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Consumptive Water Use of Pecans in Southern Arizona

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Introduction

The production of pecans [*Carya Illinoinensis* (Wangeh.) K. Koch] in Arizona has increased substantially in recent years (Parsons, 2017; Murphree, 2020). A recent economic impact study indicates more than 30,000 acres of pecans are now established in Arizona, nearly double the acreage reported in 2013 (Duval et al., 2019). The majority of Arizona pecan orchards are located in Southern Arizona with nearly all new production located in Cochise County where groundwater levels are declining due to overdraft of local aquifers (ADWR, 2018). Pecans are considered a high-water use crop due in large part to an extended growing season that begins in late March and continues through mid-November at most locations. Aside from one study that evaluated the feasibility of using infrared thermometry to schedule irrigation events (Garrot et al., 1993), there are no published data sets addressing the consumptive water use (CU) of Arizona pecans. The purpose of this bulletin is to summarize the results of a three-year study conducted in southern Arizona to 1) quantify the CU of southern Arizona pecans and 2) provide crop coefficients (Kc) and CU curves to facilitate improved irrigation management of pecans.

Methods

The project was initiated during the summer of 2013 with the installation of walk-up flux towers in pecan groves located near Sahuarita and Bowie, AZ (Figure 1). The towers extended 52′ (16 m) above the surface of the orchard and supported eddy covariance systems that consisted of a Campbell Scientific Incorporated (CSI) KH20 krypton hygrometer and CSI CSAT3 sonic anemometer connected to a CSI CR3000 data logger. (Figure 1). Eddy covariance systems measure the vertical movement of water vapor (latent heat flux; LE) above the underlying surface (pecan grove). The resulting LE values are then converted to rates of evapotranspiration or consumptive use (CU) in units of inches or millimeters per day. Measurements of pecan CU were obtained for the 2014, 2015 and 2016 growing seasons with the growing season extending from 1 March through 30 November.

The Sahuarita flux tower was in a mature stand of cv. Wichita pecans planted in 1994. The trees were planted in a square pattern with an east-west row orientation with row spacing and tree spacing within rows set to 30′ (9.1 m). Irrigation water was provided by low trajectory sprinklers located within the tree row equal distance between adjacent

Figure 1. Walk-up flux tower that supported the eddy covariance instrumentation (red circle) used to measure pecan consumptive water use (CU). Inset photograph in upper righthand corner shows eddy covariance instrumentation.

trees with irrigation amount and frequency set by the grower. The orchard employed organic production practices with tree nutrition supported with The Farm's Choice Coop Juice (2N-1P-1K). An active hedging program was ongoing in the orchard, consisting of hedging every other middle every other year. Tree height ranged from 25 to 35′ (8.5 to 10.9 m) during the study.

The Bowie flux tower was in a mature stand of cv. Western Schley pecans planted in 1978 in a square pattern with a north-south row orientation with row spacing set at 40′ (12.2 m) and tree-to-tree spacing within rows set to 20′ (6.1 m). Irrigation water was provided by low trajectory sprinklers located within the tree row with irrigation amount and frequency set by the grower. The orchard employed conventional production practices with tree nutrition supported using: 1) 180 lb N /acre split into three applications and applied in the irrigation water, 2) 120 lb K/acre and 40 lb P/acre applied pre-bloom as a dry banded application and 3) three to four applications of 5 lb Zn/acre applied as zinc sulfate in a foliar spray. An active hedging program was ongoing in the orchard, consisting of hedging every third row every year. Tree height ranged from 25 to 35′ (8.5-10.9 m) during the study.

Meteorological data provided by automated weather stations operated by the Arizona Meteorological Network (AZMET, 2023) were used to assess general climatic conditions and reference evapotranspiration values (ETos) over the course of the study. The Bowie AZMET station was located 1.5 miles (2.5 km) west-northwest of the flux tower during 2014 and 2015, then moved to a new location 2.2 miles (3.5 km) south of the flux tower in 2016. The Sahuarita AZMET station was located 2.0 miles (3.3 km) south-southeast of the flux tower. Both stations were located in open fields adjacent to pecan groves.

