Evapotranspiration Product Description

INTRODUCTION

The Oklahoma Mesonet Evapotranspiration Model is a weather-based tool that estimates daily water loss from a plant canopy through the combined processes of evaporation (from soil and plant surfaces) and plant transpiration. Using weather data from the Oklahoma Mesonet, the model calculates daily standardized reference evapotranspiration for short (ET_{os}) and tall (ET_{rs}) canopies from a hypothetical well-watered crop surface. Individual crop coefficients are applied to either the short or tall reference evapotranspiration to estimate a daily crop water loss in inches of water.

Alfalfa, corn, cotton, peanut, sorghum, soybean, and warm-season grass hay evapotranspiration values are calculated from polynomial equations that adjust the crop coefficient for physiological plant age. Tomato, watermelon, and wheat crop coefficients are set based on days from planting. Crop coefficients for cool-season grass hay, warm-season grass (bermudagrass), and cool-season grass (tall fescue) are set using an average daily air temperature. The crop coefficients for grape and general vegetable are set based on the month. Monthly crop coefficients are also used for peach and pecan, but evapotranspiration rates are calculated from pan evaporation (E_{pan}). E_{pan} is a calculated value that estimates evaporation from a Class A National Weather Service pan.

Agricultural producers can use crop evapotranspiration to help determine when to irrigate. Crop evapotranspiration values provide an estimate of water used by the plant from rainfall, irrigation and water stored in the soil. By comparing crop evapotranspiration values for the time since the last rainfall or irrigation and factoring in soil water holding capacity, producers can decide when to irrigate and how much water needs to be applied.

By comparing crop evapotranspiration values over the entire growing season to the rainfall, evapotranspiration can be used to estimate dryland crop production and quality.

The Oklahoma AgWeather site includes evapotranspiration products to help homeowners schedule watering of their lawn and yard areas. Using evapotranspiration to schedule turfgrass watering can decrease water runoff, improve grass health, and improve water use efficiency.

The Oklahoma Evapotranspiration Model operates year-round and is updated once each day using the 24-hour period from midnight to midnight CST. Updated output is available in the early morning hours.

DISCLAIMER
The Oklahoma Evapotranspiration model is intended as a guide to estimate soil water loss from both soil evaporation and plant transpiration. It is a best estimate based on the science currently available and data from the Oklahoma Mesonet system. This information is provided as a public service with the understanding that Oklahoma State University, the University of Oklahoma, and the Oklahoma Climatological Survey makes no warranties, either expressed or implied, concerning the accuracy, completeness, reliability, or suitability of the information. Nor do any of the mentioned parties warrant that the use of this information is free of any claims of copyright infringement.

CONTACTS:
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For more detailed information about the Oklahoma Mesonet Evapotranspiration products, you can contact:

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STANDARDIZED REFERENCE EVAPOTRANSPIRATION EQUATION
The calculation of crop evapotranspiration is based on the Standardized Reference Evapotranspiration Equation (ET_{sz}) recommended by the Standardization of Reference Evapotranspiration Task Committee of the Environmental and Water Resources Institute of the American Society of Civil Engineers (ASCE) in their final report of July 9, 2002. This committee defined reference evapotranspiration (ET_{ref}) as the evapotranspiration rate from a uniform surface of dense, actively growing vegetation having specified height and surface resistance, not short of soil water, and representing an expanse of at least 100 meters of the same or similar vegetation.

To calculate the estimated crop evapotranspiration the appropriate ET_{sz} , for either a short canopy (ET_{os}) or tall canopy (ET_{rs}) is multiplied by the crop coefficient (K_c). On the Oklahoma AgWeather site the K_c is based on the individual crop and crop stage. The exceptions to this are evapotranspiration calculations for pecan and peach. Crop coefficients for peach and pecan are multiplied by calculated pan evaporation, rather than the reference evapotranspiration value.

The ET_{sz} equation surfaces are defined as:
Standardized Reference Evapotranspiration Equation, Short (ET_{os}): ET_{ref} for a *short* crop with an approximate height of 0.12 m ($4^3/_4$ inches), similar to clipped grass.

