3.9 SURFACE RENEWAL MEASUREMENTS OF SENSIBLE HEAT FLUX IN AN IRRIGATED DESERT PECAN ORCHARD

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1. INTRODUCTION

In an effort to simplify the measurement of sensible heat flux (H) over plant canopies, a more recent technique to measure H has been developed by Paw U et. al. (1995). This technique estimates scalar fluxes based on a scalar signal alone, without high frequency wind velocity data. The method is simple in design, using only a high frequency thermocouple signal as the scalar to measure H_{SR}, compared to the more advanced techniques which require a thermocouple and a fast response anemometer. SR has been measured in arid environments, (central California, Italy) over grass, wheat, sorghum (Spano et al, 1997), avocado, grapevine, maize, walnut, mixed deciduous forest canopies (Paw U et al., 1995; Snyder and Paw U, 1993; Paw U and Su, 1994) and lagoons (Zapata and Martinez-Cob, 2001). SR was found in most cases to give the best results in unstable conditions and with the sensor located at canopy height for orchard or forest canopies (Paw U et. al., 1995; Snyder et al., 1996; Spano et al.,1996; Spano et al., 1997). In all cases, the SR measurements have been compared and calibrated against an EC system in order to measure its reliability.

2. METHODS

A 16.5 m tower was instrumented with micrometeorological sensors in a 5.1 ha pecan orchard located 7 km south of Las Cruces, New Mexico. The canopy height was approximately 13 m and tree spacing was 9.1 by 9.1 m. The canopy covered about 60% of the ground area, the foliated Plant Area Index was about 3.1, and the leafless Stem Area Index was about 1. Fine wire thermocouples were mounted at several heights on the tower, z = 1, 9.1, 12.8, and 17 m for the SR system. H_{SR} was calculated as:

$$H = \alpha \rho c_p \frac{a}{l+s} z_c \qquad \text{(Eq. 1)}$$

where alpha (α) is a calibration weighing factor, ρ is the density of air, c_p is the specific heat of air, a/l+s is the inverse ramp frequency and z_c is the measurement height. The H_{SR} calculations were made using software supplied by Snyder (2003). A CSAT 3-dimensional sonic anemometer was mounted at 17 m to measure H_{EC}. 30 minute averages of H were measured from both sensors.

The α calibration factor for the SR system was determined from the slope of a linear regression forced through the origin of H_{EC} against H_{SR}. Data were collected from 14 Oct – 23 Nov of 2003, 25 Feb to 5 March of 2004, and 1 April – 21 April of 2004 with two different time lags for the SR system, .25s and .5 s. The 2003 data were taken in a foliated canopy when the trees were beginning the senescent stage. The February – March 2004 data were taken in a completely defoliated canopy. The April 2004 data were taken during budburst and leaf development in the orchard to see the effect of a changing canopy cover on the SR system. A frequency histogram was calculated for the closure of the SR functions versus time of day at two different heights. The H_{SR} data had many missing values, depending on measurement height, when the structure functions could not be solved

3. RESULTS AND DISCUSSION

The regression statistics and measurement heights for the three data collection periods are presented in Table 1. The alpha values are the slope of the regression line forced through the origin of H_{EC} against H_{SR} with the corresponding r^2 for the linear regression. The standard error (SE) of H_{SR} is relative to the H_{EC} in units of W m^{-2}. The relative error (RE) represents the SE divided by the range of H_{EC} expressed as a %. The standard error (aSE) is relative to the H_{EC} after multiplying by the alpha calibration factor. The relative error (aRE) represents the aSE divided by the range of H_{EC}. The n values are the total number of 30 minute averages used for the regression statistics. The % solved represents the total number of 30 minute H_{SR} values calculated divided by the total number of 30 minute periods during the sampling time.

