Plant Water Stress Frequency and Periodicity in Western North Dakota, 1982-2019

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Water stress in plants develops during growing season periods of water deficiency when plants are unable to absorb adequate amounts of water through the roots to match the greater rate of water loss from transpiration. This differential in water loss causes cells to lose turgor resulting in wilting of plant structures. Water stress reduces plant growth and phenological development.

Water deficiency conditions are not the only environmental factors to which perennial grasses respond (Manske 2020). However, variation in frequency and periodicity of growing season months with water deficiencies can account for much of the annual variation in perennial grass herbage biomass production.

Periods of water stress occurrence can be quantitatively determined for growing season months from critical changes in temperature and precipitation data that create water deficiency conditions when precipitation amounts are lower than the variable evapotranspiration rates affected by levels of temperature. Soil water losses increase with increases in evapotranspiration demand. Evaporation rates increase as temperature increases. For each increase of 1° C in mean monthly temperature, an increase of 2 mm of monthly precipitation are required to prevent water deficiency and plant water stress.

Plants in water stress have limited growth and herbage biomass accumulation. Water stress can vary in degree from a small decrease in water potential, as in midday wilting on warm, clear days, to the lethal limit of desiccation. Early stages of water stress slow shoot and leaf growth. Leaves show signs of wilting, folding, and discoloration. Tillering and new shoot development decrease. Root production may increase. Senescence of older leaves accelerates. Rates of cell wall formation, cell division, and protein synthesis decrease. As water stress increases, enzyme activity declines and the formation of necessary compounds slows or ceases. The stomata begin to close; this reaction results in decreased rates of transpiration and photosynthesis. Rates of respiration and translocation decrease substantially with increases in water stress. When water stress becomes severe, most functions nearly or completely cease and serious damage occurs. Leaf and root mortality induced by water stress progresses from the tips to the crown. The rate of leaf and root mortality increases with increasing stress. Water stress can increase to a point that is lethal, resulting in damage from which the plant cannot recover. Plant death occurs when meristematic tissue become so dehydrated that cells cannot maintain cell turgidity and biochemical activity (Brown 1995).

A research project was conducted to determine the frequency and periodicity of water stress in perennial rangeland plants of western North Dakota for the 38 year period from 1982 to 2019 using data collected at the DREC ranch located near Manning, North Dakota. A similar complementary report by Manske et al. 2010 covered the 118 year period from 1892 to 2009 using data collected at Dickinson, North Dakota.

Plant water stress develops in plant tissue during growing season months with water deficiency conditions. The frequency, or rate of occurrence, of water stress conditions affects the percentage of total potential quantity and quality of herbage biomass produced by rangeland perennial plants, and the periodicity, or rate of reoccurrence, of water stress conditions affects the percentage of time that rangeland plant production is limited during growing season months.

Procedures

Plant water stress occurs during growing season monthly periods with water deficiency that can be identified by the ombrothermic diagram technique reported by Emberger et al. (1963). This method graphs mean monthly temperature (°C) and monthly precipitation (mm) on the same axis, with the scale of the precipitation data at twice that of the temperature data. The resulting ombrothermic diagram shows monthly periods in which precipitation is greater than the evapotranspiration rate set by the mean monthly temperature and identifies monthly periods with water deficiency conditions, unfavorable periods during which perennial plants experience water stress.

Water deficiency exists during months when the precipitation data bar drops below the temperature data curve. Ombrothermic diagrams were developed from historical climatological data of temperature and precipitation collected during the 38 year period from 1982 through 2019 at the Dickinson Research Extension Center ranch, latitude 47° 14' N, longitude 102° 50' W, Dunn County, near Manning, North Dakota, USA.

The quantity of precipitation received during each growing season was ranked on the basis of % of LTM (long-term mean) and separated into five categories. Growing seasons that received precipitation amounts at less than 50 % of LTM were considered to be in severely dry condition. Growing seasons that received precipitation amounts at less than 75% of LTM were considered to be in dry condition. Growing seasons that received precipitation amounts at greater than 75% and less than 125% of LTM were considered to be in normal condition. Growing seasons that received precipitation amounts at greater than 125% of LTM were considered to be in wet condition. Growing seasons that received precipitation amounts at greater than 150% of LTM were considered to be in extremely wet condition.

