EC2011

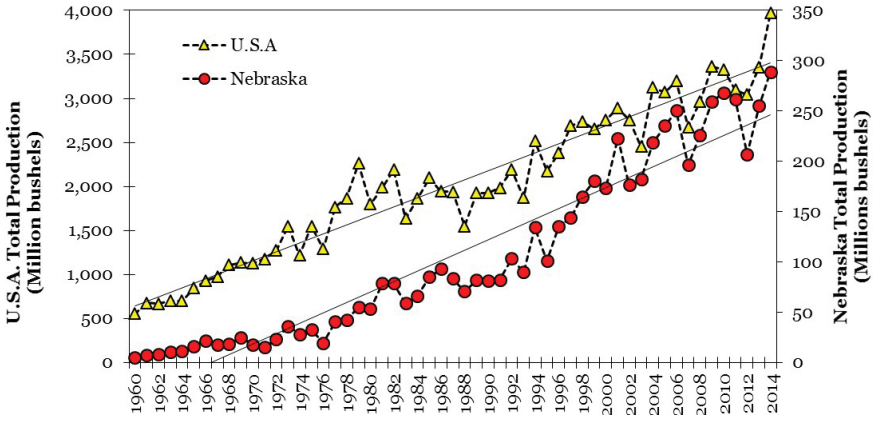
Long-Term Spatio-Temporal Variation of Soybean Evapotranspiration across Nebraska

Vivek Sharma, Post-Doctoral Research Associate
Suat Irmak, Professor and Soil and Water Resources and Irrigation Engineer

Introduction

Changing climatic conditions across the globe and increased competition for fresh water resources in agricultural, domestic, and industrial sectors can pose challenges to food security. In addition, water resources for agricultural production are facing continuous increasing restrictions due to declining groundwater levels. Potential future water limitations could be mitigated by using freshwater resources as vefficiently as possible. Efficient use of water resources in agriculture necessitates adequately quantifying crop water use, i.e., crop evapotranspiration (ETc), irrigating only when necessary, and applying the proper amount of water. Variations in ETc rates are regulated largely by potential evapotranspiration, the amount of precipitation received in a given season, irrigation amount, growth stages, soil texture, residue cover, and water stress.

Crop water use can vary substantially even within the same state, depending on the climatic conditions, soil and water management, cultivar, and hybrid and variety differences as well as differences in other management practices such as residue management. Thus, the water use rate of a given crop cannot be assumed to be similar across different climatic conditions (spatial variation); and certainly, crop water use of the same crop grown in the exact same location cannot be assumed to be similar every year (temporal variation). This extension circular quantifies and discusses the spatial and temporal variation in soybean ETc rates under irrigated and rainfed production systems across Nebraska. The state is divided into four zones based on climatic charac-



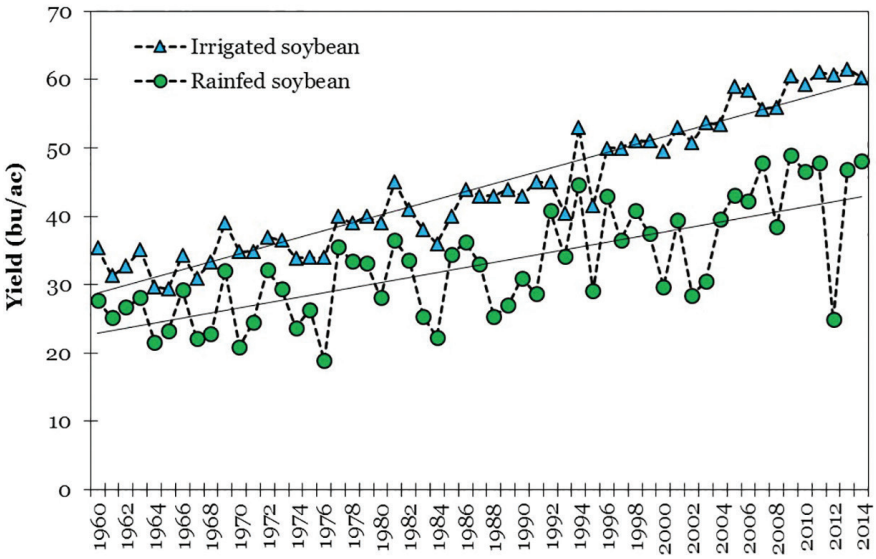


Figure 1a. (*top*) Trends in total soybean production (million bushels) in the U.S. and Nebraska from 1960 to 2014.
Figure 1b. (*bottom*) Trends in irrigated and rainfed soybean grain yield (bushels/acer) in Nebraska from 1960 to 2014.

