Effects from Environmental Factors of Light, Temperature, and Precipitation on Range Plants in the Dickinson, North Dakota, Region

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Introduction

All living things must adapt to their environment in order to survive. The three most ecologically important environmental factors that affect rangeland plant growth are light, temperature, and water (precipitation). Plant growth and development are controlled by internal regulators which 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. Successful management of the grassland ecosystems of a region requires knowledge of the climatic factors' effect on plant growth and of the relationships between plant growth and the climate of a region. This paper will attempt to describe the three most important climate factors of the Dickinson, North Dakota, region by using historical weather data and to point out some of the conditions and variables that limit plant growth and should be considered during the development of long-term grassland management strategies.

Light

Light is the ultimate source of energy and is the most important ecological factor affecting plant growth. Variations is quality, intensity, and duration of light affect plant growth. Light is necessary for photosynthesis, which is the process that converts light energy into chemical energy. The rate of photosynthesis varies with different wavelengths, but the quality (wavelength) of sunlight does not vary enough in a given region to have an important differential effect on the rate of photosynthesis. However, the intensity (measurable energy) and duration (length of day) of sunlight change with the seasons and affect plant growth. Light intensity varies greatly with the season and time of day because of changes in the angle of incidence of the sun's rays and the distance light travels through the atmosphere. Light intensity also varies with the amount of humidity and cloud cover because atmospheric moisture absorbs and scatters light rays. However, the greatest variation in intensity of light received by range plants results from the various degrees of shading from other plants. Most range plants require full sunlight or very high levels of sunlight for best growth. Shading can reduce or limit growth of range plants. Day-length period (photoperiod) is one of the most dependable cues by which plants time their activities in temperate zones. Day-length period for a given date and locality remains the same from year to year. Changes in the photoperiod function as the timer or trigger that activates or stops physiological processes which bring about growth and flowering of plants and that starts the process of hardening for resistance to low temperatures in fall and winter. Sensory receptors are areas with special pigment in the buds or leaves of a plant which detect day length and night length and can activate one or more hormone and enzyme systems that bring about physiological responses (Odum 1971, Daubenmire 1974, Barbour et al. 1987).

Temperature

Temperature is an approximate measurement of the heat energy available from solar radiation. At both low and high levels temperature limits plant growth. Most plant biological activity and growth occur only within a narrow range of temperatures, between 32°F (0°C) and 122°F (50°C). Low temperatures limit biological reactions because water becomes unavailable when it is frozen and because levels of available energy are inadequate. However, respiration and photosynthesis can continue slowly at temperatures well below 32°F if plants are "hardened". High temperatures limit biological reactions because the complex structures of proteins are disrupted or denatured. Different plant species have different optimum temperature ranges. Plant temperature requirements are generally variable with different stages of development. The optimum temperature range for photosynthesis and productivity generally varies with the photosynthetic pathway used by the plant. Cool-season plants, which are C_3 photosynthetic pathway plants, have an optimum temperature range of 50° to 77°F (10° to 25°C). Warm-season plants, which are C_4 photosynthetic pathway plants, have an optimum temperature range of 86° to 105°F (30° to 40°C) (Coyne et al. 1995). Annual and daily temperature rhythms for a region largely control the seasonal and daily activities of plants.

The frost-free period is the number of days between the last day with minimum temperatures below 32°F (0°C) in the spring and the first day with minimum temperatures below 32°F (0°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, but they require temperatures above the level that freezes water in plant tissue and soil in order to continue active growth. Many perennial plants begin active growth more than 30 days before the last frost in spring and continue growth after the first frost in fall. 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 mean daily temperature at or above 32°F(0°C). In western North Dakota the perennial plant growing season is considered to be generally from mid April through mid October. Low air temperature during the early and late portions of the growing season greatly limits plant growth rate. Plant growth is also limited after mid summer by high temperatures, high evaporation, drying winds, and low precipitation.

Water (Precipitation)

Water is essential for all plants and is an integral part of living systems. Water is ecologically important because it is a major force in shaping climatic patterns, and water is biochemically important because it is a necessary component in physiological processes. Water is the principal constituent of plant cells, usually composing over 80% of the fresh weight of herbaceous plants. Water is the primary solvent in physiological processes by which gases, minerals, and other materials enter plant cells and by which these materials are translocated to various parts of the plant. Water is the substance in which processes such as photosynthesis and other biochemical reactions occur. Water is a structural component of proteins and nucleic acids. Water is also essential for the maintenance of the rigidity of plant tissue and for cell enlargement and growth in plants (Brown 1977, Brown 1995).

Plant Water Stress

Plant water stress limits growth. Plant water stress develops in plant tissue when the rate of water loss due to transpiration exceeds the rate of water absorption by the roots. 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).

Early stages of water stress slow shoot and leaf growth. Leaves show signs of wilting, folding, and discoloration. Tillering and new shoot development are reduced. Root production may be increased. Senescence of older leaves is accelerated. Cell wall formation, cell division, and protein synthesis are reduced. As the water stress increases, enzyme activity declines and the formation of necessary compounds is reduced or ceases. The stomata begin to close, which results in decreased rates of transpiration and photosynthesis. Respiration and translocation are substantially reduced with increases in water stress. When water stress becomes severe, most functions nearly or completely cease and severe 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 and the plant cannot recover. Plant death occurs when the meristems become dehydrated beyond the limits required to maintain cell turgidity and biochemical activity (Brown 1995).

Study Area

The study area is the region around the city of Dickinson, Stark County, in southwestern North Dakota, USA.

The Dickinson region is part of a large geologic depression known as the Williston Basin, which has been filled over a period of 515 million years with accumulations of sedimentary rocks deposited in off-shore shallow seas and in near-shore marine environments, or deposited by running water on floodplains or deltas. The generally flat-lying sedimentary deposits in southwestern North Dakota have been eroded by running water and wind over a period of about 5 million years. These erosional forces have been selective in their action because hard, relatively resistant sandstone, limestone, scoria, chert, or other erosion-resistant materials were present in some of the sedimentary deposits and have remained as protective caps, while the soft, weakly consolidated, less resistant silt and clay layers have been easily washed or blown away. The landforms that have resulted from uneven sediment removal are rolling to hilly plains with gentle slopes intermingled with buttes having flat tops and steep slopes. Badlands topography has developed over the last 600,000 years near some streams and rivers from erosional forces which accelerated sediment removal when glacial ice blocked the northward flow of the drainage systems in western North Dakota. The diverted routes to the east were shorter and steeper, and the water flowing in the drainage systems caused deep rapid erosion and resulted in badlands landforms (Hunt 1974, Bluemle 1977, Trimble 1990, Bluemle 1991).

Soils in the Dickinson region have developed from weathered sedimentary deposits of soft shale, siltstone, and sandstone. Soil formation has been a long, slow process. Temperatures and precipitation levels of the area have been important in the development of the regional soils. The climate has determined the type of vegetation and the amount of annual growth, which, in turn, have influenced the amount of soil organic matter accumulated. Temperature affects the rate of oxidation of organic matter. Higher temperatures promote rapid oxidation of organic matter. Soils in regions with long periods of high temperatures contain little organic matter. Little or no oxidation of organic matter occurs in frozen soil. Soil organic matter has accumulated in the soils in the Dickinson region because the climate has cold periods during which little chemical activity takes place. Soil in the Dickinson region has frost penetration to a depth of 3 to 5 feet most years for a period of approximately 120 days (Larson et al. 1968), a condition which contributes to soil organic matter accumulation. The dark surface layer of most soils has an accumulation of 2 to 5% organic matter (Larson et al. 1968, Wright et al. 1982).

Temperature and precipitation have influenced the amount and kinds of physical and chemical weathering of the region's parent material. High average temperatures and precipitation have encouraged rapid weathering and clay formation during the summer, while low temperatures during fall, winter, and early spring have caused cracks, fissures, and breaks in the parent material and developing soil as a result of the expansion and contraction forces of frost.

Precipitation level has influenced the amount of water in the soil. The amount of water that has entered the soil has not been the same as the precipitation level, and the amount of soil water has not been the same on all parts of the landscape. The amount of soil water has been less than the amount of precipitation received in areas which have had rain run off, and the amount of soil water has been greater than the amount of precipitation received in areas which have had rain run in. The amount of soil water present has affected the rate of leaching. The depth of the downward movement of the water has not been uniform for the soils on different topographic positions on the landscape. Soil water has dissolved calcium carbonate (lime), soluble salts, exchangeable sodium, and clay particles from the upper horizons of the soil and has moved them downward into a lower horizon. The amount of these dissolved materials in the soil profile has been dependent on the amount present in the weathered parent material. The depth to which they have been moved has been variable with the amount of soil water. The layer where the dissolved material has accumulated indicates the approximate average depth of downward water movement. The depth of the accumulation layer decreases when the precipitation decreases. Soils with a high lime content have developed a layer of natural cement (hardpan) that restricts plant root penetration. Soils high in soluble salts and/or exchangeable sodium have developed accumulation layers containing sufficient amounts of these chemicals to impair plant growth. Soils high in soluble salts have developed into saline soils; soils high in exchangeable sodium have developed into sodic soils; and soils high in both have developed into saline-sodic soils (Omodt et al. 1968, Soil Survey Staff 1975, Foth 1978).