Results

The long-term (38 year) mean annual temperature was 42.1° F (5.7° C). January was the coldest month, with a mean temperature of 14.7° F (-9.6° C). July and August were the warmest months, with mean temperatures of 69.6° F (20.9° C) and 68.4° F (20.2° C), respectively (table 1). Perennial grassland plants are capable of active growth for periods longer than the frost-free period. The growing season for perennial plants was considered to be between the first 5 consecutive days in spring and the last 5 consecutive days in fall with the mean daily temperature at or above 32° F (0.0° C). In western North Dakota, the growing season for perennial plants was considered to be generally from mid April through mid October (6.0 months). The long-term mean annual precipitation was 17.3 inches (438.6 mm) (table 1). The growing season precipitation (April to October) was 14.6 inches (370.8 mm), 84.6% of the annual precipitation. The early portion of the growing season (April to July) received 9.6 inches (243.1 mm), 55.5% of the annual precipitation and 65.5% of the growing season precipitation. The latter portion of the growing season (August to October) received 5.0 inches (127.8 mm), 29.1% of the annual precipitation and 34.5% of the growing season precipitation. Total precipitation received during the nongrowing season (November through March) was only 2.7 inches (67.6 mm), 15.4% of the annual precipitation (table 2).

The long-term (38 year) ombrothermic diagram (figure 1) showed near water deficiency conditions during August, September, and October, a finding indicating that rangeland plants generally had difficulty growing and accumulating biomass during these 3 months. Favorable water relations occurred during April, May, June, and July, a period during which rangeland plants were capable of growing and accumulating herbage biomass.

Range plant growth conditions using temperature and precipitation data was determined for growing season months during 1982 to 2019 by the ombrothermic diagram technique and reported in Manske 2020. The summation of the ombrothermic water deficiency data was used to develop table 3. The perennial plant growing season is considered to be 6.0 months long from mid April through mid October. Perennial plants can grow at much lower temperatures than annual plants. The ombrothermic water deficiency conditions are determined for complete months. Water deficiency conditions for April and October are counted as half month periods (table 3).

The 8 year period of 1982 to 1989 has 48 growing season months with water deficiency conditions during 18 months, or 37.5% frequency of the total period months, for a mean of 2.3 months with water deficiency per 6.0 month growing season (table 3). The 10 year period of 1990 to 1999 has 60 growing season months with water deficiency conditions during 19 months, or 31.7% frequency of total period months, for a mean of 1.9 months with water deficiency per 6.0 months growing season (table 3). The 10 year period of 2000 to 2009 has 60 growing season months with water deficiency conditions during 19 months, or 31.7% frequency of total period months, for a mean of 1.9 months with water deficiency per 6.0 months growing season (table 3). The results from the ombrothermic water deficiency data for the 28 year period of 1982 to 2009 conforms extremely well with the long-term ombrothermic water deficiency data for the 118 year period of 1982 to 2009 (Manske et al. 2010) (table 4).

However, the results from the ombrothermic water deficiency data for the 10 year period of 2010 to 2019 does not conform with the long-term ombrothermic water deficiency data for the 118 year period of 1892 to 2009 nor for the 28 year period of 1982 to 2009. The 10 year period of 2010 to 2019 has 60 growing season months with water deficiency conditions during only 11 months, or 18.3% frequency of the total period months, for a mean of 1.1 months with water deficiency conditions per 6.0 month growing season (table 3). In addition, this 10 year period has 4 growing seasons with no water deficient months. No other 10 year period from the long-term regional data has less than 16 months of water deficiency and none have more than 2 growing seasons with no water deficient months. The 10 year period of 2010 to 2019 is an aberration that will be discussed later.

The similarity of the frequency rates of water deficiency months per 6.0 month growing season between the long-term data of 1892 to 2009 with 118 growing seasons and the data of 1982 to 2009 with 28 growing seasons is remarkable. The 118 year period of 1892 to 2009 had 20 wet growing seasons, 16.9%, that received precipitation at greater than 125% of LTM, and the 120 growing season months had water deficiency conditions during 19.5 months, or 16.3% frequency of the total period months, for a mean of 1.0 month with water deficiency per 6.0 month growing season (table 4). The 28 year period of 1982 to 2009 had 4 wet growing seasons, 14.3%, that received precipitation at greater than 125% of LTM, and the 24 growing season months had water deficiency conditions during 4.0 months, or 16.7% frequency of the total period months, for a mean of 1.0 month with water deficiency per 6.0 month growing season (table 4).

The 118 year period had 4 severely dry growing seasons, 3.4%, that received precipitation at less than 50% of LTM, and the 24 growing season months had water deficiency conditions during 18.0 months, or 75.0% frequency of the total period months, for a mean of 4.5 months with water deficiency per 6.0 month growing season (table 4). The 28 year period had 1 severely dry growing season, 3.6%, that received precipitation at less than 50% of LTM, and the 6 growing season months had water deficiency conditions during 5.0 months, or 83.3% frequency of the total period months, for a mean of 5.0 months with water deficiency per 6.0 month growing season (table 4).