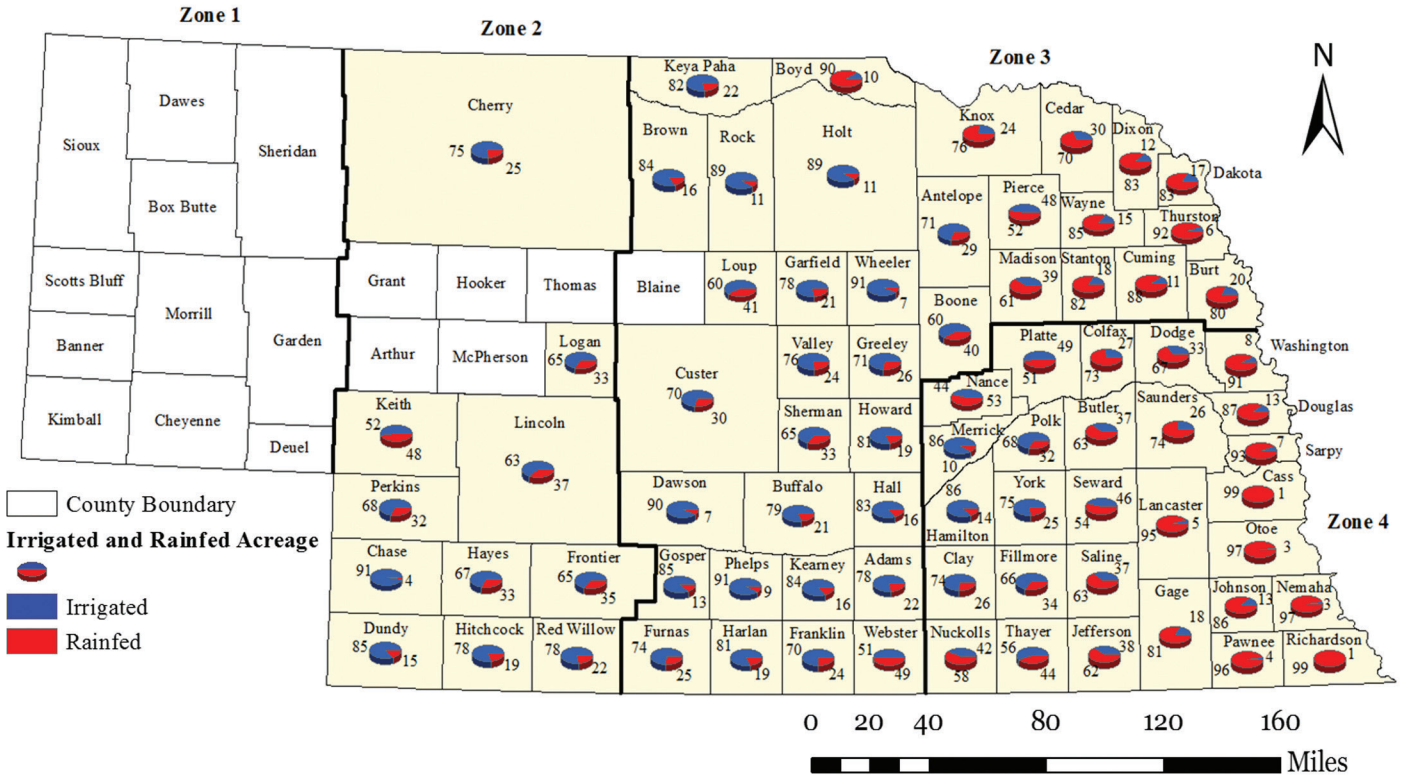


Figure 2. Long-term average percent acreage of irrigated and rainfed soybean for 76 soybean producing counties across Nebraska. Dark blue and red colors represent the percent area under irrigated and rainfed conditions, respectively. The black line represents the different climate zones across the state.

teristics, and the spatio-temporal trends and magnitudes of soybean ETc are discussed for each zone as well as statewide.

Soybeans (*Glycine max*) are an important crop grown in North America, South America, and Asia as a human food source, feed ingredient for livestock, oil for biodiesel, and many other industrial uses. Most soybeans are processed for their oil and protein for the animal feed industry. A smaller percentage is processed for human consumption and is made into products such soy milk, soy flour, soy protein, tofu, and many other retail food products. During the last four decades, the United States (U.S.) led the world in total soybean production. For example, in 2012, the U.S. produced a total of 3,042 million bushels of soybeans (34 percent of the world soybean production), which was planted on 24 percent of the total cropland with 9 percent under irrigation (USDA-NASS, 2012). Nebraska accounts for 7 percent of total U.S. soybean production, with a long-term average production of 106 million bushels.

