977. Guidelines for predicting crop water requirements. FAO Irrigation and Drainage Paper 24. FAO of the United Nations. Rome, Italy. 144 pages.
2. Harrison, D. S. 1984. Citrus water use and evapotranspiration (ET) requirements for Florida flatwoods soils. Univ. of Fla. IFAS Ag. Eng. Dept. Ext. Rpt. 84-1.
3. Jones, J. W., L. H. Allen, S. F. Shih, J. S. Rogers, L. C. Hammond, A. G. Smajstrla, and J. D. Martsolf. 1984. Estimated and measured evapotranspiration for Florida climate, crops, and soils. Univ. of Fla. IFAS Bul. 840 (Tech.).
4. Penman, H. L. 1948. Natural evaporation from open water, bare soil, and grass. Proceedings of the Royal Society, Series A. 193:120-145.
5. Rogers, J. S., L. H. Allen, Jr., and D. V. Calvert. 1983. Evapotranspiration from a humid-region developing citrus grove with grass cover. Trans. Am. Soc. Agr. Eng. 26:1778-1783, 1792.
6. Smajstrla, A. G., F. S. Zazueta, G. A. Clark, and D. J. Pitts. 1989. Irrigation scheduling with evaporation pans. Univ. of Fla. IFAS Bul. 254.

APPENDIX

Daily Penman ET_p was calculated as follows:

$$ET_p = (\Delta R_n/\lambda + \gamma E_a)(\Delta + \gamma)^{-1}$$

where ET_p = daily potential evapotranspiration, mm day^{-1}

Δ = slope of saturated air vapor pressure curve, mb °C^{-1}

R_n = net radiation, cal cm^{-2} day

λ = latent heat of vaporization of water, $59.59 - 0.055\ T_{avg}$ cal cm^{-2} mm

E_a = $0.263\ (e_a - e_d)(0.5 + 0.0062 u_2)$

e_a = vapor pressure of air = $(e_{max} + e_{min})/2$, mb

e_d = vapor pressure at dewpoint temperature T_{min}, mb

u_2 = wind speed at height of 2 m, km day^{-1}

γ = psychrometric constant = 0.66 mb °C^{-1}

T_{avg} = $(T_{max} + T_{min})/2$, °C

e_{max} = maximum vapor pressure of air during a day, mb

e_{min} = minimum vapor pressure of air during a day, mb

T_{max} = maximum daily temperature, °C

T_{min} = minimum daily temperature, °C

e_a and e_d as a function of temperature (T) were calculated as follows:

$$e(T) = 33.8639\ [(0.00738 T_{avg} + 0.8072)^8 - 0.000019\ (1.8 T_{avg} + 48) + 0.001316]$$

Δ is calculated as follows:

$$\Delta = 33.8639\ [0.05904\ (0.00738 T_{avg} + 0.8072)^7 - 0.0000342]$$

R_n is calculated as follows:

$$R_n = (1 - a)\ R_s - R_b$$

where R_n = net radiation in cal cm^{-2} day^{-1}

R_s = total incoming solar radiation, cal cm^{-2} day^{-1}

R_b = net outgoing thermal or long wave radiation

a = albedo or reflectivity of surface for R_s

The Penman (4) and Doorenbos and Pruitt (1) methods to calculate R_b are, respectively, as follows:

$$R_b = \sigma T^4\ [0.56 - 0.08 (e_d)^{0.5}]\ (1.42\ R_s/R_{so} - 0.42)$$

$$R_b = \sigma T^4\ [0.329 - 0.037 (e_d)^{0.5}]\ (1.42\ R_s/R_{so} - 0.42)$$

where σ = Stefan-Boltzmann constant (11.71×10^{-8} cal cm^{-2} day °K^{-1}

T = average air temperature in °K (°C + 273)

R_{so} = total daily cloudless sky radiation