Physiography, Soil, and Native Vegetation of the Northern Plains

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

Land resources of the Northern Plains are the source of new wealth generated by livestock agriculture. The land natural resources consist of complex ecosystems with several trophic layers of living organisms that have individual biological requirements and nonliving (abiotic) components that have changeable characteristics. Biologically effective management benefits all living and nonliving ecosystem components by meeting the biological requirements of the plants and soil organisms and by fostering the characteristics of the soil resulting in continuation of ecosystem production at potential sustainable levels. The potential productivity of healthy ecosystems are effected by the same environmental and biological factors that cause changes in physiographic landform characteristics, soil characteristics, and native vegetation types. The characteristics and relationships of the physiography, soil, and native vegetation of the Northern Plains are described in this report.

Physiographic Regions

The Northern Plains are part of the North American Interior Plains that extend from the foot of the Rocky Mountains eastward to the Canadian Shield and Appalachian Provinces and extend from the Athabasca River on the Alberta Plateau southward to the Gulf Coastal Plains (Fenneman 1931, 1946; Hunt 1974; Goodin and Northington 1985). The Interior Plains are divided east and west into the Great Plains and the Central Lowland Physiographic Provinces (Fenneman 1931, 1946). The Northern Plains are separated from the Southern Plains by the North Platte-Platte-Missouri River Valleys (Raisz 1957). The portions of the Great Plains and Central Lowland Provinces that exist in the Northern Plains are separated in North and South Dakota and Saskatchewan by an eroded east facing escarpment at the eastern extent of the Tertiary sedimentary deposits of material eroded from the Rocky Mountains that form a fluvial plain overlaying the Cretaceous bedrock (Hunt 1974). The surface landform feature that shows the location of this boundary is the east escarpment of the Missouri Coteau (Finneman 1931). In eastern Nebraska, the separation of the Great Plains and Central Lowland Provinces is the western limit of older pre-Wisconsin glacial drift which has a mantle of loess (wind deposited silt) (Fenneman 1931).

Great Plains Province

The Missouri Plateau Section and the northern portion of the High Plains Section of the Great Plains Province are separated in southern and eastern South Dakota by the north facing Pine Ridge Escarpment and the southern bluffs of the Missouri River Valley (Fenneman 1931). The portion of the High Plains that extends into the Northern Plains is divided into Pine Ridge, Sand Hills region, Loess Plain, and Goshen Hole Lowland landscape features. The Missouri Plateau, including the Alberta Plain, is divided into three sections: Glaciated, Unglaciated, and Black Hills, along with smaller domed mountains (Fenneman 1931, 1946; Hunt 1974).

Missouri Plateau Section

The Unglaciated section of the Missouri Plateau is north of the Pine Ridge Escarpment in South Dakota, south of the Missouri River in Montana, and west of the Missouri River in North and South Dakota (Fenneman 1931, 1946; Hunt 1974). Portions of this section were undoubtedly glaciated during glacial advances earlier than Wisconsin Age. However, there is little geologic evidence of older glaciation. The important distinction between the Unglaciated and Glaciated sections is the type and age of parent material from which the soil develops. The landscape surface of the Unglaciated section is highly eroded fluvial sedimentary deposits of material removed from the uplifted Rocky Mountains. Most of the deposition occurred from slow meandering streams during the Laramide Orogeny, that formed the mountains, and during the 20 to 30 million years of the late Cretaceous and early Tertiary Periods following the uplift. Intense widespread erosion of these sediments occurred from about 5 to 3 million years ago during the late Pliocene Epoch (Bluemle 2000). The extensive erosion during this period removed about 500 to 1000 feet of sediments (Fenneman 1931). These fluvial Tertiary sediments had great differences in hardness and durability. The soft and unconsolidated material was easily removed and the harder coherent material had greater resistance to weathering and to erosional forces of wind and running water. Differential erosion formed a landscape with well developed integrated drainage systems of broad mature valleys and gently rolling uplands containing widely spaced large hills and buttes with erosion resistant caps raising 500 to 650 feet above the plain (Bluemle 2000).