Figure 1a and 1b represents the trends in total soybean production in the U.S. and Nebraska as well as the irrigated and rainfed soybean yields in the state from 1960 to 2014. Soybeans are cultivated on roughly 26 percent of the total Nebraska cropland, second in acreage only to corn. Of the total soybean acres, 42 percent (2,075,317 acres) is grown under irrigated conditions. *Figure 2* represents the long-term average total soybean acreage under irrigated and rainfed conditions across the top 76 soybean growing counties in the state. In 44 (57 percent) of the soybean-growing counties in Nebraska, more than 50 percent of the acres are irrigated. For example, in the highly irrigated counties of Phelps, Wheeler, Chase, and Dawson in central Nebraska, more than 90 percent of total soybean acres are grown under irrigation. In contrast, rainfed soybean production is concentrated on the eastern edge of the state where counties such as Richardson, Cass, Nemaha, Otoe, Pawnee, Lancaster, Sarpy, Thurston, Washington, and Boyd grow less than 10 percent of the soybean acres under irrigation *(Figure 2).*

Considering the extensive soybean production under irrigated and rainfed conditions in the state, it is important to better understand the total soybean water use because it will have a significant influence on improving the overall soybean production efficiency in both irrigated and rainfed agriculture. Such analysis can assist water managers and decision makers in planning for future demand, use, and availability of water resources.

Crop evapotranspiration (ETc) can be the largest flux in the hydrological cycle and affects the soil-water balance under both irrigated and rainfed settings. In rainfed cropping systems, ETc is met by the combination of available soil water and precipitation in a crop growing season and the preseason recharge. In irrigated cropping systems, ETc is met by the combination of available soil water, precipitation, and amount of applied irrigation.

Nebraska has an interior continental location with wide climatic seasonal variations such as warm summers and extremely cold winters (Strahler and Strahler, 1984). The state's continental climate is divided into different regions: the eastern and central parts of the state have a humid/sub-humid continental climate, and the western part has a semiarid/arid climate. For example, the average precipitation in southeastern Nebraska is 36.4 inches, compared with 12.6 inches in the Panhandle (western part). Detailed description of the variation in annual, seasonal, and monthly precipitation is in the Nebraska Extension Circular *Spatial and Temporal Variability of Precipitation in Nebraska,* EC2002. Due to the variations in climatic and topographical characteristics, we divided the state into four zones *(Figure 2; solid black lines)* to evaluate the soybean water use under irrigated and rainfed conditions across the different zones.

For this publication, irrigated soybean ETc was calculated using the procedures outlined in the Nebraska Extension NebGuide, *Estimating Crop Evapotranspiration from Reference Evapotranspiration and Crop Coefficients,* G1994. Under rainfed conditions, soybean ETc was calculated using the precipitation and available soil-water holding capacity of the major soil type for each county and the equation developed by Irmak and Sharma (2015). A detailed description of monthly, seasonal, and annual reference (potential) evapotranspiration (ETref) across Nebraska from 1986 to 2012 and the irrigated and rainfed ETc calculation procedure is presented in the Nebraska Extension Circulars *Monthly, Seasonal, and Annual Spatial and Temporal Variability of Reference (Potential) Evapotranspiration Across Nebraska,* EC2003, and *Spatial and Temporal Variation of Corn Evapotranspiration Across Nebraska,* EC2010.

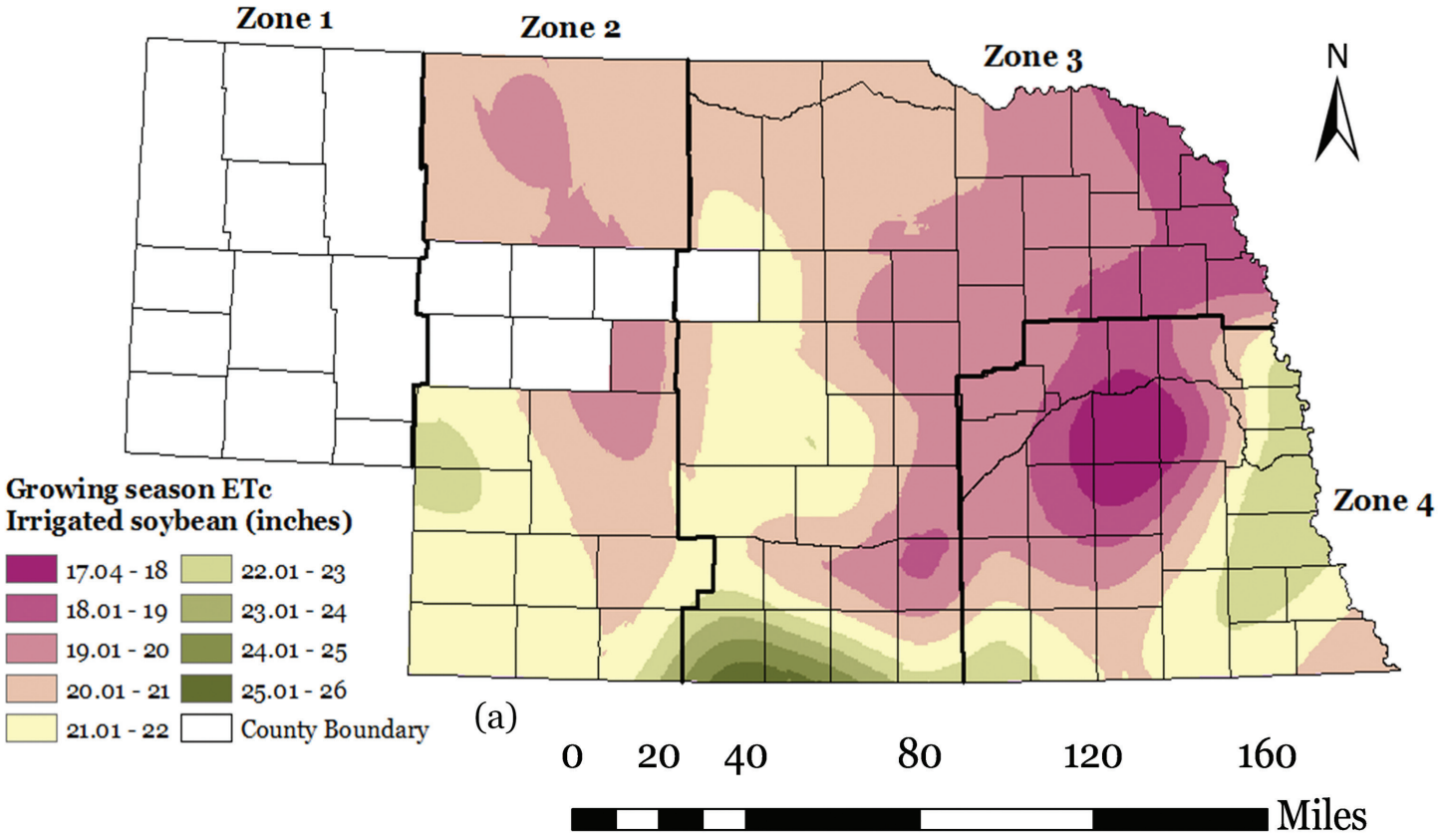
One set of soybean crop coefficient (Kc) values was used to estimate soybean ETc under irrigated conditions. Soybean Kc used in this analysis was obtained from long-term field research conducted by Irmak at the UNL Institute of Agriculture and Natural Resources South Central Agricultural Laboratory near Clay Center, Nebraska. With the differences in growing season duration for soybean across different zones used in this study, adjustments were made in the Kc values used for Zone 4 to Zone 2.

