Evapotranspiration and Crop Coefficient for Pecan Trees in El Paso, Texas

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Abstract. *In this study three-year daily actual pecan evapotranspiration (ET) was measured using an Open Path Eddy Covariance (OPEC) system for improved pecan irrigation scheduling in the west Texas. To monitor the amount and timing of water consumption of pecan trees, a monitoring network for measuring evapotranspiration with ET tower with an OPEC system, soil moisture and groundwater levels was installed at a Pecan Orchard in Tornillo, El Paso County, Texas. Three-year data (2012-2014) were analyzed and summarized in order to quantify the pecan ET at site. The results showed that the actual pecan ETs range from 1054mm to 1167mm for the growing season of March-October as compared to reference ET ranging from 1528 mm to 1635mm calculated by using ASCE standardized method. Maximum daily evapotranspiration range from 8.7mm to 9.4mm and all the maximum values occurred at the end of June and the beginning of July. The daily and monthly pecan tree crop coefficients were determined. The results from this study provide guidelines for precision irrigation for achieving better water conservation and improved production of pecans in the region.*

Key words: Pecan; Evapotranspiration; Irrigation Scheduling; Soil Moisture; Crop Coefficients;

Introduction

Irrigation water management is a major concern for pecan growers in the Southwest United States, particularly in the El Paso area because of its arid climate, with an average annual precipitation of 216 mm and an average annual evaporation of over 2,000 mm. Texas ranked second nationally in pecan production, and El Paso County has been one of the leading eight counties in pecan production with an approximately 3,500 hectares of irrigated pecan orchards. There is a great need for estimating pecan evapotranspiration (ET) accurately for improved irrigation scheduling of the pecan trees in the region. Numerous studies have been undertaken to quantify pecan evapotranspiration over past decades in both Las Cruces and El Paso pecan farms. Thomson (1974) reported that pecan consumptive water use in the El Paso-Las Cruces area ranged from 680 to 1000 mm per season depending on tree size. Miyamoto (1983) estimated that close-spaced and full-grown pecan tree ET was in the range of 1000 to 1300 mm per growing season in El Paso, Texas. Sammis et al. (2004) reported that 21-year-old trees with spacing of 9.7 x 9.7 m and a diameter of 30 cm had 1210 mm of seasonal ET averaged over two years through OPEC system measurements in the Las Cruces area, New Mexico. Liu and Sheng (2013) reported that mature trees with spacing of 9.1 x 9.1 m and a diameter of 37 cm consumed 1085 mm of water (ET) in 2007 through soil moisture measurements in the El Paso area, Texas.

The pecan water use in El Paso area is met by surface water from the Rio Grande and supplemented by the groundwater during drought years. Early spring irrigation on pecan farms in the El Paso area also uses return flow and groundwater based on the availability of Rio Grande water in early spring. Current irrigation scheduling depended on the availability of water from the Rio Grande through canals and groundwater pumping. At pecan farm in Tornillo, El Paso County, Texas, the irrigation events are about 13-16 times a year with the varying irrigation application amount from 100mm to 150 mm for each irrigation. This study aims at gaining better understanding of the evapotranspiration of the pecan trees and developing strategies for conserving water through improved irrigation scheduling in the El Paso area. To measure actual pecan ET, an OPEC system was established to monitor carbon dioxide flux, latent heat flux, sonic sensible heat flux, momentum flux, a computed sensible heat flux, temperature, humidity, horizontal wind speed and wind direction, net radiation, soil heat flux, soil temperature and soil water content in a pecan farm in El Paso, Texas since June 2010. This paper presents an estimate of evapotranspiration of mature pecan trees based on three-year (2012-2014) actual ET measurement using OPEC system at the study site. Daily and monthly crop coefficients were then developed for each year, which can be used to improve irrigation scheduling for water conservation in the pecan farms in the El Paso Area.