Soil water has also dissolved clay particles and moved the clay downward. When the soil water with dissolved clay has hit areas of dry soil, the water has been withdrawn and the clay particles have been deposited. Over time this clay film layer has built up to form what is called an argillac horizon. Low amounts of argillac horizon in a soil can be beneficial because the clay helps increase the amount of water and nutrients stored in that zone; however, when the clay accumulation becomes great, the effects can be detrimental because water movement and plant root penetration are severely restricted. Soils that have a well-developed argillac horizon are called clay-pan soils (Omodt et al. 1968, Soil Survey Staff 1975, Foth 1978).

The depth of the layer where the dissolved material accumulates is very important because the soil above this layer is the thickness of the plant growth media, which hold the nutrients and soil water needed for plant growth. Shallow soils restrict plant growth. The depth of the accumulation layer for soils in the Dickinson area ranges from 6 inches to 4 feet, but in most soils the accumulation layer has formed between 15 and 24 inches below the soil surface (Larson et al. 1968, Omodt et al. 1968, Soil Survey Staff 1975, Foth 1978, Wright et al. 1982).

The climate of western North Dakota has changed several times. A major climate change resulted when the Rocky Mountains began to uplift about 70 to 80 million years ago and formed a barrier preventing humid Pacific Ocean air masses from flowing eastward. The Great Plains became much dryer. Two million years ago the climate became cooler and more humid, and several periods of glaciation occurred. The periods of glacial advance were cool and humid. Glacial advances occurred during periods when the snow accumulation on top of the glacier during winter was greater than the amount of ice melted during the summer. The interglacial periods were warmer and drier. The changes in climate since the last glaciation period, which occurred between 100,000 and 10,000 years ago, have strongly influenced the present conditions of the region. The last ice sheet reached its maximum advance between 14,000 and 12,000 years ago. About 10,000 years ago, a sudden change in the climate to dryer and warmer summers but colder winters occurred. This major change accelerated the melting of the glacial ice. The climate was much dryer and warmer for the period between 10,000 and 5,000 years ago. Between 8,500 and 4,500 years ago the region experienced frequent summer droughts and extensive soil erosion from wind (Bluemle 1977, Bluemle 1991).

The climate changed 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 from 2,500 to 1,800 years ago and from 1,000 to 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, and other more recent drought periods occurred in the 1860's, and 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).

The native vegetation in the Dickinson region is the Wheatgrass-Needlegrass Type (Barker and Whitman 1988, Shiflet 1994) of the mixed grass prairie. The major midgrasses are western wheatgrass (*Agropyron smithii*), needle-and-thread (*Stipa comata*), green needlegrass (*Stipa viridula*), prairie Junegrass (*Koeleria pyramidata*), plains reedgrass (*Calamagrostis montanensis*), and little bluestem (*Andropogon scoparius*). The major shortgrasses are blue grama (*Bouteloua gracilis*), Sandberg's bluegrass *(Poa sandbergii*), buffalograss (*Buchloe dactyloides),* and red three-awn (*Aristida purpurea var. robusta*). The major upland sedges are threadleaf sedge (*Carex filifolia*), sun sedge (*Carex heliophila*), and needleleaf sedge (*Carex eleocharis*). The major tallgrasses are prairie sandreed (*Calamovilfa longifolia*), and sand bluestem (*Andropogon hallii*). The major forbs are white aster (*Aster ericoides),* silver-leaf scurf pea (*Psoralea argophylla)*, prairie coneflower *(Ratibida columnifera),* purple coneflower (*Echinacea augustifolia),* milkvetches (*Astragalus spp.),* scarlet gaura (*Gaura coccinea),* red false mallow (*Sphaeralcea coccinea),* fringed sage (*Artemisia frigida),* white sage (*Artemisia ludoviciana),* green sage (*Artemisia dracunculus)*, prairie goldenrod (*Solidago missouriensis),* golden aster (*Chrysopsis villosa),* stiff sunflower (*Helianthus rigidus),* and Hood's phlox (*Phlox hoodii).* The major shrubs are roses (*Rosa spp*.), western snowberry (*Symphoricarpos occidentalis*), and silver sagebrush (*Artemisia cana*). Important succulents are plains prickly pear (*Opuntia polyacantha),* and brittle prickly pear *(Opuntia fragilis*) (Stevens 1963, Zaczkowski 1972, Great Plains Flora Association 1986, Barker and Whitman 1988, Shiflet 1994).

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 (1892-1996) 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.

Water deficiency months data were developed from the historical temperature and precipitation data using a technique reported by Emberger et al. (1963). The water deficiency months data were used to identify months with unfavorable conditions for plant growth. This method plots 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 temperature and precipitation data are plotted against an axis of time. The resulting ombrothermic diagram shows general monthly trends and identifies months with conditions that are 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 (0°C).

Definition of Terms

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. *Water stress* occurs in plants when the rate of water loss by transpiration exceeds the rate at which it is replaced by absorption. *A water deficiency period* exists when the amount of rainfall is lower than potential evapotranspiration demand. The *freeze-free period* is the number of days between the average date of the last occurrence of 32°F or lower in the spring and the average date of the first occurrence of 32°F or lower in the fall and is approximately the length of growing season for annually seeded plants. *Growing season* for perennial plants roughly coincides with the period between the first 5 consecutive days in spring and the last 5 consecutive days in fall with mean daily temperature at or above 32°F (0°C).

Results and Discussion

Light

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. The equator has an almost uniform day length of 12 hours all year long. 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 path crosses the equator on its way north or south, respectively. The shortest day length (8 hours, 23 minutes) occurs at winter solstice, 21 December, when the sun's 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 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).

The phenological development of rangeland plants is triggered by changes in the length of daylight. Vegetative growth is triggered by photoperiod and temperature (Langer 1972, Dahl 1995), and reproductive initiation is triggered primarily by photoperiod (Roberts 1939, Leopold and Kriedemann 1975, Dahl 1995) but can be slightly modified by temperature and precipitation (McMillan 1957, Leopold and Kriedemann 1975, Dahl and Hyder 1977, Dahl 1995). Some plants are long-day plants and others are short-day plants. The 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. Generally, most cool-season plants with the C_3 photosynthetic pathway are long-day plants and reach flower phenophase before 21 June. The short-day plants are induced into flowering by day lengths which are shorter than a critical length and which occur during the period of decreasing day length after mid June. Generally, most warm-season plants with the C_4 photosynthetic pathway are short-day plants and reach flower phenophase after 21 June. Short-day plants are technically responding to the increase in the length of the night period rather than to the decrease in the day length (Weier et al. 1974, Leopold and Kriedemann 1975).

The annual pattern in the change in daylight duration follows the calendar 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).

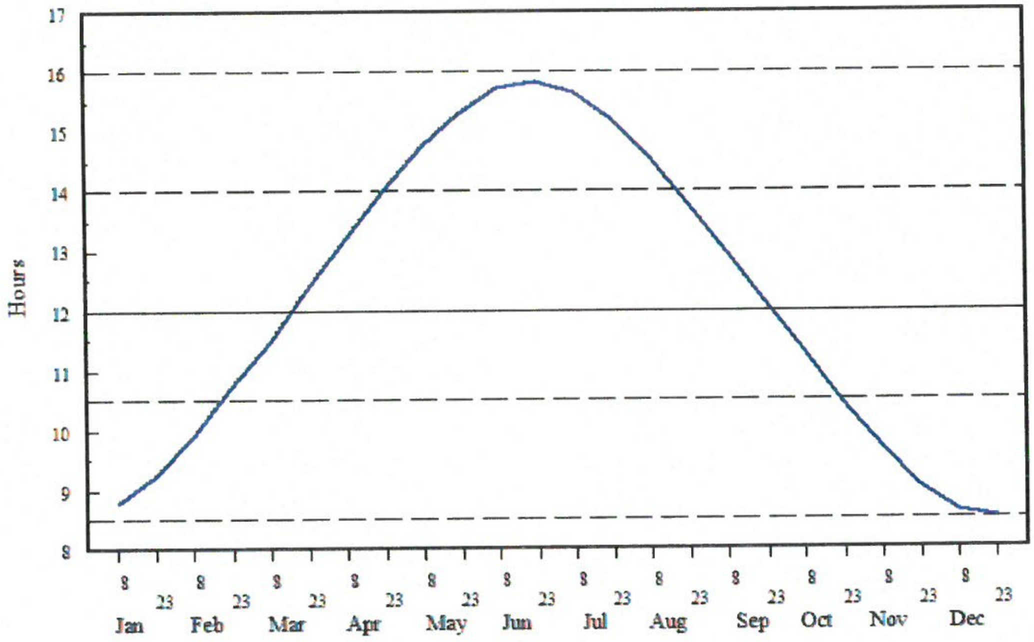

Fig. 1. Annual pattern of daylight duration at Dickinson, North Dakota.

Shading from other plants reduces the light intensity that reaches the lower leaves of an individual plant. Grass leaves grown under shaded conditions become longer, thinner (Langer 1972, Weier et al. 1974), and lower in weight than leaves in sunlight (Langer 1972). Shaded leaves have a reduced rate of photosynthesis which decreases the carbohydrate supply causing a reduction in growth rate of leaves and roots (Langer 1972). Shading increases the rate of senescence in the lower older leaves. Accumulation of standing dead leaves ties up carbon and nitrogen. Decomposition of leaf material through microbial activity can take place only after the leaves have made contact with the soil. Standing dead material that is not in contact with the soil does not decompose but breaks down slowly as a result of leaching and weathering. Under ungrazed treatments the dead leaves remain standing for several years, slowing nutrient cycles, restricting nutrient supply, and reducing soil microorganism activity in the top 12 inches of soil. Standing dead leaves shade early leaf growth in spring and therefore slow rate of growth and reduce leaf area. Long-term effects of shading, such as that which occurs in ungrazed grasslands, under shrubs, or leafy spurge, reduce the native grass species composition and increase composition of replacement species that are shade tolerant or shade adapted like smooth bromegrass and Kentucky bluegrass.