It is important to note that the quantification of crop ETc on regional (i.e., state, watershed, and county) scales is an extremely difficult task and requires certain assumptions. For example, in this study, one set of Kc values was used to quantify soybean ETc from 1986 to 2012 due to the lack of available Kc values over different years and at different locations across the state. Another assumption was made to account for only one major soil type in each county in the quantification of rainfed soybean ETc since it is very difficult to account for all soil types across Nebraska. The state has 138 soil series as well as many soil types and phases, which further differentiate the soil series. Of these soil series, 17 constitute about 49 percent of the land area (NRCS-USDA Web soil survey).

An interpolation technique was used to convert discrete ETc calculations in weather station sites to ETc maps. Thus, an uncertainty (error) is associated with these ETc maps (as it always occurs with any kind of other estimation of any other variable) due to the error(s) associated with the interpolation.

Spatial Variation of Irrigated and Rainfed Soybean Evapotranspiration

The spatial variability in irrigated and rainfed soybean ETc, along with descriptive statistics integrated over the growing season during the 27-year study period, is represented in *Figure 3a and 3b* and in *Table 1.* The white color counties in *Figure 3a and 3b* are the counties with limited soybean production, and hence not included in the analysis. For irrigated soybean, a general increasing ETc trend is observed from northern to southern Nebraska *(Figure 3a).* On a statewide average basis from 1986 to 2012, a long-term average irrigated soybean ETc of 20.4 inches (SD = 1.38 inches) was observed. A maximum ETc of 24.1 inches was observed in Furnas County (south central Nebraska) while the minimum ETc of 17.1 inches was observed in Butler County (eastern Nebraska). A small area with the lowest irrigated ETc was located over Butler, Seward, and Saunders counties due to the low ETref observed at the same locations. Detailed description of spatial variation in seasonal ETref is provided in the Nebraska Extension Circular *Monthly, Seasonal, and Annual Spatial and Temporal Variability of Reference (Potential) Evapotranspiration across Nebraska,* EC2003. Contrarily, high values of irrigated ETc were observed over the metropolitan areas of Lincoln and Omaha *(Figure 3a).* A total of seven weather stations located in and around the cities was used to calculate the ETref for those locations. ETref values were generally higher for these urban stations because they have the greatest amount of radiant energy when compared with the agricultural fields, resulting in greater ETc. Small differences in soybean ETc between zones was due to the difference in growing season duration considered in the analysis. For example, a 140-day soybean growing season in Zone 4 had an average ETc of 20.3 inches, compared with the average ETc of



