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Magnitude and Trends of Reference Evapotranspiration Rates in South Central Nebraska: Daily, Monthly, Growing Season Total, and Annual Total

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Reference evapotranspiration (ET_{ref}) is used to determine the actual water use (ET_a) rate for various crops and is one of the key variables that needs to be determined accurately for effective irrigation management. This extension circular provides information on the magnitude and temporal distribution of daily, monthly, annual, and growing season alfalfa-reference evapotranspiration (ET_{ref}) in south central Nebraska. It also discusses why long-term average ET_{ref} values may not represent non-average years or be accurate enough for irrigation management.

The most common way to calculate actual crop water use (ET_a) for a given agronomic crop is to use the ET_{ref} and crop coefficient (K_c) approach (i.e., $ET_a = ET_{ref} \times K_c$). This is described in detail in the UNL Extension NebGuide *Estimating Crop Evapotranspiration from Reference Evapotranspiration and Crop Coefficients* (G1994). This NebGuide also presents information about sources of local ET_{ref} and crop coefficients. ET_{ref} can either be measured directly using advanced evaporative flux measurement systems, including atmometers (ETgage™), or calculated from weather variables such as solar radiation, air temperature, relative humidity, and wind speed. (For more information on ET gauges see Using Modified Atmometers (ETgage™) for Irrigation Management, UNL NebGuide G1579.)

Note that ET_{ref} can represent either grass- or alfalfa-reference ET. Since alfalfa-reference ET is more commonly used in the Midwest, including Nebraska, in this publication ET_{ref} represents alfalfa-reference ET. Grass-reference ET is commonly used in other states, especially in the eastern, southern, southeastern, and western United States.

Accurate quantification of in-season ET_{ref} is necessary to make better informed and timely irrigation management decisions to meet crop water demand. In some cases, long-term average ET_{ref} values are used in place of ET_{ref} estimated with current weather data or an atmometer to calculate actual crop ET for irrigation management. However, an individual growing season can have weather conditions significantly different than the long-term average, which leads to questions about the accuracy of substituting long-term average ET_{ref} for current estimates.

Long-term average daily, monthly, growing season, and annual total ET_{ref} values from 1982 to 2008 were quantified and analyzed for a location in south central Nebraska. Year-to-year (inter-annual) variabilities of daily, monthly, seasonal, and annual ET_{ref} are presented here to assess whether long-term average ET_{ref} values

