EC716

Long-Term (1893-2012) Changes in Air Temperature, Relative Humidity and Vapor Pressure Deficit (Atmospheric Evaporative Demand) in Central Nebraska

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Changes in climate variables impact agricultural and agro-ecosystem productivity and land surface-atmosphere relationships through various direct and indirect processes. Direct processes include increased air temperature and/or carbon dioxide (CO_2) concentration, changes in solar radiation reaching the earth's surface, and changes in hydrologic parameters such as precipitation, runoff, and stream flow. Indirect processes include changed intensity and frequency of disturbances of wildfires, pests, and diseases. Changes in climate variables can have direct impact on agricultural productivity. For example, a small increase in minimum or maximum air temperature can have a substantial impact on some of the physiological functions of crops which, in turn, impact crop growth, development, and yield, even under well managed farming operations. Air temperature especially can alter many basic agricultural practices and productivity indices.

This Extension Circular presents long-term analyses and quantifies changes in trends and magnitudes of several climatic variables (maximum, minimum and average air temperature, relative humidity, and vapor pressure deficit) directly linked to agricultural and agro-ecosystem productivity. Analyses were conducted for Central City in central Nebraska from 1893 to 2012. Some of the potential implications of changes in climatic variables on agricultural productivity are discussed.

Warming of the earth's atmosphere between about 0.54 and 1.08°F since the late 19th century has been reported. These warming trends perhaps result from the combination of growing greenhouse gas emissions (external) and natural changes in air temperature. The global mean land-surface-air temperature has risen by about 1.33°F over the past 100 years (1906-2005) and is predicted to increase by 1.98 to 11.52°F by 2100, according to the Intergovernmental Panel on Climate Change, 2007. The atmospheric CO_2 concentration (CO_2 mole fractions) measured at Mauna Loa, Hawaii (a location where atmospheric contamination from greenhouse gas emissions is minimal) has increased from 315.71 parts per million (ppm) in March 1958 to 394.28 ppm in December 2012 (20 percent increase) (*Figure 1*). The increase was statistically significant ($P < 2X10^{-50} < 0.05$) at the 95 percent confidence level. The CO_2 concentration has been steadily increasing at a rate of 1.468 ppm per year since 1958.