Daily estimates of ETos were computed from AZMET data using the ASCE Standardized Reference Evapotranspiration Equation (Walter et al., 2005). Crop coefficients were computed by dividing the daily values of CU by ETos. No attempt was made to develop basal Kcs (well-watered crop with dry surface soil) due to frequent irrigation events and variable surface moisture (e.g., shaded tree row vs unshaded middle). The resulting Kcs from this study should therefore be defined as mean or average Kcs (ASCE, 2016).

Results and Discussion

Measured monthly values of pecan CU are provided in Table 1 for Sahuarita and Bowie for the 2014, 2015 and 2016 growing seasons. Average monthly and seasonal totals for the three years of the study are provided in the final two columns of Table 1. Growing season CU averaged 52.5″ (1334 mm) at Sahuarita and 51.4″ (1306 mm) at Bowie, differing by just 2% for the three years of study. Year-to-year variation in CU proved similar, ranging from 49.4 to 54.8″ (1255 to 1392 mm) at Sahuarita and 50.1 to 54.5″ (1272-1384 mm) at Bowie. Peak water use occurred in the latter half of June and early July, reflecting peak levels of evaporative demand as estimated using ETos. The lowest CU occurred at the beginning and end of the growing season when evaporative demand was lowest and canopy development was either limited (March & April) or declining due to cold temperatures and frost (November). Average monthly CU at the two locations differed by less than 5% in most months (Table 1).

The seasonal CU values obtained from this study are

Table 1. Monthly totals of measured pecan consumptive water use (CU) for the 2014, 2015 and 2016 growing seasons and the overall mean for the period 2014-16 at Sahuarita and Bowie, Arizona.

	2014		2015		2016		2014-2016 Mean	
	Sahuarita	Bowie	Sahuarita	Bowie	Sahuarita	Bowie	Sahuarita	Bowie
Month	inches	inches	inches	inches	inches	inches	inches	inches
Mar	2.7	2.1	1.9	1.8	1.6	2.2	2.0	2.0
Apr	4.9	4.1	4.8	4.6	3.6	5.1	4.4	4.6
May	8.8	7.5	6.9	7.2	7.0	8.3	7.6	7.7
Jun	10.8	9.3	8.9	8.2	8.5	8.0	9.4	8.5
Jul	7.4	8.4	7.5	7.5	9.1	9.4	8.0	8.4
Aug	7.0	7.0	7.4	8.0	7.5	7.2	7.3	7.4
7.4	5.4	5.4	5.4	5.8	6.7	6.2	5.8	5.8
Oct	5.0	4.8	4.3	4.7	6.0	5.6	5.1	5.0
Nov	2.7	1.6	2.3	2.4	3.4	2.0	2.8	2.0
Total	54.8	50.1	49.4	50.2	53.3	54.0	52.5	51.4

similar to regional studies previously conducted in New Mexico and Texas. Miyamoto (1983) found pecan CU in orchards near Las Cruces, NM and El Paso, TX was greatly impacted by tree size and density with mature pecans using between 39.4″ (1000 mm) and 51.2″ (1300 mm) during an April through October growing season. Sammis et al. (2004) measured the CU of flood irrigated pecans near Las Cruces, NM for two growing seasons extending from April through November and found CU ranged from 46.1″ (1170 mm) to 49.6″ (1260 mm). Bawazir and King (2004) measured the CU of a mature pecan orchard near Las Cruces, NM for two growing seasons and reported water use for a March through November growing season in the range of 51.7″ to 54.5″ (1314 to 1384 mm).

Consumptive Use Curve & Table

Pecan CU curves that provide CU as a function of day of the year were developed from the measured daily CU values. The resulting CU curves for Sahuarita and Bowie proved similar, and the two data sets were merged to facilitate the development of a single pecan CU curve (Fig. 2) for southern Arizona.

