ESTIMATING PECAN WATER USE THROUGH REMOTE SENSING IN LOWER RIO GRANDE

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ABSTRACT

Pecan is a major crop in Lower Rio Grande Basin. Currently there exist about 30,000 acres (12,000 ha) of pecan orchards at various stages of growth which consumes about 40 percent of irrigation water in the area. Crop evapotranspiration (ET) varies with age, soil type and method of management. The ET variation and lack of information on optimum crop ET result in significant variation in productivity and income. In order to maximize the returns from limited water resources, there is a need for a better understanding of pecan optimum ET. ET was measured using three eddy covariance flux towers, which were installed in selected fields in the irrigated area. This paper describes a process where remotely sensed data from ASTER were combined with ground level information to estimate pecan ET and crop coefficient (K_c) throughout the area. The measured cumulative annual pecan ET were determined as 1470 mm (4.82 ft) compared to a predicted value of 1415 mm (4.68 ft) using the remote sensing model. Regression summary for measured ET as depended variable resulted in Standard Error of Estimate (SEE) of 0.86 mm/day and adjusted R^2 of 0.9045 for 363 days of measured data.

INTRODUCTION

Dona Ana County, NM is ranked as No. 1 in the nation in pecan production. Currently, there are about 1,056 producers growing pecans in about 30,000 acres (12,000 ha). The state produces an average of 45 million pounds (20 million kg) of pecan annually with a value of about $100 million. Although water management is critical in the productivity of pecan, limited information is available on the spatial and temporal variability of water use by pecan. In addition, the question is complicated due to variation in pecan age, method of soil management, pruning and the carryover stress effect on pecan water use and yield.

Traditionally, ET has been calculated using crop coefficient (Kc) of pecan multiplied by reference evapotranspiration as:

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$$ET = K_c \times ET_r \qquad (1)$$

Where ET is the actual water use for the crop and ET_r is the reference evapotranspiration calculated from various equations such as Penman-Monteith (Allen, 1986), Blaney-Criddle (1950) or Hargreaves-Samani (1982, 1985, 1986). However, this traditional method of estimating pecan ET in New Mexico results in gross overestimation or underestimation of the true water use of the crop due to the variation in crop age, crop density, pruning, fertigation and lack of irrigation scheduling. This paper describes a remote sensing procedure for estimating real-time pecan ET in Lower Rio Grande Valley. The objective of this research was to evaluate the potential for application of remote sensing technology to evaluate the water use by various pecan orchards in Dona Ana County and to assess the potential for increasing the productivity of pecan in the area.

REMOTE SENSING MODEL

In this study, the Regional ET Estimation Model (REEM) (Samani et al, 2005) was used to calculate the daily ET for pecan orchards in Lower Rio Grande Valley. The model calculates the latent heat flux (LE) as a residual of the energy balance on surface:

$$LE = R_n - G - H \qquad (2)$$

where, LE is the latent heat flux, R_n is the net radiation flux at the surface, G is the soil heat flux and H is the sensible heat flux to the air. All are in $MJ/m^{-2}day^{-1}$.

Daily net radiation over crop canopy was calculated using a methodology developed by Samani et al. (2005) as:

$$R_n = R_{ni}\left(\frac{R_s}{R_{si}}\right) \qquad (3)$$

where, R_n is the daily net radiation in $MJm^{-2}day^{-1}$, R_s is daily short wave solar radiation in $MJm^{-2}day^{-1}$, R_{ni} is incident clear sky net radiation in W/m^2 at 11 am, and R_{si} is the incident short wave solar radiation in W/m^2 at 11 am.

The satellite data used in this study were from the Advanced Spaceborne Thermal Emission and Reflection (ASTER) radiometer on NASA's Terra satellite (Yamaguchi et al. 1998). It has a 60 km wide swath and a 16-day repeat cycle. However, data are not always available on a 16-day cycle at all locations. Satellite data from ASTER were used to calculate albedo, Normalized Difference Vegetation Index (NDVI) and surface temperature for the study area. The ASTER sensor makes multispectral observations in three wavelength regions which include visible to near infrared (VNIR), shortwave infrared (SWIR), and thermal infrared (TIR). The ASTER data used in this study came from the Land Processes Distributed Active Archive (LPDAAC) and consisted of the following:

