Environmental Factors to Consider during Planning of Management for Range Plants in the Dickinson, North Dakota, Region, 1892-2010

Llewellyn L. Manske PhD
Range Scientist
North Dakota State University
Dickinson Research Extension Center

Introduction

The three most ecologically important environmental factors affecting rangeland plant growth are light, temperature, and water (precipitation). Plant growth and development are controlled by internal regulators that are modified according to environmental conditions. Length of daylight, temperature, precipitation, seasonal precipitation pattern, soil moisture, and evaporation are the environmental factors that affect plant growth in a region. Native vegetation and naturalized plants function as meteorologic instruments capable of measuring all the integrated climatic factors. The type of vegetation in a region is a result of the total effect of the long-term climatic factors for that region. Plant communities experience annual dynamic changes in response to annual climatic variability. A research project was conducted to describe the three most important environmental factors in western North Dakota and to identify some of the conditions and variables that limit range plant growth. Rangeland managers should consider these factors during the development of long-term management strategies.

Study Area

The study area is the region around the city of Dickinson, Stark County, in southwestern North Dakota, USA. The native vegetation in the Dickinson region is the Wheatgrass-Needlegrass Type (Stevens 1963, Zaczkowski 1972, Great Plains Association 1986, Barker and Whitman 1988, Shiflet 1994) of the mixed grass prairie.

The climate of western North Dakota has changed several times during geologic history (Manske 1999). The most recent climate change occurred about 5,000 years ago, to conditions like those of the present, with cycles of wet and dry periods. The wet periods have been cool and humid, with greater amounts of precipitation. A brief wet period occurred around 4,500 years ago. Relatively long periods of wet conditions occurred in the periods between 2,500 and 1,800 years ago and between 1,000 and 700 years ago. Recent short wet periods occurred in the years from 1905 to 1916, 1939 to 1947, and 1962 to 1978. The dry periods have been warmer, with reduced precipitation and recurrent summer droughts. A widespread, long drought period occurred between the years 1270 and 1299, an extremely severe drought occurred from 1863 through 1875, and other more recent drought periods occurred from 1895 to 1902, 1933 to 1938, and 1987 to 1992. The current climatic pattern in the Dickinson region is cyclical between wet and dry periods and has existed for the past 5,000 years (Bluemle 1977, Bluemle 1991, Manske 1994a).

Methods

Daylight duration data for the Dickinson location of latitude 46° 48' N, longitude 102° 48' W, were tabulated from daily sunrise and sunset time tables compiled by the National Weather Service, Bismarck, North Dakota.

Temperature and precipitation data were taken from historical climatological data (1892-2010) collected at the Dickinson Research Center, latitude 46° 53' N, longitude 102° 49' W, elevation 2,500 feet, Dickinson, North Dakota. The Dickinson Research Center is a benchmark weather station. The weather data collection site has been located in its present position since February 1893.

A technique reported by Emberger et al. (1963) was used to develop water deficiency months data from the historical temperature and precipitation data. The water deficiency months data were used to identify months with conditions unfavorable for plant growth. This method plots mean monthly temperature (ºC) and monthly precipitation (mm) on the same axis, with the scale of the precipitation data at twice that of the temperature data. The temperature and precipitation data are plotted against an axis of time. The resulting ombrothermic diagram shows general monthly trends and identifies months with conditions unfavorable for plant growth. Water deficiency conditions exist during months when the precipitation data bar drops below the temperature data curve and plants are under water stress. Plants are under temperature stress when the temperature curve drops below the freezing mark (0º C).

Results and Discussion

Light

Light is the most important ecological factor affecting plant growth (Manske 2000). Light is necessary for photosynthesis, and changes in day length (photoperiod) regulate the phenological development of rangeland plants. Changes in the day length function as the timer or trigger that activates or stops physiological processes initiating growth and flowering and that starts the process of hardening for resistance to low temperatures in fall and winter. Most range plants require full sunlight or very high levels of sunlight for best growth. Light intensities are reduced by cloud cover and shading from other plants (Odum 1971, Daubenmire 1974, Barbour et al. 1987).

The tilt of the earth's axis in conjunction with the earth's annual revolution around the sun produces the seasons and changes the length of daylight in temperate zones. Dickinson (Fig. 1) has nearly uniform day and night lengths (12 hours) during only a few days, near the vernal and autumnal equinoxes, 20 March and 22 September, respectively, when the sun's apparent path crosses the equator as the sun travels north or south, respectively. The shortest day length (8 hours, 23 minutes) occurs at winter solstice, 21 December, when the sun's apparent path is farthest south of the equator. The longest day length (15 hours, 52 minutes) occurs at summer solstice, 21 June, when the sun's apparent path is farthest north of the equator. The length of daylight during the growing season (mid April to mid October) oscillates from about 13 hours in mid April, increasing to nearly 16 hours in mid June, then decreasing to around 11 hours in mid October (Fig. 1). Some plants are long-day plants and others are short-day plants. Long-day plants reach the flower phenological stage after exposure to a critical photoperiod and during the period of increasing daylight between mid April and mid June. Short-day plants are induced into flowering by day lengths that are shorter than a critical length and that occur during the period of decreasing day length after mid June (Langer 1972, Weier et al. 1974, Leopold and Kriedemann 1975, Dahl 1995).

The annual pattern in the change in daylight duration follows the seasons and is the same every year for each region. Grassland management strategies based on phenological growth stages of the major grasses can be planned by calendar date after the relationships between phenological stage of growth of the major grasses and time of season have been determined for a region, with consideration of a possible variation of about ± 7 days to accommodate annual potential modification from temperature and precipitation (Manske 1980).

Temperature

Temperature, an approximate measurement of the heat energy available from solar radiation, is a significant factor because both low and high temperatures limit plant growth (Manske 2000). Most plant biological activity and growth occur within only a narrow range of temperatures, between 32º F (0º C) and 122º F (50º C) (Coyne et al. 1995).

In the Dickinson, North Dakota, area, the long-term (119-year) mean annual temperature is 40.9º F (4.9º C) (Table 1). January is the coldest month, with a mean temperature of 11.5º F (-11.4º C). July and August are the warmest months, with mean temperatures of 68.7º F (20.4º C) and 67.0º F (19.5º C), respectively. Months with mean monthly temperatures below 32.0º F (0.0º C) are too cold for active plant growth. From November to March each year, plants in western North Dakota cannot conduct active plant growth because mean temperatures are below 32º F (Table 1). Soils are frozen to a depth of 3 to 5 feet for a period of 4 months (121 days) (Larson et al. 1968). The frost-free period is the number of days between the last day with minimum temperatures below 32º F (0º C) in the spring and the first day with minimum temperatures below 32º F (0º C) in the fall and is approximately the length of growing season for annually seeded plants. The frost-free period for western North Dakota generally lasts for 120 to 130 days, from mid to late May to mid to late September (Ramirez 1972). Perennial grassland plants are capable of growing for periods longer than the frost-free period. The growing season for perennial plants is 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 32º F (0º C). In western North Dakota the growing season for perennial plants is considered to be generally from mid April through mid October (6.0 months, 183 days). The early and late portions of the 6-month growing season have very limited plant activity and growth. The period of active plant growth is generally 5.5 months (168 days).

The Dickinson area has large annual and diurnal changes in monthly and daily air temperatures. The range of seasonal variation of average monthly temperatures between the coldest and warmest months is 57.3° F (31.8° C) (Table 1), and temperature extremes at Dickinson have a range of 161.0° F (89.4° C), from the highest recorded summer temperature of 114.0° F (45.6° C) to the lowest recorded winter temperature of -47.0° F (-43.9° C). The diurnal temperature change is the difference between the minimum and maximum temperatures observed over a 24-hour period. The average diurnal temperature change during winter is 22.0° F (12.2° C), and the change during summer is 30.0° F (16.7° C). The average annual diurnal change in temperature is 26.0° F (14.4° C) (Jensen 1972). The large diurnal change in temperature during the growing season, which has warm days and cool nights, is beneficial for plant growth because of the effect on the photosynthetic process and respiration rates (Leopold and Kriedemann 1975).

Precipitation

Water (precipitation) is essential for plants and is an integral part of living systems (Manske 2000). Water is ecologically important because it is a major force in shaping climatic patterns, and water is biochemically important because it is necessary component in physiological processes (Brown 1995). Plant water stress limits growth. 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 (Brown 1977).
The long-term (119-year) annual precipitation for the area of Dickinson, North Dakota, is 16.03 inches (407.15 mm). Long-term mean monthly precipitation is shown in Table 1. The growing season precipitation (April to October) is 13.54 inches (343.76 mm) and is 84.47% of the annual precipitation. June has the greatest monthly precipitation, at 3.55 inches (90.14 mm). The seasonal distribution of precipitation (Table 2) shows the greatest amount of precipitation occurring in the spring (7.29 inches, 45.51%) and the least amount occurring in winter (1.55 inches, 9.69%). Total precipitation received for the 5-month period of November through March averages less than 2.5 inches (15.66%). The precipitation received in the 3-month period of May, June, and July accounts for 50.72% of the annual precipitation (8.13 inches).

The annual and growing season precipitation levels and percent of the long-term mean for 119 years (1892 to 2010) are shown in Table 3. Drought conditions exist when precipitation amounts for a month, growing season, or annual period are 75% or less of the long-term mean. Wet conditions exist when precipitation amounts for a month, growing season, or annual period are 125% or greater of the long-term mean. Normal conditions exist when precipitation amounts for a month, growing season, or annual period are greater than 75% and less than 125% of the long-term mean. Between 1892 and 2010, 14 drought years (11.76%) (Table 4) and 15 wet years (12.61%) (Table 5) occurred. Normal annual precipitation amounts were received during 90 years (75.63%) (Table 3). The area experienced 18 drought growing seasons (15.13%) (Table 6) and 21 wet growing seasons (17.65%) (Table 7). Normal growing-season precipitation amounts were received during 80 years (67.23%) (Table 3).

Temperature and Precipitation

Temperature and precipitation act together to affect the physiological and ecological status of range plants (Manske 2000). The balance between rainfall and potential evapotranspiration determines a plant's biological situation. When the amount of rainfall is less than potential evapotranspiration demand, a water deficiency exists. Under water deficiency conditions, plants are unable to absorb adequate water to match the transpiration rate, and plant water stress develops.