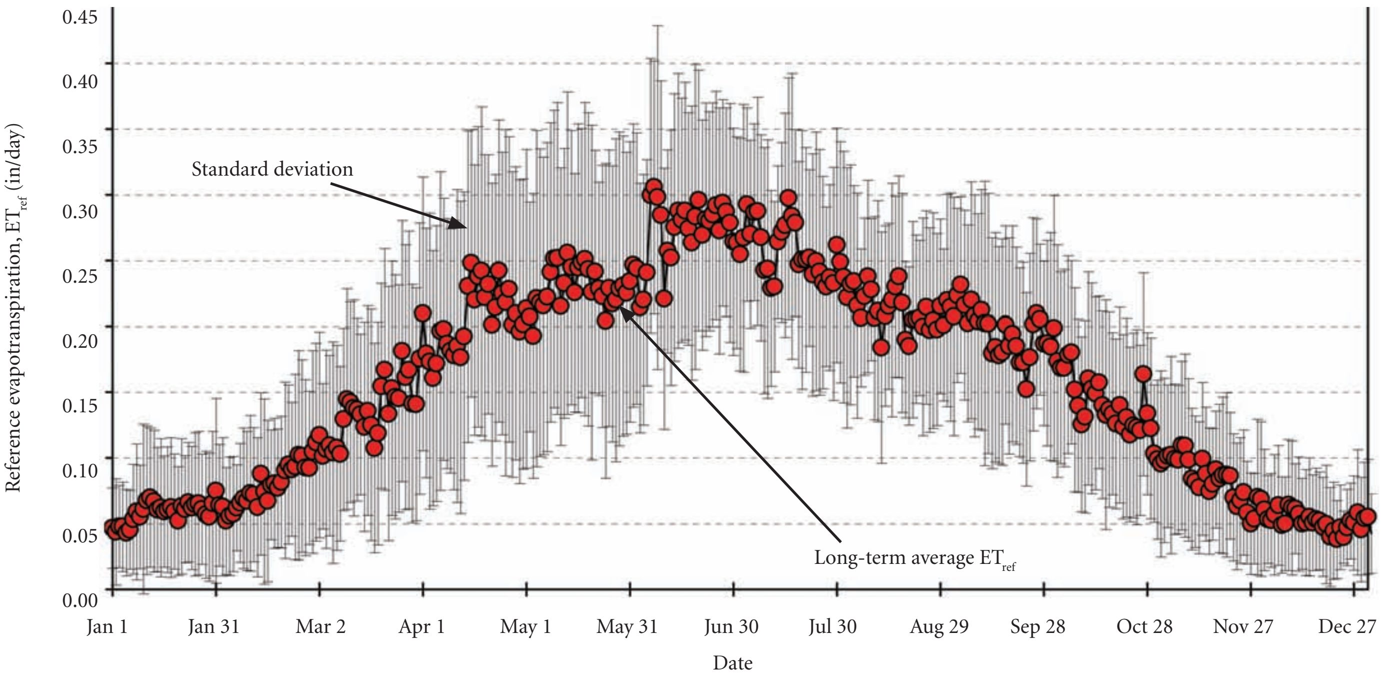

Figure 1. Long-term average (1982-2008) seasonal distribution of daily alfalfa-reference evapotranspiration (ET_{ref}) in south central Nebraska (Clay Center). Each data point represents an average of 27 daily ET_{ref} values (1982-2008). The vertical bars indicate the standard deviation in ET_{ref} for a given day.

could accurately represent a single year for the purpose of irrigation management. In a year that's below or above average, using long-term average ET_{ref} values may not accurately represent the current growing season and may not be effective for calculating actual crop water use for irrigation management.

Distribution of Daily Reference Evapotranspiration for the Calendar Year

Daily ET_{ref} values for 1982-2008 were obtained from the High Plains Regional Climate Center Web site (www.phrcc.unl.edu) for the Clay Center automated weather station at UNL's South Central Agricultural Laboratory (latitude: 40° 57' N; longitude of 98° 13', with a mean sea level elevation of 1,811 ft). Long-term average values represent the average of daily ET_{ref} values from this period. For any given day, 27 ET_{ref} values (one from each year) were averaged. The standard deviation values also were calculated for each day and included on the graph. The standard deviation is a measure of the variability or dispersion of the ET_{ref} values in each period. A small standard deviation indicates that the data points are close to the mean, while a large standard deviation indicates that the data are spread out over a wide range of values. *Figure 1* shows the distribution of long-term average daily ET_{ref} values for a calendar year (January 1-December 31) for Clay Center.

As observed in *Figure 1*, the ET_{ref} was low early in the year and gradually increased through the spring and into summer, then decreased gradually toward the end of the year. The ET_{ref} ranged from 0.05 inch per day in winter to 0.30 inch per day in June and July. The peak ET_{ref} in south central Nebraska occurs from early June to mid or late July. The long-term annual average daily ET_{ref} is 0.16 inch per day, the annual maximum value is 0.31 inch per day, and the minimum is 0.04 inch per day. The long-term growing season average daily ET_{ref} — 0.23 inch per day — is greater than the annual average, and the minimum growing season ET_{ref} — 0.15 inch per day — is greater than the annual minimum. The annual maximum of 0.31 inch per day occurs during the growing season.

The annual average standard deviation is 0.08 inch per day, the maximum is 0.13 inch per day, and the minimum is 0.02 inch per day. When only the growing season (May 1 – September 30) is considered, the seasonal average standard deviation is similar to the annual average (0.09 inch per day); the growing season maximum deviation is the same as annual maximum deviation (0.13 inch per day). However, the minimum standard deviation is slightly higher for the growing season than the annual minimum deviation (0.05 inch per day for the growing season and 0.02 inch per day for the annual).