The 118 year period had 14 dry growing seasons, 11.9%, that received precipitation at less than 75% of LTM, and the 84 growing season months had water deficiency conditions during 44.0 months, or 52.4% frequency of the total period months, for a mean of 3.1 months with water deficiency per 6.0 month growing season (table 4). The 28 year period had 3 dry growing seasons, 10.7%, that received precipitation at less than 75% of LTM, and the 18 growing season months had water deficiency conditions during 9.0 months, or 50.0% frequency of the total period months, for a mean of 3.0 months with water deficiency per 6.0 month growing season (table 4).

The 118 year period had 80 normal growing seasons, 67.8%, that received precipitation at greater than 75% and less than 125% of LTM, and the 480 growing season months had water deficiency conditions during 150.0 months, or 31.3% frequency of the total period months, for a mean of 1.9 months with water deficiency per 6.0 month growing season (table 4). The 28 year period had 20 normal growing seasons, 71.4%, that received precipitation at greater than 75% and less than 125% of LTM, and the 120 growing season months had water deficiency conditions during 38.0 months, or 31.7% frequency of the total period months, for a mean of 1.9 months with water deficiency per 6.0 month growing season (table 4).

The total 118 growing seasons from the years of 1892 to 2009, received precipitation at the wet, dry, and normal % of LTM, and the 708 growing season months had water deficiency conditions during 231.5 months, or 32.7% frequency of the total period months, for a mean of 2.0 months with water deficiency per 6.0 month growing season (table 4). The total 28 growing seasons from the years of 1982 to 2009, received precipitation at the wet, dry, and normal % of LTM, and the 168 growing season months had water deficiency conditions during 56.0 months, or 33.3% frequency of the total period months, for a mean of 2.0 months with water deficiency per 6.0 month growing season (table 4). The typical 6.0 month growing season from the period of 1892 to 2009 had 2.0 months with water deficiency conditions. The typical 6.0 month growing season from the period of 1982 to 2009 had 2.0 months with water deficiency conditions. The typical 6.0 month growing season for the past 118 years has had a mean of 2.0 months with water deficiency. That has been the normal growing season in western North Dakota.

Most Northern Plains agricultural producers manage the land with the assumption that the typical 6.0 month growing season should receive adequate levels of precipitation that result in zero months with water deficiency conditions. Unfortunately, growing seasons that have zero months with water deficiency are rare in western North Dakota. During the 118 growing seasons of 1893 to 2009, growing seasons that had zero months with water deficiency only occurred seven times, 1912, 1920, 1941, 1951, 1982, 1985, and 1998, for a long-term frequency of occurrence of 5.9% of the growing seasons, at about 1 growing season without water deficiency in 16 or 17 years (Manske et al. 2010). During the 28 growing seasons of 1982 to 2009, growing seasons that had zero months with water deficiency only occurred one time, 1982, for a long-term frequency of occurrence of 3.6% of the growing seasons, at 1 growing season without water deficiency in 28 years (table 3).

During the 10 growing seasons of 2010 to 2019, growing seasons that had zero months with water deficiency occurred four times, 2013, 2015, 2016, and 2019, for a remarkable frequency of 40% of the growing seasons, at a mean of 1 growing season without water deficiency in 2.5 years (table 3). The 2019 growing season had extremely wet conditions from receiving 23.14 inches of precipitation at 158.52% of LTM, and had a mean of 3.31 inches of rain per month. The 2013 growing season had wet conditions from receiving 21.56 inches of precipitation at 147.70% of LTM, and had a mean of 3.08 inches of rain per month. The 2015 and 2016 growing seasons had normal conditions from receiving a mean of 16.20 inches of precipitation at 110.95% of LTM, and had a mean of 2.31 inches of rain per month. The 10 year mean growing season precipitation received was 16.43 inches, 112.53% of LTM, and had a mean of 2.35 inches of rain per month. This decade of aberrations had 60 growing season months with water deficiency condition during only 11 months, or 18.3% frequency of the total period months, for a mean of 1.1 month with water deficiency per 6.0 month growing season.

No other ten year period than 2010 to 2019 has had as few as 11 months with water deficiency, for only 18.3% frequency of the total decade growing season months. The ten year period of 1920 to 1929 had the second fewest at 16 months with water deficiency, for 26.7% frequency of the total decade growing season months. The ten year period of 1930 to 1939 had the greatest amount of water deficient months in recorded weather data for western North Dakota at 25 months, for 41.7% frequency of the total decade growing season months.