The ombrothermic graph technique reported by Emberger et al. (1963) was intended to identify the monthly periods in which water deficiency conditions exist. This technique assumes that most plants experience some level of water stress during water deficiency periods. This technique is not sensitive enough to identify the degree of water stress experienced by plants or the level of long-term damage. This technique does not identify periods shorter than 1 month because the temperature and precipitation data are summarized on a monthly basis. This characteristic in the data set forces a default assumption that water deficiency conditions shorter than a month do not cause long-lasting negative effects and that short-term water stress causes minimal damage from which plants recover. It also assumes that stored soil water is adequate to compensate for plant transpiration losses during periods of water deficiency shorter than a month.

Monthly periods with water deficiency conditions are identified on the ombrothermic graphs when the precipitation data bar drops below the temperature data curve. On the ombrothermic graphs, periods during which plants are under low-temperature stress are indicated when the temperature curve drops below the freezing mark of 0.0º C (32.0º F).

The ombrothermic relationships for Dickinson, North Dakota, are shown for each month from 1892 to 2010 in Figure 3. Temperature data for the following months are missing from the historical records: April, August, and September, 1892; June, and July, 1894; April, 1895; June, July, and August, 1897; July, August, September, October, November, and December, 1902; and January, and February, 1903.

The 119-year period (1892 to 2010) had a total of 714 months during the growing season. Of these growing season months, 233.0 months have had water deficiency conditions. This condition indicates that range plants were under water stress during 32.63% of the growing-season months (Fig. 3, Tables 8 and 9). This amounts to an average of 2.0 months during every 6.0-month growing season that range plants have been limited in growth and herbage biomass accumulation because of water stress. The converse indicates that only 4.0 months of an average year have conditions in which plants can grow without water stress.

Favorable water relations occur during May, June, and July, and most of the growth in range plants occurs during these three months (Goetz 1963, Manske 1994b). May and June appear to be the most important months for dependable precipitation. Only 16 (13.45%) of the 119 years have had water deficiency conditions during May, and 12 years (10.08%) have had water deficiency conditions during June. But only 3 years (2.52%), 1897, 1900, and 1936, have had water deficiency conditions in both May and June of the same year. Forty-five (37.82%) of the 119 years have had water deficiency conditions in July. Only 2 years, 1900 and 1936, have had water deficiency conditions in May, June, and July of the same year (Fig. 3, Tables 8 and 9).

The long-term ombrothermic graph for the Dickinson area (Fig. 2) shows that near water deficiency conditions exist for August, September, and October. August and September have had water deficiency conditions in 52.94% and 49.58% of the years, respectively, and October has had water deficiency conditions in 47.06% of the years (Table 9). These 3 months make up 42% of the growing season, and they have water deficiency conditions more than half the time. During the 119-year period, August, September, and/or October have had water deficiency conditions in 89.9% of the years. The water relations in August, September, and October limit range plant growth and herbage biomass accumulation.

Water Stress

Plant water stress develops in plant tissue when the rate of water loss through transpiration exceeds the rate of water absorption by the roots. Water stress in plants occurs during water deficiency periods, which develop when the amount of rainfall is less than evapotranspiration demand (Manske 2000). Water deficiency periods in which 75% or less of the long-term mean precipitation is received are droughts. Drought conditions are traditionally considered to be long periods, i.e. 12 months for a full year or 6 months for a complete growing season, but water deficiency periods of 1 month are long enough to limit herbage production greatly and warrant consideration and recognition. Drought years have occurred 11.8% of the time. Drought growing seasons have occurred 15.1% of the time. Water deficiency months have occurred 32.6% of the time. Water deficiency has occurred in May and June 13.4% and 10.1% of the time, respectively. July has had water deficiency conditions less than 40% of the time. August, September, and October have had water deficiency conditions more than 50% of the time. These deficiencies cause levels of water stress that limit the quantity and quality of plant growth and can limit livestock production if not considered during the development and implementation of long-term grazing management strategies.

Conclusion

The vegetation in a region is a result of the total effect of the long-term climatic factors for that region. The three most ecologically important environmental factors that affect rangeland plant growth are light, temperature, and water (precipitation).

Light is the most important ecological factor because it is necessary for photosynthesis. Shading of sunlight by cloud cover and from other plants affects plant growth. Day-length period is important to plant growth because it functions as a trigger to physiological processes. Most cool-season plants reach flower phenophase between mid May and mid June. Most warm-season plants flower between mid June and mid September. Daylight duration oscillation for each region is the same every year and changes with the seasons. Grassland management based on phenological growth stages of the major grasses can be planned by calendar date.

Plant growth is limited by both low and high temperatures and occurs within only a narrow range of temperatures, between 32° and 122° F. Perennial plants have a 6-month growing season, between mid April and mid October. Diurnal temperature changes with warm days and cool nights are beneficial for plant growth. A mixture of cool- and warm-season plants is highly desirable because the herbage biomass production is more stable over wide variations in seasonal temperatures. The dynamic expression of plant growth in a community can respond to a wide range of temperature conditions because the grass species in a mixture of cool- and warm-season species have a wide range of optimum temperatures.

Water is essential for living systems. Average annual precipitation is 16 inches at Dickinson, with 84% occurring during the growing season and 51% of the annual precipitation occurring in May, June, and July. Plant water stress occurs when the rate of water loss by transpiration exceeds the rate of replacement by absorption. Years with drought conditions have occurred 11.8% of the time during the past 119 years. Growing seasons with drought conditions have occurred 15.1% of the time.

Water deficiencies exist when the amount of rainfall is lower than evapotranspiration demand. Temperature and precipitation data can be used in ombrothermic graphs to identify monthly periods with water deficiencies. During the past 119 years, 32.6% of the growing season months have had water deficiency conditions that have placed range plants under water stress. This amounts to an average of 2.0 months during every 6-month growing season that range plants were limited in growth and herbage biomass accumulation. May, June, and July have had water deficiency conditions 13.4%, 10.1%, and 37.8 of the time, respectively. Most range grass growth occurs during this 3-month period when 51% of the annual precipitation occurs. August, September, and October have had water deficiency conditions 52.9%, 49.6% and 47.1% of the time, respectively. One month with water deficiency conditions causes plants to experience water stress severe enough to reduce herbage biomass production. Development of successful management strategies for grassland ecosystems of a region requires knowledge of the environmental factors affecting plant growth and consideration of the conditions that limit range plant growth.

Acknowledgment

I am grateful to Sheri Schneider for assistance in processing the weather data, compilation of the tables and figures, and production of this manuscript.

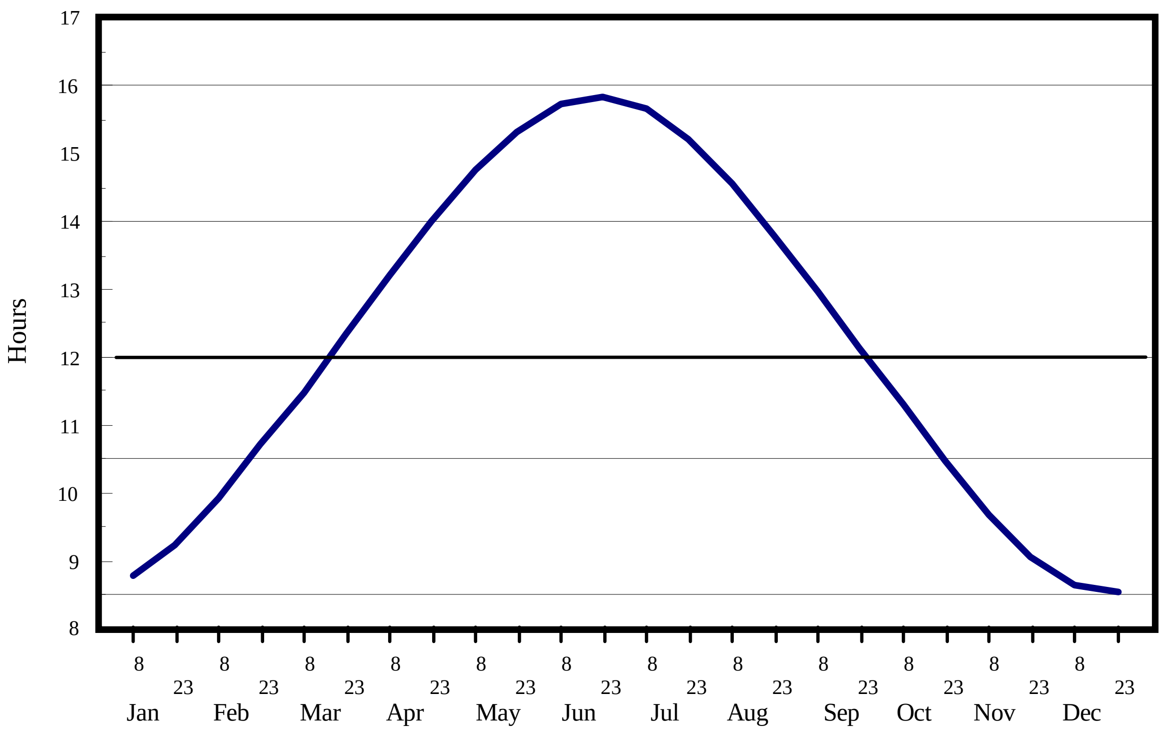

Fig. 1. Annual pattern of daylight duration at Dickinson, North Dakota.

Table 1. Long-term (1892-2010) mean monthly temperature and monthly precipitation at Dickinson, ND.

	º F	º C	in.	mm
Jan	11.48	-11.40	0.41	10.39
Feb	15.25	-9.31	0.41	10.34
Mar	26.21	-3.22	0.74	18.71
Apr	41.56	5.31	1.41	35.76
May	52.77	11.54	2.34	59.39
Jun	61.96	16.65	3.55	90.14
Jul	68.74	20.41	2.24	56.92
Aug	67.01	19.45	1.71	43.38
Sep	56.09	13.38	1.34	33.97
Oct	43.74	6.52	0.95	24.20
Nov	28.44	-1.98	0.54	13.62
Dec	16.89	-8.39	0.41	10.33
	MEAN		**TOTAL**	
	40.85	**4.91**	**16.03**	**407.15**

Table 2. Seasonal percentage of mean annual precipitation distribution (1892-2010).