The standard deviation shows that there is significant variation from one year to another for each day of the year. For example, in early June when ET_{ref} is at its peak value, the standard deviation was about 0.10 inch per day. The peak ET_{ref} in the first week of June ranged from 0.20 to 0.40 inch per day for the 27-year period. For example, the long-term average ET_{ref} for June 10 is 0.22 inch per day and the standard deviation is 0.10 inch per day. Thus, for any given year, the ET_{ref} for June 10 can fluctuate from 0.12 inch per day to 0.32 inch per day, depending on weather conditions (solar radiation, air temperature, wind speed, and relative humidity, which are the drivers of ET_{ref}). An-

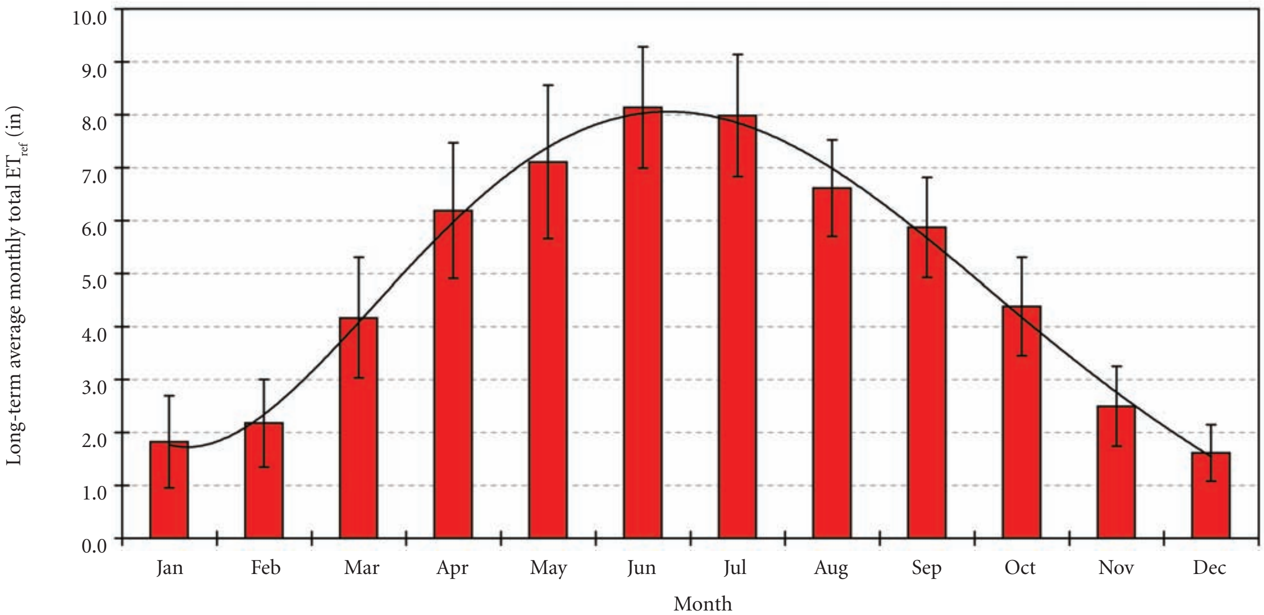

Figure 2. Distribution of monthly total alfalfa-reference evapotranspiration (ET_{ref}) for the calendar year in south central Nebraska. Each data point (vertical bar) represents an average of 27 monthly total ET_{ref} values (1982-2008). The vertical lines on the data bars indicate the standard deviation in ET_{ref} for a given month.

other example is given for April 25, when the maximum standard deviation value (0.13 inch per day) for the entire year was observed. The long-term average ET_{ref} for April 25 is 0.22 inch per day. From 1982 to 2008 the ET_{ref} for April 25 ranged from 0.09 inch per day to 0.35 inch per day, depending on weather conditions.