Temperature

The Dickinson, North Dakota, area experiences severe, windy, dry winters with little snow accumulation. The springs are relatively moist in most years, and the summers are often droughty but

Table 1. Long-term mean monthly temperature and monthly precipitation, 1982-2015.

	°F	°C	in.	mm
Jan	10.89	-11.73	0.42	10.57
Feb	14.69	-9.62	0.39	9.99
Mar	25.90	-3.39	0.72	18.26
Apr	41.51	5.29	1.42	36.04
May	52.87	11.60	2.32	59.01
Jun	62.07	16.70	3.55	90.21
Jul	68.55	20.31	2.20	55.94
Aug	66.84	19.35	1.76	44.62
Sep	55.85	13.25	1.32	33.44
Oct	43.84	6.58	0.91	23.21
Nov	28.11	-2.16	0.53	13.40
Dec	16.70	-8.50	0.40	10.14
	MEAN		**TOTAL**	
	40.65	**4.81**	**15.94**	**404.83**

are interrupted periodically with thunderstorms. The long-term (105 years) mean annual temperature is 40.7°F (4.8°C) (Table 1). January is the coldest month, with a mean temperature of 10.9°F (-11.7°C). July and August are the warmest months, with mean temperatures of 68.5°F (20.3°C) and 66.8°F (19.3°C), respectively. Months with mean monthly temperatures below 32.0°F (0.0°C) are too cold for active plant growth. Low temperatures define the growing season for perennial plants, which is generally from mid April to mid October (6.0 months, 183 days). During the other 6 months each year, plants in western North Dakota cannot conduct active plant growth because of low temperatures. Soils are frozen to a depth of 3 to 5 feet for a period of 4 months (120 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).

Land areas that are distant from large bodies of water generally have large fluctuations in seasonal and daily temperatures. The Dickinson area does not have any large bodies of water, and the climate data show 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 57.6°F (32.0°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 temperature difference between the minimum and maximum temperature 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. Warm days increase the photosynthetic rate, and cool nights reduce the respiration rate (Leopold and Kriedemann 1975).

Grassland vegetation has optimum temperature ranges, which vary with growth stage and photosynthetic pathway. Cool-season (C_3) plants have lower optimum temperatures for photosynthesis and do not use water as efficiently as do warm-season (C_4) plants. High temperatures above 77.0°F (25.0°C) limit the growth of cool-season plants. High temperatures above 95.0 to 105.0°F (35.0° to 40.0°C) limit the growth of warm-season plants. Growing season temperatures below 50.0°F (10.0°C) during the day limit cool-season growth. Temperatures below 86.0°F (30.0°C) limit warm-season growth. Cool- and warm-season plants have different growth rates at the various temperatures experienced during the growing season.

Table 2. Seasonal precipitation distribution, 1982-2015.

Season	**in.**	**%**
Winter (Jan, Feb, Mar)	1.53	9.60
Spring (Apr, May, Jun)	7.29	45.73
Summer (Jul, Aug, Sep)	5.28	33.12
Fall (Oct, Nov, Dec)	1.84	11.55
TOTAL	**15.94**	

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	96.30	13.30	337.82	98.66
1893	11.63	295.40	72.96	9.09	230.89	67.43
1894	15.47	392.94	97.05	13.65	346.71	101.26
1895	11.76	298.70	73.78	9.44	239.78	70.03
1896	18.48	469.39	115.93	13.19	335.03	97.85
1897	13.52	343.41	84.82	7.76	197.10	57.57
1898	11.92	302.77	74.78	10.24	260.10	75.96
1899	17.27	438.66	108.34	15.64	397.26	116.02
MEAN	**14.43**	**366.40**	**89.98**	**11.54**	**293.08**	**85.56**
1900	11.78	299.21	73.90	9.33	236.98	69.21
1901	12.92	328.17	81.11	9.77	248.16	72.48
1902	16.07	408.18	100.82	11.12	282.45	82.49
1903	16.90	429.26	106.02	14.90	378.46	110.53
1904	15.19	385.83	95.29	11.40	289.56	84.57
1905	16.55	420.37	103.82	14.29	362.97	106.01
1906	20.46	519.68	128.36	16.80	426.72	124.63
1907	13.67	347.22	85.76	12.10	307.34	89.76
1908	19.48	494.79	122.21	16.03	407.16	118.92
1909	21.26	540.00	133.38	18.91	480.31	140.28
MEAN	**16.43**	**417.27**	**103.07**	**13.47**	**342.01**	**99.89**

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	83.84	10.91	277.11	80.93
1911	15.62	396.75	97.99	12.96	329.18	96.14
1912	19.06	484.12	119.57	17.85	453.39	132.42
1913	11.93	303.02	74.84	10.11	256.79	75.00
1914	22.74	577.60	142.66	20.46	519.68	151.78
1915	19.75	501.65	123.90	17.95	455.93	133.16
1916	18.40	467.36	115.43	14.73	374.14	109.27
1917	9.25	234.95	58.03	7.33	186.18	54.38
1918	12.36	313.94	77.54	11.01	279.65	81.68
1919	8.37	212.60	52.51	6.69	169.93	49.63
MEAN	**15.08**	**383.08**	**94.62**	**13.00**	**330.20**	**96.44**
1920	15.81	401.57	99.18	14.59	370.59	108.23
1921	15.76	400.30	98.87	12.51	317.75	92.80
1922	18.20	462.28	114.18	14.22	361.19	105.49
1923	19.73	501.14	123.78	18.37	466.60	136.28
1924	15.12	384.05	94.86	12.90	327.66	95.70
1925	12.19	309.63	76.47	10.49	266.45	77.82
1926	13.11	332.99	82.25	10.48	266.19	77.74
1927	19.59	497.59	122.90	16.15	410.21	119.81
1928	15.30	388.62	95.99	13.74	349.00	101.93
1929	17.21	437.13	107.97	10.67	271.02	79.15
MEAN	**16.20**	**411.53**	**101.65**	**13.41**	**340.66**	**99.50**

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	86.51	10.99	279.15	81.53
1931	16.17	410.72	101.44	13.51	343.15	100.22
1932	17.24	437.90	108.16	14.77	375.16	109.57
1933	11.50	292.10	72.15	9.07	230.38	67.28
1934	7.91	200.91	49.62	6.61	167.89	49.04
1935	15.00	381.00	94.10	12.04	305.82	89.32
1936	6.72	170.69	42.16	3.88	98.55	28.78
1937	16.28	413.51	102.13	13.92	353.57	103.26
1938	16.65	422.91	104.45	13.07	331.98	96.96
1939	15.75	400.05	98.81	14.12	358.65	104.75
MEAN	**13.70**	**348.01**	**85.95**	**11.20**	**284.43**	**83.07**
1940	17.12	434.85	107.40	15.16	385.06	112.46
1941	31.88	809.75	200.00	30.50	774.70	226.26
1942	19.75	501.65	123.90	17.78	451.61	131.90
1943	15.06	382.52	94.48	12.56	319.02	93.18
1944	20.63	524.00	129.42	16.08	408.43	119.29
1945	12.22	310.39	76.66	8.79	223.27	65.21
1946	14.50	368.30	90.97	12.18	309.37	90.36
1947	18.86	479.04	118.32	16.93	430.02	125.59
1948	16.11	409.19	101.07	12.89	327.41	95.62
1949	10.77	273.56	67.57	8.11	205.99	60.16
MEAN	**17.69**	**449.33**	**111.98**	**15.10**	**383.49**	**112.00**

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	94.92	10.56	268.22	78.34
1951	16.70	424.18	104.77	14.45	367.03	107.20
1952	11.97	304.04	75.09	9.83	249.68	72.92
1953	19.39	492.51	121.64	17.37	441.20	128.86
1954	16.33	414.78	102.45	13.46	341.88	99.85
1955	14.65	372.11	91.91	12.66	321.56	93.92
1956	12.70	322.58	79.67	11.04	280.42	81.90
1957	22.15	562.61	138.96	20.17	512.32	149.63
1958	12.18	309.37	76.41	9.42	239.27	69.88
1959	13.45	341.63	84.38	11.56	293.62	85.76
MEAN	**15.47**	**392.81**	**97.02**	**13.05**	**331.52**	**96.82**
1960	10.23	259.84	64.18	8.54	216.92	63.35
1961	13.90	353.06	87.20	12.65	321.31	93.84
1962	18.34	465.84	115.06	16.41	416.81	121.74
1963	18.94	481.08	118.82	16.17	410.72	119.96
1964	18.74	476.00	117.57	17.28	438.91	128.19
1965	21.63	549.40	135.70	20.08	510.03	148.96
1966	16.69	423.93	104.71	14.93	379.22	110.76
1967	14.24	361.70	89.34	12.51	317.75	92.80
1968	15.73	399.54	98.68	13.81	350.77	102.45
1969	16.37	415.80	102.70	14.26	362.20	105.79
MEAN	**16.48**	**418.62**	**103.39**	**14.66**	**372.47**	**108.78**