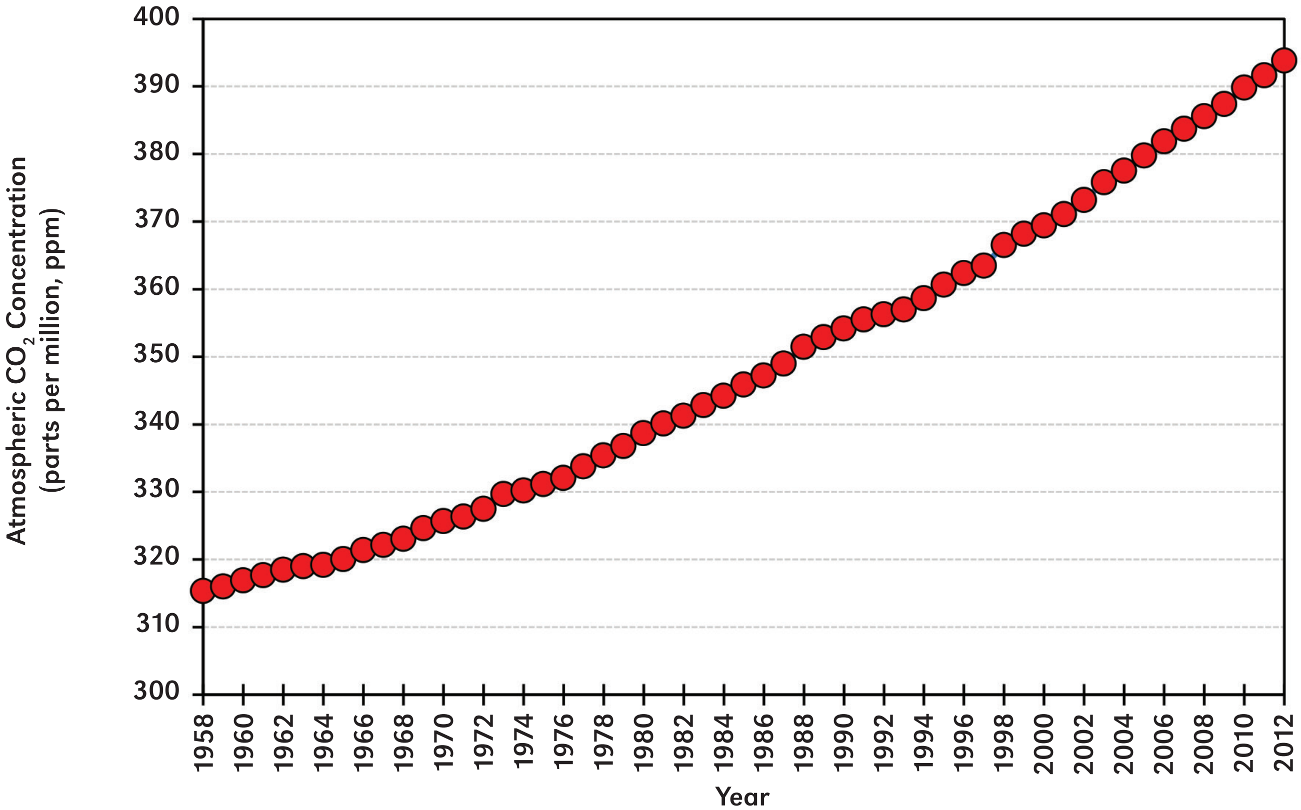

Figure 1. Annual mean atmospheric CO_2 concentration measured at Mauna Loa, Hawaii (*www.esrl.noaa.gov*).

While these increases in air temperature and CO_2 concentration may seem small for humans, the implications for plant physiological functions and, in turn, impact(s) on agricultural practices and productivity can be significant. Increased extreme (maximum) air temperature may seem to have a negative impact on crops, but increased temperatures coupled with increased CO_2 concentration may actually enhance the photosynthesis/transpiration process, resulting in greater yields. An increase in air temperature may encourage proliferation of weeds and pests. However, increased air temperature also may increase soil evaporation and evapotranspiration, which may further limit freshwater availability for agricultural production. The increase in air temperature may not always result in increased evaporation and evapotranspiration because an increase in evaporative losses is dependent on other factors in addition to air temperature. A unit increase in evapotranspiration as a result of a unit increase in temperature also is a function of how other climatic variables change. If air temperature increases while solar radiation and wind speed decreases, evapotranspiration may not increase. These dynamics need further research in order to develop best management practices for better adapting agricultural practices to changing climate to sustain or enhance agricultural and agro-ecosystem productivity. In this context, while so much discussion and analyses take place on global climate change, it is imperative that the analyses are made for local/regional conditions so that local changes can be quantified and local best management practices can be developed and implemented. In this Extension Circular, the Central City location was selected for analyses from 1893-2012. Work is underway to conduct similar analyses for several other locations in Nebraska to capture the climatic gradient differences from the eastern to western parts of the state.

Study Location

Central City, Neb., is located in the Central Platte River Basin, which is one of the largest agro-ecosystem regions in Nebraska with field corn, soybean, seed corn, irrigated and rainfed grasslands, and alfalfa cultivation. Additional vegetation surfaces include a riparian corridor along the Platte River and rainfed croplands. The study location is in a transition zone between subhumid and semiarid climatic zones with cold and windy winters and warm and humid summers. The wind speed is usually highest during the spring months (March to late May or early June) and in the fall. The long-term (1893-2008) average annual precipitation in the area generally is 25.6 inches, with significant fluctuations between years ranging from 14 inches in 1966 to 39.3 inches in 2008.

Distribution and Trends in Maximum, Minimum, and Average Air Temperature

Distribution of daily maximum, minimum, and average air temperatures (T_{max}, T_{min} and T_{avg}, respectively), from 1893 to 2012 are presented in *Figures 2a, b,* and *c*, respectively. In the figures, each data column represents a one-year period and has 365 or 366 data points. Thus, the total number of data points from Jan. 1, 1893, to Dec. 31, 2012, is 43,829.