These findings suggest that for an average year, the long-term average ET_{ref} values may be used to estimate actual crop water use rates for a given crop; however, for a non-average year, daily ET_{ref} values may deviate significantly from the long-term average values and may not be accurate enough to be used for irrigation management. In a non-average year, a measured or locally estimated ET_{ref} value should be used. While using the long-term average ET_{ref} value may be feasible for design or other purposes, its use for in-season irrigation management may result in false actual crop water use information in a non-average year. Unfortunately, identifying the current year as average or above or below average can be quite challenging. Thus, using measured or estimated ET_{ref} (from ET_{gages}, the High Plains Regional Climate Center Web site, or other sources) is always a better strategy.

It also should be noted that while the ET_{ref} may be high early in the growing season (April-June), actual crop water use during this period is much less than it is later in the growing season when plant growth stages are more advanced. Crop coefficients for agronomic crops are small early in the season; for example, the crop coefficient for 6-leaf corn is 0.35, for soybean at the second node stage it's 0.40, and for winter wheat at the visible crown stage it's 0.50. Although the ET_{ref} may be high early in the season, since it is multiplied by the crop coefficient to obtain actual crop water use, the resulting rate will be

Table I. Long-term average monthly total alfalfa-reference evapotranspiration (*ET_{ref}*), monthly average *ET_{ref}* and their standard deviations. Each value represents an average of 27 values (1982-2008).

Month	*Long-term average monthly total ET_{ref} (in/month)*	*Standard deviation*	*Long-term monthly average ET_{ref} (in/day)*	*Standard deviation*
January	1.82	0.87	0.06	0.03
February	2.18	0.83	0.08	0.03
March	4.17	1.14	0.13	0.04
April	6.19	1.28	0.21	0.04
May	7.10	1.45	0.23	0.05
June	8.14	1.14	0.27	0.04
July	7.98	1.15	0.26	0.04
August	6.61	0.91	0.21	0.03
September	5.87	0.94	0.20	0.03
October	4.38	0.93	0.14	0.03
November	2.50	0.75	0.08	0.03
December	1.62	0.53	0.05	0.02

low in early plant growth stages. Early in the season, soil evaporation is the dominant component of actual ET and transpiration is minimal. As crops progress toward mid season, transpiration becomes the dominant component of actual ET, especially after full canopy cover.

Distribution of Monthly Total Reference Evapotranspiration

Long-term average (1982-2008) monthly total ET_{ref} values are presented in *Figure 2*. The total values along with the standard deviations are given in *Table I*. The monthly total ET_{ref} ranged from 1.6 inches per month in December

Table II. Long-term average climatic variables for Clay Center, Neb. (1982-2005).

Weather variable	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Annual average or total*
Wind speed at 6.6 ft (mph)	8.0	8.3	9.2	10.1	8.9	7.8	6.5	5.8	6.9	7.4	8.3	8.0	8.0
Average air temperature (°F)	25.2	28.9	38.5	49.5	60.6	70.5	74.8	73.0	64.4	51.8	37.2	26.8	50.2
Relative humidity (%)	73.8	73.6	69.8	66.3	71.3	70.2	73.2	74.5	68.8	67.2	72.9	74.5	71.3
Solar radiation (cal cm^2/day)	179	241	323	404	464	535	535	471	380	270	179	153	344
Precipitation (in)	0.4	0.9	1.6	2.3	4.4	4.3	3.7	3.3	2.5	1.8	1.3	0.7	27.1

to 8.1 inches per month in June. On average, the peak ET_{ref} occurred in June; however, from year to year, the month for peak ET_{ref} varies from May to August. In the 27-year period, there were five years (1989, 1992, 1994, 1997, and 2004) when monthly total ET_{ref} was greater in May than in June and 11 years (1982, 1983, 1984, 1986, 1987, 1991, 1995, 1997, 1997, 2003, and 2005) when it was greater in July than in June. There were only three years (1983, 1984, and 2003) when monthly total ET_{ref} in August were greater than those in June. Thus, during the 27-year period, the peak ET_{ref} month was in May 18% of the time, in June 31%, in July 40%, and in August,11%.