AST_07 – Surface Reflectance (VNIR, SWIR) in the visible and near-infrared regions with 15 and 30 m spatial resolutions, respectively.
AST_08 – Surface Kinetic Temperature - 90 m spatial resolution

The data were time-referenced and annotated with ancillary information, including radiometric and geometric calibration coefficients, and geolocation information. In addition, the data were corrected for parameters such as atmospheric effects and variations in emissivity. The image processing software package ENVI® (Research Systems, Inc. Boulder, Colorado) and its many tools were used for data processing described here. The Normalized Difference Vegetation Index (NDVI) was calculated using ASTER sensor bands 3 and 2 as:

$$\mathrm{NDVI} = \frac{\rho_3 - \rho_2}{\rho_3 + \rho_2} \tag{4}$$

Where, ρ_i is the reflectance in band i.

Albedo (α) was calculated using the methodology described by Liang (2001):

$$\begin{aligned} \alpha = 0.484\rho_1 + 0.335\rho_3 - 0.324\rho_5 + 0.551\rho_6 \\ +0.305\rho_8 - 0.367\rho_9 - 0.0015 \end{aligned} \tag{5}$$

Where, ρ_i is the reflectance in band i

The spectral range for various wavelengths used in the model are shown in table 1.

Incident net radiation (R_{ni}) values for the time of satellite overpass, which was about 11 AM (MST), were calculated using a modified form of Campbell (1977):

$$R_{ni} = (1-\alpha)R_{si} + \varepsilon_a \delta (T_a + 273)^4 - \varepsilon_0 \ \delta (T_c + 273)^4 \tag{6}$$

where R_{ni} is incident (instantaneous) net radiation (W/m²), R_{si} is incoming incident incoming short wave radiation (W/m²), α is surface albedo (dimensionless) , ε_a and ε_0 are dimensionless atmospheric and surface emmisivities respectively, and δ is the Stephan-Boltzmann constant (5.67×10^{-8} $MJm^{-2}K^{-4}$). T_a and T_c are incident near surface temperature and incident surface temperature respectively.

Incident Soil heat flux (G_i) at the time of satellite overpass was calculated using an equation recommended by Samani et al. (2005) as:

$$\frac{G_i}{R_{ni}} = 0.26e^{(-1.97\mathrm{NDVI})} \tag{7}$$

Choudhury (1991) recommended an equation similar to equation 7 where the ratio of G_i/R_{ni} was calculated from values of leaf area index (LAI). The incident sensible heat flux (Hi) was calculated by combining the aerodynamic equation with Monin-Obukhov similarity function (Tasumi 2003). The aerodynamic equation (Tasumi, 2003) is defined as

$$H_i = \rho_a C_p \frac{T_{as} - T_a}{r_{ah}} = \rho_a C_p \frac{\Delta T}{r_{ah}} \tag{8}$$

where ρ_a is the air density (kg/m^3), Cp is specific heat of air (1004 J/kg/K), T_{as} is the aerodynamic surface temperature in Kelvins (K), T_a is the air temperature (K), and rah is the aerodynamic surface resistance. Equation 7 was combined with Monin-Obukov function to solve for ΔT and r_{ah} using two reference points. A relationship was developed between ΔT and canopy temperature. The surface temperature values were used to calculate $\Delta T = T_{as}-T_a$ which was then used in equation 8 to calculate sensible heat for various pixels.

The evaporative fraction (E_f) for each pixel is defined as the ratio of the latent heat flux to the available energy and is calculated using the values of H_i, G_i, and R_{ni}:

$$E_f = \frac{R_{ni} - G_i - H_i}{R_{ni} - G_i} \tag{9}$$

Once the evaporative fraction is calculated and assuming that evaporative fraction is constant over the 24 hour period, the daily ET can be calculated by multiplying Ef by daily available energy as:

$$ET = E_f (R_n - G) \tag{10}$$

Assuming a negligible daily G value (Allen, 1998), daily ET can be calculated simply by multiplying Ef by the daily net radiation (R_n).

FIELD MEASUREMENTS

The eddy covariance technique, using one-propellor eddy covariance (OPEC) systems, was used on the towers to measure sensible heat (H) component of surface energy. The eddy covariance technique estimates sensible heat flux at the surface from the covariance between the fluctuations of vertical wind speed with temperature:

$$H = \rho c_p COV\left[wT\right] \tag{11}$$

Where, H is the sensible heat flux to the air (W/m^2) , ρ is the density of moist air (g/m^3), c_p is the heat capacity of air at constant pressure (J/g ^{o}C), *w* is the vertical air velocity (m/s), *T* is temperature of the air (^{o}C), *COV* is the covariance between *w* and *T* during the sampling period. Data were collected at 8 Hz and statistical summaries of 30-minute means processed online using battery powered CR23X data loggers (Campbell Scientific Inc.).