Overall, there was an increasing trend in T_{max}. The lowest daily maximum temperature was observed on Feb. 11, 1899, as -12.31°F, and the warmest day in the last 120 years was 116°F on July 24, 1936, during the Dust Bowl when summer T_{max} values remained above 100°F, especially during July and August (*Figure 2a*). The 120-year average T_{max} is 62.9°F. When compared to the Dust Bowl era, the highest T_{max} in year 2012 was observed on July 29, 2012, as 103.4°F (12.6°F lower than the T_{max} observed on July 24, 1936). One interesting observation in T_{max} is the clear and steady increase in minimum values of T_{max} (warming trend), especially since the early 1990s. The maximum air temperature increased by 2.7°F from 1893 to 2012. This increase was statistically significant. The largest decadal increase in T_{max} occurred from 1981 to 1990 and also from 1991 to 2000 as 3.7°F per decade. The recent warming trend (1980-2000) is much larger than during the Dust Bowl era because in the 1930s the sharp increase in air temperature occurred only for three years (1934, 1936, and 1939), whereas the recent warming is steady, especially for the minimum values of T_{max}.

The daily minimum air temperature distribution (*Figure 2b*) also showed a clear increase (warming), especially since the mid-1960s. The lowest minimum air temperature (usually occurs at nighttime) also had an increasing trend. The coldest day in the last 120 years was observed on Jan. 12, 1912, as -36.3°F. The highest value in T_{min} was on July 4, 1934, as 80°F. There was a sharp increase in the maximum values of T_{min} (warming) from the early 1920s to the end of the Dust Bowl era, and the maximum values in T_{min} remained very high at around 80°F until the mid-1950s. There was a slight decline in the maximum T_{min} values in the last five to six decades and a steady increase in the minimum values of T_{min} (narrower daily temperature range). The 120-year average T_{min} is 38.9°F. The T_{min} increased by 4.3°F from 1893 to 2012. This increase was also statistically significant. The warming trend in the last 120-years is more visible in the average air temperature (T_{avg}) (*Figure 2c*) with the steady increase in the lowest T_{avg} values. T_{avg} ranged from -23°F, also on Jan. 12, 1912, to 96.5°F on July 12, 1939. The 120-year average T_{avg} is 50.9°F. The T_{avg} increased by 3.5°F from 1893 to 2012, but the increase was not statistically significant.

Relative Humidity

Distribution of daily average relative humidity is presented in *Figure 3*. The humidity, which is an indication of moisture content of the air, impacts plant physiological functions and climate indices including evapotranspiration, transpiration, vapor pressure deficit, etc. Vapor pressure deficit, which will be discussed in the next section, is one of the primary drivers of transpiration and evapotranspiration processes and also impacts the plant leaf stomatal behavior. The relative humidity (RH) ranged from 19.6 on Jan. 24, 1961, to 100 percent. A significant upward shift of the magnitude in RH was observed starting in 1929-1930. The greatest magnitude of increase (between 2 and 3 percent) occurred in three different decades: 1911-1920, 1961-1970, and 2001-2008. Interestingly, some of the steady and consecutive days of greatest (100 percent) humidity values were observed during the Dust Bowl era when highest temperatures also were observed. The lowest values of maximum daily average humidity values were observed in two distinct periods: from 1898 to 1908 and from 1921 to 1928. There was not a clear increasing or decreasing pattern or trend in the minimum values of daily humidity. The 120-year average humidity was 58.3 percent. The increase in humidity from 1893 to 2012 was 4.3 percent, and it was statistically significant. While the increase in humidity may seem modest, a small increase in humidity can cause substantial changes in plant response to various climatic variables.

Vapor Pressure Deficit

Distribution and trends in daily average vapor pressure deficit are presented in *Figure 4*. The vapor pressure deficit, which is an indicator of atmospheric moisture demand or atmospheric evaporative demand, fluctuated from near zero to as high as 4.4 kPa on July 2, 1936. The vapor pressure is expressed as a pressure unit in kilopascals (kPa) (1 kPa = 0.145 psi = 0.00987 atm = 0.01 bar = 7.5001 torr). The daily average vapor pressure deficit exhibited a relatively small increasing trend. There were considerable upward and downward trends. As expected, the highest atmospheric moisture demands were observed during the Dust Bowl period in the 1930s, but the atmospheric moisture deficit started to increase substantially in the late 1920s and in 1930 before the Dust Bowl era started; it continued to remain very high until the mid-1940s. During the extreme drought period in the early 1930s, the maximum values of vapor pressure deficit remained above 3.0-3.5 kPa, which is a very high range that causes extreme evaporation/evapotranspiration rates, especially if wind speeds also are large. There was another peak vapor pressure deficit