Season	in.	%
Winter (Jan, Feb, Mar)	1.55	9.69
Spring (Apr, May, Jun)	7.29	45.51
Summer (Jul, Aug, Sep)	5.29	32.98
Fall (Oct, Nov, Dec)	1.90	11.83
TOTAL	16.03	

Table 3a. Precipitation for total year and growing season and percent of long-term mean (LTM) for Dickinson, ND, weather data, (1892-1899, 1900-1909).

	Total Year 12 Months			**Growing Season, Apr - Oct 7 Months**		
	inches	mm	% of LTM	inches	mm	% of LTM
1890	-	-	-	-	-	-
1891	-	-	-	-	-	-
1892	15.35	389.89	95.76	13.30	337.82	98.27
1893	11.63	295.40	72.55	9.09	230.89	67.16
1894	15.47	392.94	96.51	13.65	346.71	100.86
1895	11.76	298.70	73.36	9.44	239.78	69.75
1896	18.48	469.39	115.29	13.19	335.03	97.46
1897	13.52	343.41	84.34	7.76	197.10	57.34
1898	11.92	302.77	74.36	10.24	260.10	75.66
1899	17.27	438.66	107.74	15.64	397.26	115.56
MEAN	**14.43**	**366.40**	**89.99**	**11.54**	**293.09**	**85.26**
1900	11.78	299.21	73.49	9.33	236.98	68.94
1901	12.92	328.17	80.60	9.77	248.16	72.19
1902	16.07	408.18	100.25	11.12	282.45	82.16
1903	16.90	429.26	105.43	14.90	378.46	110.09
1904	15.19	385.83	94.76	11.40	289.56	84.23
1905	16.55	420.37	103.25	14.29	362.97	105.59
1906	20.46	519.68	127.64	16.80	426.72	124.13
1907	13.67	347.22	85.28	12.10	307.34	89.41
1908	19.48	494.79	121.53	16.03	407.16	118.44
1909	21.26	540.00	132.63	18.91	480.31	139.72
MEAN	**16.43**	**417.27**	**102.49**	**13.47**	**342.01**	**99.49**

Table 3b. Precipitation for total year and growing season and percent of long-term mean (LTM) for Dickinson, ND, weather data, (1910-1919, 1920-1929).

	Total Year 12 Months			**Growing Season, Apr - Oct 7 Months**		
	inches	mm	% of LTM	inches	mm	% of LTM
1910	13.34	338.84	83.22	10.91	277.11	80.61
1911	15.62	396.75	97.44	12.96	329.18	95.76
1912	19.06	484.12	118.91	17.85	453.39	131.89
1913	11.93	303.02	74.42	10.11	256.79	74.70
1914	22.74	577.60	141.86	20.46	519.68	151.18
1915	19.75	501.65	123.21	17.95	455.93	132.63
1916	18.40	467.36	114.79	14.73	374.14	108.84
1917	9.25	234.95	57.71	7.33	186.18	54.16
1918	12.36	313.94	77.11	11.01	279.65	81.35
1919	8.37	212.60	52.22	6.69	169.93	49.43
MEAN	**15.08**	**383.08**	**94.09**	**13.00**	**330.20**	**96.06**
1920	15.81	401.57	98.63	14.59	370.59	107.80
1921	15.76	400.30	98.32	12.51	317.75	92.43
1922	18.20	462.28	113.54	14.22	361.19	105.07
1923	19.73	501.14	123.08	18.37	466.60	135.73
1924	15.12	384.05	94.33	12.90	327.66	95.32
1925	12.19	309.63	76.05	10.49	266.45	77.51
1926	13.11	332.99	81.79	10.48	266.19	77.44
1927	19.59	497.59	122.21	16.15	410.21	119.33
1928	15.30	388.62	95.45	13.74	349.00	101.52
1929	17.21	437.13	107.36	10.67	271.02	78.84
MEAN	**16.20**	**411.53**	**101.08**	**13.41**	**340.67**	**99.10**

Table 3c. Precipitation for total year and growing season and percent of long-term mean (LTM) for Dickinson, ND, weather data, (1930-1939, 1940-1949).

	Total Year 12 Months			**Growing Season, Apr - Oct 7 Months**		
	inches	mm	% of LTM	inches	mm	% of LTM
1930	13.79	350.27	86.03	10.99	279.15	81.20
1931	16.17	410.72	100.88	13.51	343.15	99.82
1932	17.24	437.90	107.55	14.77	375.16	109.13
1933	11.50	292.10	71.74	9.07	230.38	67.02
1934	7.91	200.91	49.35	6.61	167.89	48.84
1935	15.00	381.00	93.58	12.04	305.82	88.96
1936	6.72	170.69	41.92	3.88	98.55	28.67
1937	16.28	413.51	101.56	13.92	353.57	102.85
1938	16.65	422.91	103.87	13.07	331.98	96.57
1939	15.75	400.05	98.26	14.12	358.65	104.33
MEAN	**13.70**	**348.01**	**85.47**	**11.20**	**284.43**	**82.74**
1940	17.12	434.85	106.80	15.16	385.06	112.02
1941	31.88	809.75	198.88	30.50	774.70	225.36
1942	19.75	501.65	123.21	17.78	451.61	131.37
1943	15.06	382.52	93.95	12.56	319.02	92.80
1944	20.63	524.00	128.70	16.08	408.43	118.81
1945	12.22	310.39	76.23	8.79	223.27	64.95
1946	14.50	368.30	90.46	12.18	309.37	90.00
1947	18.86	479.04	117.66	16.93	430.02	125.09
1948	16.11	409.19	100.50	12.89	327.41	95.24
1949	10.77	273.56	67.19	8.11	205.99	59.92
MEAN	**17.69**	**449.33**	**110.36**	**15.10**	**383.49**	**111.56**

Table 3d. Precipitation for total year and growing season and percent of long-term mean (LTM) for Dickinson, ND, weather data, (1950-1959, 1960-1969).

	Total Year 12 Months			**Growing Season, Apr - Oct 7 Months**		
	inches	mm	% of LTM	inches	mm	% of LTM
1950	15.13	384.30	94.39	10.56	268.22	78.03
1951	16.70	424.18	104.18	14.45	367.03	106.77
1952	11.97	304.04	74.67	9.83	249.68	72.63
1953	19.39	492.51	120.96	17.37	441.20	128.34
1954	16.33	414.78	101.87	13.46	341.88	99.45
1955	14.65	372.11	91.39	12.66	321.56	93.54
1956	12.70	322.58	79.23	11.04	280.42	81.57
1957	22.15	562.61	138.18	20.17	512.32	149.03
1958	12.18	309.37	75.98	9.42	239.27	69.60
1959	13.45	341.63	83.91	11.56	293.62	85.42
MEAN	**15.47**	**392.81**	**96.48**	**13.05**	**331.52**	**96.44**
1960	10.23	259.84	63.82	8.54	216.92	63.10
1961	13.90	353.06	86.71	12.65	321.31	93.47
1962	18.34	465.84	114.41	16.41	416.81	121.25
1963	18.94	481.08	118.16	16.17	410.72	119.48
1964	18.74	476.00	116.91	17.28	438.91	127.68
1965	21.63	549.40	134.94	20.08	510.03	148.37
1966	16.69	423.93	104.12	14.93	379.22	110.32
1967	14.24	361.70	88.84	12.51	317.75	92.43
1968	15.73	399.54	98.13	13.81	350.77	102.04
1969	16.37	415.80	102.12	14.26	362.20	105.37
MEAN	**16.48**	**418.62**	**102.82**	**14.66**	**372.46**	**108.35**

Table 3e. Precipitation for total year and growing season and percent of long-term mean (LTM) for Dickinson, ND, weather data, (1970-1979, 1980-1989).

	Total Year 12 Months			Growing Season, Apr - Oct 7 Months		
	inches	mm	% of LTM	inches	mm	% of LTM
1970	20.16	512.06	125.77	17.90	454.66	132.26
1971	21.25	539.75	132.57	18.58	471.93	137.29
1972	20.76	527.30	129.51	18.57	471.68	137.21
1973	13.53	343.66	84.41	11.83	300.48	87.41
1974	14.15	359.41	88.27	12.45	316.23	91.99
1975	17.71	449.83	110.48	15.26	387.60	112.75
1976	12.68	322.07	79.10	10.84	275.34	80.10
1977	23.13	587.50	144.30	18.65	473.71	137.80
1978	17.63	447.80	109.98	15.17	385.32	112.09
1979	12.81	325.37	79.91	11.12	282.45	82.16
MEAN	**17.38**	**441.48**	**108.43**	**15.04**	**381.94**	**111.11**
1980	12.58	319.53	78.48	10.73	272.54	79.28
1981	15.76	400.30	98.32	14.27	362.46	105.44
1982	26.58	675.13	165.82	22.53	572.26	166.47
1983	12.59	319.79	78.54	10.18	258.57	75.22
1984	15.54	394.72	96.95	13.61	345.69	100.56
1985	16.98	431.29	105.93	14.63	371.60	108.10
1986	21.68	550.67	135.25	18.87	479.30	139.43
1987	15.92	404.37	99.32	13.06	331.72	96.50
1988	9.20	233.68	57.39	6.56	166.62	48.47
1989	12.78	324.61	79.73	10.74	272.80	79.36
MEAN	**15.96**	**405.41**	**99.57**	**13.52**	**343.36**	**99.88**

Table 3f. Precipitation for total year and growing season and percent of long-term mean (LTM) for Dickinson, ND, weather data, (1990-1999, 2000-2009).

	Total Year 12 Months			**Growing Season, Apr - Oct 7 Months**		
	inches	mm	% of LTM	inches	mm	% of LTM
1990	12.37	314.20	77.17	11.36	288.54	83.94
1991	14.86	377.44	92.70	13.83	351.28	102.19
1992	14.24	361.70	88.84	11.47	291.34	84.75
1993	16.98	431.29	105.93	14.46	367.28	106.84
1994	17.50	444.50	109.17	15.80	401.32	116.74
1995	21.13	536.70	131.82	18.64	473.46	137.73
1996	17.07	433.58	106.49	13.36	339.35	98.72
1997	16.78	426.21	104.68	14.74	374.40	108.91
1998	24.04	610.62	149.97	20.51	520.95	151.55
1999	15.82	422.91	98.69	14.20	360.68	104.92
MEAN	**17.08**	**435.92**	**106.55**	**14.84**	**376.86**	**109.63**
2000	16.11	409.19	100.50	11.91	302.51	88.00
2001	18.89	479.81	117.84	17.74	450.60	131.08
2002	17.59	446.79	109.73	15.47	392.94	114.31
2003	15.80	401.32	98.57	11.45	290.83	84.60
2004	13.08	332.23	81.60	10.26	260.60	75.81
2006	19.14	486.16	119.40	16.48	418.59	121.77
2006	12.77	324.36	79.67	11.01	279.65	81.35
2007	13.14	333.76	81.97	11.79	299.47	87.11
2008	12.03	305.56	75.05	9.33	236.98	68.94
2009	19.80	502.92	123.52	13.97	354.84	103.22
MEAN	**15.84**	**402.21**	**98.79**	**12.94**	**328.70**	**95.62**

Table 3g. Precipitation for total year and growing season and percent of long-term mean (LTM) for Dickinson, ND, weather data, (2010-2019, 2020-2029).