Although July was the most frequent month for peak ET_{ref}, in most years the magnitude of monthly total ET_{ref} in June was greater than in July. (Magnitude is the difference in ET_{ref} in inches between the two months.) For example, in 1988, the monthly total ET_{ref} in June was 3.0 inches higher than the ET_{ref} in July. The standard deviation for the monthly total ET_{ref} ranged from 0.53 inch per month in winter to as much as 1.45 inch per month in May *(Table I)* with an annual average deviation of 1.0 inch. Thus, using long-term monthly average ET_{ref} can cause up to 1.0 inch per month error in the growing season.

In *Figure 2*, ET_{ref} showed a typical bell-shaped distribution with the lowest values in winter (November-February), gradually increasing toward summer and decreasing again in fall as the solar radiation, air temperature, and wind speed decreases. One of the main reasons that ET_{ref} is higher in June than in July, although the monthly average air temperature is higher in July than in June, is wind speed. In south central Nebraska, wind speed is highest in spring (mid-March until end of June) and decreases starting in July. This higher wind speed in June is the main reason that June is the peak ET_{ref} month. On a long-term average, the amount of incoming solar radiation on the surface is the same for June and July in south central Nebraska with approximately 535 cal/cm^2/day (or 2,249 Jcal/cm^2/day = 22.4 MJ/m^2/day). The highest wind speed in the area usually occurs in March (9.2 mph) and April (10.2 mph) and the lowest wind speed usually occurs in July (6.5 mph) or August (5.8 mph). The long-term average weather variables for Clay Center are reported in *Table II*.

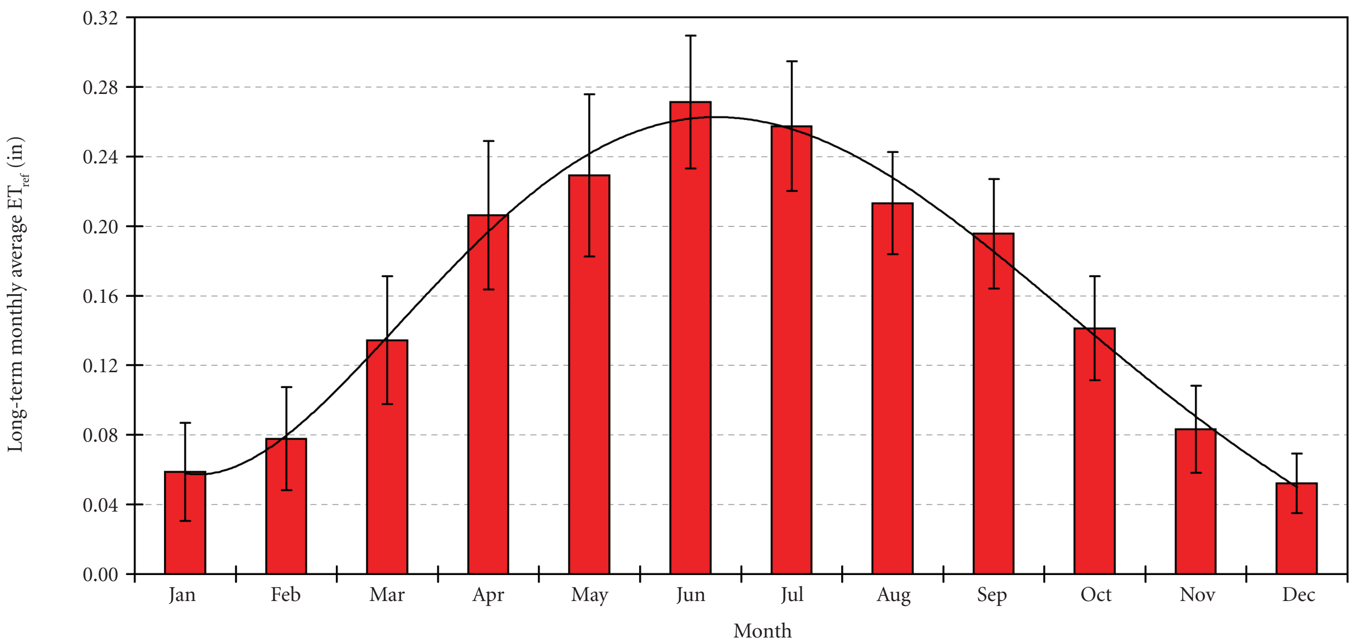

Figure 3. Long-term monthly average alfalfa-reference evapotranspiration (ET_{ref}) for south central Nebraska (Clay Center, 1982-2008). Each data point (vertical bar) represents an average of 27 monthly total ET_{ref} value (1982-2008). The vertical line on the data bar indicates the standard deviation in ET_{ref} for a given month.