The foliated canopy from 2003 had the poorest regression statistics. The sensor at canopy height (12.8 m) showed better agreement than at 17 m height. Also the percent solved of the SR functions was much higher for the canopy height data (86%) than the 17 m data (46%). At .7h (9.1 m), or the zero plane displacement height, alpha values were close to 1 for the defoliated canopy and the canopy development stage (α = 1.04, 1.06), with r^2 = .73 and .79 respectively. The RE were less than 10% without

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using the alpha calibration for both 2004 periods at 9.1 m height. The SE and RE increased when using the alpha calibration at 9.1 m. For the canopy development stage, the 12.8 m H_{SR} showed good agreement with H_{EC}. The 12.8 m data showed better closure of the SR functions than at 9.1 m as well. The foliated canopy from 2003 had lower magnitudes and more negative fluxes of H_{EC} than the 2004 data as would be expected from a transpiring canopy in an oasis. The poorer statistics when the canopy is foliated are likely due to the regular row interruptions of the canopy. This characteristic is maximized when the foliage is full. Thus the assumptions of horizontal homogeneity are not met when the sensor is below about 1.2 h.

The reliability of the SR method as a tool for measuring H in energy balance systems is dependent on its ability to continuously make measurements. For reasons that are not clear as of yet, the SR system did not solve for H_{SR} continuously during periods where wind speeds are generally lower and the magnitude of the sensible heat flux is close to zero (Figure 1). The system was least reliable during nighttime and early morning, which are generally characterized by stable conditions.

4. CONCLUSIONS

For tall pecan canopies the SR method shows the best agreement with the EC method when measured at .7h. Also it has better agreement during times when there is a large positive flux of H during midday. The SR method also was most reliable during daytime periods. The lack of closure of the SR functions during stable periods may not be a concern if using SR as a tool to measure water use. During stable periods less sensible heat is being exchanged than during unstable periods and usually nighttime data is not included in energy balance measurements of LE. It is important to conduct full growing season experiments to determine if the SR method is reliable for measuring consumptive water use of pecans or other row crops.

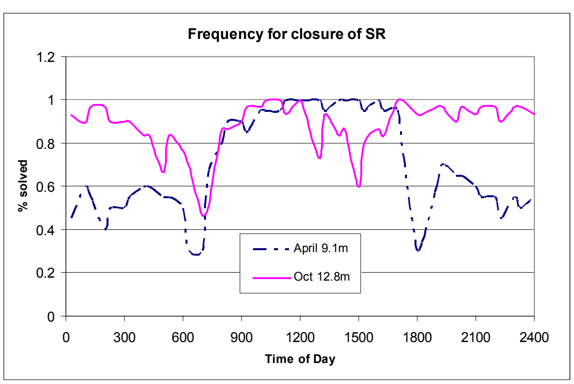

Figure 1. Frequency histogram showing what time of day the SR method was most reliable for solving for H_{SR}.

Table 1. Performance statistics for three stages of growth; foliated, defoliated, and emerging foliage canopies. Symbols are defined in the text.

lag	z	alpha	r^2	SE	aSE	RE	aRE	n	% solved
2003 Foliated Canopy (13 Oct - 12 Nov)									
0.25	12.8	0.24	0.4	121	29	26	6	1205	80
0.5	12.8	0.26	0.43	108	42	23	9	1291	86
0.25	17	0.21	0.35	143	30	31	6	592	39
0.5	17	0.21	0.37	142	29	31	6	695	46
2004 Defoliated Canopy (26 Feb - 6 Mar)									
0.25	1	3.68	0.58	17	62	2	9	233	61
0.5	1	4.11	0.65	14	56	2	8	254	67
0.25	9.1	1.06	0.74	48	51	9	9	239	63
0.5	9.1	1.04	0.73	47	49	9	9	285	75
2004 Emerging foliage stage (1 April - 21 April)									
0.25	9.1	1.06	0.79	53	56	8	9	648	74
0.5	9.1	1.07	0.82	47	50	8	9	712	81
0.25	12.8	0.7	0.66	89	62	14	10	705	80
0.5	12.8	0.7	0.72	79	56	13	9	767	87

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