No other ten year period than 2010 to 2019 has had as great of a mean growing season precipitation amount as 16.43 inches (112.53% of LTM) per 6.0 month growing season. The ten year period of 1940 to 1949 had the second greatest mean growing season precipitation with an 8.1% reduction at 15.10 inches (103.42% of LTM) per 6.0 month growing season. The ten year period of 1970 to 1979 had the third greatest mean growing season precipitation with an 8.5% reduction at 15.04 inches (103.01% of LTM) per 6.0 month growing season.

The eight year period of 1982 to 1989 had a mean growing season precipitation amount with a 20.2% reduction at 13.12 inches (89.86% of LTM) per 6.0 month growing season. The ten year period of 1990 to 1999 had a mean growing season precipitation amount with a 15.6% reduction at 13.87 inches (95.00% of LTM) per 6.0 month growing season. The ten year period of 2000 to 2009 had a mean growing season precipitation amount with a 10.7% reduction at 14.68 inches (100.55% of LTM) per 6.0 month growing season.

The 10 year period of 2010 to 2019 is distinctly dissimilar to any other 10 year period in 128 years in western North Dakota and had 1 growing season with extremely wet conditions from a mean of 23.14 inches of precipitation at 158.52% of LTM, and had a mean of 0.0 months with water deficiency per 6.0 month growing season. This 10 year period had 2 growing seasons with wet conditions from a mean of 20.46 inches of precipitation at 140.13% of LTM, and had a mean of 1.3 months with water deficiency per 6.0 month growing season. This 10 year period had 6 growing seasons with normal conditions from a mean of 15.18 inches of precipitation at 104.01% of LTM, and had a mean of 0.8 months with water deficiency per 6.0 month growing season. This 10 year period had 1 growing season with dry conditions from a mean of 9.16 inches of precipitation at 62.75% of LTM, and had a mean of 3.5 months with water deficiency per 6.0 month growing season (table 5).

The combined 28 year period of 1982 to 2009 had 4 growing seasons with wet conditions from a mean of 19.50 inches of precipitation at 133.56% of LTM, and had a mean of 1.0 months with water deficiency per 6.0 month growing season. This 28 year period had 20 growing seasons with normal conditions from a mean of 13.85 inches of precipitation at 94.86% of LTM, and had a mean of 1.9 months of water deficiency per 6.0 month growing season. This 28 year period had 3 growing seasons with dry conditions from a mean of 10.05 inches of precipitation at 68.84% of LTM, and had a mean of 3.0 months of water deficiency per 6.0 month growing season. This 28 year period had 1 growing season with severely dry conditions from a mean of 5.30 inches of precipitation at 36.31% of LTM, and had a mean of 5.0 months of water deficiency per 6.0 month growing season.

The 8 year period 1982 to 1989 had 2 growing seasons with wet conditions from a mean of 19.73 inches of precipitation at 135.13% of LTM, and had a mean of 0.8 months with water deficiency per 6.0 month growing season. This 8 year period had 4 growing seasons with normal conditions from a mean of 12.40 inches of precipitation at 84.97% of LTM, and had a mean of 2.1 months with water deficiency per 6.0 month growing season. This 8 year period had 1 growing season with dry conditions from a mean of 10.60 inches of precipitation at 72.61% of LTM, and had a mean of 3.0 months with water deficiency per 6.0 month growing season. This 8 year period had 1 growing season with severely dry conditions from a mean of 5.30 inches of precipitation at 36.31% of LTM, and had a mean of 5.0 months with water deficiency per 6.0 month growing season (table 5).

The ten year period of 1990 to 1999 had 1 growing season with wet conditions from a mean of 19.69 inches of precipitation at 134.88% of LTM, and had a mean of 1.5 months with water deficiency per 6.0 month growing season. This 10 year period had 8 growing seasons with normal conditions from a mean of 13.79 inches of precipitation at 94.44% of LTM, and had a mean of 1.9 months with water deficiency per 6.0 month growing season. This 10 year period had 1 growing season with dry conditions from a mean of 8.68 inches of precipitation at 59.46% of LTM, and had a mean of 2.5 months with water deficiency per 6.0 month growing season (table 5).

The ten year period of 2000 to 2009 had 1 growing season with wet conditions from a mean of 18.85 inches of precipitation at 129.13% of LTM, and had a mean of 1.0 month with water deficiency per 6.0 month growing season. This 10 year period had 8 growing seasons with normal conditions from a mean of 14.63 inches of precipitation at 100.24% of LTM, and had a mean of 1.8 months with water deficiency per 6.0 month growing season. This 10 year period had 1 growing season with dry conditions from a mean of 10.87 inches of precipitation at 74.46% of LTM, and had a mean of 3.5 months with water deficiency per 6.0 month growing season (table 5).