	Total Year 12 Months			**Growing Season, Apr - Oct 7 Months**		
	inches	mm	% of LTM	inches	mm	% of LTM
2010	19.07	484.38	118.97	16.00	406.40	118.22
2011						
2012						
2013						
2014						
2015						
2016						
2017						
2018						
2019						
MEAN						
2020						
2021						
2022						
2023						
2024						
2026						
2026						
2027						
2028						
2029						
MEAN						

Table 4. Years with annual precipitation amounts of 75% or less of the long-term mean (LTM).

	Year	%LTM
1	1936	41.92
2	1934	49.35
3	1919	52.22
4	1988	57.39
5	1917	57.71
6	1960	63.82
7	1949	67.19
8	1933	71.74
9	1893	72.55
10	1895	73.36
11	1900	73.49
12	1898	74.36
13	1913	74.42
14	1952	74.67

Table 5. Years with annual precipitation amounts of 125% or more of the long-term mean (LTM).

	Year	%LTM
1	1941	198.88
2	1982	165.82
3	1998	149.97
4	1977	144.30
5	1914	141.86
6	1957	138.18
7	1986	135.25
8	1965	134.94
9	1909	132.63
10	1971	132.57
11	1995	131.82
12	1972	129.51
13	1944	128.70
14	1906	127.64
15	1970	125.77

Table 6. Years with growing-season precipitation amounts of 75% or less of the long-term mean (LTM).

	Year	%LTM
1	1936	28.67
2	1988	48.47
3	1934	48.84
4	1919	49.43
5	1917	54.16
6	1897	57.34
7	1949	59.92
8	1960	63.10
9	1945	64.95
10	1933	67.02
11	1893	67.16
12	1900	68.94
13	2008	68.94
14	1958	69.60
15	1895	69.75
16	1901	72.19
17	1952	72.63
18	1913	74.70

Table 7. Years with growing-season precipitation amounts of 125% or more of the long-term mean (LTM).

	Year	%LTM
1	1941	225.36
2	1982	166.47
3	1998	151.55
4	1914	151.18
5	1957	149.03
6	1965	148.37
7	1909	139.72
8	1986	139.43
9	1977	137.80
10	1995	137.73
11	1971	137.29
12	1972	137.21
13	1923	135.73
14	1915	132.63
15	1970	132.26
16	1912	131.89
17	1942	131.37
18	2001	131.08
19	1953	128.34
20	1964	127.68
21	1947	125.09

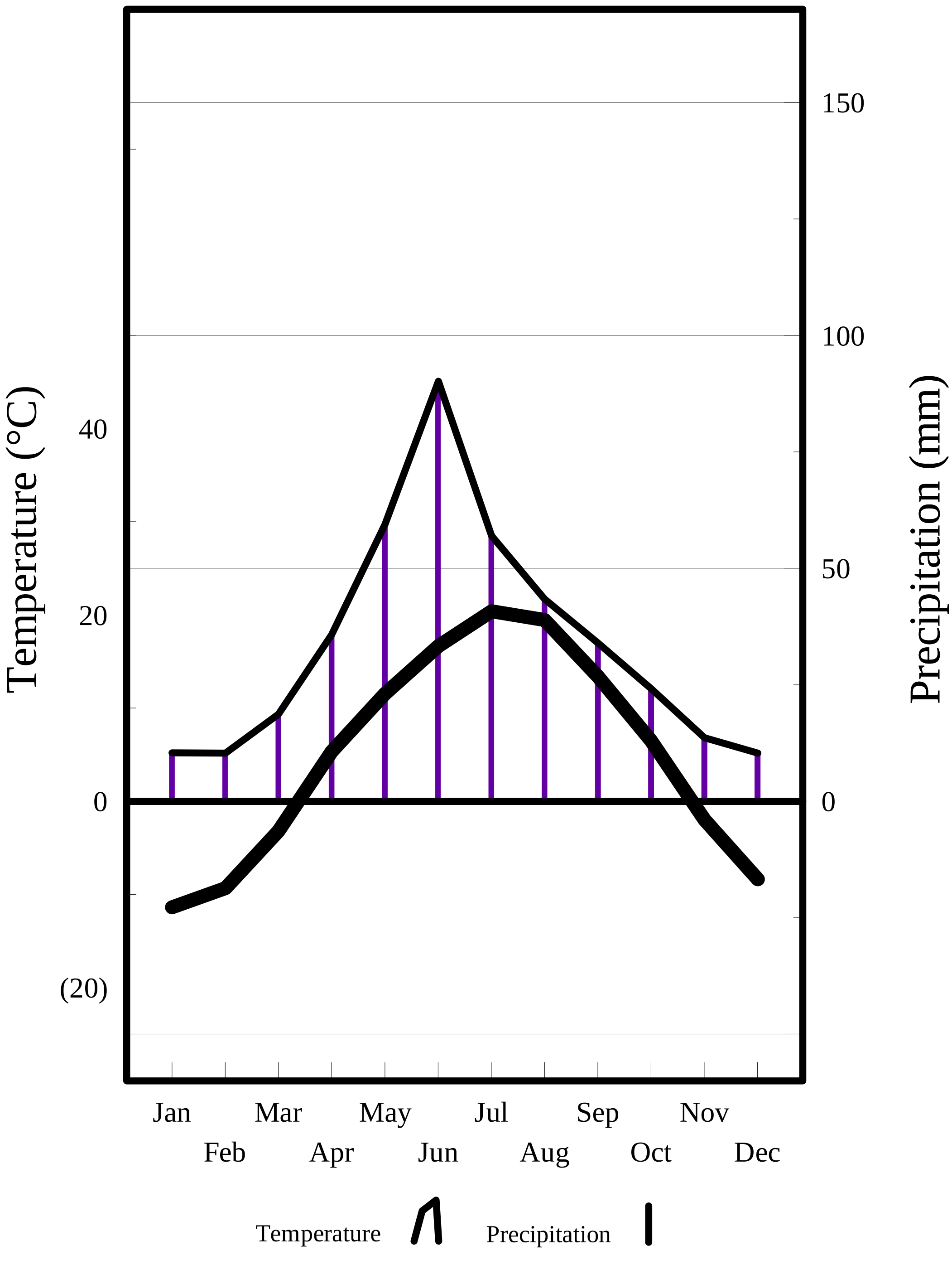

Fig. 2. Ombrothermic diagram of long-term (1892-2010) mean monthly temperature and monthly precipitation at Dickinson, North Dakota.

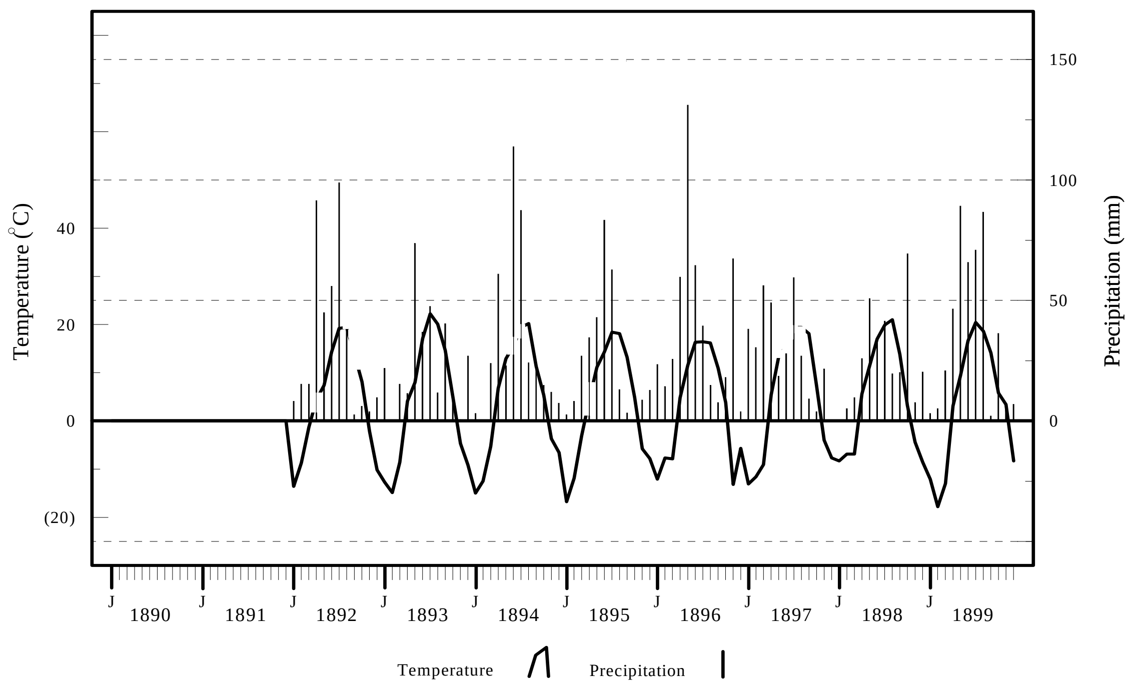

Fig. 3a. Ombrothermic diagram of 1892-1899 mean monthly temperature and monthly precipitation at Dickinson, North Dakota.