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	126.47	17.90	454.66	132.79
1971	21.25	539.75	133.31	18.58	471.93	137.83
1972	20.76	527.30	130.24	18.57	471.68	137.76
1973	13.53	343.66	84.88	11.83	300.48	87.76
1974	14.15	359.41	88.77	12.45	316.23	92.36
1975	17.71	449.83	111.10	15.26	387.60	113.20
1976	12.68	322.07	79.55	10.84	275.34	80.42
1977	23.13	587.50	145.11	18.65	473.71	138.35
1978	17.63	447.80	110.60	15.17	385.32	112.54
1979	12.81	325.37	80.37	11.12	282.45	82.49
MEAN	**17.38**	**441.48**	**109.04**	**15.04**	**381.94**	**111.55**
1980	12.58	319.53	78.92	10.73	272.54	79.60
1981	15.76	400.30	98.87	14.27	362.46	105.86
1982	26.58	675.13	166.75	22.53	572.26	167.14
1983	12.59	319.79	78.98	10.18	258.57	75.52
1984	15.54	394.72	97.49	13.61	345.69	100.96
1985	16.98	431.29	106.52	14.63	371.60	108.53
1986	21.68	550.67	136.01	18.87	479.30	139.99
1987	15.92	404.37	99.87	13.06	331.72	96.88
1988	9.20	233.68	57.72	6.56	166.62	48.66
1989	12.78	324.61	80.18	10.74	272.80	79.67
MEAN	**15.96**	**405.41**	**100.13**	**13.52**	**343.36**	**100.28**

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

	Total Year 12 Months			**Growing Season, Apr - Oct 7 Months**		
	inches	mm	% of LTM	inches	mm	% of LTM
1990	12.37	314.20	77.60	11.36	288.54	83.79
1991	14.86	377.44	93.22	13.83	351.28	102.01
1992	14.24	361.70	89.33	11.47	291.34	84.61
1993	16.98	431.29	106.52	14.46	367.28	106.66
1994	17.50	444.50	109.79	15.80	401.32	116.54
1995	21.13	536.70	109. 79	18.64	473.46	137.49
1996	17.07	433.58	132.56	13.36	339.35	98.55
1997	-	-	-	-	-	-
1998	-	-	-	-	-	-
1999	-	-	-	-	-	-
MEAN	**16.31**	**414.20**	**102.30**	**14.13**	**358.94**	**104.83**

Rates of evaporation are dependent on temperatures; as average temperatures decrease, the rates of evaporation decrease, and as temperatures increase, the rates of evaporation increase. The relationship between temperature and evaporation levels affects the ratio of cool-season to warm-season grasses in the plant species composition. The native vegetation in the Dickinson area generally has a mixture of 60% cool-season and 40% warm-season species. North of the region, the lower average temperature and the lower evaporation rate result in an increase in the percentage of cool-season species. South of the region, the higher average temperature and the greater evaporation rate result in an increase in the percentage of warm-season species. A mixture of cool- and warm-season species is highly desirable because the different species can express optimum growth over a wide range of temperatures and extend the period of plant growth during the growing season.

Higher temperatures increase evaporation. When the evaporation rate exceeds the soil water supply, plants experience water stress. Water stress increases the rate of senescence. Senescent leaves are lower in nutritional quality than actively growing leaves. Thus the annual variation in temperature, evaporation, water stress, and senescence rate is responsible for the variation in nutritional quality of herbage from year to year.

Precipitation

The long-term (105 years) annual precipitation for the area of Dickinson, North Dakota, is 15.94 inches (404.8 mm). The long-term mean monthly precipitation is shown on Table 1. The growing season precipitation (April to October) is 13.48 inches (342.39 mm) and is 84.57% of the annual precipitation. June has the greatest monthly precipitation, at 3.55 inches (90.21 mm).

Rainfall in the Dickinson area occurs in a Plains Precipitation Pattern (Humphrey 1962), with the seasonal distribution of precipitation greatest in spring and early summer, and dry winters. This distribution pattern is controlled by three major air masses that dominate the weather of the region at various times of the year (Redmann 1968). The Pacific air mass dominates the region from September through January, a period which is generally dry because the orographic effect of the Rocky Mountains causes a rain shadow as the air mass moves east. The mean monthly precipitation during this dry period is only 0.71 inches (18.09 mm). The Polar air mass dominates the region from February through May, a period with mean monthly precipitation of 1.21 inches (30.77 mm). The month of June has a combination of Gulf, Polar, and Pacific air masses mixing to develop a relatively rainy period with a monthly precipitation average of 3.55 inches (90.21 mm). The summer months of July and August are dominated by the Gulf air mass, with little mixing of other air masses and a reduction of monthly precipitation to 1.98 inches (50.19 mm), which comes generally in intermittent thunderstorms. The change from the dominance of one air mass to the next results in transition periods which can vary annually. Differences in the transition periods are contributing factors in the variation in conditions from year to year.

The seasonal distribution of precipitation (Table 2) shows the greatest amount of precipitation occurring in the spring (7.29 inches, 45.73%) and the least amount occurring in winter (1.53 inches, 9.60%). Total precipitation for the 5 month period of November through March averages less than 2.5 inches (15.32%) of precipitation. The precipitation received in the 3 month period of May, June, and July accounts for 50.63% of the annual precipitation (8.07 inches).

The annual and growing season precipitation levels and percent of the long-term mean for 105 years (1892 to 1996) are shown in Table 3. The decades of the 1930's, 1890's, 1910's, and 1950's were the 4 driest decades, respectively. The decades of the 1930's and 1890's had zero wet years and zero wet growing seasons, and both sets of decades had 3 drought years and 3 drought growing seasons each. The decade of 1910's had 3 drought years and 3 drought growing seasons, and 1 wet year and 3 wet growing seasons. The 1950's had zero drought years and 2 drought growing seasons, and 1 wet year and 2 wet growing seasons. The decades of the 1940's, 1970's, and 1960's

Table 4. Years with precipitation amounts for 12 months with 75% or less of the long-term mean (LTM).

	Year	%LTM
1	1936	42.16
2	1934	49.62
3	1919	52.51
4	1988	57.72
5	1917	58.03
6	1960	64.18
7	1949	67.57
8	1933	72.15
9	1893	72.96
10	1895	73.78
11	1900	73.90
12	1898	74.78
13	1913	74.84

Table 5. Years with precipitation amounts for 12 months with 125% or more of the long-term mean (LTM).

	Year	%LTM
1	1941	200.00
2	1982	166.75
3	1977	145.11
4	1914	142.66
5	1957	138.96
6	1986	136.01
7	1965	135.70
8	1909	133.38
9	1971	133.31
10	1995	132.56
11	1972	130.24
12	1944	129.42
13	1906	128.36
	1970	126.47

were the wettest decades, respectively. The decades of the 1940's had 2 wet years and 3 wet growing seasons, and 1 drought year and 2 drought growing seasons. The decade of the 1970's had 4 wet years and 4 wet growing seasons, and zero drought years and zero drought growing seasons. The decade of 1960's had 1 wet year and 2 wet growing seasons, and 1 drought year and 1 drought growing season. The decade of the 1920's had near long-term precipitation for the mean growing season and annual period, and had zero drought years and growing seasons, and had zero wet years and only 1 wet growing season.

Thirteen drought years (12.4%) occurred between 1892 and 1996, with precipitation amounts of 75% or less of the long-term mean. The 6 driest drought years were 1936, 1934, 1919, 1988, 1917, and 1960, respectively (Table 4). Fourteen wet years (13.3%) had precipitation amounts of 125% or more of the long-term mean. The 6 wettest years were 1941, 1982, 1977, 1914, 1957, and 1986, respectively (Table 5). Annual precipitation amounts at normal levels, between 75% and 125% of the long-term mean, occurred during 78 years (74.29%) (Table 3).

Seventeen drought growing seasons (16.2%) occurred between 1892 and 1996. The 6 driest growing seasons were 1936, 1988, 1934, 1919, 1917, and 1897, respectively (Table 6). The area experienced 19 wet growing seasons (18.1%). The 6 wettest growing seasons were 1941, 1982, 1914, 1957, 1965, and 1909, respectively (Table 7). Growing season precipitation amounts at normal levels, between 75% and 125% of the long-term mean, occurred during 69 years (65.71%) (Table 3).

Temperature and Precipitation

Temperature and precipitation act together to affect the physiological and ecological status of range plants. The biological situation of a plant at any point in time is determined by the balance between rainfall and potential evapotranspiration. The higher the temperature, the greater the rate of evapotranspiration and the greater the need for rainfall to maintain homeostasis. When rainfall is lower 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. Range plants

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

	Year	%LTM	% of Water Stress Months	% Months with Water Stress
1	1936	28.78	5.5	92
2	1988	48.66	4.0	67
3	1934	49.04	4.5	75
4	1919	49.63	4.0	67
5	1988	54.38	4.5	75
6	1917	57.57	4.5	75
7	1897	60.16	3.5	58
8	1949	63.35	3.0	50
9	1960	65.21	2.5	42
10	1945	67.28	3.0	50
11	1933	67.43	1.5	25
12	1893	69.21	4.0	67
13	1900	69.88	3.0	50
14	1958	70.03	2.5	42
15	1901	72.48	4.0	67
16	1952	72.92	3.0	50
17	1913	75.00	2.5	42

have mechanisms that help reduce the damage from water stress, but some degree of reduction in herbage production occurs.