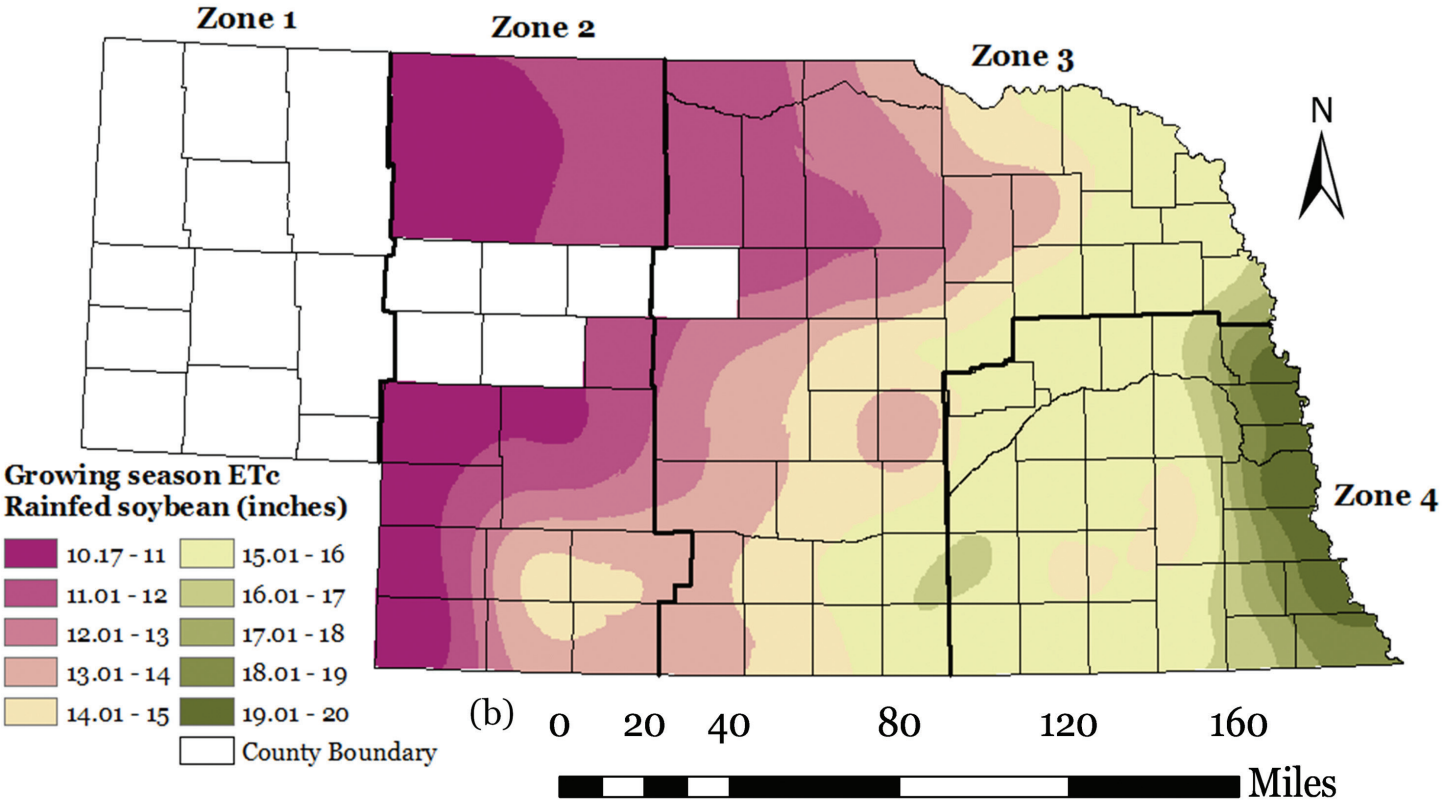


Figure 3a (*top*) and b. (*bottom*) Spatial distribution of long-term (1986–2012) average growing season (a) irrigated and (b) rainfed soybean evapotranspiration (ETc, inches) across Nebraska.

Table 1. Descriptive statistics for statewide and zone-wise growing season irrigated and rainfed soybean evapotranspiration (ETc, inches) from 1986 to 2012 across Nebraska.

Irrigated Soybean	*Average (inches)*	*Standard deviation (inches)*	*Maximum (inches)*	*County*	*Minimum (inches)*	*County*
Statewide	20.4	1.38	24.1	Furnas	17.1	Butler
Zone 1	-	-	-	-	-	-
Zone 2	21.1	0.74	22.0	Perkins	19.6	Logan
Zone 3	20.2	1.30	24.1	Furnas	18.4	Dakota
Zone 4	20.3	1.60	22.8	Otoe	17.1	Butler

Rainfed Soybean	*Average (inches)*	*Standard deviation (inches)*	*Maximum (inches)*	*County*	*Minimum (inches)*	*County*
Statewide	14.7	2.11	19.3	Boyd	10.4	Franklin
Zone 1	-	-	-	-	-	-
Zone 2	12.0	1.50	14.0	Hayes	10.4	Dundy
Zone 3	14.2	1.35	16.2	Burt	11.5	Keya Paha
Zone 4	16.5	1.60	19.3	Cass	14.7	Lancaster

21.1 inches and 20.2 inches in Zone 2 and Zone 3, respectively, where soybeans had a growing season duration of 112 and 120 days, respectively. *Table 1* also includes the counties with maximum and minimum ETc for irrigated soybean.