Materials and Methods

To monitor water consumption of pecan trees, a monitoring network was established at a Pecan orchard in Tornillo, El Paso County, Texas. It is located about 65 kilometers southeast from the city of El Paso. The soil profile at this site includes loam to a depth of 0.38 m, silty fine sand from 0.38 m to 0.94 m, silty clay from 0.94 m to 1.09 m, loam from 1.09 m to 1.47 m, silty clay from 1.47 m to 1.75 m, loam from 1.75 m to 2.39 m, clay from 2.39 m to 2.72 m, and fine sand (saturated) from 2.72 m to 2.89 m (not through) from a hand-augured borehole. For loam in El Paso, field capacity is 27 to 35%. The permanent wilting point for loam in El Paso ranges from 12 to 20% (Miyamoto, 1983). The pecans are approximately 10.55 m high and 0.32 m in diameter with spacing of 9.1x 9.1m. The number of pecan trees per hectare near the ET tower is 103 on average. Its canopy area measured at noon is 61.4 m^2. One tree occupied a surface area of 82.8m^2. Maximum pecan root depth was observed to be 1.62 to 2.29 m from four different dug holes with a depth to 2.44 m in this farm. An average maximum pecan root zone depth was determined to be 1.83 m. The observed groundwater depth varied from 2.21 to 2.73 m below land surface during the period from February 2008 to May 2009.

An 18-meter high ET tower with an Open Path Eddy Covariance (OPEC) system manufactured by Campbell Scientific, Inc. has been in operation in this field covering over two thousand acres since June 2010. The OPEC system methodology is not described here for brevity. Blanford and Gay (1992) presented a complete description of the equipment and theory behind OPEC. In addition, a standard Campbell weather station located a mile away from the ET tower for measuring climate variables and daily evaporation. The weather station data were used to calculate grass reference ET using ASCE's standardized equation (ASCE, 2005) and infilling the missing data at ET tower using regression method. Daily and monthly pecan crop coefficients were determined from the grass reference ET and actual ET measured using the OPEC system.

Results and Discussion

Soil Moisture and Irrigation

Based on the three-year (2012-2014) recorded soil moisture data in 30cm top soil in the pecan farm (as shown in Figure 1), the number of irrigation events and timing of irrigation in each year are almost same. Most of the irrigation events for this pecan orchard occurred when the soil moisture approached the minimum tolerance line. This indicates that pecan irrigation practice follows to some degree the behavior of crop and hydrological conditions in the soil. Generally, the irrigation started on March and last irrigation had taken place in the end of October each year. As shown in Figure 1, the total numbers of irrigation events were 14, 14 and 15 times during the growing season from March to October in the year of 2012, 2013 and 2014, respectively. Soil moisture observation shows that similar irrigation amounts were applied in 2012 and 2013 with 14 irrigation events. However, the irrigation in 2014 is slightly different from previous years with 15 times of irrigation events and the application rates in summer were somewhat smaller than previous years, particularly in July and August they are much smaller per irrigation as demonstrated by lower soil moisture (Figure 1).