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 also cannot identify periods shorter than one month because most temperature and precipitation data are collected and summarized by meteorologists 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 the 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 that plants are under low-temperature stress are indicated when the temperature curve drops below the freezing mark of 0.0° C (32.0° F). The long-term ombrothermic graph for the Dickinson area (Fig. 2) shows near water deficiency conditions exist for the months of August, September, and October, a finding which indicates that range plants generally may have a difficult time growing and accumulating herbage biomass during these 3 months. Favorable water

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

	Year	%LTM	% of Water Stress Months	% Months with Water Stress
1	1941	226.26	0.0	0
2	1982	167.14	0.0	0
3	1914	151.78	0.5	8
4	1957	149.63	1.0	17
5	1965	148.96	0.5	8
6	1909	140.28	1.0	17
7	1986	139.99	1.0	17
8	1977	138.35	1.5	25
9	1995	138.27	1.5	25
10	1971	137.83	3.0	50
11	1972	137.76	1.0	17
12	1923	136.28	1.0	**17**
13	1915	133.16	1.5	25
14	1970	132.79	1.5	25
15	1912	132.42	0.0	0
16	1942	131.90	0.5	8
17	1953	128.86	1.0	17
18	1964	128.19	1.5	25
19	1947	125.59	2.5	42

relations occur during the months of May, June, and July, which indicates that range plants should be able to grow and accumulate herbage biomass during these 3 months.

The ombrothermic relationships for Dickinson, North Dakota, are shown for each month from 1892 to 1996 in Figure 3. Some of the early monthly temperature data are missing from the historical records. The months with missing temperature data are: 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 105 year period (1892 to 1996) had a total of 630 months during the growing season. Of these growing season months, 208.0 months have had water deficiency conditions, which indicates that range plants were under water stress during 33.02% 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.

Only 6 of the 105 years (Fig. 3, Table 8) have had all months during the 6 month growing season with no water deficiency. In each growing season month of 1912, 1920, 1941, 1951, 1982, and 1985, the amounts and distribution of the precipitation were adequate to prevent water stress in plants.

Nine years (8.57%) have had water deficiency conditions for 0.5 months during the growing season. Sixty-five years (61.90%) have had water deficiency conditions for 1.0 to 2.5 months during the growing season. Twenty-one years (20.00%) have had water deficiency conditions for 3.0 to 4.0 months during the growing season. Three years (2.86%), 1897, 1917, and 1934, have had water deficiency conditions for 4.5 months during the growing season. Only 1 year (0.95%), 1936, has had water deficiency conditions for 5.5 months during the growing season. None of the 105 years has had water deficiency conditions for all 6.0 months of the growing season (Fig. 3, Table 8).

The decade of the 1930's had the highest level of water deficiency, of the 11 decades evaluated, with water deficiency conditions during 42% of the growing season months (Fig. 3, Table 8). The 10 year period from 1895 to 1904 had 49% of the growing season months with water deficiency conditions, the highest level of water deficiency for any 10 year period.

The decades of the 1920's and 1960's had 27% and 28% of the growing season months with water deficiency conditions, respectively (Fig. 3, Table 8); these were the lowest levels of water deficiency conditions during the 11 decades evaluate. The 10 year period from 1907 to 1916 had only 19.17% of the growing season months with water deficiency conditions, the lowest level of water deficiency conditions for any 10 year period during the 105 years evaluated. The human population of western North Dakota greatly increased during this period, and this low incidence of water deficiency may have given the newcomers a false sense of the potential production levels of this area. The long-term mean level of water deficiency conditions is 33.02% of the growing season months for the 105 years between 1892 and 1996 (Table 9).

May, June, and July are the 3 most important precipitation months and therefore constitute the primary period of production for range plant communities. May and June appear to be the most important months for dependable precipitation. Only 16 (15.24%) of the 105 years have had water deficiency conditions during May, and 10 years (9.52%) have had water deficiency conditions during June. But only 3 years (2.86%), 1897, 1900, and 1936, have had water deficiency conditions in both May and June of the same year. Forty (38.10%) of the 105 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).

Most of the growth in range plants occurs in May, June, and July. The upland sedges complete 100% of their growth in leaf and flower stalk height by 30 June. The cool-season grasses complete 100% of their growth in leaf and flower stalk height by 30 July. The warm-season grasses complete 100% of their growth in leaf height and 91% of their growth in flower stalk height by 30 July (Goetz 1963, Manske 1994b). Peak aboveground herbage biomass production usually occurs during the last 10 days of July, a period which coincides with the time when 100% of the growth in height has been attained (Manske 1994b). Range grass growth coincides with the 3 month period of May, June, and July, when 51% of the annual precipitation occurs.

August, September, and October are not dependable for positive water relations. August and September have water deficiency conditions for 50.48% and 51.43% of the years, respectively, and October has water deficiency conditions for 49.52% 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. The water relations in August, September, and October limit range plant growth and herbage biomass accumulation.

Water Stress

Water stress in plants occurs during water deficiency periods, which occur when rainfall is lower than evapotranspiration demand. Water stress in range plants can be minor to severe and can last from a few hours to several years. Rain deficiency periods in which 75% or less of the long-term mean precipitation is received are called 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 greatly limit herbage production and warrant consideration and recognition.

Plants experiencing water stress conditions respond at different inhibitory levels in relationship to the severity of the water deficiency. Plants in water

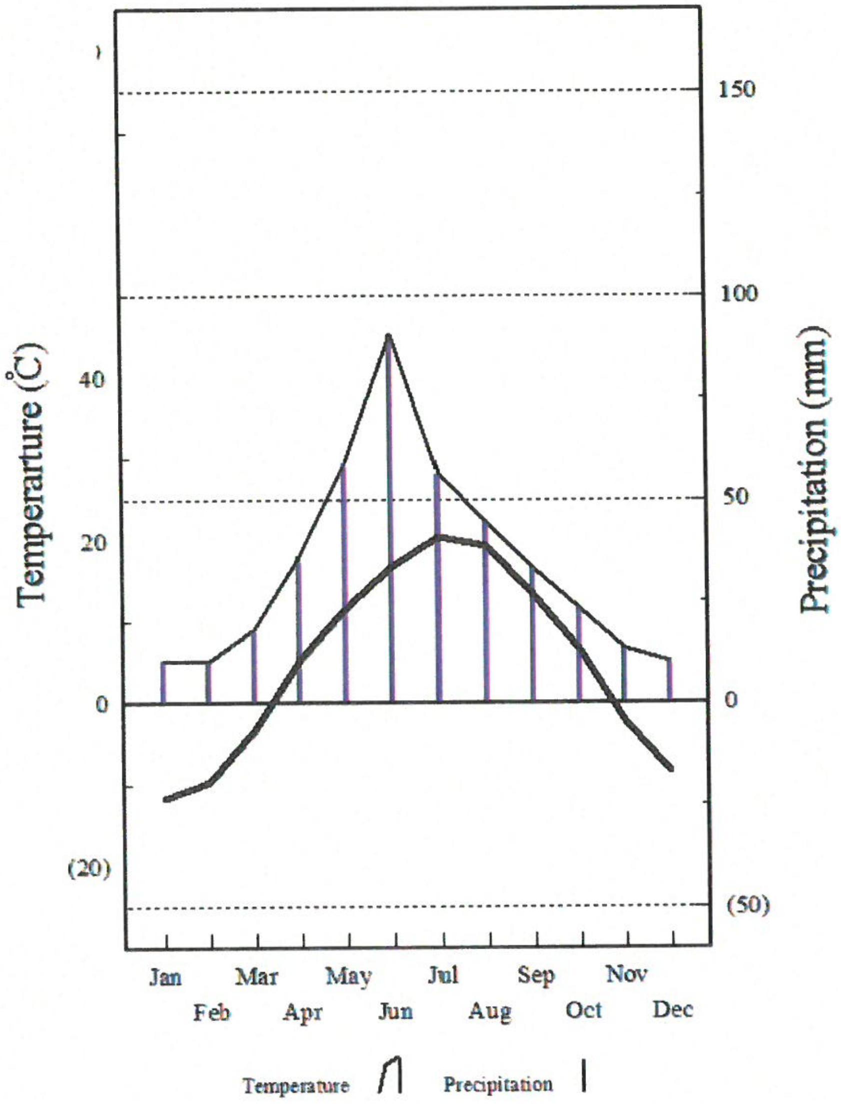

Fig. 2. Ombrothermic diagram of long-term (1892-1996) mean monthly temperature and monthly precipitation at Dickinson, North Dakota.

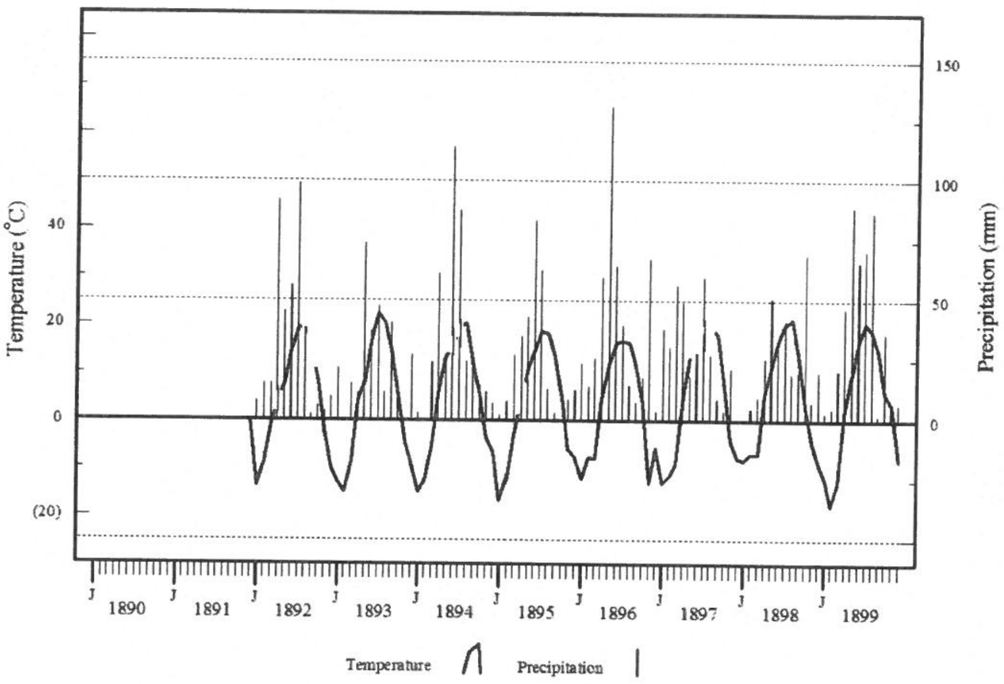

Fig. 3a. Ombrothermic diagram of 1892-1899 mean monthly temperature and monthly precipitation at Dickinson, North Dakota.