The OPEC sensors was placed about 7 m above the canopy. The ground heat flux (G) was measured using soil heat flux plates (model HFT3, REBS Inc.) under the plant canopies. The ground heat flux plates were placed about 1 cm in the ground at location that best represented both open and shaded canopies. Net radiation (R_n) was measured using net radiometers (Model Q7.1, REBS Inc.) mounted about 2.5 m above the canopy. The latent heat flux (LE) was determined using energy balance (equation 2)

RESULTS

Figure 1 compares the measured and predicted daily ET for a mature pecan orchard in Lower Rio Grande Valley. The daily ET values in figure 1 were measured by OPEC system. The estimated ET values were from REEM remote sensing model. The measured cumulative annual pecan ET was1470 mm or 4.82 ft compared with 1415 mm or 4.64 ft predicted from remote sensing model. Regression summary for measured ET as depended variable resulted in Standard Error of Estimate (SEE) of 0.86 mm/day, adjusted R^2 of 0.9045, and a slope and intercept of 1.03 and 0.03 respectively.

Figure 2 shows the variability of pecan water use in the valley. The variability is caused by pecan density, age, variety, and variation in nutrient and water availability. This demonstrates the value of real time large scale ET estimation compared to theoretical methods and/or point measurements.

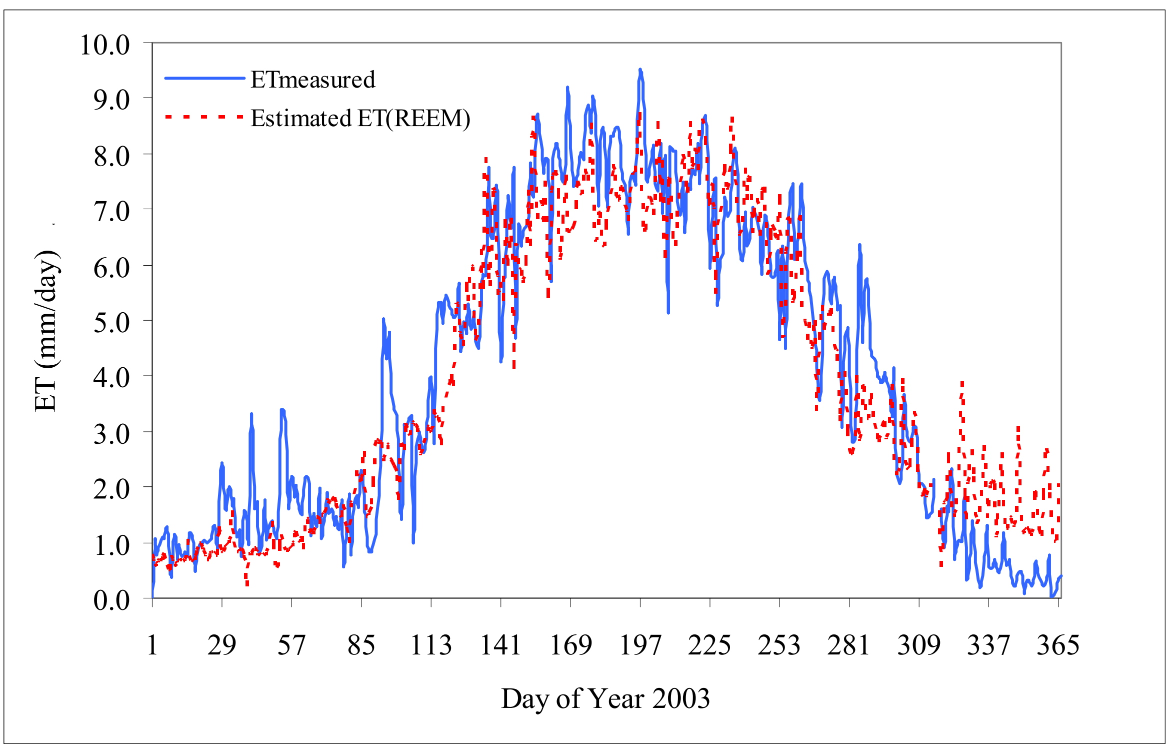

Figure 1. Measured and Predicted (REEM) Annual ET for a Mature Pecan Orchard in Lower Rio Grande Valley during Year 2003