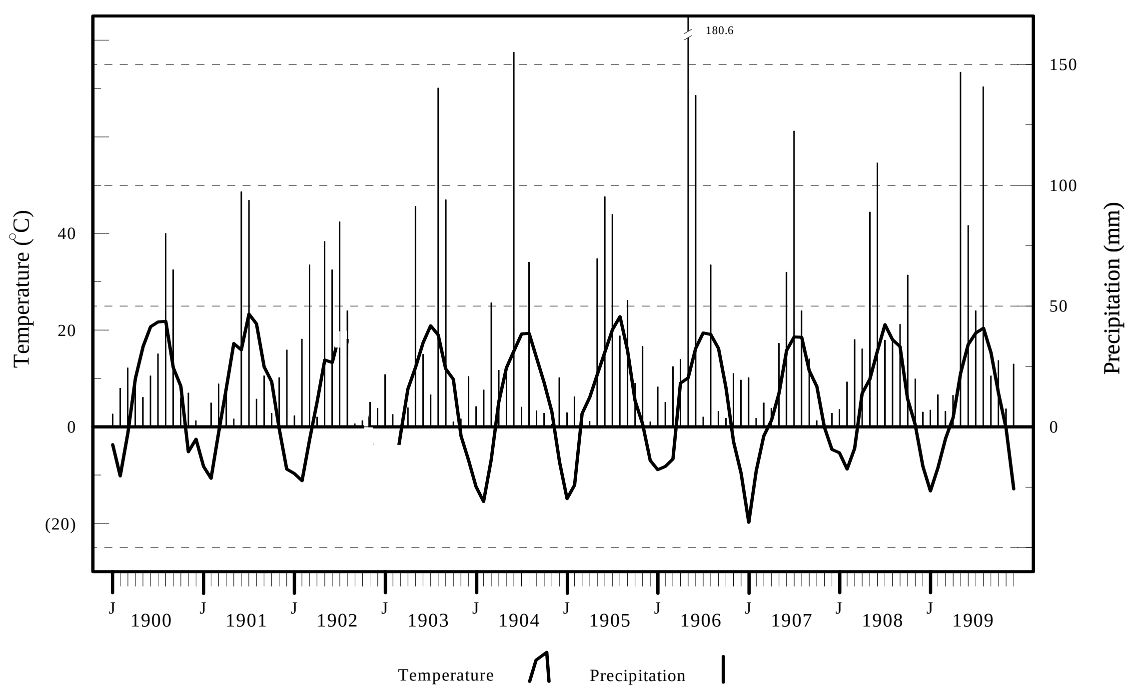

Fig. 3b. Ombrothermic diagram of 1900-1909 mean monthly temperature and monthly precipitation at Dickinson, North Dakota.

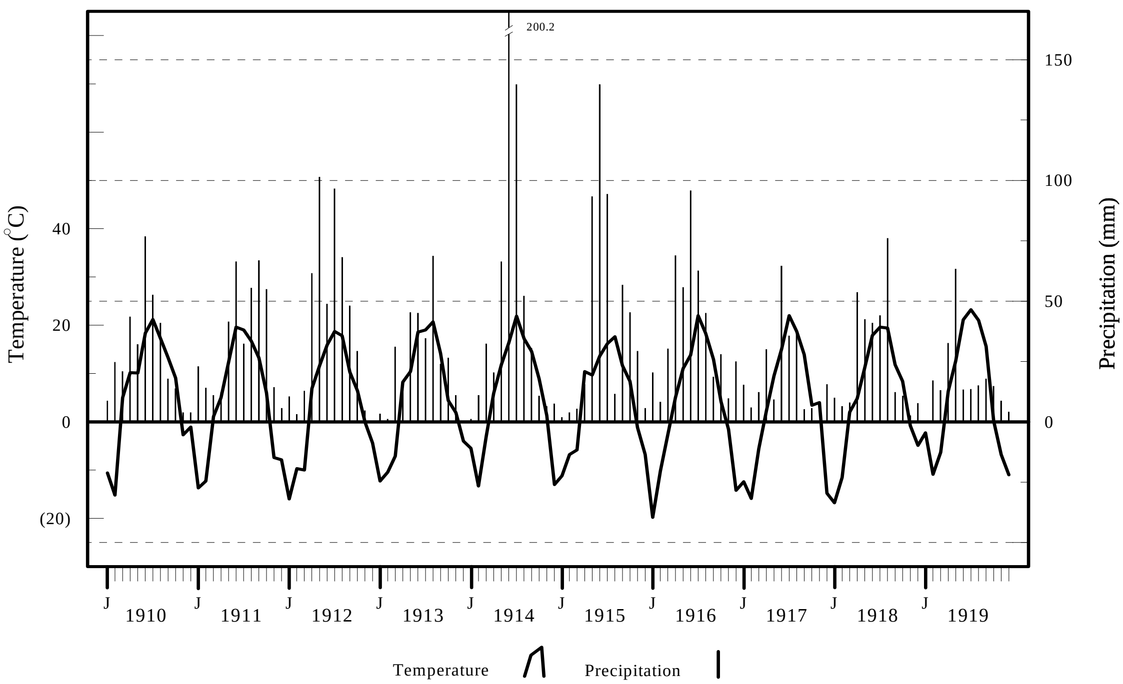

Fig. 3c. Ombrothermic diagram of 1910-1919 mean monthly temperature and monthly precipitation at Dickinson, North Dakota.

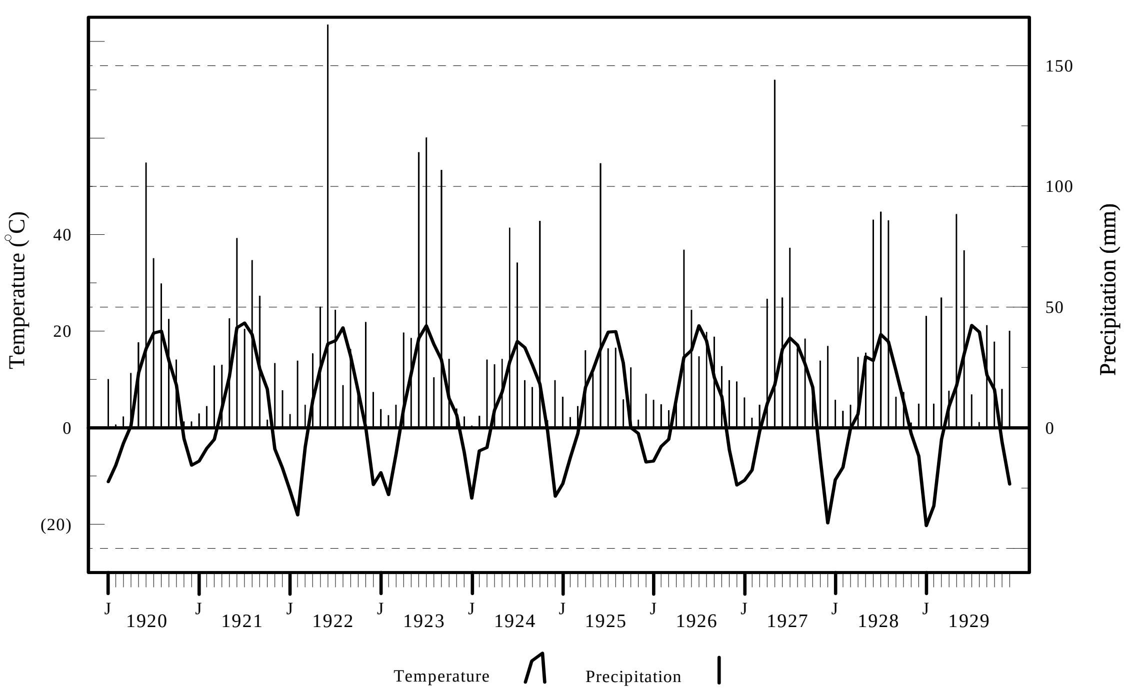

Fig. 3d. Ombrothermic diagram of 1920-1929 mean monthly temperature and monthly precipitation at Dickinson, North Dakota.

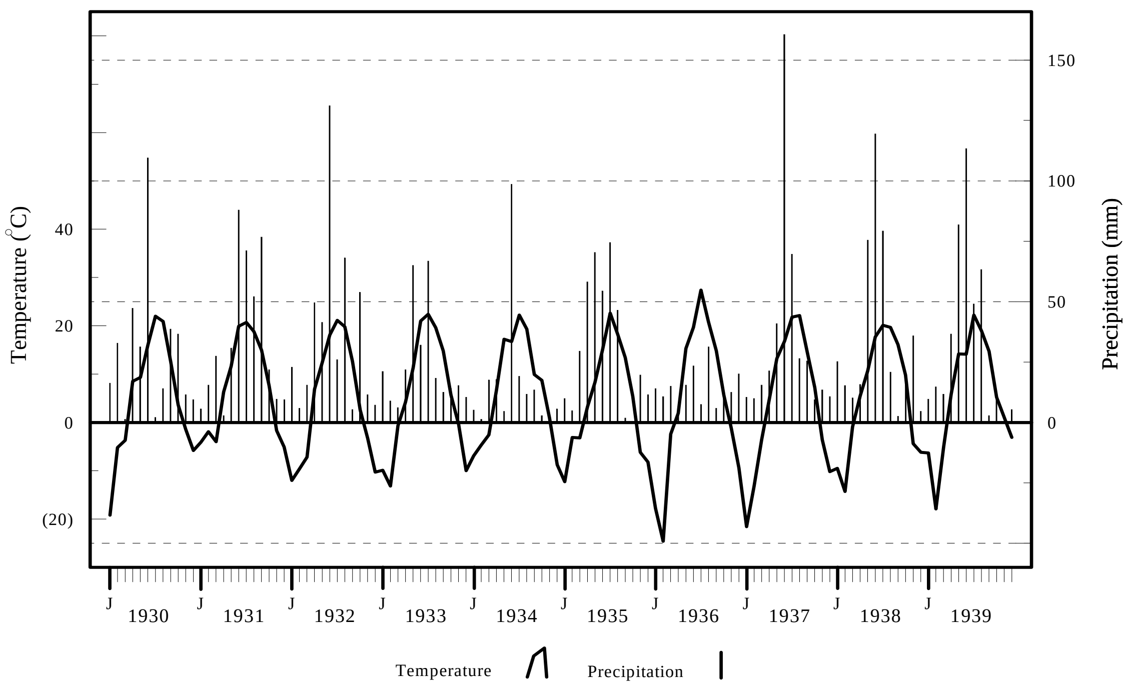

Fig. 3e. Ombrothermic diagram of 1930-1939 mean monthly temperature and monthly precipitation at Dickinson, North Dakota.