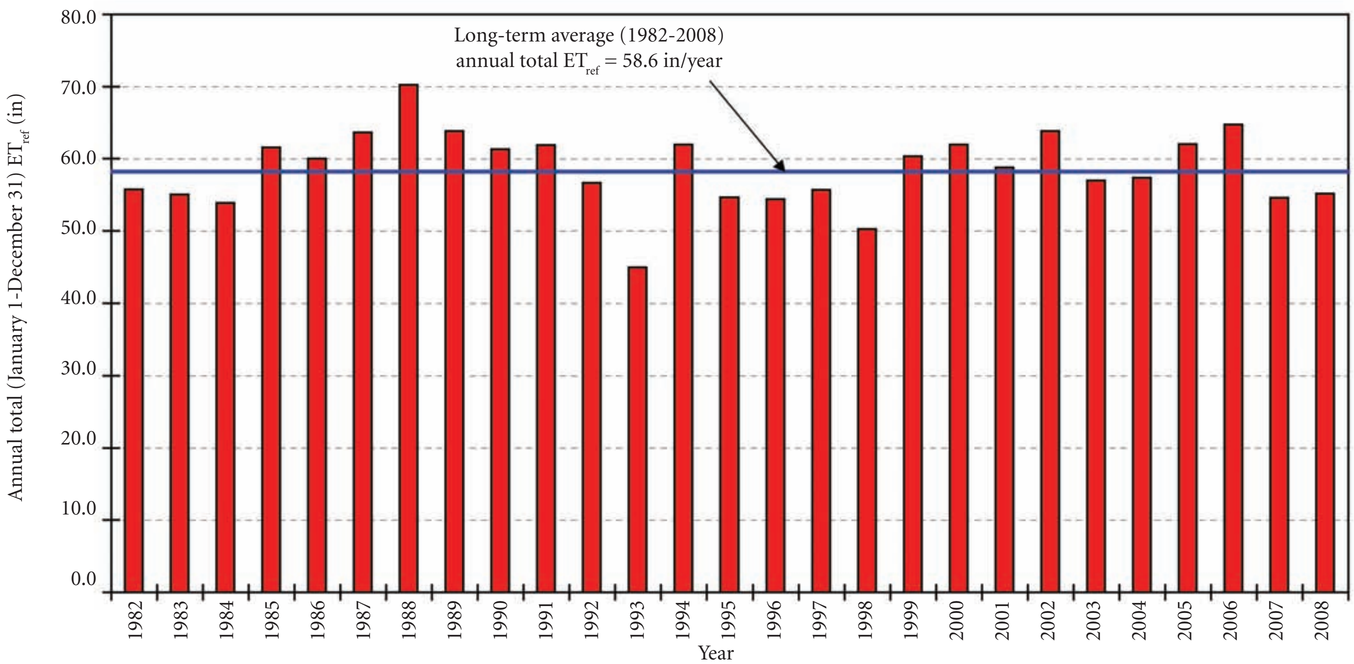

Figure 4. **Annual total alfalfa-reference evapotranspiration (ET_{ref}) for south central Nebraska (Clay Center, 1982-2008). Each data point (vertical bar) represents a total ET_{ref} from January 1 to December 31 of each year.**