For rainfed soybeans, the highest ETc values were observed in Zone 4. The values decline by 0.36 inches for every 25 miles from east to west across the state. A long-term average rainfed soybean ETc of 12.0 inches, 14.2 inches, and 16.5 inches was observed in Zone 2, Zone 3, and Zone 4, respectively. This variation was due to variation in precipitation and available soil-water holding capacity across the state. For example, Irmak and Sharma in the Nebraska Extension Circular *Spatial and Temporal Variability of Precipitation in* soybean ETc for Zone 2, Zone 3, and Zone 4, respectively. The variability in irrigated and rainfed ETc was mainly due to the additional amount of irrigation water that was applied in

Nebraska, EC2002, showed that for every 25 miles from east to west across the state, the seasonal precipitation declines by 0.38 inches. On average, irrigated soybean ETc is 43 percent, 30 percent, and 19 percent higher, compared with the rainfed a given growing season as well as differences in soil and crop characteristics and management practices under irrigated and rainfed conditions.

Differences in Irrigated and Rainfed Soybean Evapotranspiration

Figure 4 shows the difference in irrigated and rainfed soybean ETc using frequency distribution of pooled data from 1986 to 2012 for 76 major soybean growing counties, along with the long-term average ETc. Histogram distribution shows the range and variation in irrigated and rainfed soybean ETc across Nebraska. For irrigated soybean ETc, the histogram frequency peaks between 20 to 22 inches, com-

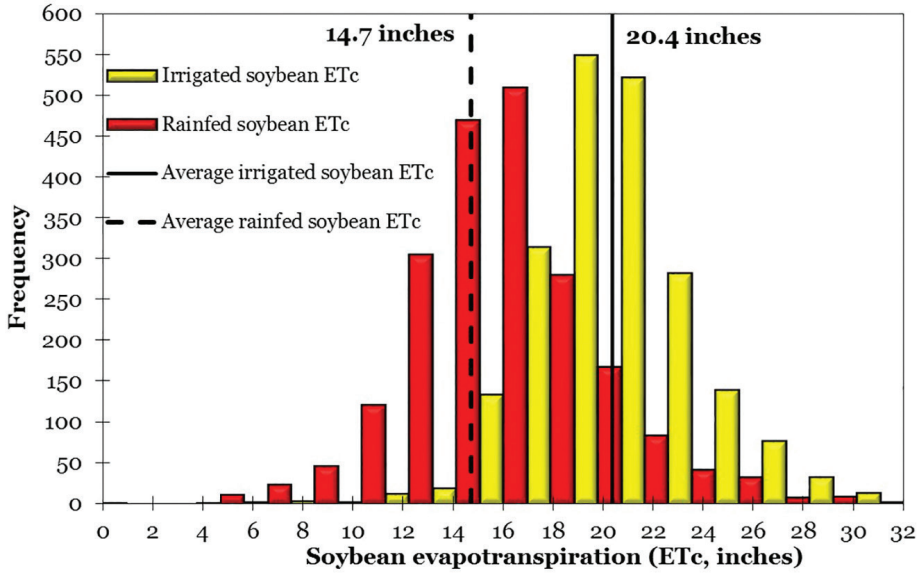


Figure 4. Histogram (frequency) distribution of irrigated and rainfed soybean evapotranspiration (ETc, inches). Dotted and solid black lines indicate the long-term (1986–2012) average irrigated and rainfed soybean evapotranspiration (ETc), respectively.