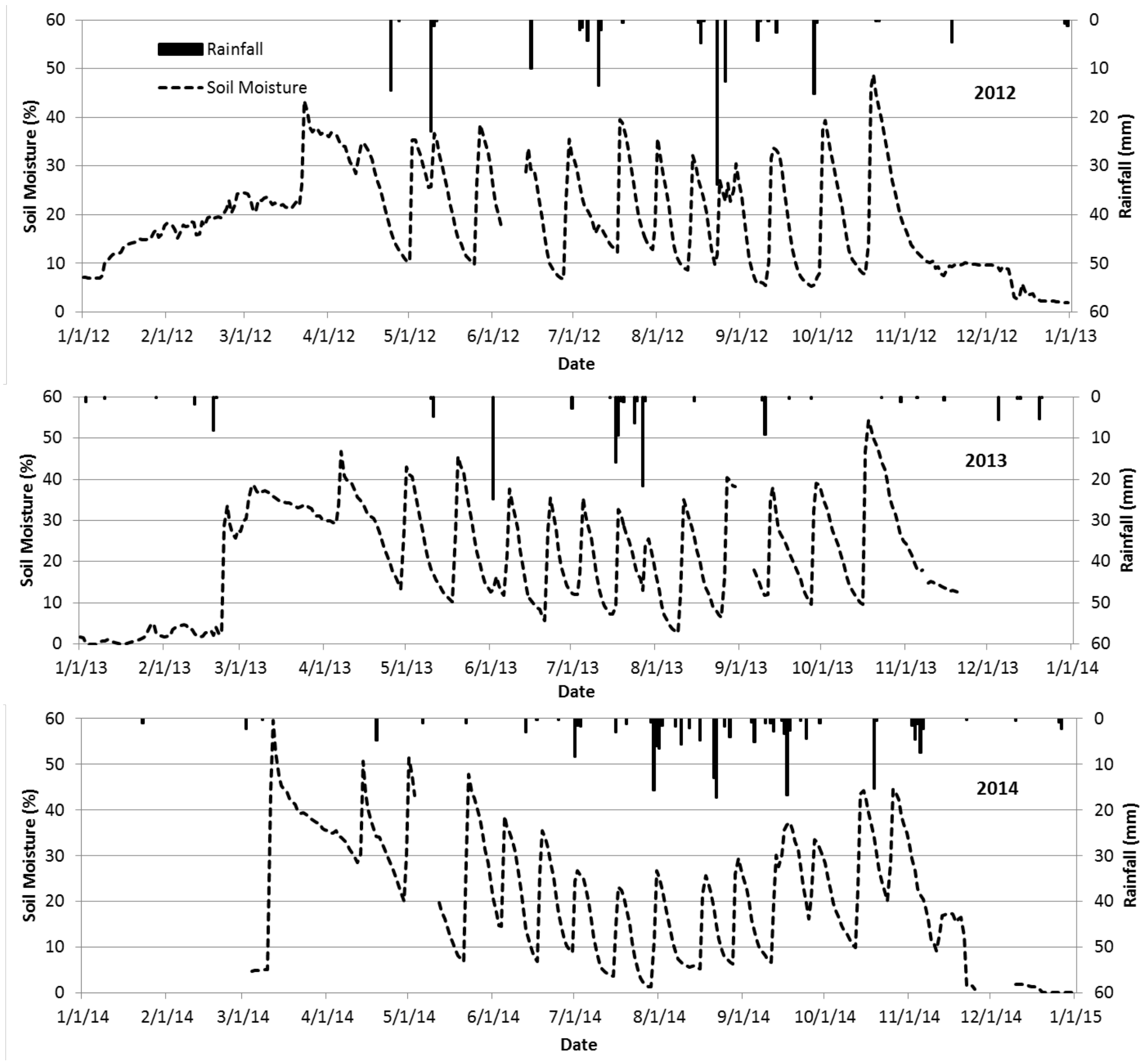

Figure 1. Soil moisture status and precipitation events for the years of 2012, 2013, 2014 at the pecan farm

Pecan Evapotranspiration

The ASCE standardized reference evapotranspiration equation (ASCE, 2005) was employed to derive reference ET from climate variables that measured in the standard weather station located one mile apart from the ET tower. The calculated daily reference ET values and measured daily pecan ET from the OPEC system observations were shown in Figure 2. As shown in Figure 2, the maximum ET of 8.7 mm/day, 9.4mm/day and 9.2mm/day were observed on 7/1/2012, 6/22/2013 and 7/1/2014, respectively. Average pecan ET is 4.5, 4.8 and 4.3 mm/day during the growing season from March 1 to October 31, which is the similar growing season as in previous studies (Miyamoto, 1983; Sammis et al., 2004; and Liu and Sheng, 2013).