Standardized Reference Evapotranspiration Equation, Tall (ET_{rs}): ET_{ref} for a *tall* crop with an approximate height of 0.50 m ($19^3/_4$ inches), similar to full-cover alfalfa.

The two surfaces are similar to known full-cover crops of clipped grass and alfalfa that have received widespread use as ET_{ref} across the United States. As a part of the standardization, the ASCE Penman-Monteith (ASCE-PM) equation and associated equations for calculating aerodynamic and bulk surface resistance have been combined and condensed into a single equation that is applicable to both surfaces.

The Oklahoma Mesonet calculation of daily ET_{ref} uses daily time steps and sets the soil heat flux term G equal to zero.

ASCE Standardized Reference Equation (ET_{sz}):

$$ET_{sz} = \frac{0.408\Delta(R_n - G) + \gamma \dfrac{C_n}{T + 273} u_2(e_s - e_a)}{\Delta + \gamma(1 + C_d\, u_2)}$$

where:

ET_{sz} = standardized reference crop evapotranspiration for short (ET_{os}) or tall (ET_{rs}) surfaces (mm d^{-1} for daily time steps or mm h^{-1} for hourly time steps),

R_n = calculated net radiation at the crop surface (MJ m^{-2} d^{-1} for daily time steps or MJ m^{-2} h^{-1} for hourly time steps),

G = soil heat flux density at the soil surface (MJ m^{-2} d^{-1} for daily time steps or MJ m^{-2} h^{-1} for hourly time steps),

T = mean daily or hourly air temperature at 1.5 to 2.5-m height (°C),

u_2 = mean daily or hourly wind speed at 2-m height (m s^{-1}),

e_s = saturation vapor pressure at 1.5 to 2.5-m height (kPa), calculated for daily time steps as the average of saturation vapor pressure at maximum and minimum air temperature,

e_a = mean actual vapor pressure at 1.5 to 2.5-m height (kPa),

Δ = delta, the slope of the saturation vapor pressure-temperature curve (kPa °C^{-1}),

γ = psychrometric constant (kPa °C^{-1}),

C_n = numerator constant that changes with reference type and calculation time step, and

C_d = denominator constant that changes with reference type and calculation time step.

Table 1 provides values for C_n and C_d. The values for C_n consider the time step and aerodynamic roughness of the surface (i.e., reference type). The constant in the denominator, C_d, consider the time step, bulk surface resistance, and aerodynamic roughness of the surface (the latter two terms vary with reference type, time step and daytime/nighttime). C_n and C_d were derived by simplifying several terms within the ASCE-PM equation and rounding the result. Daytime is defined as occurring when the average net radiation, R_n, during an hourly period is positive.

Table 1 --- Values for C_n and C_d in ET_{sz}

Calculation Time Step	Short Reference, ET_{os}		Tall Reference, ET_{rs}		Units for ET_{os} and ET_{rs}	Units for R_n and G
	C_n	C_d	C_n	C_d		
Daily	900	0.34	1600	0.38	mm d^{-1}	MJ m^{-2} d^{-1}
Hourly during daytime	37	0.24	66	0.25	mm h^{-1}	MJ m^{-2} h^{-1}
Hourly during nighttime	37	0.96	66	1.7	mm h^{-1}	MJ m^{-2} h^{-1}

Table 2 --- ASCE Penman-Monteith Terms Standardized for Application of the Standardized Reference Evapotranspiration Equation

Term	ET_{os}	ET_{rs}
Reference vegetation height, h	0.12 m ($4^3/_4$ inches)	0.50 m ($19^3/_4$ inches)
Height of air temperature and humidity measurements, z_h	1.5-2.5 m	1.5-2.5 m
Height corresponding to wind speed, z_w	2.0 m	2.0 m
Zero plane displacement height	0.08 m	0.08 m [a]
Latent heat of vaporization	2.45 MJ kg^{-1}	2.45 MJ kg^{-1}
Surface resistance, r_s, daily	70 s m^{-1}	45 s m^{-1}
Surface resistance, r_s, daytime	50 s m^{-1}	30 s m^{-1}
Surface resistance, r_s, nighttime	200 s m^{-1}	200 s m^{-1}
Value of R_n for predicting daytime	>0	>0
Value of R_n for predicting nighttime	≤0	≤0

[a] The zero plane displacement height for ET_{rs} assumes that the wind speed measurement is over clipped grass, even though the reference type is tall.