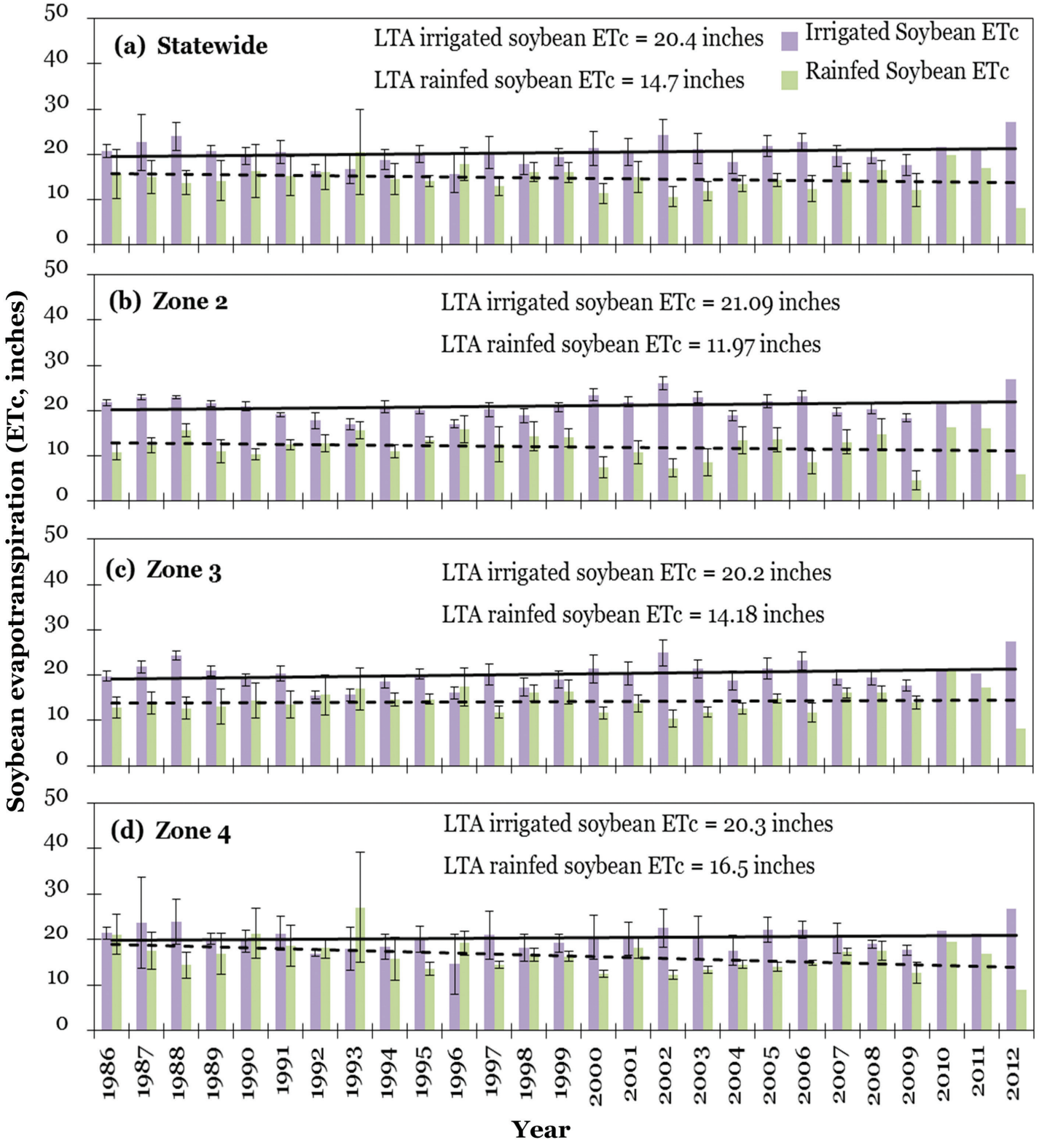


Figure 5. Inter-annual variation in average irrigated and rainfed soybean evapotranspiration (ETc, inches) for statewide (a), Zone 2 (b), Zone 3 (c), and Zone 4 (d) from 1986 to 2012 (LTA: long-term average).

pared with 14 to 16 inches for rainfed soybean ETc. On a statewide average basis, the irrigated soybean ETc is about 25 percent higher than the rainfed soybean ETc.

Temporal Variation of Irrigated and Rainfed Soybean Evapotranspiration

The trend analysis of irrigated and rainfed soybean ETc was examined on a statewide scale as well as for all the zones considered in this study. The temporal variation in irrigated and rainfed soybean ETc, along with the standard deviation statewide, and for Zone 2, Zone 3, and Zone 4 from 1986 to 2012 is presented in *Figure 5a, 5b, 5c, and 5d.* Black solid and dotted lines represent the trend in irrigated and rainfed ETc, respectively. For irrigated soybean, a nonsignificant ($P > 0.05$) increasing ETc trend was observed on a statewide scale as well as for all zones, with an average increase of 0.06 inches/year, 0.07 inches/year, 0.08 inches/year, and 0.04 inches/year for statewide, Zone 2, Zone 3, and Zone 4, respectively.

On a statewide scale, the maximum irrigated soybean ETc was observed during the drought of 2012, with the magnitude of ETc 25 percent higher than the long-term average value of 20.4 inches. For the same year, maximum ETc in Zone 2, Zone 3, and Zone 4 was 22 percent, 26 percent, and 24 percent higher than the long-term average values of 21.1 inches, 20.2 inches, and 20.3 inches, respectively. Large fluctuations in irrigated ETc between 1986 and 2012 were due to the variation in the climatic conditions. For example, high irrigated ETc values were observed in the drought years of 1987, 1988, 2000, 2002, and 2012, with a statewide seasonal average precipitation of 13.8 inches, 12.91 inches, 9.54 inches, 8.46 inches, and 6.07 inches, respectively.