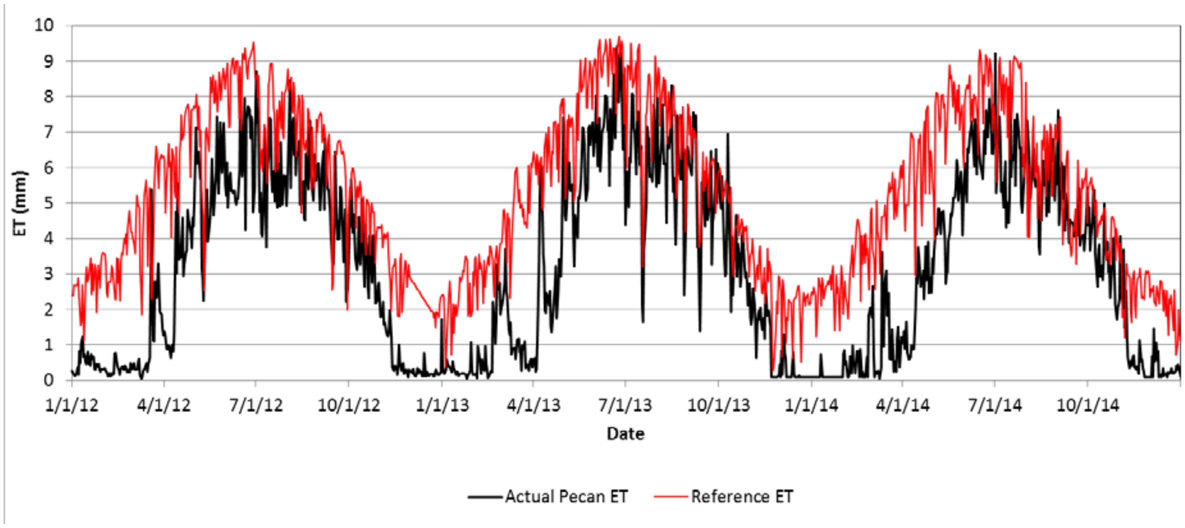

Figure 2. Measured actual pecan ET by OPEC system and calculated reference ET using ASCE standardized equation for the year of 2012-2014 at the study site.

The comparison of monthly measured pecan ET in this study with other studies (Miyamoto, 1983; Sammis et al., 2004; and Liu and Sheng, 2013) is shown in Table 1. The recent studies (Miyamoto, 1983; Sammis et al., 2004; and Liu and Sheng, 2013) showed the annual pecan ET value is in range of 1000 to 1460 mm for mature trees in the El Paso-Las Cruces area. The annual pecan ET value that was measured by OPEC system in this study from 2012 to 2014 were 1153mm, 1248mm and 1112mm, respectively and they are in this reported range. The total seasonal evapotranspiration measured with the OPEC system in the study site were 1097, 1167 and 1054mm for 2012, 2013 and 2014 respectively. The pecan growing season was identified as March 1 to October 31 in this pecan farm based on the previous studies and specific conditions of the study site. Miyamoto (1983) estimated a mature pecan orchard's consumptive use as 1310 mm for the growing season of April 1 through October 15. Miyamoto (1983)'s study involved orchards that were 8 to 35 years old and ranged in trunk diameter from 13 to 45 cm and heights from 7.4 m to 18.8 m located in El Paso, Texas, and Las Cruces, New Mexico areas. Sammis et al. (2004) reported the seasonal pecan ET values of 1260mm for 2001 and 1170mm for 2002, and an average of 1210mm for the growing season of from April to November (Table 1). Sammis et al. (2004)'s study was conducted for the mature pecan farm with the tree spacing of 9.7 m x 9.7 m, average orchard height of 12.8 m and with an average tree diameter at breast height of 30 cm. In this study, the pecan trees are approximately 10.6 m high and 32 cm in diameter with spacing of 9.1m x 9.1m. Hence, the results from this study are comparable to the other studies (Miyamoto, 1983; Sammis et al., 2004; and Liu and Sheng, 2013) since the pecan orchards of the study area contain mature pecans trees and similar in grass cover, tree size and irrigation conditions.