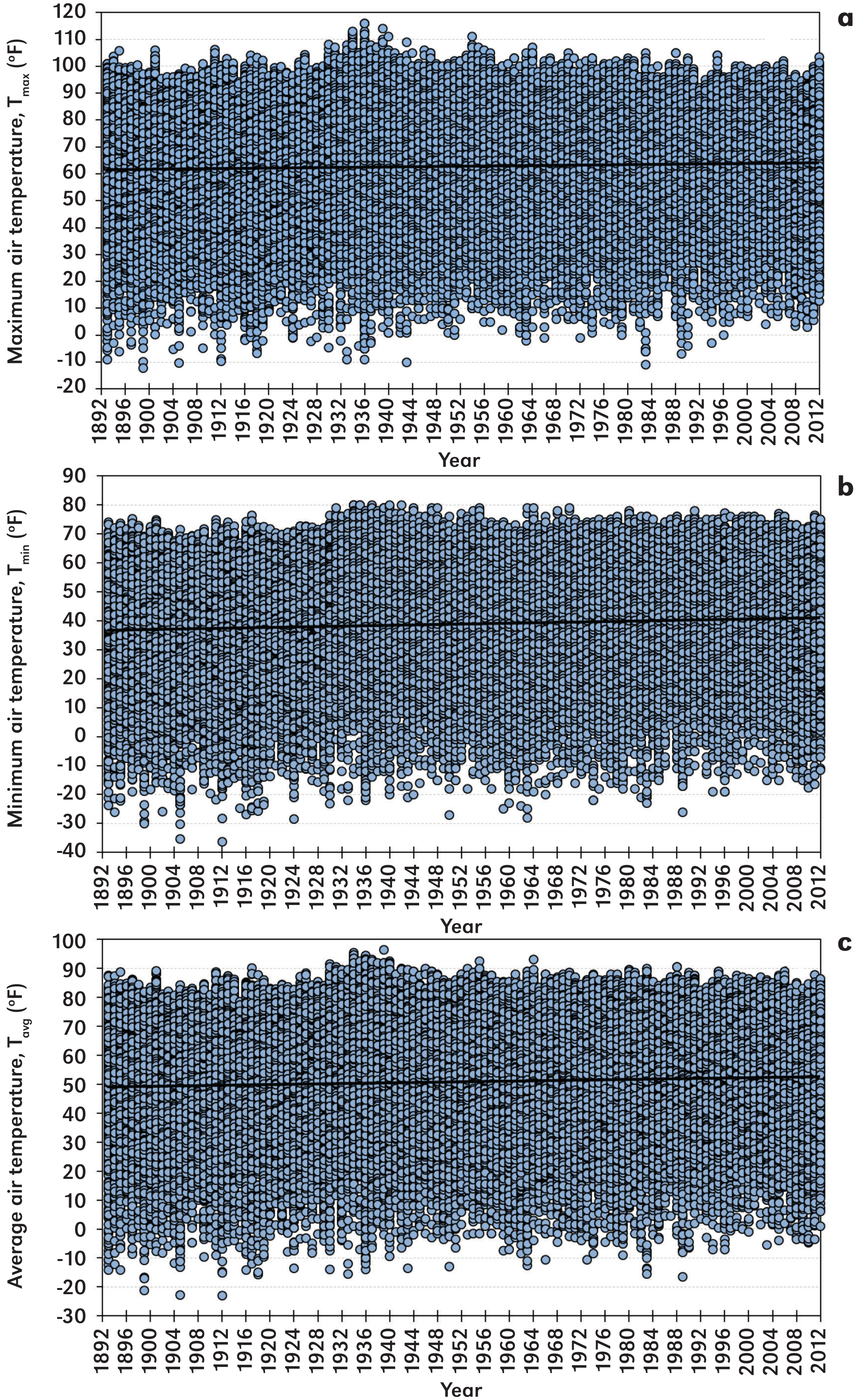

Figure 2. Distribution and trends in daily maximum, minimum, and average air temperature [T_{max} (a), T_{min} (b), and T_{avg} (c), respectively] from 1893 to 2012 in central Nebraska (Central City area).