We do not know the complete reason why the weather conditions during the decade of 2010 to 2019 were so different from any other decade in the 128 years of recorded weather data for western North Dakota. The global climate has been experiencing various levels of change for some time. Polar and glacial ice has been melting at higher rates than in the past because of an increase in average world temperature and has caused a measurable rise in sea level. There has been an increase in the quantity of carbon dioxide (CO_2), nitrogenoxides (NO), ozone (O_3), methane (CH_4), and chlorofluorcarbons (chlorine (CI) and/or fluorine (F) added to hydrocarbons) occurring in the atmosphere. Water vapor makes up about 95% of the worlds greenhouse gases which absorb infrared radiation and reflect it back to earth which is an absolutely essential natural phenomenon required for life to exist on earth but this process might be working a little harder than needed.

A ten year period is too short of a time period to show what the future climate change for the Northern Plains will eventually be. However, the factors that change the global climate must have had some effect on the increase in the quantity and distribution of precipitation during this ten year period. We would need these conditions to continue for another ten to twenty years before it could be labeled as climate change.

Other than factors that change global climates, there are two factors that may have also contributed to this ten year increase in regional precipitation levels. These are: from the changes in increased atmospheric water vapor resulting from increased water evaporation off the surfaces of Lake Sakakawea, Lake Oahe, and Fort Peck Lake, and from the precautionary practice of cloud seeding with silver iodide (AgI) and dry ice (solid CO_2) to reduce the degree and extent of damage from hail. Unfortunately, these factors have not been quantified and the degree of their influence, if any, is not known.

Periodicity as percent of reoccurrence of water deficiency conditions during growing season months was not evenly distributed. Percent periodicity of water deficiency follow similar patterns during the periods of 1892 to 2009 and 1982 to 2009 (table 6). April had water deficiency around 17% to 18% of the time. May and June had water deficiency around 10% to 14% of the time. July had water deficiency around 38% to 39% of the time. August had water deficiency around 53% to 54% of the time. September had a wider range of water deficiency during 50% to 60% of the time. October had water deficiency around 32% to 47% of the time (table 6). April, May, and June had relatively low periodicity of water deficiency. July and October had relatively moderate periodicity of water deficiency. August and September had relatively high periodicity of water deficiency for greater than half the time (table 6).

Percent periodicity of water deficiency during 2010 to 2019 followed a pattern quite dissimilar to that of 1892 to 2009 and 1982 to 2009 (table 6). April had no water deficiency conditions. May, June, July, and September had relatively low periodicity of reoccurrence of water deficiency at around 10% to 20%. August had low moderate periodicity of water deficiency at 30% of the time. October had moderate periodicity of water deficiency at 40% of the time (table 6). The period of 2010 to 2019 only had a total of 11 growing season months with water deficiency at a low frequency rate of 18.3% which had never been this low of growing season months with water deficiency during the past 128 years in western North Dakota.

The early portion of the growing season, April to July, received a mean of 65.5% of the growing season precipitation. The latter portion of the growing season, August to October, received a mean of 34.5% of the growing season precipitation. Rangeland perennial plants produced most of their growth in leaf and flower stalk height (Goetz 1963) and in herbage biomass weight (Manske 1994) during the early portion of the growing season, May, June, and July, because of the low periodicity of water deficiency and the generally advantageous water conditions. The high periodicity of water deficiency conditions during August, September, and October limited rangeland plant growth and herbage biomass accumulation.

Discussion

The 6.0 month perennial plant growing season, mid April to mid October, had water deficiency conditions at a frequency of 33.3% during the 28 year period of 1982 to 2009, and at a frequency of 32.7% during the 118 year period of 1892 to 2009, for a mean of 2.0 months with water deficiency per 6.0 month growing season. The frequency of one third of the growing season months with water deficiency was the normal weather conditions for western North Dakota for 118 years. The recent decade of 2010 to 2019, which has had some effect from the factors that change global climate, had increased quantities of precipitation, improved distribution of precipitation, and reduced frequency of water deficiency to 18.3%, for a mean of only 1.1 months with water deficiency per 6.0 months growing season.