The monthly ET reached its maximum value in August at the rates of 188mm/month in 2012, 220mm/month in June in 2013, and 201mm/month in 2014 (Table 1). Except for Liu and Sheng (2013)'s study, the maximum monthly ET values are all occurred either July or/and August in all years in all studies (Miyamoto, 1983; Sammis et al., 2004). From Table 1 it can be concluded that the monthly ET pattern of this study is close to Sammis et al. (2004) in terms of pattern and magnitude of the monthly ET values. The three years average seasonal pecan ET in this study was 1106mm, is about 8% lower than Sammis et al (2004) reported value in average and 15% lower than the Miyamoto(1983) reported value in average. Considering all the other factors that affect the pecan ET are similar, the main reason for the lower pecan ET values in the Tornillo Farm, El Paso is attributed to the fact that there is insufficient irrigation in this study site due to surface water shortage in the farm. The evapotranspiration rate under water stress condition tends to be lower than the evapotranspiration rate in full irrigated crops without water shortage.

Table 1. Comparison of monthly evapotranspiration (ET) in this study with other studies from the literature (mm)

Studies	Growing season	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Seasonal
Sammis (2004), 2001	Apr1-Nov20		88	177	202	**221**	**210**	185	136	40	1260
Sammis (2004), 2002	Apr1-Nov6		136	176	218	**199**	**198**	170	73		1170
Miyamoto (1983)	Apr1-Oct15		70	119	225	278	**290**	239	86		1307
Liu & Sheng (2013)	Mar12-Nov11	7	58	86	101	156	194	228	236	21	1086
This Study 2012	March1-Oct31	37	88	168	184	180	**188**	141	110		1097
This Study 2013	March1-Oct31	34	88	176	**220**	189	189	157	113		1167
This Study 2014	March1-Oct31	34	67	145	**201**	187	177	137	106		1054

Notes: Underlined values are the highest monthly ET values

Pecan Crop Coefficients for Irrigation Scheduling

Improved irrigation water management requires accurate scheduling of irrigations which in turn requires an accurate calculation of daily crop evapotranspiration. Crop coefficients are the basic parameters in estimating evapotranspiration on a daily basis for the irrigation scheduling. The crop coefficient (K_c) is defined as the ratio of measured evapotranspiration (ET)/potential evapotranspiration (ET_0) referenced to grass. As shown in Figure 3, three daily crop coefficient equations were developed for pecan trees based on the day of year (DY) as the independent variable for each year. The fourth-order polynomials were fit to the calculated Kc data for 2012, 2013 and 2014 with the coefficient of determination of 0.80, 0.83 and 0.81, respectively. The polynomial equations are as follow:

$$Kc = 0.0000000006DY^4 - 0.0000006DY^3 + 0.0001DY^2 - 0.0072DY + 0.1842 \quad \text{For 2012} \qquad (1)$$
$$Kc = 0.0000000004DY^4 - 0.0000004DY^3 + 0.0001DY^2 - 0.0068DY + 0.1962 \quad \text{For 2013} \qquad (2)$$
$$Kc = 0.0000000005DY^4 - 0.0000005DY^3 + 0.0001DY^2 - 0.0063DY + 0.1294 \quad \text{For 2014} \qquad (3)$$

As can be seen in Figure 3 and equations (1), (2) and (3) that the coefficients of developed daily K_c equation polynomial are consistent and essentially the same value. The crop coefficient and evapotranspiration increased until maximum leaf area occurred in end of July and the start of August. The daily K_c equations developed in this study showed the similar tendency as the developed daily crop coefficients equations by Sammis et al. (2004) for pecan using both day of year and growing degree days as the base using 2001 and 2002 OPEC system measured ET data in Las Cruces, New Mexico, about 125 kilometers north of our study site. Our equations developed for three years are consistent between the years and the general tendency of all polynomials are the same (as in Figure 3), and can be used to estimate daily K_c values with higher accuracy in El Paso area.