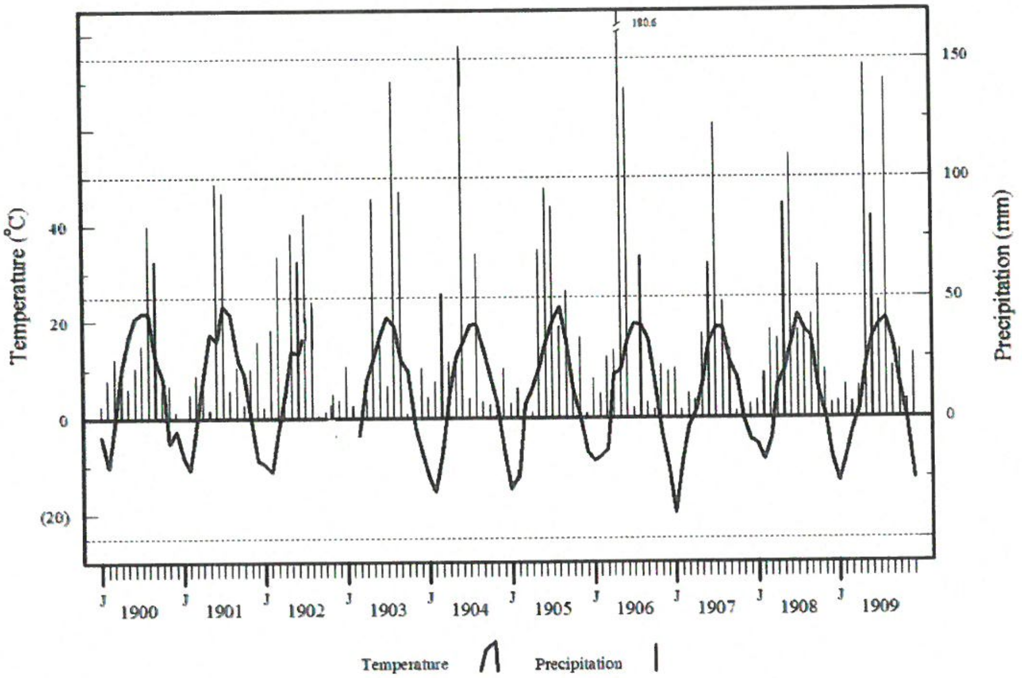

Fig. 3b. Ombrothermic diagram of 1900-1909 mean monthly temperature and monthly precipitation at Dickinson, North Dakota.

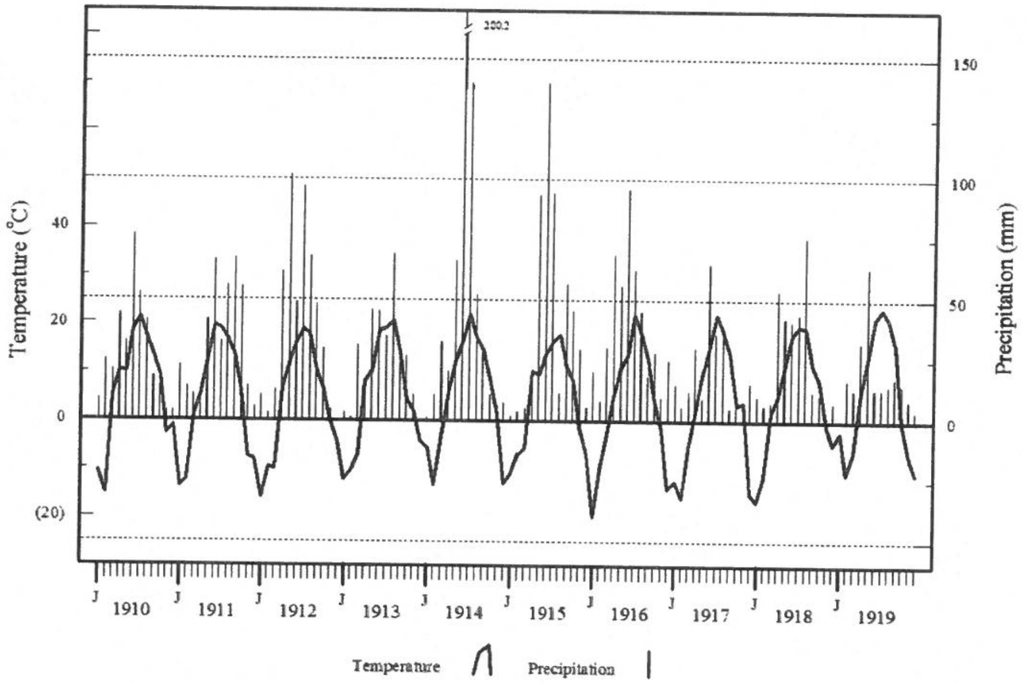

Fig. 3c. Ombrothermic diagram of 1910-1919 mean monthly temperature and monthly precipitation at Dickinson, North Dakota.

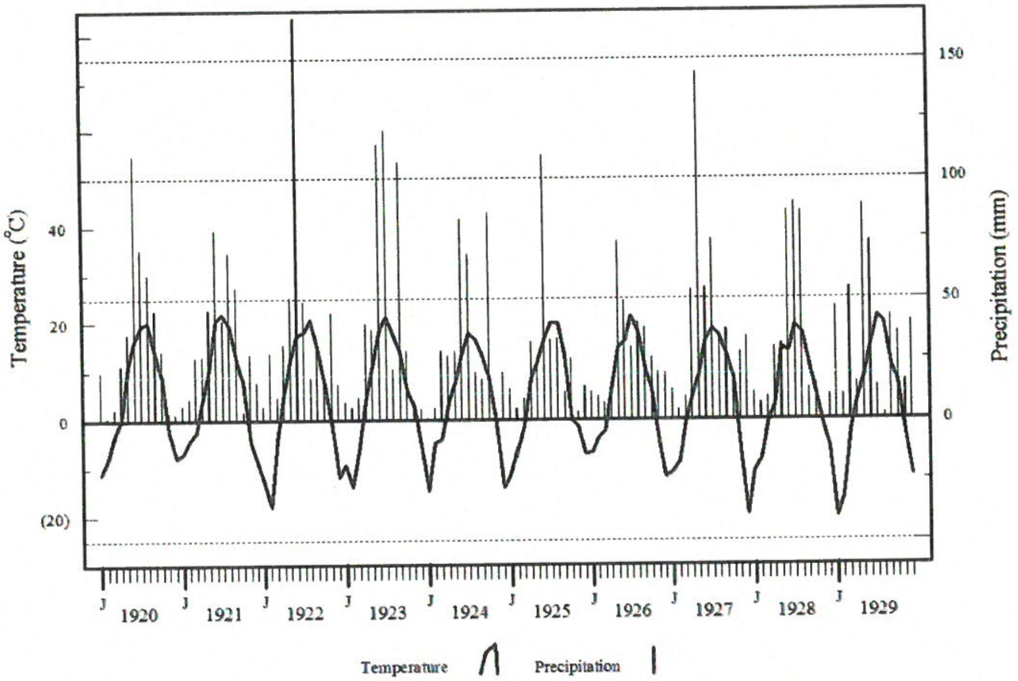

Fig. 3d. Ombrothermic diagram of 1920-1929 mean monthly temperature and monthly precipitation at Dickinson, North Dakota.

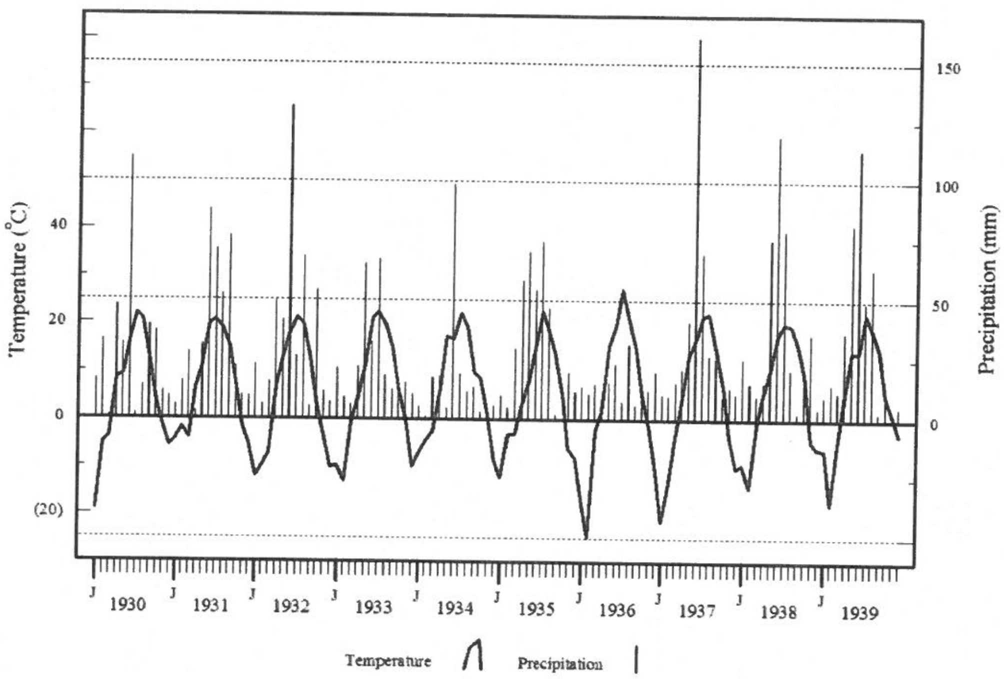

Fig. 3e. Ombrothermic diagram of 1930-1939 mean monthly temperature and monthly precipitation at Dickinson, North Dakota.