Other details:
1) Maximum daily clear-sky solar radiation (R_s0):

Using 5 years of Mesonet data from a number of sites throughout the state, J.D. Carlson developed regression equations for R_s0 as a function of daily extraterrestrial solar radiation, R_a, and station elevation.

From May through October (the hazier summer period), the data showed lower values of R_s0/R_a as compared to the remainder of the year. Accordingly, the year is divided into two main periods with a transition month between each main period. The scheme used is as follows, where station elevation is in meters:

Julian Day	R_s0 Calculation
1-104, 288-366	R_s0 = [0.720+4.88*10-5(Elev)] R_a
105-134, 257-287	R_s0 = [0.705+5.07*10-5 (Elev)] R_a
135-256	R_s0 = [0.685+5.28*10-5 (Elev)] R_a

2) Average daily saturation vapor pressure. This variable is calculated as the average of the saturation vapor pressure at the maximum temperature and that at the minimum temperature.

3) Average actual vapor pressure. This variable is calculated as the average of the 5-minute values of vapor pressure throughout the day.

4) Slope of vapor pressure curve, Delta (Δ): In calculation of this variable, the daily average temperature is used rather than using a constant.

MEASURED PARAMETERS

The 5-minute average weather variables from Mesonet that are used to calculate $ET_{\underline{sz}}$ are:

Solar Radiation (Watts/meter^2, W/m^2)
2-m Wind Speed (meters/second, m/s)
1.5 m Air Temperature (degrees Centigrade, °C)
1.5 m Relative Humidity (percent, %)
Station Pressure (kilo-pascal, kPa)

Dew point, when needed, is calculated from the air temperature and relative humidity. At station sites not measuring 2-meter wind speed, an objective analysis scheme is used to interpolate a value. Daily average air temperature is calculated as the average of the maximum and minimum temperature for the day.

PAN EVAPORATION (E_{pan}) CALCULATION

The model uses equations from the United Nations Food and Agriculture Organization Irrigation and Drainage Paper Number 24 (FAO-24) to calculate pan evaporation. A green fetch of 100 m is assumed. The pan coefficient (K_p) is a function of the daily average 2-meter wind speed, the daily average relative humidity, and the fetch. In addition, the wind speed and relative humidity values are constrained to be within certain limits.

$$E_{pan} \text{ (in inches)} = \frac{ET_{os}}{[0.3023-(0.0286*WS2_{avg})+(0.130*L_n(RH_{avg}))]}$$

where:

ET_{os} = Standardized Reference Evapotranspiration, *short*
$WS2_{avg}$ = daily average 2-meter wind speed in m/s, minimum cutoff is 0.97 m/s and maximum cap is 8.1 m/s
RH_{avg} = daily average relative humidity in %, minimum cutoff is 30% and maximum cap is 84%
L_n = natural logarithm

CROP EVAPOTRANSPIRATION CALCULATION

An estimated daily crop evapotranspiration is calculated for alfalfa, corn, cotton, general vegetable, grass hay, peanut, sorghum, soybean, tomato, turfgrass, watermelon and wheat from the appropriate Standardized Reference Equation (ET_{sz}) and a crop coefficient (K_c) adjusted for physiological plant age. ET for peach and pecan is calculated from pan evaporation (E_{pan}).

Crop ET = ET_{sz} x Crop K_c

where:

Crop ET = the evapotranspiration of the specified crop
ET_{sz} = standardized reference crop evapotranspiration for short (ET_{os}) or tall (ET_{rs}) surfaces, and
Crop K_c = crop coefficient.