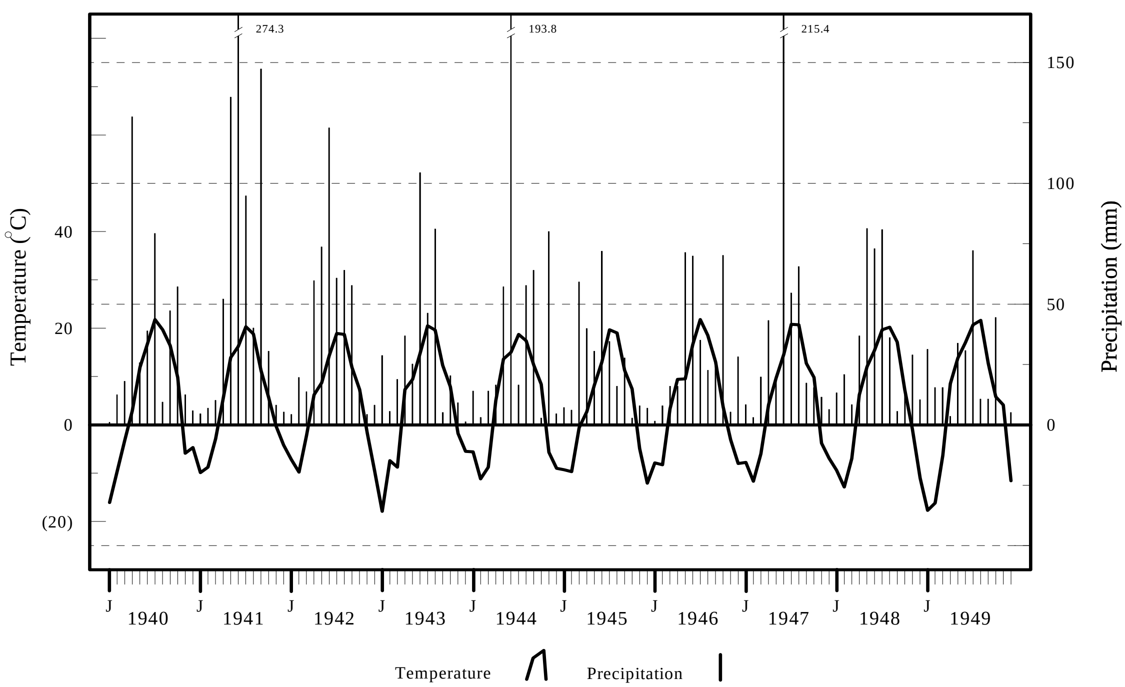

Fig. 3f. Ombrothermic diagram of 1940-1949 mean monthly temperature and monthly precipitation at Dickinson, North Dakota.

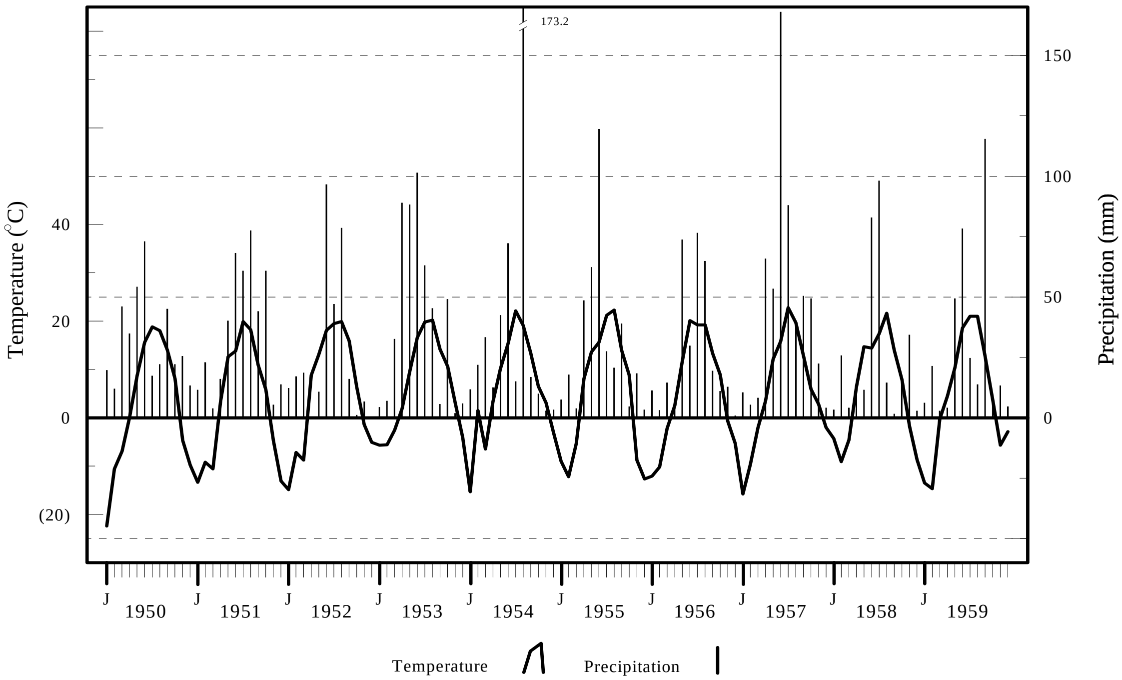

Fig. 3g. Ombrothermic diagram of 1950-1959 mean monthly temperature and monthly precipitation at Dickinson, North Dakota.

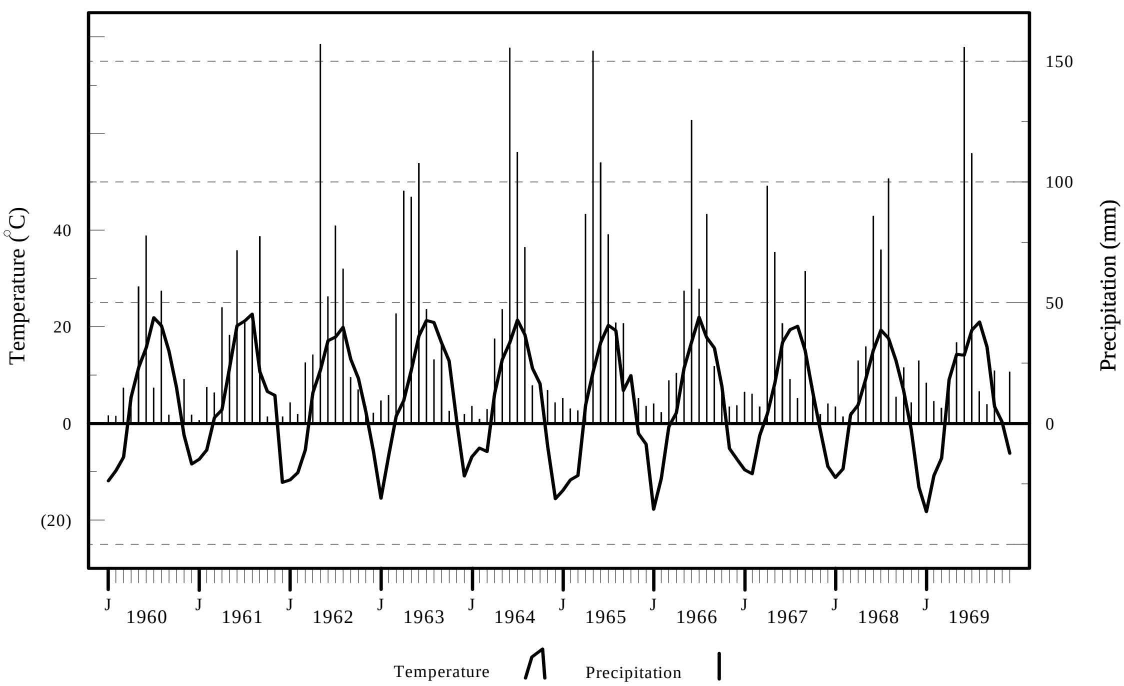

Fig. 3h. Ombrothermic diagram of 1960-1969 mean monthly temperature and monthly precipitation at Dickinson, North Dakota.

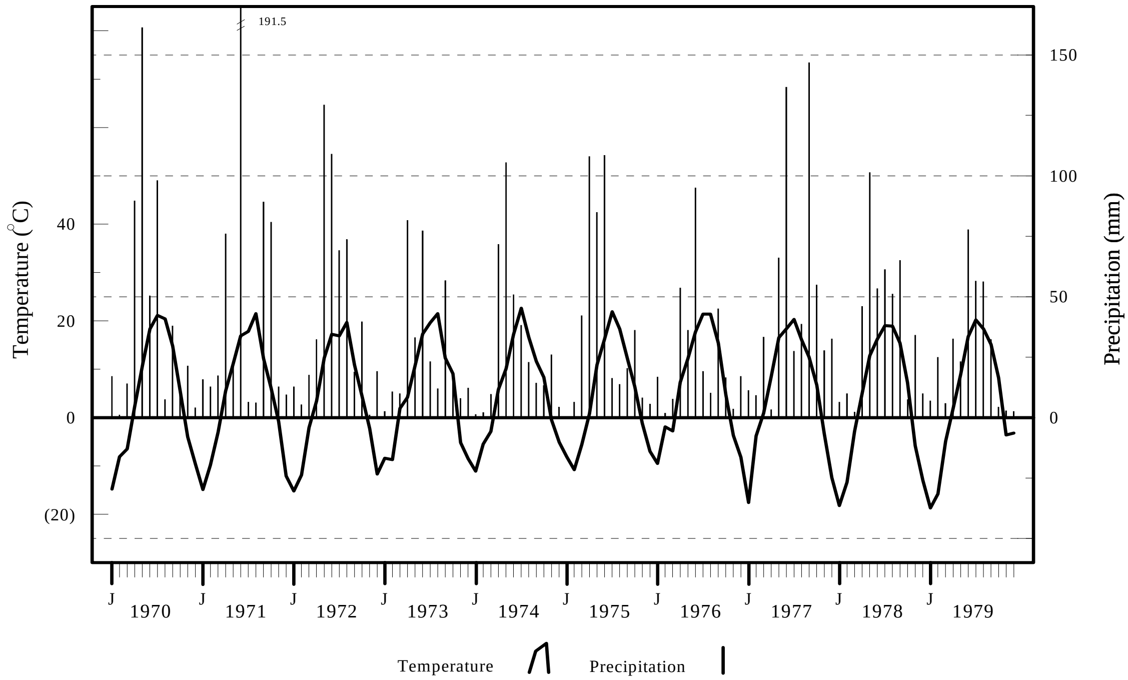

Fig. 3i. Ombrothermic diagram of 1970-1979 mean monthly temperature and monthly precipitation at Dickinson, North Dakota.