Distribution of Long-term Monthly Average Reference Evapotranspiration

Long-term monthly average ET_{ref} values are presented in *Figure 3* and monthly average ET_{ref} and the standard deviations are reported in *Table I*. The lowest monthly average ET_{ref} occurs in December (0.05 inch per day); the highest average (0.27 inch per day) is in June. Monthly average ET_{ref} showed a similar bell-shaped distribution, increasing from winter to mid summer and decreasing again toward fall as the magnitude of solar radiation, wind speed, and air temperature decreases. July's average ET_{ref} (0.26 inch per day) was similar to the peak month of June. The standard deviations varied in a narrow range from 0.02 inch in winter to 0.05 inch in May. Again, the monthly average ET_{ref} values reported in *Figure 3* and *Table 1* are the average of 27 years and may or may not represent daily crop water use in a given year. For example, the standard deviation for July is 0.04 inch per day and the monthly average ET_{ref} value is 0.26 inch per day.

If this long-term average ET_{ref} value is to be used to calculate the actual crop water use (ET_a) for a given day in July in a current year, and if the crop coefficient (K_c) is 1.10 (typical value for corn near tassel or silking stage), the actual crop water use would be $ET_a = ET_{ref} \times K_c = 0.26 \times 1.10 = 0.29$ inch per day. However, the standard deviation for July is 0.04 inch per day (*Table I*), so the ET_a value can range between 0.24 and 0.33 inch per day. This may not seem like a large deviation, but the deviation could be accumulated for each day of the month. Over a whole season, this can lead to a large cumulative error. Therefore, use of long-term monthly average ET_{ref} value to calculate daily ET_a for irrigation management is not a good strategy as it can result in significant errors in estimating actual crop water requirement in a "non-average" year. Direct measurement or estimation of ET_{ref} in the current year is a more effective and accurate strategy for accurately determining irrigation requirement.

Distribution of Annual (Calendar Year) Total Reference Evapotranspiration

Figure 4 shows the annual (January 1-December 31) total ET_{ref} for each year from 1982 to 2008. The annual total ET_{ref} ranged from 44.9 inches per year in 1993 to 70.3 inches per year in 1988. The wettest year in the 27-year period at this site near Clay Center was 1993 with 41.3 inches. The driest year in this period was 1988 with only 16.7 inches of rainfall. The long-term average annual total ET_{ref} was calculated as 58.6 inches per year (see solid horizontal line in *Figure 4*). The ET_{ref} was lower than average in 2007 and 2008 because after 1993, these were the two wettest years in the 27-year period. Annual total rainfall was 40.6 inches in 2008 and 39.2 inches in 2007. Wet years tend to have lower ET_{ref} rates because the weather is usually cooler and cloudier with higher relative humidity. The long-term average annual rainfall at this site is about 27 inches.

Year 1992 is a good example of an average year in terms of ET_{ref} and rainfall. The annual total ET_{ref} was 56.6 and rainfall was 28.2 inches. There was no clear increasing or decreasing trend in annual total ET_{ref} in the last 27 years.