CROP COEFFICIENTS (K_c)

<u>Alfalfa</u>

Alfalfa ET = ET_{os} * Alfalfa K_c

Alfalfa K_c = $(A+Bx+Cx^2+Dx^3+Ex^4+Fx^5)*1.21$

where, x = fraction of cut cycle elapsed, and

Parameter	Prior to 1st cutting	Other cuttings	Cut date after Sept 15
A	0.5477	0.3092	0.2839
B	1.768	-0.9799	1.592
C	-2.152	19.03	-2.217
D	0.7751	-47.44	0.8450
E	0	45.40	0
F	0	-15.38	0
K_c minimum	0.6	0.24	0.24
K_c maximum		1.33	1.1

x Calculation prior to First Cutting
Before first cutting, x is a fraction of the accumulated degree day value based on a 41°F minimum (DD_{41}). Calculation of degree days begins on January 1st or from the date of the last 22°F temperature event since January 1st.

The pertinent formulas are:

$$x = (CDD/750) \qquad [\text{if } x > 1, \text{ set } x = 1]$$

$$CDD = \text{sum}(DD_{41} \text{ from StDate})$$

$$DD_{41} = \frac{(T_{MAX} + T_{MIN})}{2} - 41°F \qquad [\text{if } DD_{41} < 0, \text{ set } DD_{41} = 0]$$

where:
CDD = the cumulative daily DD_{41} from start date
DD_{41} = degree day value based on a minimum of 41°F
StDate = start date based on January 1 or last 22°F minimum temperature, whichever is later
T_{MAX} = daily maximum air temperature at 1.5 m, and
T_{MIN} = daily minimum air temperature at 1.5 m.

x Calculation after First Cutting and before or on Sept. 15
After the first cutting, x is a fraction of a 28 day maximum growth cycle.

$$x = (\text{day of year - cut date})/28 \text{ days} \qquad [\text{if } x > 1, \text{ then } x = 1]$$

x Calculation for last cutting, where cut date is after Sept. 15

$$x = (\text{day of year - cut date})/35 \text{ days} \qquad [\text{if } x > 1, \text{ then } x = 1]$$

(from Mike Kizer and J.D. Carlson, 2004)

Corn

Corn ET = ET_{os} * Corn K_c

Corn K_c = $(0.450-0.692x+9.581x^2-15.101x^3+6.614x^4) * 1.21$

Corn K_c minimum = 0.48 (for x<1)

where,
x = [(Day of Year - Planting Date)/Relative Maturity Days]
and if x>1, set x=1, before calculating the crop coefficient.

When the number of days from planting is equal to the number of relative maturity days, x=1, then the Corn K_c drops from 1.0 to 0.24, linearly over the next 14 days. The Corn K_c then remains at 0.24 until the start of the next planting date.

The default Relative Maturity Days for corn is 120 days. The default Planting Date is April 15.

(from Mike Kizer and J.D. Carlson, 2004)

Cotton

Cotton ET = ET_{os} * Cotton K_c

Cotton K_c = $(0.330-2.323x+16.897x^2-24.919x^3+10.504x^4) * 1.21$

Cotton K_c minimum = 0.30 (for x<1)

where,
x = [(Day of Year - Planting Date)/Relative Maturity Days]
and if x>1, set x=1, before calculating the crop coefficient.

When the number of days from planting is equal to the number of relative maturity days, x=1, then the Cotton K_c drops from 0.6 to 0.24, linearly over the next 14 days. The Cotton K_c then remains at 0.24 until the start of the next planting date.

The default Relative Maturity Days for cotton is 160 days. The default Planting Date is May 15.

(from Mike Kizer and J.D. Carlson, 2004)

Grape

Grape ET = ET_{os} * Grape K_c

Grape K_c by the month

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
.2	.2	.25	.45	.65	.75	.75	.7	.55	.45	.35	.2

(from United Nations Food and Agricultural Organization (FAO) data, 2002)

The default Season Start Date for grape is March 1.

Grass Hay

Grass Hay ET = ET_{os} * Grass Hay K_c

Warm-season Grass Hay

Before first cutting:

$$K_c = 0.55+0.6151x+2.380x^2-5.105x^3+2.562x^4$$

When the average daily air temperature is below 50°F, the warm-season grass hay K_c = 0.2.

where:
x = [(day of year - StDate)/28 days] [If x > 1, set x = 1], and
StDate = Integer [(2.333*latitude)+43.8].