Growing seasons that have zero months with water deficiency are the ideal conditions that agricultural producers plan for or at least hope for. But in western North Dakota, growing seasons that had no water deficiency were abnormal events. During the 118 year period of 1892 to 2009, growing seasons with no water deficiency occurred at the low frequency of 5.9% of the years. During the 28 year period of 1982 to 2009, growing seasons with no water deficiency occurred at a lower frequency of 3.6% of the years. This low frequency of occurrence changed during the recent decade of 2010 to 2019 to a rate of 40.0% of the years, which may or may not continue into future decades.

The quantity of precipitation received during a growing season was variable and affected perennial plant growth differently. During the 28 year period of 1982 to 2009, precipitation received in amounts less than 50% of LTM caused severely dry conditions during 3.6% of the growing seasons, precipitation received in amounts less than 75% of LTM caused dry conditions during 10.7% of the growing seasons, precipitation received in amounts greater than 75% and less than 125% of LTM caused normal conditions during 71.4% of the growing seasons, precipitation received in amounts greater than 125% of LTM caused wet conditions during 14.3% of the growing seasons, and no growing seasons received greater than 150% of LTM. During the 118 year period of 1892 to 2009, precipitation was received at very similar rates, precipitation received in amounts less than 50% of LTM caused severely dry conditions during 3.4% of the growing seasons, precipitation received in amounts less than 75% of LTM caused dry conditions during 11.9% of the growing seasons, precipitation received in amounts greater than 75% and less than 125% of LTM caused normal conditions during 67.8% of the growing seasons, precipitation received in amounts greater than 125% of LTM caused wet conditions during 16.9% of the growing seasons, and no growing seasons received greater than 150% of LTM. During the recent decade of 2010 to 2019 precipitation was received at greater rates and with improved distribution, precipitation was not received in amounts less than 50% of LTM, precipitation received in amounts less than 75% of LTM caused dry conditions during 10.0% of the growing seasons, precipitation received in amounts greater than 75% and less than 125% of LTM caused normal conditions during 60.0% of the growing seasons, precipitation received in amounts greater than 125% of LTM caused wet conditions during 20.0% of the growing seasons, precipitation received in amounts greater than 150% of LTM caused extremely wet conditions during 10.0% of the growing seasons.

The growing seasons of the period of 1982 to 2009, had water deficiency conditions that reoccurred at a mean periodicity rate of 19.7% during the months, April to July, in the early portion of the growing season and reoccurred at a mean periodicity rate of 48.8% during the months, August to October, in the latter portion of the growing season. The growing seasons of the period of 1892 to 2009, had water deficiency conditions that reoccurred at a similar mean periodicity rates of 19.7% during the months, April to July, in the early portion of the growing season and reoccurred at a mean periodicity rate of 49.6% during the months, August to October, in the latter portion of the growing season. The growing seasons of the recent decade of 2010 to 2019, had water deficiency conditions that reoccurred at very dissimilar mean periodicity rates of 10% during the months, April to July, in the early portion of the growing season and reoccurred at a mean periodicity rate of 30.0% during the months, August to October, in the latter portion of the growing season.

Water deficiency conditions during growing season months has remained at the same mean frequency rate of 33%, for a mean of 2.0 months with water deficiency per 6.0 month growing season during the past 28 year period of 1982 to 2009 and the past 118 year period of 1892 to 2009. This long-term frequency rate of growing season months with water deficiency has caused sufficient water stress in perennial rangeland plants that have limited herbage biomass productivity in quantity and quality that has, subsequently, resulted in reduced livestock weight performance.

Frequency rate of growing season months with water deficiency improved with an increase in quantity of precipitation and improvement in water distribution during the recent decade of 2010 to 2019. If these conditions continue into the future, we will need to make upward adjustments to our pasture stocking rates and heavier calf weaning weights. On the other hand, if these conditions do not continue, the future climate change for the Northern Plains won’t be as bountiful as the past decade of 2010 to 2019.

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Table 1. Long-term mean temperature and precipitation, 1982-2019.					
		Mean Monthly Temperature		Monthly Precipitation	
		°F	°C	in.	mm
	Jan	14.72	-9.60	0.43	10.93
	Feb	18.28	-7.62	0.44	11.28
	Mar	29.21	-1.55	0.76	19.42
	Apr	41.58	5.32	1.43	36.28
	May	53.63	12.02	2.61	66.31
	Jun	63.14	17.30	3.20	81.38
	Jul	69.61	20.89	2.33	59.18
	Aug	68.37	20.20	1.99	50.62
	Sep	56.12	13.87	1.71	43.32
	Oct	43.76	6.53	1.33	33.70
	Nov	29.08	-1.62	0.56	14.14
	Dec	17.72	-7.93	0.47	12.04
		MEAN		**TOTAL**	
		42.10	5.65	17.26	438.61