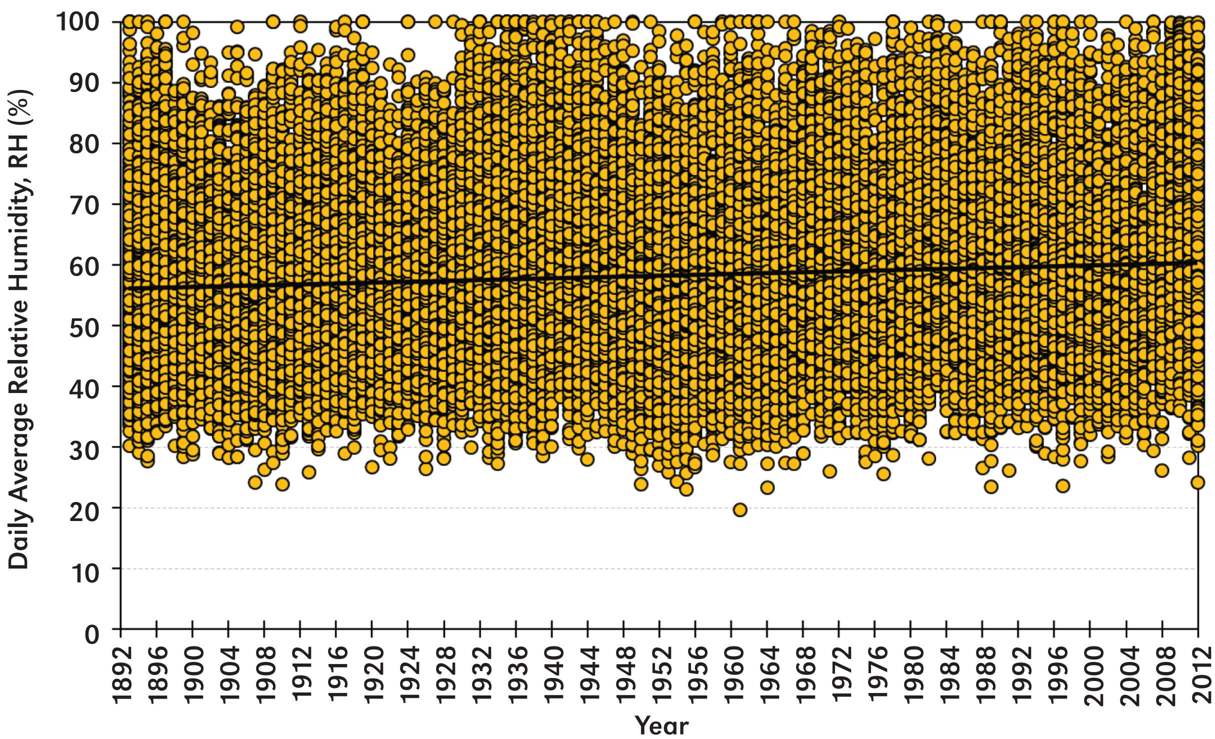

Figure 3. Distribution and trends in daily average relative humidity (RH) from 1893 to 2012 in central Nebraska (Central City area).

