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Important Factors to model Climate Change Effects on Evapotranspiration

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Although growers have considerable control over crop production, a major concern is the anticipated increase in evapotranspiration (ET) due to global warming. ET rates, however, are also affected by radiation, humidity, wind speed, crop morphology, and crop physiology in addition to temperature. Crop ET (ET_c) is commonly estimated as the product of reference ET (ET_o) and a crop coefficient (K_c), and the main factors affecting K_c values are net radiation, aerodynamic resistance, and canopy resistance differences between the reference and crop surfaces. The standardized ET_o equation has fixed values for the canopy resistance (r_c), and different values are likely for other crops. The r_c values might also adjust with increasing CO_2 and higher temperature. Aerodynamic resistance (r_a) depends on atmospheric stability, wind speed, and surface roughness. The relative aerodynamic contributions of sensible heat to ET_o and ET_c could change if the canopy development or the wind speed climatology are modified by global warming. In this paper, we will discuss how the ET_o and K_c values vary with microclimate and how K_c values and ET_o rates might react to global warming.

Methodology

The standardized reference evapotranspiration equation was developed to estimate the ET from a "short", 0.12 m height, dense canopy (ET_o) or a "tall", 0.5 m height, dense canopy (ET_r), where both surfaces have known albedo, roughness, and canopy characteristics. Since management factors affect real ET, an equation that perfectly matches the ET of a reference surface will never be found for all management conditions, thereby, justifying the standardized equation for reference ET. A slightly modified version of the standardized daily reference evapotranspiration equation (Allen et al., 2005) using net radiation (R_n) in MJ m^{-2} d^{-1}, mean daily temperature (T) in °C, saturation vapour pressure (e_s) in kPa at the mean air temperature, mean daily actual (e) vapour pressure in kPa, slope of the saturation vapour pressure curve (Δ) in kPa $°C^{-1}$ at the mean daily air temperature, and the psychrometric constant (γ) in kPa $°C^{-1}$ is:

$$ET_o = \frac{0.408(R_n) + \gamma\left(\frac{C_n}{T+273}\right)\left(\frac{e_s - e}{r_a}\right)}{\Delta + \gamma\left(1 + \frac{r_c}{r_a}\right)} \tag{1}$$

where C_n=187200 combines the air density, specific heat, and latent heat of vaporization. The respective canopy resistance values are r_c=70 and r_c=45 s m^{-1} for short and tall canopies, and the aerodynamic resistances are $r_a=208/u_2$ and $r_a=118.3/u_2$ for short and tall canopies, respectively, using wind speed measured at 2 m height (m s^{-1}). Because of rounding, Eq. 1 is slightly different from the daily equation in Allen et al. (2005).

Equation 1 was used to compute ET_o and ET_r values using one year of daily data from 17 California Irrigation Management Information System (CIMIS) stations having widely different climates. Linear regressions of ET_r versus ET_o through the origin were computed to estimate the "local" K_c for 0.5 m height alfalfa. In all cases, the slope of the ET_r versus ET_o regression line closely matched the slope of a line from the origin to the mean July values for ET_r and ET_o. Therefore, the alfalfa K_c values should be closely related to the mean July weather data. A comparison was made by calculating correlation coefficient values between each weather variable and the estimated K_c factors.

Results

Table 1 shows estimated K_c values for alfalfa using all daily data from 2003 for 17 CIMIS stations. The correlation matrix between weather variables and the K_c values is shown in Table 2. Assuming that the slopes are indicative of $K_c = ET_r/ET_o$ at the various locations, Table 2 shows that the K_c is clearly related to ET_o. The poor correlation with R_s, indicates that K_c values differ mainly because of aerodyanamic factors. There are high correlations between T_x and K_c and between e_s-e and K_c, but there is also a high correlation between T_x and e_s-e. Consequently, spatial differences in K_c factor seem to be mainly related to variations in e_s-e. While e_s will rise with global warming, recent decades show no global increase in e_s-e (Roderick & Farquhar, 2000) presumably because the vapour pressure is also rising. Therefore, we expect that alfalfa K_c values will remain relatively constant. Increased stomatal resistance in response to higher CO_2 concentration could increase canopy resistance and it might counteract temperature-induced ET increases to a small extent. Changes in wind speed could impact on ET rates, but little information is available on global warming effects on wind speed.

Station	K_c
Torrey Pines	1.16
Oxnard	1.19
Otay Lake	1.20
SLO west	1.23
Pt.SanPedro	1.24
Oakville	1.26
Tulelake	1.28
Escondido2	1.28
Concord	1.29
Browns Valley	1.30
Belridge	1.31
Denair	1.31
Madera	1.34
Buntingville	1.35
Stratford	1.37
Oasis	1.40
Indio	1.47

Table 1. Crop coefficient (K_c) estimated as the slope of daily ET_r vs ET_o through the origin using data from 17 CIMIS stations in 2003.

	ET_o	R_s	T_x	T_n	u_2	T_d	e_s-e	K_c
ET_o	1.00	0.54	0.96	0.59	0.74	-0.45	0.98	0.94
R_s	0.54	1.00	0.50	-0.27	0.34	-0.75	0.49	0.37
T_x	0.96	0.50	1.00	0.62	0.56	-0.34	0.99	0.87
T_n	0.59	-0.27	0.62	1.00	0.40	0.32	0.63	0.63
U_2	0.74	0.34	0.56	0.40	1.00	-0.34	0.61	0.78
T_d	-0.45	-0.75	-0.34	0.32	-0.34	1.00	-0.41	-0.41
e_s-e	0.98	0.49	0.99	0.63	0.61	-0.41	1.00	0.91
K_c	0.94	0.37	0.87	0.63	0.78	-0.41	0.91	1.00

Table 2. Correlation matrix for mean July ET_o, solar radiation (R_s), high (T_x) and low (T_n) temperature, 2-m wind speed (u_2), dew point (T_d), vapour pressure deficit (e_s-e), and estimated K_c (i.e., slope of ET_r Vs. ET_o using daily data for the year 2003 from 17 CIMIS stations). Note that e_s=f(T_x) and e=f(T_d).

Conclusions

Our analysis and recent trends in temperature and humidity indicate that the impact of global warming on crop coefficients are likely to be insignificant if the vapour pressure deficit remains relatively constant and the wind speeds are unaffected.

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