Table 2. Seasonal precipitation distribution.			
		Inches	Percent
	Average Annual Precipitation	17.26	
	Growing Season (Apr-Oct)	14.60	(84.59%)
	Apr, May, Jun, Jul	9.57	(55.45%)
	Aug, Sep, Oct	5.03	(29.14%)
	Nongrowing Season (Nov-Mar)	2.66	(15.41%)

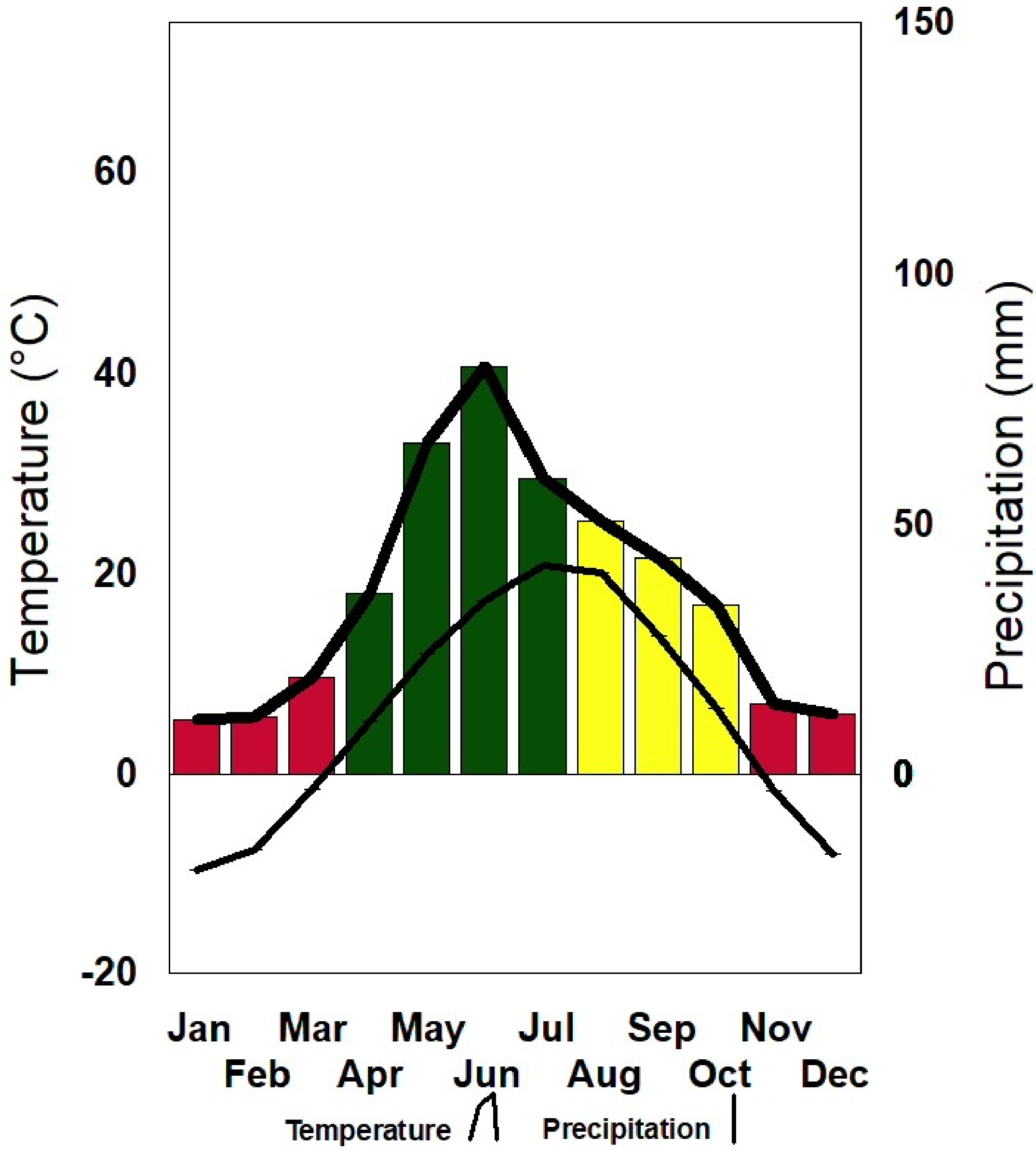

Figure 1. Ombrothermic diagram of long-term mean monthly temperature and monthly precipitation at the DREC Ranch, western North Dakota, 1982-2019.

Table 3. Growing season months with water deficiency conditions that caused water stress in perennial plants.