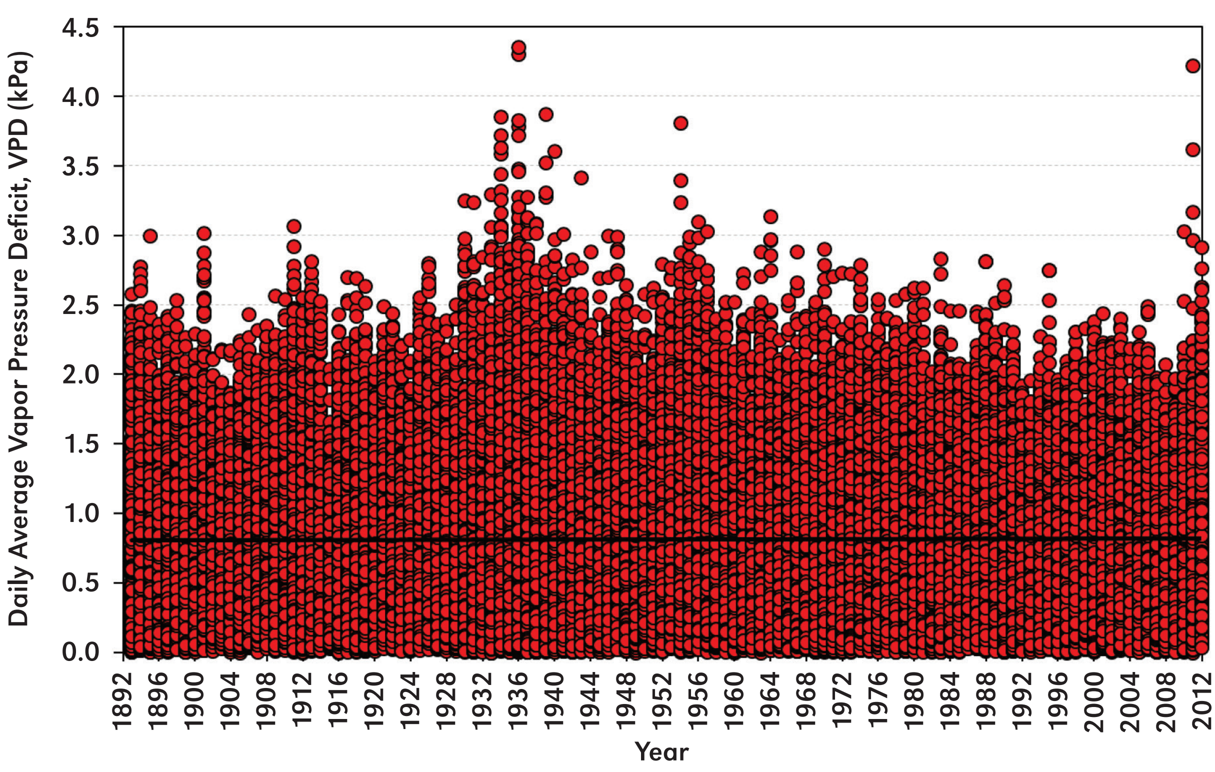

Figure 4. Distribution and trends in daily average vapor pressure deficit (VPD, atmospheric moisture demand or evaporative demand) from 1893 to 2012 in central Nebraska (Central City area).

around 3.8 kPa in 1956. The last extreme atmospheric demand period was observed in 2012, with the daily average vapor pressure deficit reaching 4.2 kPa. When comparing the dryness of the atmospheric conditions in 2012 to the Dust Bowl era in terms of atmospheric moisture content, year 2012 was much less dry than the Dust Bowl period. During the early 1930s, the atmospheric evaporative demand remained extremely high for many days, months, and years, whereas the extreme vapor pressure deficit values were observed for only a few days in 2012. From 1957 until around 2009, the maximum values of vapor pressure deficit showed a steady decline with some fluctuations, although the average values remained relatively constant, indicating that there were fewer days per year, as compared with the period before 1957, with high vapor pressure deficits (i.e., higher than 2.0 kPa). The 120-year average vapor pressure deficit is 0.82 kPa, and the 120-year standard deviation is 0.63 kPa. There was a 0.0084 kPa increase in daily average vapor pressure deficit from 1893 to 2012, but the increase was not statistically significant. While this value may seem very small, it is a daily average value and is actually a large change that can increase the evaporative losses (because evapotranspiration is most sensitive to changes in vapor pressure deficit) and also can impact the plant physiological functions.

Potential Implications of Changes in Air Temperature

In another extensive and more detailed temperature change study (EC715, *Climate Change Impact on Air Temperature, Daily Temperature Range, Growing Degree Days and Spring and Fall Frost Dates in Nebraska*), it was shown that while maximum temperature generally had increasing trends in some locations in Nebraska, substantial decreases in maximum temperature were also observed in other locations during summer and late summer periods. Since the duration of grain development and grain fill in cereals is primarily determined by air temperature, decreases in the maximum temperature during this time can prolong the maturity of the crops, resulting in improved crop yields if other climatic, soil and management practices, and other yield-impacting factors are favorable. Therefore, decreases in maximum temperature can result in positive impacts on crop physiological development, dry matter accumulation, and grain yield, especially during silking and grain-fill growth stages for maize, and during pod formation and pod-filling stages for soybean. Additionally, decreases in maximum temperature can reduce evapotranspiration losses and reduce or moderate crop water stress, resulting in a reduction of water requirements for crop production, enhancing crop water productivity (Skaggs and Irmak, 2012; Irmak et al., 2012).