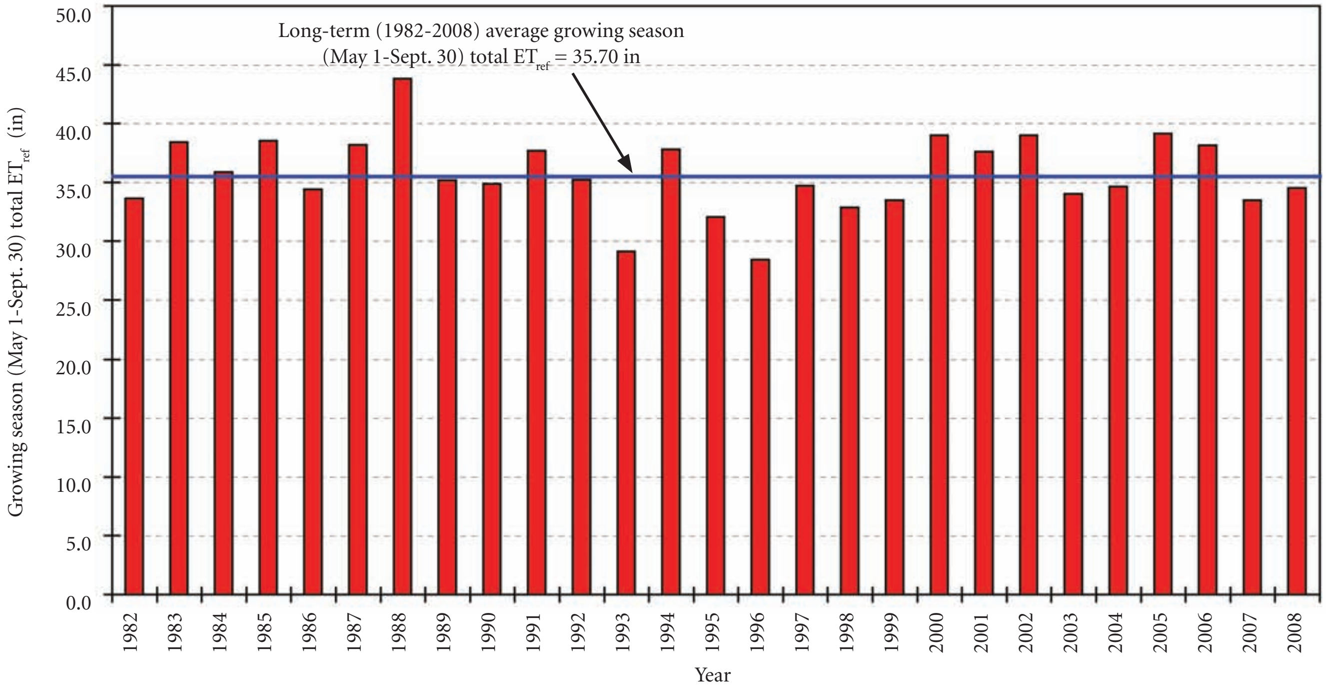

Figure 5. Growing season (May 1-September 30) total alfalfa-reference evapotranspiration (ET_{ref}) for south central Nebraska (Clay Center, 1982-2008).

Distribution of Growing Season Total Reference Evapotranspiration

While annual total ET_{ref} values are useful and important for long-term planning of water resources development, the total ET_{ref} during the growing season is specifically important in terms of within-season water management practices. Growing season total ET_{ref} values from 1982 to 2008 are presented in *Figure 5*. While growing season changes with the type of crop and location, for this publication it is considered to be May 1 to September 30. The growing season total ET_{ref} showed a significant variation from year to year due to weather conditions. It ranged from 28.4 inches per season in 1996 to 43.8 inches in 1988. While 1993 was the wettest year in the 27-year period at the Clay Center location, the seasonal total ET_{ref} was lower in 1996 than in 1993 due to lower wind speeds, air temperature, and solar radiation from May to September. The long-term average growing season ET_{ref}, was 35.7 inches (see horizontal, solid line in *Figure 5*). There was no clear increasing or decreasing trend in annual total ET_{ref} for the period.

Recommendation

Based on the analysis of 27 years of data from the south central Nebraska location, it is strongly recommended that measured or estimated ET_{ref} data from the current year be used with proper crop coefficients to calculate actual crop water use for irrigation management.

Sources of Current Season ET_{ref} Values

Two main sources of daily ET_{ref} values are available for Nebraska.

The High Plains Regional Climate Center Web site at *www.hprcc.unl.edu* reports on about 60 automated weather stations in Nebraska and many other stations in North Dakota, Kansas, South Dakota, and Colorado, and reports ET_{ref} data daily.

Atmometers (ETgages) can provide in-season measurements. Information about ETgage operational characteristics, installation, maintenance, data interpretation, and how this tool can be used to measure ET_{ref} for irrigation management are detailed in the UNL Extension publication, *Using Modified Atmometers (ETgage™) for Irrigation Management* (G1579), available online at *www.ianrpubs.unl.edu/sendIt/g1579.pdf*. As a part of a widespread Nebraska effort to implement newer tools/technologies for irrigation management, the Nebraska Agricultural Water Management Demonstration Network (*water.unl.edu/cropswater/nawmdn*) provides weekly ET_{ref} information from gauges at more than 200 locations across Nebraska.

This publication has been peer reviewed.

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