	Apr	May	Jun	Jul	Aug	Sep	Oct
1980	No Data						
1981	No Data						
1982	▨	▨	▨	▨	▨	▨	▨
1983	■					■	
1984		■		■		■	
1985				■			
1986					■		■
1987	■		■			■	■
1988	■		■	■	■	■	■
1989				■	■	■	
1990				■	■	■	
1991				■	■		
1992		■				■	■
1993					■	■	■
1994				■	■	■	
1995			■			■	
1996	■						■
1997					■		
1998	■					■	
1999							■
2000						■	
2001		■			■		■
2002						■	
2003					■		
2004					■		
2005				■	■	■	
2006				■			
2007				■	■	■	■
2008				■	■	■	
2009					■	■	
2010					■		■
2011							■
2012					■	■	
2013	▨	▨	▨	▨	▨	▨	▨
2014				■		■	■
2015	▨	▨	▨	▨	▨	▨	▨
2016	▨	▨	▨	▨	▨	▨	▨
2017		■	■	■			■
2018					■		
2019	▨	▨	▨	▨	▨	▨	▨

1982-2019 38 Years

■ Months with water deficiency

▨ Year with no water deficiency

Table 4. Comparison of growing season (GS) months with water deficiency (WD) conditions at Dickinson, 1892-2009, 118 growing seasons and at DREC ranch, 1982-2009, 28 growing seasons, both in western North Dakota.

118 GS, 1892-2009, Dickinson					28 GS, 1982-2009, DREC ranch				
No. of GS	Period GS months	No. of WD months	% of months WD	No. of months WD/6.0 mo. GS	No. of GS	Period GS months	No. of WD months	% of months WD	No. of months WD/6.0 mo. GS
Wet Growing Seasons with Precipitation greater than 125% of LTM									
20	120	19.5	16.3%	1.0/6.0 mo. GS	4	24	4.0	16.7%	1.0/6.0 mo. GS
Severely Dry Growing Seasons with Precipitation less than 50% of LTM									
4	24	18.0	75.0%	4.5/6.0 mo. GS	1	6	5.0	83.3%	5.0/6.0 mo. GS
Dry Growing Seasons with Precipitation less than 75% of LTM									
14	84	44.0	52.4%	3.1/6.0 mo. GS	3	18	9.0	50.0%	3.0/6.0 mo. GS
Normal Growing Seasons with Precipitation greater than 75% and less than 125% of LTM									
80	480	150.0	31.3%	1.9/6.0 mo. GS	20	120	38.0	31.7%	1.9/6.0 mo. GS
Total Growing Seasons with Precipitation at Wet, Dry, and Normal % of LTM									
118	708	231.5	32.7%	2.0/6.0 mo. GS	28	168	56.0	33.3%	2.0/6.0 mo. GS

Table 5. Plant Water Stress feasibility as affected by quantity of growing season (GS) precipitation received ranked by % LTM and the resulting number of months with water deficiency (WD) during four decade periods.

Growing Season Condition Precipitation Rank	% LTM		1982-1989 8 yrs #GS	1982-1989 8 yrs WD mo.	1990-1999 10 years #GS	1990-1999 10 years WD mo.	2000-2009 10 years #GS	2000-2009 10 years WD mo.	2010-2019 10 years #GS	2010-2019 10 years WD mo.
Severely Dry		<50%	1	5.0	0	-	0	-	0	-
Dry		<75%	1	3.0	1	2.5	1	3.5	1	3.5
Normal	>75%	<125%	4	2.1	8	1.9	8	1.8	6	0.8
Wet		>125%	2	0.8	1	1.5	1	1.0	2	1.3
Extremely Wet		>150%	0	-	0	-	0	-	1	0.0

Table 6. Periodicity as percent of reoccurrence of water deficiency (WD) during growing season (GS) months from three study periods.

Growing Seasons Periods	#WD mo. % of yrs	Apr	May	Jun	Jul	Aug	Sep	Oct	Total WD mo.	WD mo. per GS
1892-2009 118 yrs	# WD mo.	20	16	12	45	62	59	55	231.5	2.0
	% of yrs	16.9	13.6	10.2	38.1	52.5	50.0	46.6	32.7%	
1982-2009 28 yrs	# WD mo.	5	3	3	11	15	17	9	56.0	2.0
	% of yrs	17.9	10.7	10.7	39.3	53.6	60.7	32.1	33.3%	
2010-2019 10 yrs	# WD mo.	0	1	1	2	3	2	4	11.0	1.1
	% of yrs	0.0	10.0	10.0	20.0	30.0	20.0	40.0	18.3%	

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