In some locations, substantial increases in maximum temperature were also observed, especially in the very high (90-100°F or greater) temperature ranges. In general, increased air temperature shortens the phenological phases and limits the optimal growth and development of the crop. Increases in maximum temperature for extended periods, which was observed in Nebraska throughout the 2012 growing season, can reduce the number of kernels per ear in maize and number of grains per pod in soybean, resulting in reduced yields. Furthermore, during extreme maximum temperature periods, plant water stress, even in well-watered plant conditions, may occur due to greater vapor pressure difference between the atmosphere and plant canopy. This is due to the physiological response of the plants to extreme temperatures that plant stomata may not be able to maintain the increased rate of plant water uptake demand. As a response to this extreme moisture demand and stress, plants will likely close their stoma, which reduces the transpiration rate and dry matter accumulation. These processes will show variation depending on the other environmental/climatic variables such as solar radiation, sun angle (which impacts the light distribution as well as interception above and within the canopy that influences photosynthesis/transpiration rate), wind speed and direction and, perhaps more importantly, the crop response to extreme maximum air temperatures will be dictated by the interactions of these environmental factors.

Increases in minimum air temperature, which usually occur during the nighttime, may have significant implications in crop productivity. Nighttime increases in temperature can result in greater plant respiration, which is a physiological process opposite to transpiration. Plants respire approximately 50 percent of the carbon produced through photosynthesis and the other 50 percent, roughly, is used for maintaining many plant physiological functions (growth, nutrient uptake and processing, propagation, etc.). Changes in air temperature and CO_2 concentration will certainly impact the respiration, photosynthesis, transpiration, and crop productivity. However, quantification and the direction of the magnitude of impact(s) is an extremely difficult task, and carefully designed research is needed to understand the dynamics of the interactions between the change in climate variables and plant physiology and productivity, especially for local climate and management conditions. Nevertheless, transpiration is mainly driven by sunlight, air temperature, and soil/plant water availability during the daytime and results in dry matter production and accumulation by the plant. Since minimum air temperature is the main driver of plant maintenance respiration during nighttime, increases in minimum air temperature can accelerate the respiration process, increase dry matter consumption for plant maintenance at night, and can result in reduction in crop yields.

In general, as mentioned in other publications (see EC717, *Long-term (1893-2012) Changes in Monthly Growing Season and Annual Precipitation Trends and Magnitudes in Central Nebraska*), there is an increasing trend in extreme precipitation events in central Nebraska, but there are significant declines in precipitation in other (western) locations, indicating spatial variability of change in climate variables, even within the same state. The increase in intensity of the rainfall means there is an increase in precipitation events that may not be beneficial to recharging soil profile due to an increase in potential for runoff and flooding. These are a strong function of the distribution of the precipitation during the growing season. Additional disadvantages may be an increase in the need for plant protection since increases in precipitation events will most likely increase relative humidity, the risk of nutrient leaching as the magnitude of a single precipitation event increases, loss of soil organic matter and erosion. The possible increase in drought, which can further limit water supplies for irrigation, and extreme weather events may cause lower harvestable yields, greater within-field yield variability, and possible reductions in suitable areas for cultivating traditional crops. These changes in climate and interactions with soil and crop require developing improved and more carefully designed crop, soil, and water (irrigation) management practices coupled with cultivating new drought-tolerant (or drought resistant) crops, as existing management practices/recommendations may not be able to fully account for the impacts of changes occurring in climatic variables (especially coupled with increases in both air temperature and CO_2 concentration) in effective crop management practices for optimum productivity. Our related research shows that changes in climate variables produce varying impacts in different locations in the same state. Therefore, it is important that research is conducted locally to develop best management farming practices for a specific location/region under changing climate.

Resources

Irmak, S., I. Kabenge, K. Skaggs, and D. Mutiibwa. 2012. Trend and magnitude of changes in climate variables and reference evapotranspiration over 116-year period in the Platte River Basin, central Nebraska-USA. *Journal of Hydrology* 420-421: 228-244.

Skaggs, K.E., and S. Irmak. 2012. Long-term trends in air temperature distribution and extremes, growing degree days, and spring and fall frosts for climate impact assessments on agricultural practices in Nebraska, USA. *Journal of Applied Meteorology and Climatology* 51:2060–2073.doi:dx.doi.org/10.1175/JAMC-D-11-0146.1.

Skaggs, K.E., and S. Irmak. 2013. Climate change impact on air temperature, daily temperature range, growing degree days and spring and fall frost dates in Nebraska. UNL Extension Circular EC715.

Irmak, S. 2013. Long-term (1893-2012) changes in monthly, growing season and annual precipitation trends and magnitudes in central Nebraska, UNL Extension Circular EC717.

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