The CU curve exhibits a steady increase in CU from budbreak (late March) through mid-June with values peaking in late June. Consumptive use declines rather quickly with the onset of the monsoon in early July, then decreases in a nearly linear fashion through mid-October, before exhibiting a rapid decline in November with the onset of cold and/or freezing temperatures.

The CU curve in Figure 2 was used to generate weekly

Figure 2. Measured values of pecan consumptive water use (CU) obtained at Sahuarita and Bowie from 2014-16. The red curve represents the best-fit pecan CU curve for the combined data set.

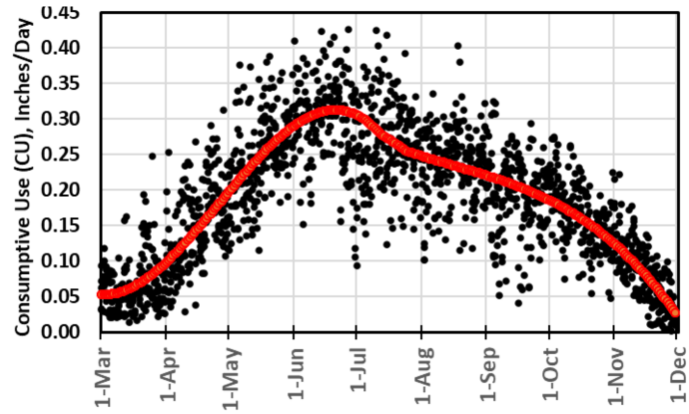

Table 2. Weekly estimates of Pecan consumptive water use (CU) for southern Arizona.

Week Ending	Pecan CU inches/Week		Weeek Ending	Pecan CU Inches/Week
7 Mar	0.38		25 Jul	1.82
14 Mar	0.41		1 Aug	1.76
21 Mar	0.47		8 Aug	1.71
28 Mar	0.57		15 Aug	1.67
4 Apr	0.70		22 Aug	1.62
11 Apr	0.84		29 Aug	1.58
18 Apr	1.00		5 Sep	1.54
25 Apr	1.17		12 Sep	1.49
2 May	1.34		19 Sep	1.44
9 May	1.51		26 Sep	1.38
16 May	1.68		3 Oct	1.31
23 May	1.83		10 Oct	1.23
30 May	1.96		17 Oct	1.15
6 Jun	2.06		24 Oct	1.05
13 Jun	2.14		31 Oct	0.94
20 Jun	2.18		7 Nov	0.81
27 Jun	2.18		14 Nov	0.67
4 Jul	2.14		21 Nov	0.51
11 Jul	2.04		28 Nov	0.33
18 Jul	1.92		**TOTAL**	52.52

totals of pecan CU during the growing season (Table 2). Total growing season CU is presented at the bottom of Table 2 and corresponds closely with the measured values of CU (Table 1).

Crop Coefficient (Kc) Curve and Table

Crop coefficient (Kc) curves were developed from seasonal plots of the daily ratios of pecan CU to ETos computed using the ASCE Standardized Reference Evapotranspiration Equation (Walter et al., 2005). Because the Kc curves for Sahuarita and Bowie were similar in shape and magnitude, the Kc data sets from both locations were merged to form a single Kc curve (Figure 3).

Crop Coefficients increase rapidly from budbreak through mid-June, then remain nearly constant during the summer months before increasing to a fall peak in mid-October. Crop coefficients decline rapidly with the onset of cold/freezing temperatures in November. The greatest variation in Kcs occurs in spring when sparse foliage development limits transpiration, generally resulting in low CU and Kcs. The variability in spring Kcs results when precipitation and irrigation events enhance surface evaporation for short periods, resulting in higher CU and increased Kcs.

The Kc curve presented in Figure 3 was used to produce

Table 3. Weekly pecan crop coefficients (Kc) for use with reference evapotranspiration (ETos) values computed using the ASCE Standardized Reference Evapotranspiration Equation. Details on how to generate the Kc curve using a 5th order polynomial with day of year as the independent variable are provided at the bottom of table.