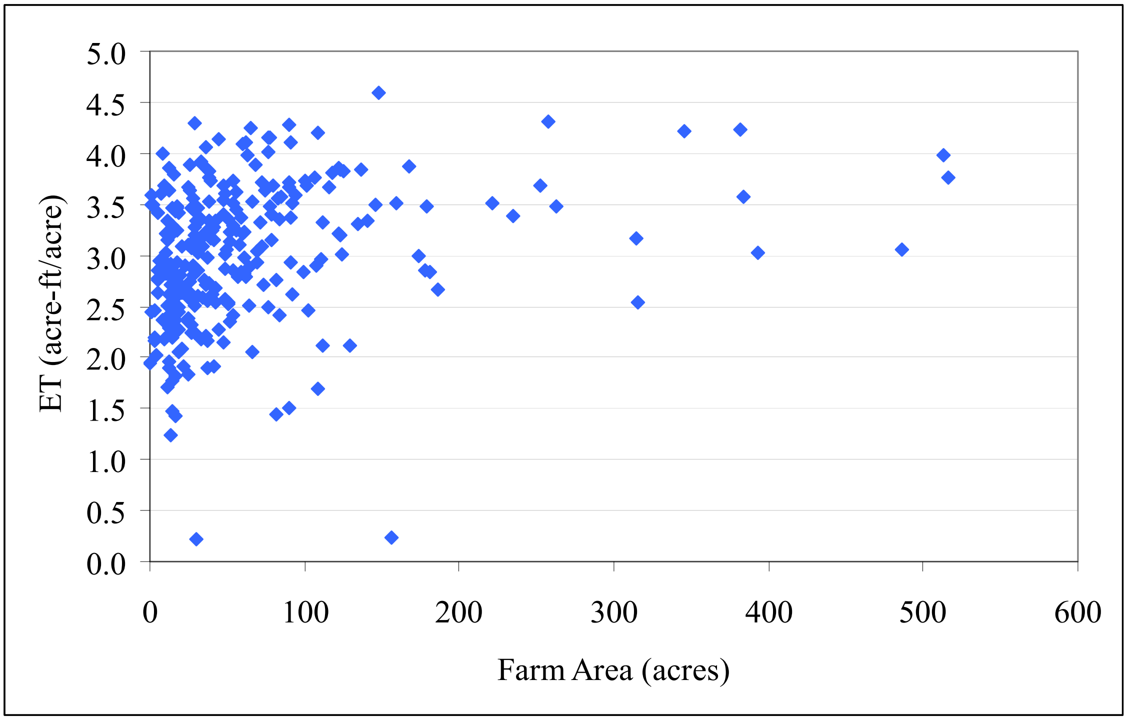

Figure 2. Annual ET (acre-ft/acre/year) Predicted (REEM) versus Individual Farm Acreage in Lower Rio Grande Valley

CONCLUSION

Results from this study showed that remote sensing could estimate pecan water use in the Lower Rio Grande reasonably well. The measured cumulative annual pecan ET were determined as 1470 mm (4.82 ft) compared with 1415 mm (4.64 ft) predicted from remote sensing model. Regression summary for measured ET as depended variable resulted in Standard Error of Estimate (SEE) of 0.86 mm/day and adjusted R^2 of 0.9045 for 363 days of measured data. The largest error occurred during December. This error was caused by lack of available satellite images. Water use by pecan orchards varied spatially and temporally.

Table 1. Wavelengths for various spectral bands in ASTER

Subsystem	Band No.	Spectral range (µm)	Spatial Resolution (m)
VNIR	**1**	**0.52-0.6**	
	2	**0.63-0.69**	**15**
	3	**0.76-0.86**	
SWIR	**4**	**1.600-1.700**	
	5	**2.145-2.185**	
	6	**2.185-2.225**	**30**
	7	**2.235-2.285**	
	8	**2.295-2.365**	
	9	**2.360-2.430**	
TIR	**10**	**8.125-8.475**	
	11	**8.475-8.825**	
	12	**8.925-9.275**	**90**
	13	**10.25-10.95**	
	14	**10.95-11.65**	

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