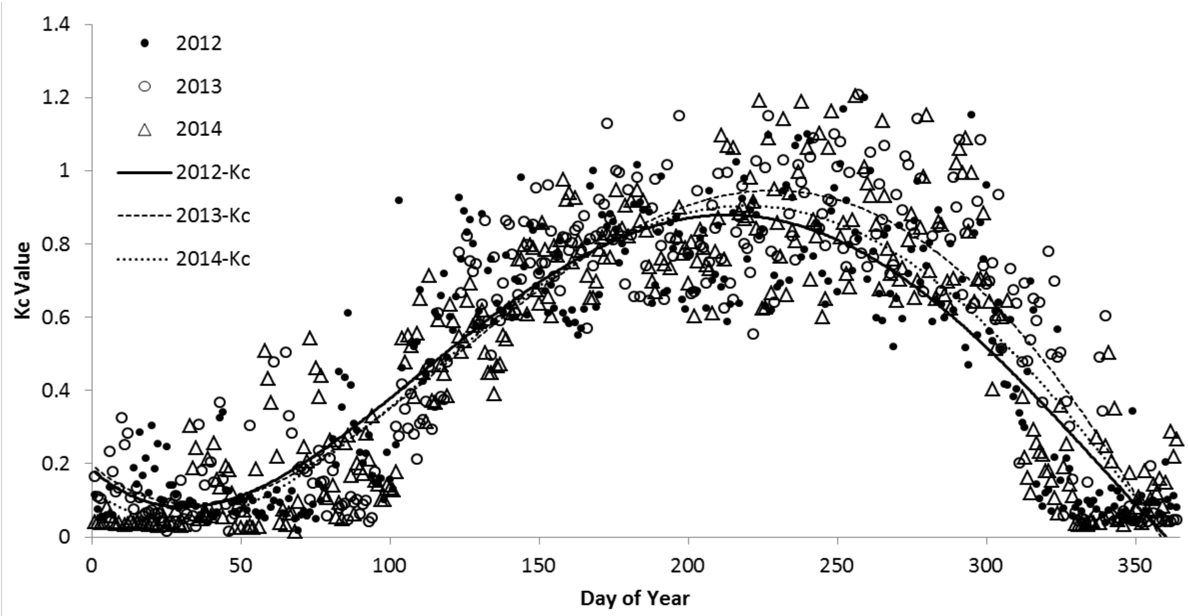

Figure 3. Daily crop Coefficient for pecan trees using day of the year as a time base for 2012-2014

Based on the measured monthly pecan ET values and calculated reference ET by ASCE's standardized equation (ASCE, 2005); the monthly crop coefficients for pecan are estimated for 2012, 2013 and 2014 (Figure 4). Each month K_c values are consistent with little discrepancies among the study years and the monthly K_c values for all year are smaller than 1.0 with an average highest monthly K_c values of 0.89occurred in August. According to other studies in the region (Miyamoto, 1983; Sammis et al., 2004; and Liu and Sheng, 2013), the K_c values derived from this study are smaller than others, indicating that the deficit irrigation that inhibits the evapotranspiration process and possible yield lost under water stress conditions in the study site.

Figure 4 shows the comparison of monthly K_c values to other studies in the region. The general tendency and values from this study is similar to Sammis et al (2004)'s study, except that their reported values are consistently higher than the values derived from this study with exception of October. Miyamoto's pecan K_c values for the months of April and May were lower than Sammis et al. (2004)'s values and the values reported in this study for all three years. During the middle and later growing season, the Miyamoto (1983)'s K_c values are much higher than both Sammis's values and values from this study with values over 1.0 for July, August and September. One possible cause for such a difference is that the Miyamoto's K_c values were derived under more ideal environment that facilitated by the experimental farm of Texas AgriLife Research Center with sufficient irrigation and possible high pecan evapotranspiration under favorable conditions. This indicates that there is still potential pecan yield increase in the Tornillo pecan farm in this study. In general, the developed daily and monthly pecan tree crop coefficients from this study can be used in pecan irrigation scheduling in similar pecan farms with the similar climate and water management conditions as the El Paso area, Texas.