Week Ending	Kc		Weeek Ending	Kc
7 Mar	0.36		25 Jul	1.03
14 Mar	0.36		1 Aug	1.03
21 Mar	0.38		8 Aug	1.03
28 Mar	0.43		15 Aug	1.03
4 Apr	0.49		22 Aug	1.04
11 Apr	0.56		29 Aug	1.06
18 Apr	0.63		5 Sep	1.07
25 Apr	0.70		12 Sep	1.09
2 May	0.76		19 Sep	1.11
9 May	0.82		26 Sep	1.13
16 May	0.88		3 Oct	1.14
23 May	0.92		10 Oct	1.15
30 May	0.96		17 Oct	1.14
6 Jun	0.99		24 Oct	1.12
13 Jun	1.01		31 Oct	1.07
20 Jun	1.02		7 Nov	1.00
27 Jun	1.03		14 Nov	0.88
4 Jul	1.03		21 Nov	0.71
11 Jul	1.03		28 Nov	0.48
18 Jul	1.03			

Equation to predict Kc as a function of day of year (DOY)*

$$Kc=A_0 - A_1*DOY + A_2*DOY^2 - A_3*DOY^3 = A_4*DOY^4 - A_5*DOY^5$$

Where:
$A_0 = 3.4992$
$A_1 = 1.2829 * 10^{-1}$
$A_2 = 1.8461 * 10^{-3}$
$A_3 = 1.1483 * 10^{-5}$
$A_4 = 3.2830 * 10^{-8}$
$A_5 = 3.5374 * 10^{-11}$

*Applicable for DOY = 60 to 334

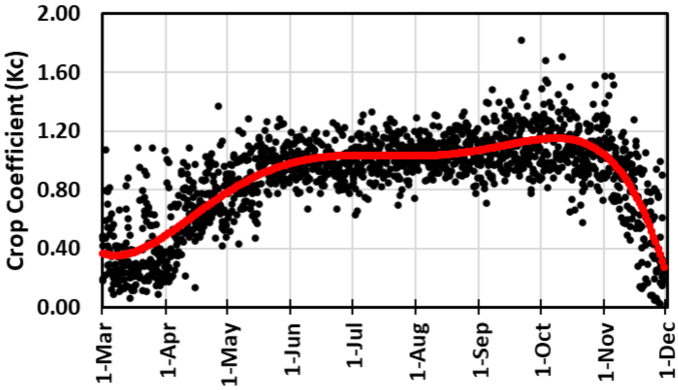

Figure 3. Daily crop coefficients (Kcs) obtained by dividing pecan consumptive water use (CU) by values of reference evapotranspiration (ETos) computed using the ASCE Standardized Reference ET Equation for the 2014, 2015 and 2016 growing seasons at Sahuarita and Bowie. The red curve represents the best-fit seasonal Kc curve for the combined data set.

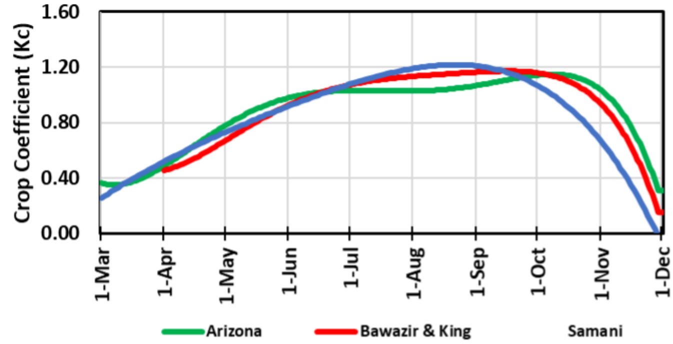

Figure 4. Comparison of crop coefficient (Kc) curve obtained from this study (Arizona) with curves developed in New Mexico by Bawazir and King (2004) and Samani (2011). All curves were derived using ETos computed using the ASCE Standardized Reference ET Equation.

weekly Kc values for the growing season beginning with the first week of March and ending on 28 November. These weekly Kc values are summarized in Table 3. Details on how to generate the Kc curve using a 5th order polynomial with day of year as the independent variable are provided at the bottom of Table 3.