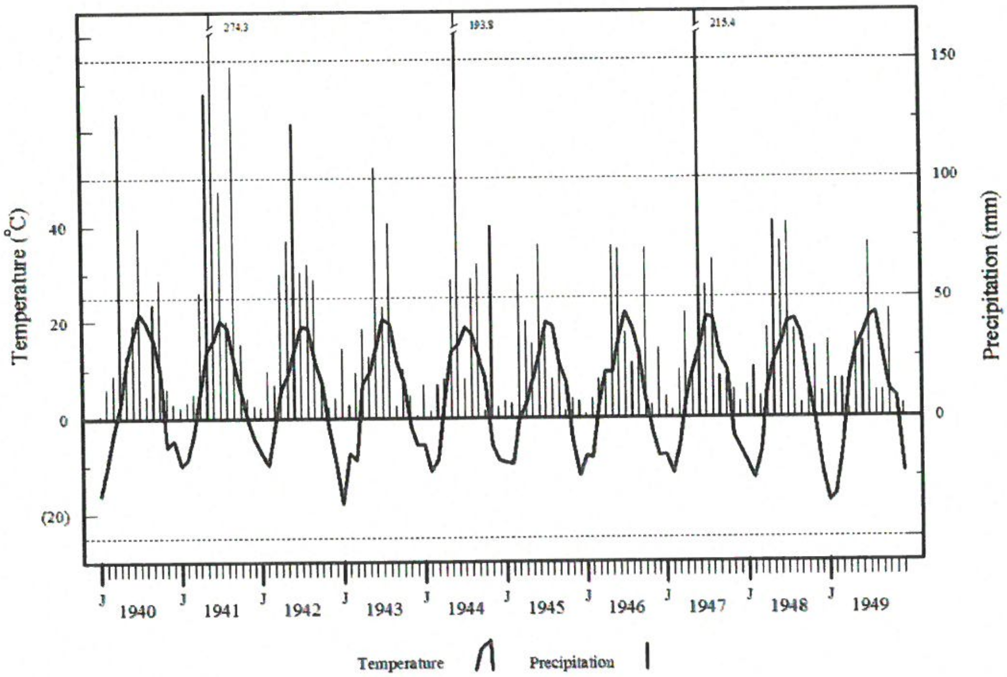

Fig. 3f. Ombrothermic diagram of 1940-1949 mean monthly temperature and monthly precipitation at Dickinson, North Dakota.

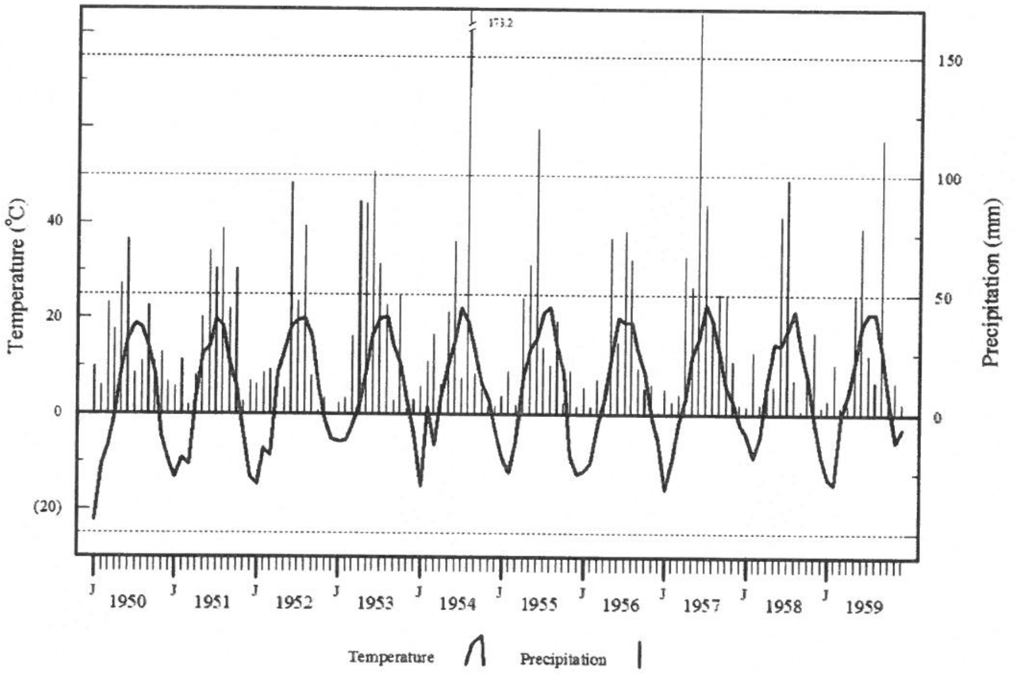

Fig. 3g. Ombrothermic diagram of 1950-1959 mean monthly temperature and monthly precipitation at Dickinson, North Dakota.

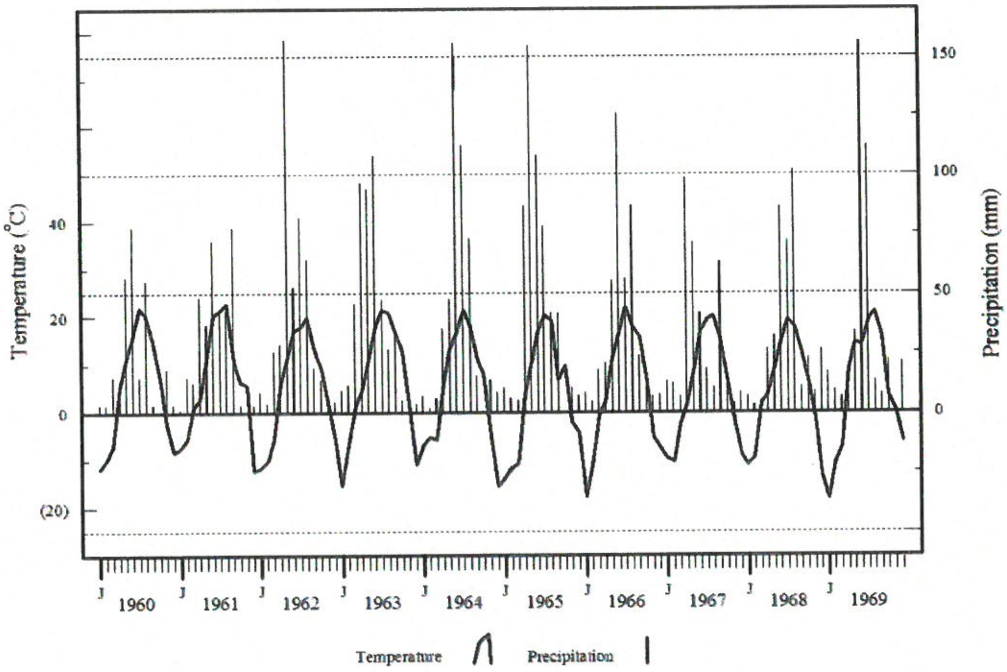

Fig. 3h. Ombrothermic diagram of 1960-1969 mean monthly temperature and monthly precipitation at Dickinson, North Dakota.

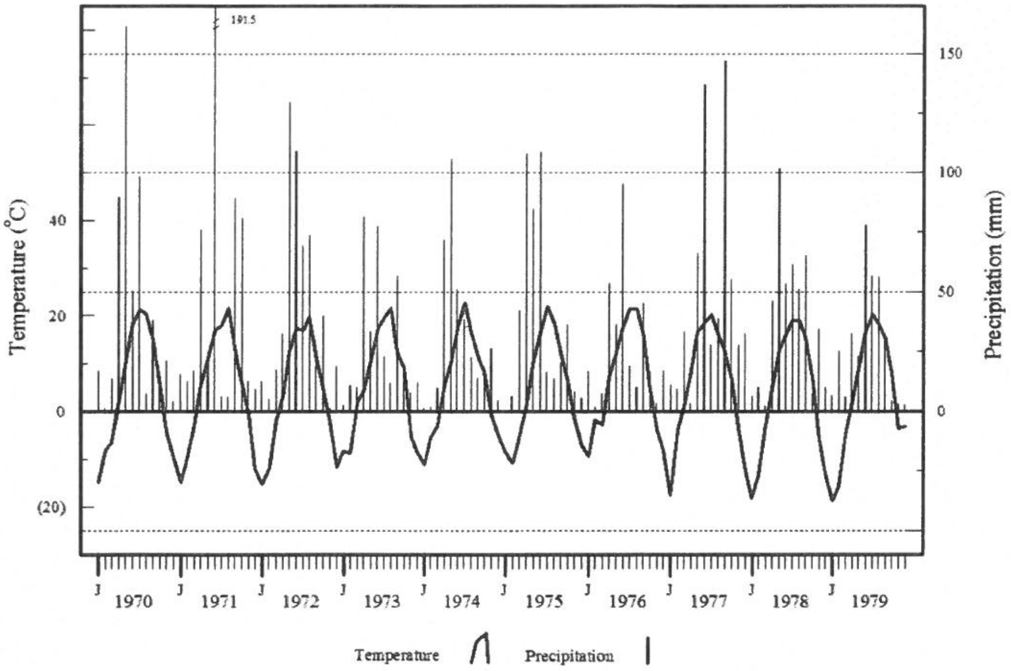

Fig. 3i. Ombrothermic diagram of 1970-1979 mean monthly temperature and monthly precipitation at Dickinson, North Dakota.