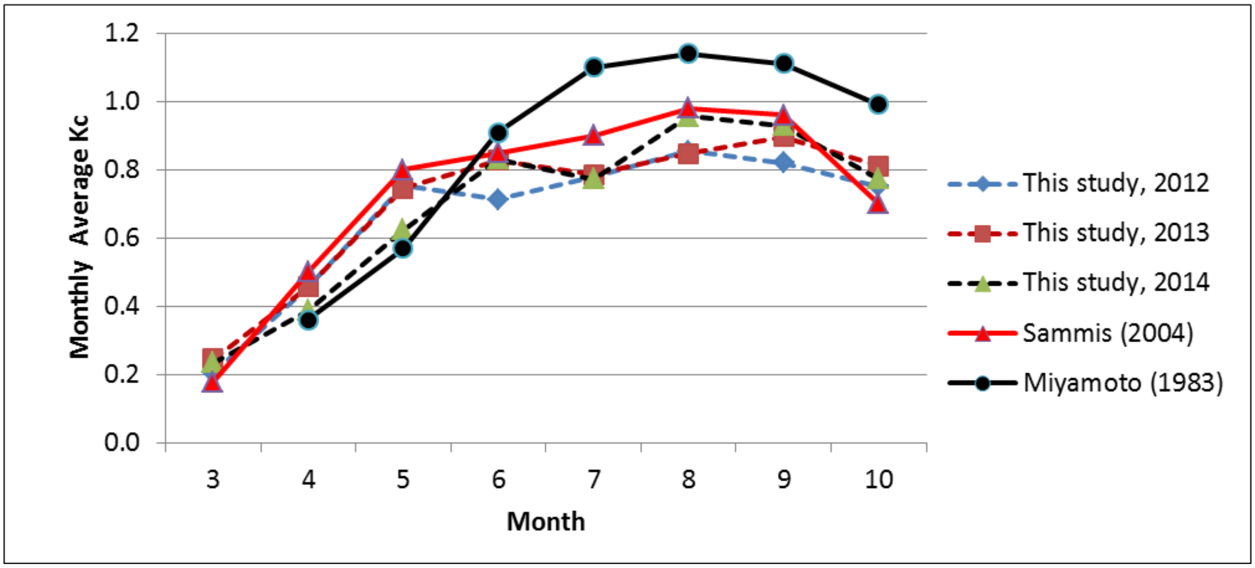

Figure 4. Comparison of monthly average crop coefficients in this study with other studies from the literature for the same region

Conclusions

Pecan irrigation in El Paso, Texas is surface water from the upper Rio Grande in a normal year and the combination of surface water of the upper Rio Grande and local groundwater in drought year. Pecan growers in this region have concerns about irrigation water management and improvement of pecan production. An OPEC system was established to monitor and quantify the consumptive water use of pecan in El Paso, Texas. Daily reference ET was derived through the ASCE standardized reference evapotranspiration equation using measured climate parameters from the standard weather station installed in the study site. Actual pecan ET was measured by OPEC system that is installed in the middle of pecan farm from 2010. A daily pecan crop coefficient equations and monthly crop coefficient values were derived from using actual pecan ET and calculated reference ET. Both ET values and K_c values were compared with other studies that reported in the literature for the same region with similar conditions.

The results from the study indicate that the actual pecan ETs was 1097mm, 1167mm and 1054mm for growing season of March-October. Maximum daily evapotranspiration were 8.7mm, 9.4mm and 9.2mm for 2012, 2013, 2014 and all the maximum values were observed at the end of June and the beginning of July. The maximum K_c value is 0.89 on August, indicating that there is still potential for increasing pecan yield in the Tornillo pecan orchard through improving irrigation scheduling practices or increasing water use efficiency. The crop coefficients developed in this study can be used in a water balance irrigation scheduling model which could be used in conjunction with other irrigation scheduling techniques to improve irrigation management of pecans.

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