Two regional sources provide Kc data/curves appropriate for use with the ASCE Standardized Reference Evapotranspiration Equation (Bawazir and King, 2004; Samani, 2011) and thus can be compared to the Kc curve developed in this study (Figure 4). The Kc curves developed from the regional studies exhibit a similar seasonal pattern and generally compare favorably with the Kc curve derived from this study (Figure 4).

Estimating Pecan Consumptive Use

Consumptive use of southern Arizona pecans can be estimated in two ways using the results of this study. The simplest way is to use the CU estimates obtained from the CU curve (Figure 2) that are summarized on a weekly basis in Table 2. If, for example, a weekly CU value is needed for the week ending 8 August, simply go to Table 2 and locate the CU value associated with the week in question which is 1.71″. Divide the weekly values by 7 if daily values of CU are required for that week (Daily CU = 1.71″/7 ~ 0.24″).

The second option available to estimate pecan CU is to use the Kcs that are summarized on a weekly basis in Table 3 to adjust values of ETos obtained from the local AZMET weather station using the following equation:

CU = Kc * ETos

To implement this estimation procedure, select the proper Kc from Table 3 which is 1.03 for or the week ending 8 August. Next, obtain the weekly total of ETos from the local AZMET station. A portion of the 2021 August AZMET monthly summary for Sahuarita is provided in Figure 5. Sum the ETos values in the column labeled ETo STD for the seven days ending on 8 August (outlined in red). The weekly ETos value is 1.70″. Insert the weekly Kc and ETos values in the equation above to obtain the estimate of CU:

CU = 1.03 * 1.70″ = 1.75″/week

Both CU estimation procedures should produce similar values in most circumstances. However, during periods with unusual (relative to long-term averages) or variable weather, the CU procedure using Kcs and current ETos will provide more reliable estimates because the AZMET ETos values reflect recent/current weather conditions.

Adjusting Results for Immature Orchards

This study did not evaluate the CU of immature orchards. Procedures have been developed that adjust Kcs for mature orchards to values appropriate for use with young orchards based on effective canopy cover (ECC) determined by estimating the fraction of the orchard floor that is shaded at solar noon (Wang et al., 2007; Samani et al., 2011; ASCE, 2016). Wang et al. (2007) developed adjustments specific for pecans in New Mexico and found the adjustment factor (Wang AF) was equal to 1.33*ECC (Table 5). The Wang AFs assume a well-watered orchard with a dry soil surface and are better suited for use with basal Kcs. The Wang AFs will likely underestimate CU of immature orchards unless adjustments are made to account for periods when the surface soil is wet as a result of irrigation and precipitation.

ARIZONA METEOROLOGICAL NETWORK MONTHLY SUMMARY

Sahuarita
August 2021

	AIR TEMP			DEW	REL HUM			SOIL T		WIND		SOL	RAIN	ETo	ETo	HEAT UNITS		
Aug	MX	MN	AV	PT	MX	MN	AV	4	20	AV	MX			AZ	STD	55	50	45
1	94	71	82	70	95	36	71	88	84	2.0	9	634	0.00	.24	.22	26	31	36
2	97	72	84	67	91	32	61	91	85	2.5	15	646	0.00	.26	.24	26	31	36
3	99	71	83	66	88	24	59	94	86	2.0	11	657	0.00	.26	.24	26	31	36
4	102	69	83	65	86	20	58	95	88	2.7	8	666	0.00	.27	.26	26	31	36
5	102	72	87	67	85	21	54	96	89	2.2	12	646	0.00	.27	.25	27	32	37
6	98	72	83	67	87	31	61	97	90	2.9	15	554	0.00	.24	.22	26	31	36
7	97	69	84	66	92	31	58	96	91	3.1	13	644	0.00	.26	.24	25	30	35
8	95	72	83	64	79	35	54	96	91	4.5	19	574	0.00	.24	.25	26	31	36

ETos = 1.70"

Figure 5. A portion of the AZMET monthly summary for August 2021 at Sahuarita. Red box outlines the daily reference evapotranspiration (ETos) values making up the weekly total of 1.70".