(The crop start date (StDate) begins on May 3 (day 123) for southern Oklahoma, extending to May 10 (day 130) for northern Oklahoma, with a 28-day growing period before first cutting.)

For all other cuttings:

$$K_c = 0.55+0.6151x+2.380x^2-5.105x^3+2.562*x^4$$

where, x is the fraction elapsed of a 28-day cut cycle,
x = [(day of year - cut date)/28 days] [If x > 1, set x = 1].

The default Season Start Date for warm-season grass hay is May 3.

(from Charles Taliaferro, Mike Kizer, and J.D. Carlson, 2003)

Cool-season Grass Hay

The cool-season grass coefficient is 0.93, when the average daily air temperature is 40°F or higher. When the average daily air temperature is lower than 40°F, the cool-season grass winter coefficient is 0.65.

The default Season Start Date for cool-season grass hay is March 1.

(Coefficient values from Turf Irrigation Management Series: II, Converting Reference Evapotranspiration into Turf Water Use, AZ1195, 12/2000, University of Arizona.)

Peach

Peach ET = E_{pan} x Peach K_c

where:
E_{pan} = Pan evaporation calculated from ET_{os}, and
Peach K_c = Peach crop coefficient for use with E_{pan}

Peach K_c by month

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Early	0.2	0.2	0.2	0.5	0.5	1.1	0.6	0.6	0.6	0.6	0.2	0.2
Mid	0.2	0.2	0.2	0.5	0.5	0.9	1.1	0.6	0.6	0.6	0.2	0.2
Late	0.2	0.2	0.2	0.5	0.5	0.9	1.1	1.1	0.6	0.6	0.2	0.2

Note: At pit hardening, stage 2, the coefficient is 1.1. Immediately after harvest growers want to greatly reduce water, so the coefficient is dropped to 0.6. (from Mike Smith, 2003)

The default Season Start Date for peach is April 1.

Peanut

Peanut ET = ET_{os} * Peanut K_c

Peanut K_c = $(-1.644+12.050x-17.155x^2+7.499x^3+0.0x^4) * 1.21$

Peanut K_c minimum = 0.36 (for $x<1$)

where,
x = [(Day of Year - Planting Date)/Relative Maturity Days]
and if x>1, set x=1, before calculating the crop coefficient.

When the number of days from planting is equal to the number of relative maturity days, x=1, then the Peanut K_c drops from 0.91 to 0.24, linearly over the next 14 days. The Peanut K_c then remains at 0.24 until the start of the next planting date.

The default Relative Maturity Days for Spanish peanuts is 140 days and for runner peanuts is 150 days. The default Planting Date is May 15 for both types.

(from Mike Kizer and J.D. Carlson, 2004)

Pecan

Pecan ET = E_{pan} x Pecan K_c

where,
E_{pan} = Pan evaporation calculated from ET_{os}, and
Pecan K_c = Pecan crop coefficient for use with E_{pan}

Pecan K_c by month

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
0.2	0.2	0.2	0.2	0.5	0.8	1.0	0.9	0.5	0.2	0.2	0.2

(from Texas Pecan Handbook, 2004)

The default Season Start Date for pecan is May 1.

Sorghum

Sorghum ET = ET_{os} * Sorghum K_c

Sorghum $K_c = (-0.236+2.906x+2.314x^2-11.941x^3+7.405x^4) * 1.21$

Sorghum K_c minimum = 0.36 (for $x<1$)

where,
x = [(Day of Year - Planting Date)/Relative Maturity Days]
and if $x>1$, set $x=1$, before calculating the crop coefficient.

When the number of days from planting is equal to the number of relative maturity days, $x=1$, then the Sorghum K_c drops from 0.54 to 0.24, linearly over the next 14 days. The Sorghum K_c then remains at 0.24 until the start of the next planting date.

The default Relative Maturity Days for sorghum is 135 days. The default Planting Date is May 15.