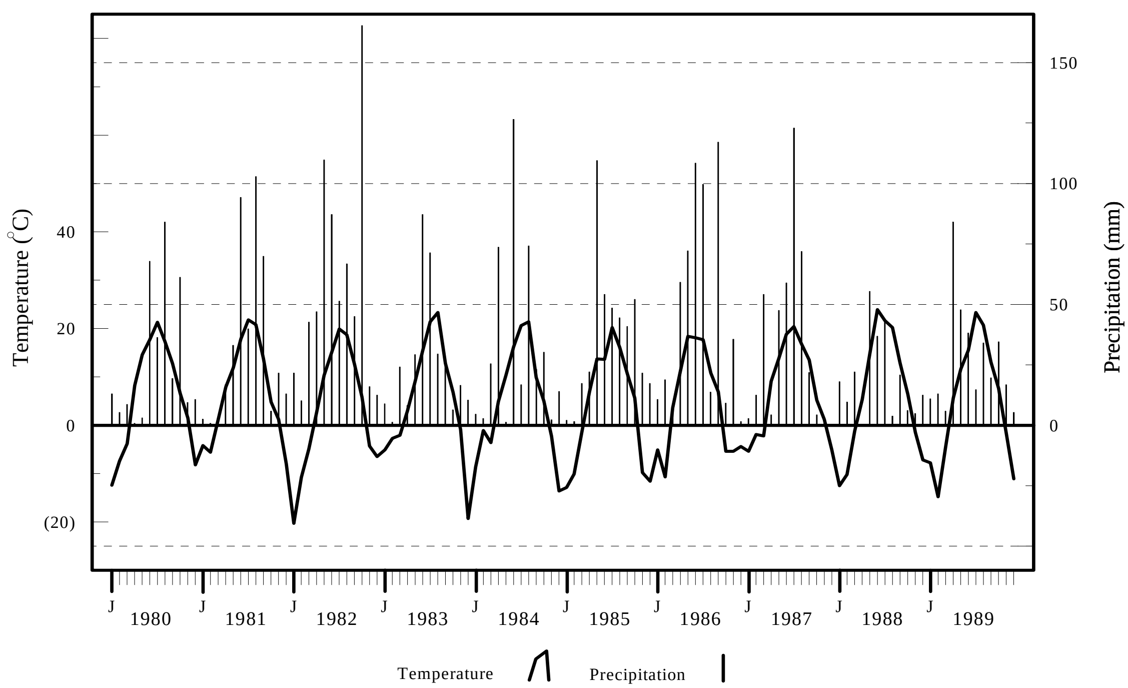

Fig. 3j. Ombrothermic diagram of 1980-1989 mean monthly temperature and monthly precipitation at Dickinson, North Dakota.

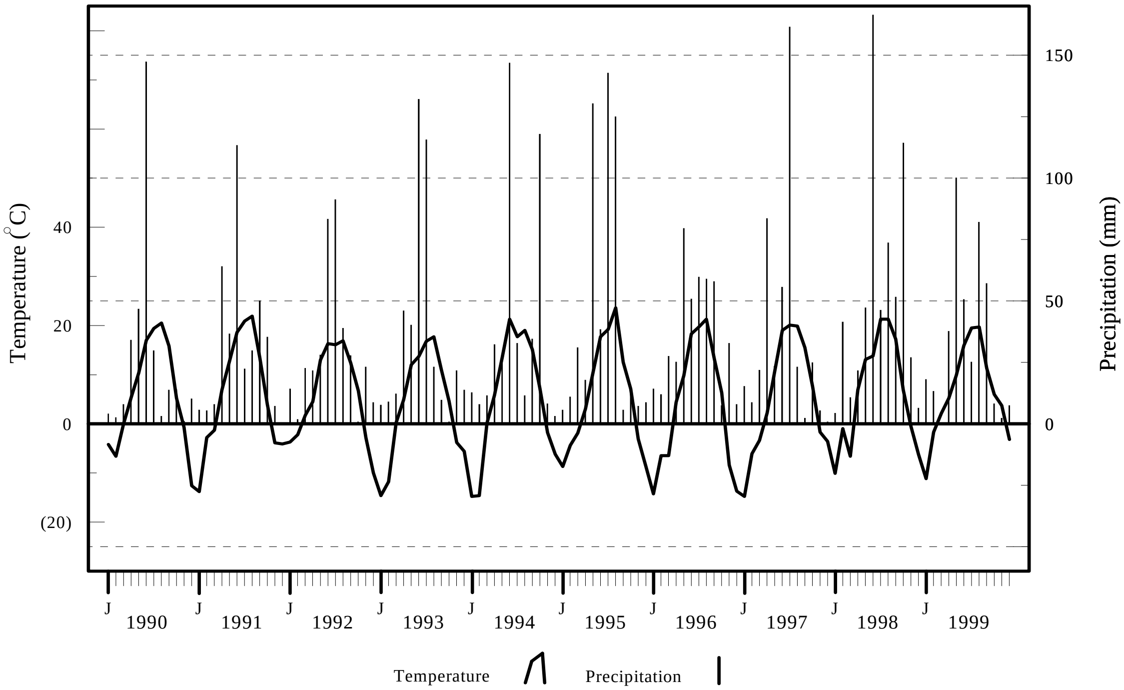

Fig. 3k. Ombrothermic diagram of 1990-1999 mean monthly temperature and monthly precipitation at Dickinson, North Dakota.

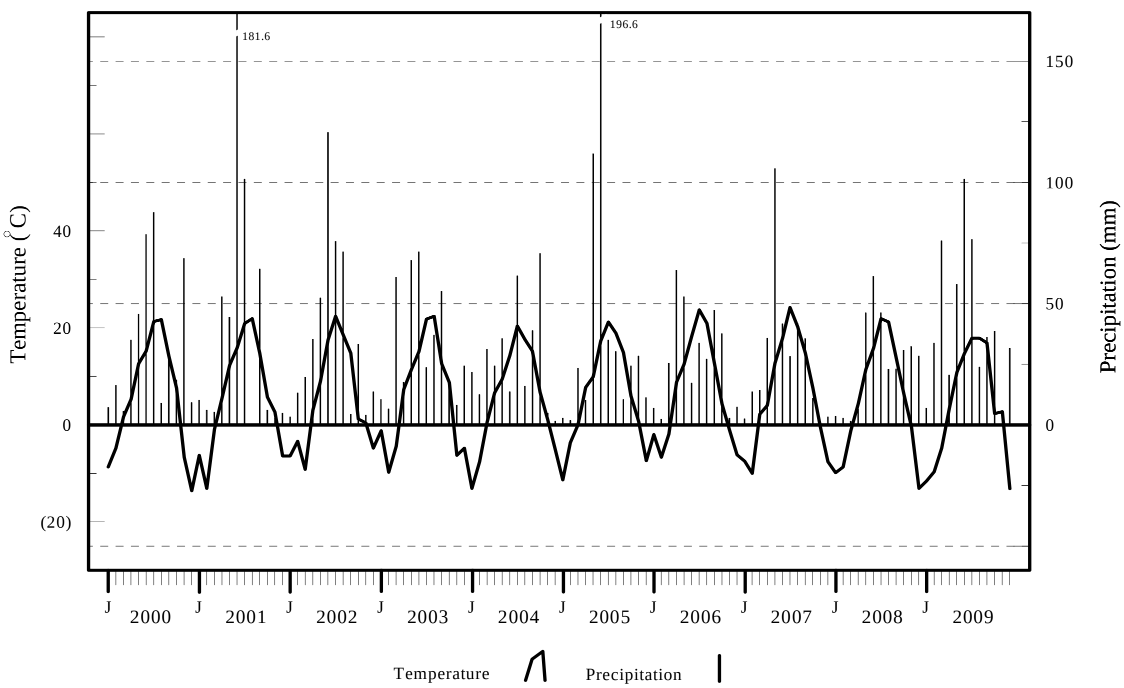

Fig. 3l. Ombrothermic diagram of 2000-2009 mean monthly temperature and monthly precipitation at Dickinson, North Dakota.

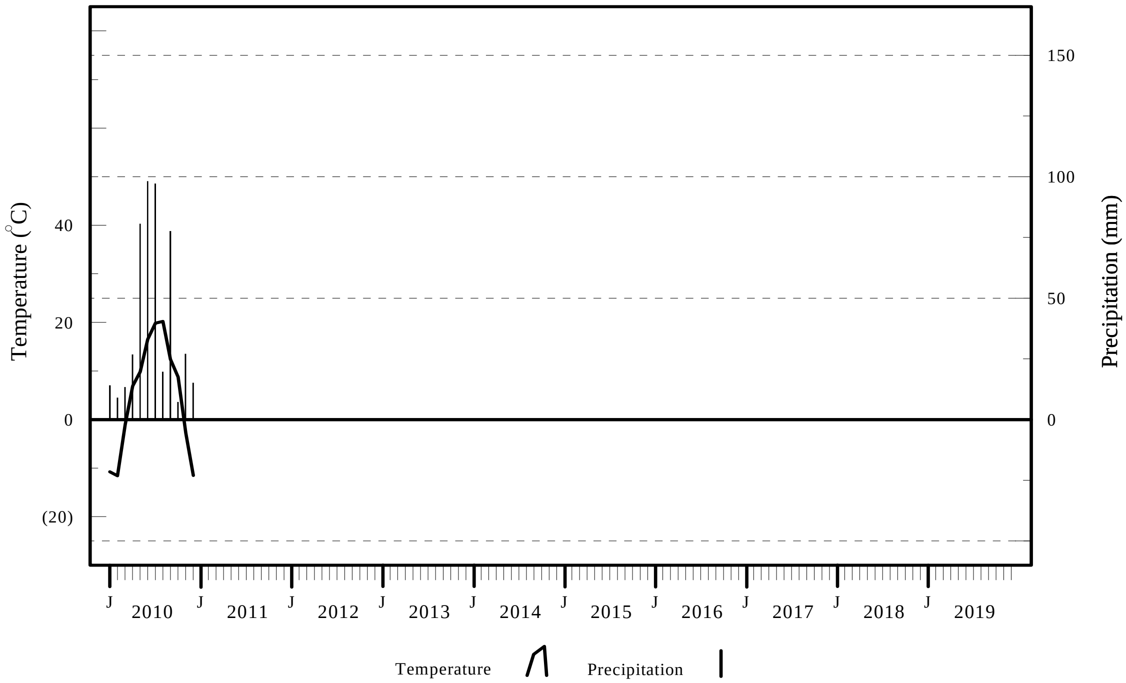

Fig. 3m. Ombrothermic diagram of 2010-2019 mean monthly temperature and monthly precipitation at Dickinson, North Dakota.