Table 4. Adjustment factors (AF) for young orchards based on effective canopy cover (ECC) measured as the fraction of the orchard floor shaded at solar noon (Wang et al., 2007; Samani et al., 2011). The Wang AFs assume well-watered trees (no stress), dry soil surface and little or no vegetation in the row middles and are better suited for orchards using drip irrigation. The Samini AFs assume well-watered trees, variable surface moisture with little or no vegetation in the row middles and are better suited for orchards irrigated with flood or sprinkler irrigation.

ECC	Wang AF	Samani AF
.10	0.13	0.54
.20	0.27	0.60
.30	0.40	0.66
.40	0.53	0.72
.50	0.67	0.78
.60	0.80	0.84
.70	0.93	0.90
.80	1.00	0.96
0.86	1.00	1.00

The Wang AFs should provide reasonable estimates of CU in immature orchards that utilize drip irrigation provided surface wetness and vegetation are limited.

Samani et al. (2011) used satellite assessments of ECC to develop AFs (Samani AF) for immature flood-irrigated pecan orchards in the Las Cruces area. Their adjustment factors (Table 5) included periods when the soil surface was wet following irrigation or rainfall events and thus are better suited for use with the mean Kcs values provided in this report. Caution is still warranted when using these AFs given the spatial and temporal differences in surface wetness that are possible when using flood as opposed to sprinkler irrigation.

Assuming the ECC of the pecan orchard in the example above (Figure 5) was 0.4 and irrigated with sprinklers, the Kc adjustment process proceeds as follows:

1. Obtain the Samani AF for ECC = 0.4 from Table 5
   AF = 0.72
2. Multiply the AF by the Kc value
   Adjusted Kc = 0.72 * 1.03 = 0.74
3. Multiply Adjusted Kc by ETos obtained from Figure 5 to obtain CU
   CU = 0.74 * 1.70" = 1.26"

The AFs are designed to adjust Kc values as indicated above. They should work equally well if using the CU values in Table 2. Simply multiply the CU values in Table 2 by the appropriate AF based on the orchard ECC value.

Summary Comments

Growing season CU of pecans averaged 52.5" (1334 mm) at Sahuarita and 51.4" (1306 mm) at Bowie during the three years of this study. Year-to-year variation in CU proved similar and small, ranging from 49.4 to 54.8" (1255 to 1392 mm) at Sahuarita and 50.1 to 54.5" (1272 to 1384 mm) at Bowie. The CU and Kc data sets collected at Sahuarita and Bowie were similar and allowed for the development of single CU and Kc curves applicable for southern Arizona. Crop coefficients and Kc curves were developed for use with ASCE Standardized Reference Evapotranspiration Equation (ETos) to facilitate the estimation of CU from ETos. The CU and Kc values developed from these data sets should be representative of southern Arizona pecan orchards irrigated with sprinklers. Consumptive use estimates may be in error early in the growing season in orchards irrigated with flood or drip irrigation where differences in both the aerial extent and frequency of surface wetting may differ from orchards irrigated with sprinklers. These errors should dissipate quickly as the foliage develops in April (see Sammis et al., 2004).

Appropriate caution is recommended when using the results of this study at lower elevations in central and western Arizona where warmer temperatures will lead to earlier spring budbreak and later fall foliage decline. Most likely, some adjustments to the early and late season portions of CU and Kc curves will be required. Use of an adjusted Kc curve in conjunction with local AZMET ETos data would be the preferred means of estimating pecan CU because the AZMET data will reflect the higher evaporative demand at these lower elevations.

The CU estimates provided in this bulletin must be adjusted to determine the amount of water required for an irrigation event. To determine irrigation water requirements, it is necessary to subtract effective precipitation (precipitation not lost to runoff and deep percolation), then adjust the resulting value for the application efficiency of the irrigation system (Howell, 2003) and salinity management (Walworth, 2011). Adjustments for irrigation efficiency and salinity increase the irrigation water requirement above CU, often by a substantial amount.

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