(from Mike Kizer and J.D. Carlson, 2004)

Soybean

Soybean ET = ET_{os} * Soybean K_c

Soybean $K_c = (A+Bx+Cx^2+Dx^3+Ex^4) * 1.21$

Parameter	X<=0.375	X>0.375
A	0.18	7.05091
B	0.949	-47.6328
C	0	121.536
D	0	-126.106
E	0	45.8315
K_c minimum	0.2	--

Soybean K_c minimum = 0.24 (for x<1)

where,
x = [(Day of Year - Planting Date)/Relative Maturity Days]
and if x>1, set x=1, before calculating the crop coefficient.

When the number of days from planting is equal to the number of relative maturity days, x=1, then the Soybean K_c drops from 0.82 to 0.24, linearly over the next 14 days. The Soybean K_c then remains at 0.24 until the start of the next planting date.

The default Relative Maturity Days for maturity group III soybeans is 132, group IV 148 days, group V 153 days and group VI 163 days. The default Planting Date for group III and IV soybeans is May 11 and for group V and VI June 16.

(from Mike Kizer and J.D. Carlson, 2004)

Tomato

Tomato ET = ET_{os} * Tomato K_c

Tomato K_c by by days from planting

Crop Stage	Early	Vegetative	Flowering/Early Fruit	Late
Stage length	20 days	30 days	40 days	20 days
Tomato K_c	0.6	0.6-1.15 (linear increase over this period)	1.15	0.9

(from United Nations Food and Agricultural Organization (FAO) data, 2002)

The default Planting Date for tomato is April 10.

Turfgrass

Turfgrass ET = ET_{os} * Turfgrass K_c

Warm-season grass Turfgrass K_c:

The warm-season grass coefficient is 0.7, when the average daily air temperature is 50°F or higher. When the average daily air temperature is below 50°F, the warm-season grass coefficient is set at 0.2.

The default Season Start Date for warm-season grass hay is May 3.

Cool-season grass Turfgrass K_c:

The cool-season grass coefficient is 0.93, when the average daily air temperature is 40°F or higher. When the average daily air temperature is lower than 40°F, the cool-season grass coefficient is set at 0.65.

The default Season Start Date for cool-season turfgrass is March 1 and for warm-season turfgrass May 1.

(Turfgrass coefficient values derived from the Turf Irrigation Management Series: II, Converting Reference Evapotranspiration into Turf Water Use, AZ1195, 12/2000, University of Arizona. Bermudagrass temperature range from *Bermudagrass "The Sports Turf of the South"* by Richard L. Duble, Texas Agricultural Extension Service.Tall fescue temperature range from Dennis Martin, 2003.)

Vegetable - General

General Vegetable ET = ET_{os} * General Vegetable K_c

General Vegetable K_C by month

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
.1	.3	.4	.7	.9	1.0	1.1	1.1	.8	.5	.3	.1

(from Albert Sutherland, 2003)

The default Planting Date for all vegetables is March 1.

Watermelon

Watermelon ET = ET_{os} * Watermelon K_c

Watermelon K_C by days from planting

Watermelon K_c	0.4	0.4-1.0 (linear increase over the period)	1.0	0.75
Short Season	10 days	20 days	20 days	30 days
Mid Season	15 days	25 days	25 days	30 days
Long Season	20 days	30 days	30 days	30 days

(from United Nations Food and Agricultural Organization (FAO) data, 2002)

The default Relative Maturity Days for early-season watermelon is 80 days, mid-season 95 days and late-season 110 days. The default Planting Date for all watermelon groups is May 1.

<u>Wheat</u>

Wheat ET = ET_{os} * Wheat K_c

Wheat Kc by days from planting

Crop stage	Over-winter	Early spring	Mid	Late
Length	Planting date to Feb. 27	55 days	40 days	20 days
Wheat K_c	0.7	0.7-1.15 (linear increase over this period)	1.15	1.15-0.25 (linear decrease over this period)

(from United Nations Food and Agricultural Organization (FAO) data, 2002)

The default Planting Date for wheat is Oct 1.

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Edited: March 24, 2005