Table 8a. Months when temperature and precipitation conditions caused water stress for perennial plants (1892-1899, 1900-1909).

	APR	MAY	JUN	JUL	AUG	SEP	OCT	# Months	% 6 Months 15 Apr-15 Oct
1890								-	-
1891								-	-
1892					■	■	■	2.5	42
1893					■		■	1.5	25
1894		■			■			2.0	33
1895					■	■	■	2.5	42
1896					■	■		2.0	33
1897		■	■		■	■	■	4.5	75
1898			■		■	■		3.0	50
1899						■		1.0	17
								19.0	**40**
1900	■	■	■	■			■	4.0	67
1901	■	■			■	■	■	4.0	67
1902	■					■	■	2.0	33
1903	■		■	■			■	3.0	50
1904		■		■		■	■	3.5	58
1905	■				■			1.5	25
1906				■		■	■	2.5	42
1907							■	0.5	8
1908				■	■			2.0	33
1909						■		1.0	17
								24.0	**40**

Table 8b. Months when temperature and precipitation conditions caused water stress for perennial plants (1910-1919, 1920-1929).

	APR	MAY	JUN	JUL	AUG	SEP	OCT	# Months	% 6 Months 15 Apr-15 Oct
1910						■	■	1.5	25
1911				■				1.0	17
1912								0.0	0
1913	■			■		■		2.5	42
1914							■	0.5	8
1915	■				■			1.5	25
1916						■		1.0	17
1917		■		■	■	■	■	4.5	75
1918						■	■	1.5	25
1919			■	■	■	■		4.0	67
								18.0	**30**
1920								0.0	0
1921				■			■	1.5	25
1922					■		■	1.5	25
1923					■			1.0	17
1924					■	■		2.0	33
1925		■		■	■	■		4.0	67
1926	■			■				1.5	25
1927					■		■	1.5	25
1928						■		1.0	17
1929				■	■			2.0	33
								16.0	**27**

Table 8c. Months when temperature and precipitation conditions caused water stress for perennial plants (1930-1939, 1940-1949).

	APR	MAY	JUN	JUL	AUG	SEP	OCT	# Months	% 6 Months 15 Apr-15 Oct
1930				■	■			2.0	33
1931	■							0.5	8
1932				■		■		2.0	33
1933			■		■	■		3.0	50
1934		■		■	■	■	■	4.5	75
1935						■	■	1.5	25
1936		■	■	■	■	■	■	5.5	92
1937					■	■	■	2.5	42
1938					■	■	■	2.5	42
1939						■		1.0	17
								25.0	**42**
1940					■			1.0	17
1941								0.0	0
1942							■	0.5	8
1943						■		1.0	17
1944				■			■	1.5	25
1945				■	■		■	2.5	42
1946	■			■	■	■		3.5	58
1947		■				■	■	2.5	42
1948					■	■	■	2.5	42
1949	■		■		■	■		3.5	58
								18.5	**31**

Table 8d. Months when temperature and precipitation conditions caused water stress for perennial plants (1950-1959, 1960-1969).

	APR	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**# Months**	**% 6 Months 15 Apr-15 Oct**
1950				■	■			2.0	33
1951								0.0	0
1952	■	■				■	■	3.0	50
1953						■		1.0	17
1954				■		■	■	2.5	42
1955				■	■		■	2.5	42
1956			■			■	■	2.5	42
1957					■			1.0	17
1958		■			■	■		3.0	50
1959	■			■	■			2.5	42
								20.0	**33**
1960	■			■		■	■	3.0	50
1961				■	■		■	2.5	42
1962						■	■	1.5	25
1963					■		■	1.5	25
1964						■	■	1.5	25
1965							■	0.5	8
1966						■	■	1.5	25
1967				■	■			2.0	33
1968						■		1.0	17
1969					■	■		2.0	33
								17.0	**28**

Table 8e. Months when temperature and precipitation conditions caused water stress for perennial plants (1970-1979, 1980-1989).

	APR	MAY	JUN	JUL	AUG	SEP	OCT	# Months	% 6 Months 15 Apr-15 Oct
1970					■		■	1.5	25
1971		■		■	■			3.0	50
1972						■		1.0	17
1973				■	■		■	2.5	42
1974				■	■	■	■	3.5	58
1975				■	■	■		3.0	50
1976				■	■			2.0	33
1977	■			■				1.5	25
1978							■	0.5	8
1979							■	0.5	8
								19.0	**32**
1980	■	■		■		■		3.5	58
1981				■			■	1.5	25
1982								0.0	0
1983					■		■	1.5	25
1984		■		■				2.0	33
1985								0.0	0
1986					■			1.0	17
1987	■					■	■	2.0	33
1988	■		■		■	■	■	4.0	67
1989				■	■	■		3.0	50
								18.5	**31**

Table 8f. Months when temperature and precipitation conditions caused water stress for perennial plants (1990-1999, 2000-2009).

	APR	MAY	JUN	JUL	AUG	SEP	OCT	# Months	% 6 Months 15 Apr-15 Oct
1990				■	■	■		3.0	50
1991				■	■			2.0	33
1992							■	0.5	8
1993					■	■	■	2.5	42
1994		■		■	■			3.0	50
1995						■	■	1.5	25
1996							■	0.5	8
1997					■	■		2.0	33
1998								0.0	0
1999				■			■	1.5	25
								16.5	**28**
2000					■	■		2.0	33
2001					■		■	1.5	25
2002						■		1.0	17
2003				■	■			2.0	33
2004			■		■			2.0	33
2005	■			■	■	■		3.5	58
2006			■	■	■			3.0	50
2007				■			■	1.5	25
2008	■				■	■		2.5	42
2009					■			1.0	17
								20.0	**33**

Table 8g. Months when temperature and precipitation conditions caused water stress for perennial plants (2010-2019, 2020-2029).

	APR	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**# Months**	**% 6 Months 15 Apr-15 Oct**
2010					■		■	1.5	25
2011									
2012									
2013									
2014									
2015									
2016									
2017									
2018									
2019									
								1.5	**25**
2020									
2021									
2022									
2023									
2024									
2025									
2026									
2027									
2028									
2029									

Table 9. Months when temperature and precipitation conditions caused water stress for perennial plants for 119 years (1892-2010).

	APR	MAY	JUN	JUL	AUG	SEP	OCT	# Months	% 6 Months 15 Apr-15 Oct
TOTAL	20	16	12	45	63	59	56	233.0	33
% of 119 YEARS	16.8	13.4	10.1	37.8	52.9	49.6	47.1		

Literature Cited

Barbour, M.G., J.H. Burk, and W.D. Pitts. 1987. Terrestrial plant ecology. The Benjamin/Cummings Publishing Co., Menlo Park, CA. 634p.

Barker, W.T., and W.C. Whitman. 1988. Vegetation of the Northern Great Plains. Rangelands 10:266-272.

Bluemle, J.P. 1977. The face of North Dakota: the geologic story. North Dakota Geological Survey. Ed. Series 11. 73p.

Bluemle, J.P. 1991. The face of North Dakota: revised edition. North Dakota Geological Survey. Ed. Series 21. 177p.

Brown, R.W. 1977. Water relations of range plants. Pages 97-140. *in* R.E. Sosebee (ed.) Rangeland plant physiology. Range Science Series No. 4. Society for Range Management. Denver, CO.

Brown, R.W. 1995. The water relations of range plants: adaptations to water deficits. Pages 291-413. *in* D.J. Bedunah and R.E. Sosebee (eds.). Wildland plants: physiological ecology and developmental morphology. Society for Range Management. Denver, CO.

Coyne, P.I., M.J. Trlica, and C.E. Owensby. 1995. Carbon and nitrogen dynamics in range plants. Pages 59-167. *in* D.J. Bedunah and R.E. Sosebee (eds.). Wildland plants: physiological ecology and developmental morphology. Society for Range Management. Denver, CO.

Dahl, B.E. 1995. Development morphology of plants. Pages 22-58. *in* D.J. Bedunah and R.E. Sosebee (eds.). Wildland plants: physiological ecology and developmental morphology. Society for Range Management. Denver, CO.

Daubenmire, R.F. 1974. Plants and environment. John Wiley and Sons. New York, NY. 422p.

Dickinson Research Center. 1892-2010. Temperature and precipitation weather data.

Emberger, C., H. Gaussen, M. Kassas, and A. dePhilippis. 1963. Bioclimatic map of the Mediterranean Zone, explanatory notes. UNESCO-FAO. Paris. 58p.

Great Plains Flora Association. 1986. Flora of the Great Plains. University Press of Kansas. Lawrence, KS. 1392p.

Goetz, H. 1963. Growth and development of native range plants in the mixed grass prairie of western North Dakota. M.S. Thesis, North Dakota State University, Fargo, ND. 165p.

Jensen, R.E. 1972. Climate of North Dakota. National Weather Service, North Dakota State University, Fargo, ND. 48p.

Langer, R.H.M. 1972. How grasses grow. Edward Arnold. London, Great Britain. 60p.

Leopold, A.C., and P.E. Kriedemann. 1975. Plant growth and development. McGraw-Hill Book Co. New York, NY. 545p.

Larson, K.E., A.F. Bahr, W. Freymiller, R. Kukowski, D. Opdahl, H. Stoner, P.K. Weiser, D. Patterson, and O. Olsen. 1968. Soil survey of Stark County, North Dakota. U.S. Government Printing Office, Washington, DC. 116p.+plates.

Manske, L.L. 1980. Habitat, phenology, and growth of selected sandhills range plants, Ph.D. Thesis, North Dakota State University, Fargo, ND. 154p.

Manske, L.L. 1994a. History and land use practices in the Little Missouri Badlands and western North Dakota. Proceedings- Leafy spurge strategic planning workshop. USDI National Park Service, Dickinson, ND. p. 3-16.