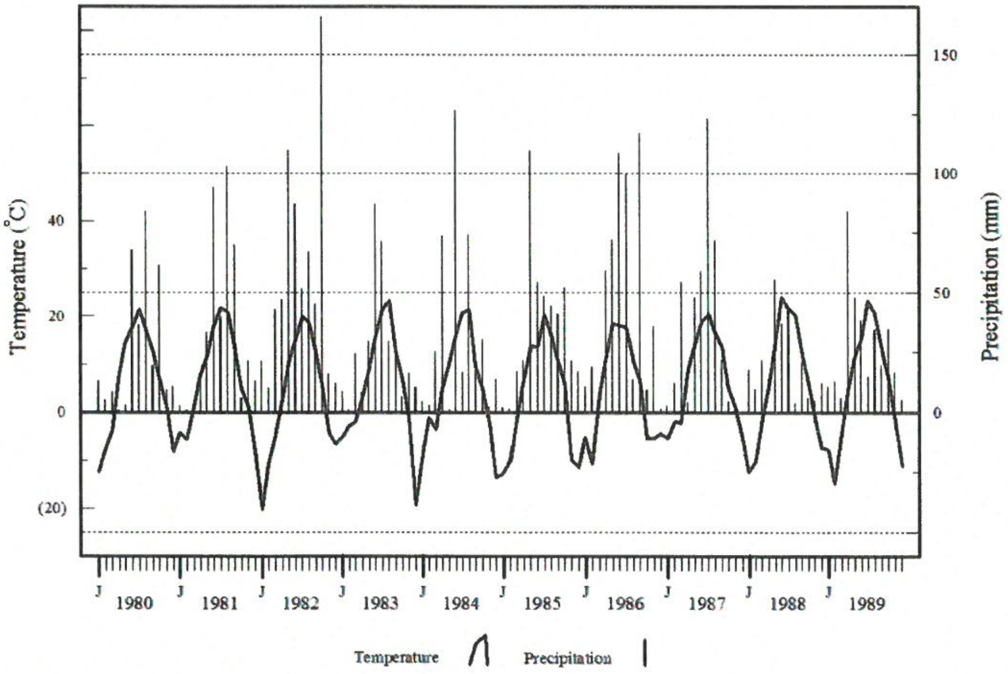

Fig. 3j. Ombrothermic diagram of 1980-1989 mean monthly temperature and monthly precipitation at Dickinson, North Dakota.

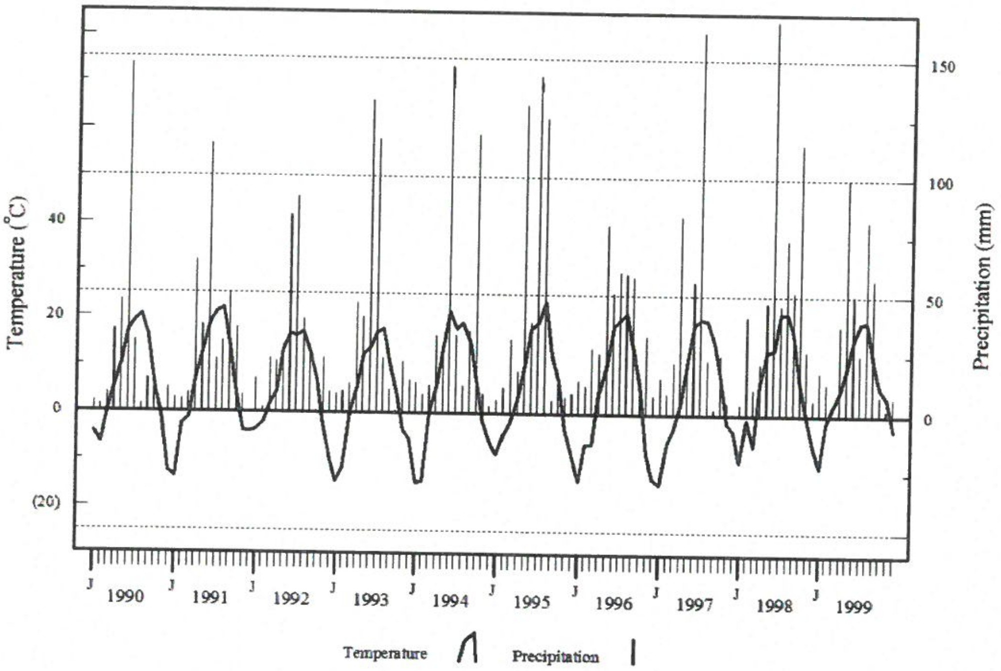

Fig. 3k. Ombrothermic diagram of 1990-1999 mean monthly temperature and monthly precipitation at Dickinson, North Dakota.

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 (1990-1996).

	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										
1998										
1999										
								13.0	**31**	**05**

Table 9. Months when temperature and precipitation conditions caused water stress for perennial plants for 113 years (1892-1996).

	APR	MAY	JUN	JUL	AUG	SEP	OCT	# Months	% 6 Months 15 Apr-15 Oct
TOTAL	18	16	10	40	53	54	52	208.0	33
% of 113 YEARS	17.1	15.2	9.5	38.1	50.5	51.4	49.5		

stress have slow leaf growth and decreased photosynthetic activity. Plant height and herbage biomass accumulation are reduced. Leaf senescence, which reduces nutritional quality of forage, is increased with water stress. Plant vigor is decreased, the amount of carbohydrate storage is reduced, and root biomass is reduced. Rate of sexual reproduction is diminished as the result of a decrease in seed stalk numbers and height, and a reduction in numbers of seeds in the seed heads. Rate of vegetative reproduction is reduced because the number of axillary buds and the number of secondary tillers decrease. Basal cover is reduced because of mortality to entire plants or portions of plants, and open spaces in the plant community increase because of a decrease in plant numbers. The species composition shifts to an increase in species with advanced water stress resistance mechanisms and a decrease in drought-susceptible species. Occurrence of some forbs and weedy species increases because of the ability to exploit the open spaces. Quantity and quality of wildlife habitat diminish. Livestock performance is decreased because of the reductions in the quantity and quality of available forage, which in turn cause a reduction in milk production and a corresponding lowering of calf rate of gain and lower weaning weight. During extended periods of water stress, stocking rates generally need to be reduced.

Drought years have occurred 12.4% of the time. Drought growing seasons have occurred 16.2% of the time. Water deficiency months have occurred 33.0% of the time. Water deficiency has occurred in the months of May and June 15% and 10% 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. Water deficiency periods lasting for a month place plants under water stress that is severe enough to reduce herbage biomass production. These levels of water stress are a major factor limiting the quantity and quality of plant growth in the Dickinson area 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. Changes in time of year and time of day coincide with changes in the angle of incidence of the sun's rays, which cause variations in light intensity. 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 in plants. 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 calendar. 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 only within 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 temperatures of warm days and cool nights are beneficial for plant growth. Cool-season plants have lower optimum temperatures for photosynthesis than do warm-season plants, and cool-season plants do not use water as efficiently as do warm-season plants. Temperature affects evaporation rates, which affect the ratios of cool-season to warm-season plants in the plant communities. 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 different optimum temperatures.

Water is essential for living systems. Average annual precipitation is nearly 16 inches at Dickinson, with 85% 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 12.4% of the time during the past 105 years. Growing seasons with drought conditions have occurred 16.2% 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 105 years, 33.0% 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 15.2%, 9.5%, and 38.1% of the time, respectively. August, September, and October have had water deficiency conditions 50.5%, 51.4% and 49.5% of the time, respectively. One month with water deficiency conditions causes water stress in plants severe enough to reduce herbage biomass production.

Most of the growth in range grasses occurs in May, June, and July. In the Dickinson, North Dakota, area 100% of range grass leaf growth in height and 91% to 100% of range grass flower stalk growth in height are completed by 30 July. Peak aboveground herbage biomass production usually occurs during the last 10 days of July, a period which coincides with the time during which 100% of the growth in height is being attained. Most range grass growth occurs during the three month period of May, June, and July, when 51% of the annual precipitation occurs. Grassland management strategies for a region should consider the environmental factors that affect and limit range plant growth.

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Literature Citation for this Reviewed Range Research Report should be as follows:

Manske, L.L. 1997. Effects from environmental factors of light, temperature, and precipitation on range plants in the Dickinson, North Dakota, region. NDSU Dickinson Research Extension Center. Range Research Report DREC 97-1015. Dickinson, North Dakota. 41 p.