In the case of rainfed soybean ETc, decreasing trends were observed from 1986 to 2012 on a statewide basis and for all zones except Zone 3, where rainfed ETc had an increasing trend. On average, there was a nonsignificant decrease of 1.93 inches ($P > 0.05$) and a significant decrease of 5.06 inches ($P < 0.05$) in ETc in Zone 2 and Zone 4, respectively, with an overall reduction of 1.96 inches ($P > 0.05$) on a statewide basis. The significant reduction in rainfed soybean ETc in Zone 4 was due to substantially lower total seasonal precipitation in recent years. For example, in Zone 4, average precipitation values of 12.3 inches, 13.3 inches, 15.5 inches, 14.8 inches, 13.1 inches, and 8.1 inches were observed in 2002, 2003, 2004, 2005, 2009, and 2012, respectively, compared with the long-term average of 18 inches. A small increase in rainfed soybean ETc of 0.5 inches in Zone 3 from 1986 to 2012 was explained by an increasing trend for precipitation. Irmak and Sharma in the Nebraska Extension Circular *Spatial and Temporal Variability of Precipitation across Nebraska,* EC2002 reported a roughly 0.6 inch increase in seasonal precipitation from 1986 to 2012 in Zone 3.

Summary

In this extension circular, spatial and temporal variation in irrigated and rainfed soybean ETc was analyzed on a statewide and zonal scale from 1986 to 2012. The results present the following insights:

For irrigated soybeans, a general increasing ETc trend was observed from northern to southern Nebraska. From 1986 to 2012 a long-term average irrigated soybean ETc of 20.4 inches (standard deviation = ±1.4 inches), 21.1 inches (standard deviation = ±0.74 inches), 20.2 inches (standard deviation = ±1.3 inches), and 20.3 inches (standard deviation = ±1.6 inches) was observed for the statewide scale of Nebraska, Zone 2, Zone 3, and Zone 4, respectively.

For rainfed soybean ETc, there was a general decreasing trend of ETc from east to west, with a decline of 0.36 inches for every 25 miles. The long-term statewide average was 14.70 (standard deviation = ±2.1 inches). By zone, the average rainfed soybean ETc of 12.0 inches (standard deviation = ±1.5 inches), 14.2 inches (standard deviation = ±1.3 inches), and 16.5 inches (standard deviation = ±1.6 inches) was observed in Zone 2, Zone 3, and Zone 4, respectively.

On average, the irrigated soybean ETc was approximately 25 percent, 43 percent, 30 percent, and 19 percent higher than rainfed soybean ETc for the state of Nebraska, Zone 2, Zone 3, and Zone 4, respectively.

For irrigated soybeans, a nonsignificant ($P > 0.05$) increasing ETc trend was observed statewide, with an average increase of 0.06 inches/year. Among zones, the nonsignificant increasing irrigated ETc trends of 0.07 inches/year, 0.08 inches/year, and 0.04 inches/year were observed for Zone 2, Zone 3, and Zone 4, respectively.

In the case of rainfed soybean ETc, a decreasing trend was observed from 1986 to 2012 statewide and for all zones, with the exception of Zone 3, where rainfed ETc had an increasing trend. On average, there was a nonsignificant decrease of 1.93 inches ($P > 0.05$) in Zone 2 and a significant decrease of 5.06 inches ($P < 0.05$) in ETc for Zone 4, with an overall reduction of 1.96 inches ($P > 0.05$) on a statewide basis. The significant reduction in rainfed soybean ETc in Zone 4 was due to substantially lower total seasonal precipitation in recent years.

Resources

Irmak, S., and V. Sharma. 2014. Spatial and temporal variability of precipitation across Nebraska. *Nebraska Extension Circular EC2002*. http://extensionpublications.unl.edu/assets/pdf/ec2002.pdf

Irmak, S., and V. Sharma. 2014. Monthly, seasonal and annual spatial and temporal variability of reference (potential) evapotranspiration across Nebraska. Nebraska *Extension Circular EC2003*. http://extensionpublications.unl.edu/assets/pdf/ec2003.pdf

Irmak, S., and V. Sharma. 2015. Spatial and temporal variability of corn evapotranspiration across Nebraska. *Nebraska Extension Circular EC2010*. http://extensionpublications.unl.edu/assets/pdf/ec2010.pdf

Irmak, S. 2009. Estimating crop evapotranspiration from reference evapotranspiration and crop coefficients. Nebraska *Extension Circular G1994*. http://extensionpublications.unl.edu/assets/pdf/g1994.pdf

Sharma, V., and S. Irmak. 2012a. Mapping spatially interpolated precipitation, reference evapotranspiration, actual evapotranspiration and net irrigation requirements in Nebraska: Part I. Precipitation and reference evapotranspiration. *Transactions of the ASABE*, 55(3): 907–921.

Sharma, V., and S. Irmak. 2012b. Mapping spatially interpolated precipitation, reference evapotranspiration, actual evapotranspiration and net irrigation requirements in Nebraska: Part II. Actual crop evapotranspiration and net irrigation requirement. *Transactions of the ASABE*, 55(3): 923–936.

Strahler, A. N., and A. H. Strahler. 1984. Elements of Physical Geography. 3rd ed. New York, N.Y., John Wiley and Sons, Inc.

USDA-NASS. 2012. Census of agriculture. Washington, D.C. USDA National Agricultural Statistics Service.

This Extension publication has been peer-reviewed.

Extension is a Division of the Institute of Agriculture and Natural Resources at the University of Nebraska—Lincoln cooperating with the Counties and the United States Department of Agriculture.