In addition to the high relief from erosion resistant capped remnant hills and buttes on the landscape, several isolated domed mountain groups with 1500 to 2000 foot rise formed on the Missouri Plateau. These laccolithic mountains developed from the upward push of rising igneous intrusions (molten magma) that did not penetrate through to the surface but caused a diastrophic bulge with a single fold in the uplifted sediments. Differential erosion has since exposed the underlying tilted strata (Froiland and Weedon 1990) and sometimes the intrusive rock (Robinson and Davis 1995). Along with the large dome uplifted Black Hills in South Dakota and Wyoming, which is treated as a separate section, the Sweetgrass Hills, and the Highwood, Bearpaw, Little Rocky, Moccasin, Judith, and Big Snowy mountains in Montana are smaller domed mountain groups (Fenneman 1931, Hunt 1974). The Highwood and Bearpaw domed mountains include extinct volcanoes (Fenneman 1931).

Drainage of the Missouri Plateau during the highly erosional period of the Pliocene (5 to 3 million years ago) was primarily north and northeast towards the Hudson Bay area. The climate became cooler about 2.6 million years ago and, about 700,000 years ago, the climate was cold enough to produce continental glaciers (Bluemle 2000). Early glacial advances blocked the northward paths of the rivers draining the Unglaciated section and diverted water flow into steeper southern routes. The increased gradient of several rivers caused drastic downcutting through areas of poorly consolidated, soft, fine textured sediments resulting in formation of badland regions (Fenneman 1931).

The Glaciated section of the Missouri Plateau is north of the Missouri River in Montana, including the Alberta Plain between the foot of the Rocky Mountains and the Missouri Coteau Escarpment in Canada, and extends southward between the Missouri River and the east escarpment of the Missouri Coteau in North and South Dakota (Fenneman 1931, Hunt 1974). The section has a mantle of glacial and glacier related drift deposited between 70,000 and 10,000 years ago during the Wisconsin Age. The Missouri Coteau has 500 to 600 feet of terminal moraine deposits. The thick deposits of unsorted glacial sediment are a result of the large quantities of additional rock and sediments picked up from beneath the ice and forced upward into the glacier along shear planes that were generated by great internal stress (Bluemle 2000) when the advances of numerous glaciers were forced to progress up the steep escarpment of Tertiary deposited fluvial sediments. Large masses of stagnant ice remained buried under debris on the Coteau area for about 3000 years following the northern retreat of the last continental glacier. As the stagnant blocks of ice melted, the overlying material slumped down forming depressions (Bluemle 2000). The resulting topography is an irregular surface with closely spaced hills of 100 to 150 feet in height enclosing basins, or kettles, that usually contain ponds (Fenneman 1931). The drainage is local and completely unintegrated with only a few short streams.

The glaciated areas north of the Missouri River and on the Alberta Plain have a mantle of till and outwash. The topography is generally rough. The plain is dissected by broad river valleys that have entrenched 200 to 400 feet. The upland areas contain several erosional remnants that have local relief of about 1000 to 2000 feet. The Cypress Hills in Saskatchewan are the highest and have a height tall enough that they were not overriden by glacial ice. The gravel capped Cypress Hills were part of an ancient valley where a thick layer of rock from the Rocky Mountains was deposited by rivers. This heavy gravel layer protected the surface during the severe erosional period of the late Pliocene, while surrounding higher areas were eroded down to levels below the gravel layer forming an inverted topography (Fenneman 1931).

High Plains Section

A small portion of the High Plains Section of the Great Plains Province exists between the Pine Ridge Escarpment in South Dakota and the North Platte-Platte River Valley in Nebraska and is included within the Northern Plains (Fenneman 1931, 1946; Hunt 1974). Contrary to the erosional surface of the Unglaciated section of the Missouri Plateau north of Pine Ridge, the northern portion of the High Plains is primarily a depositional surface. The uplands of Pine Ridge north of the Niabrara River are exposed Tertiary fluvial sediments of the Arikaree Formation deposited during the Miocene and have a gently rolling to nearly flat topography. The Goshen Hole Lowland located in western Nebraska south of the west end of Pine Ridge is a landform about 50 miles wide and 150 miles long where the North Platte River removed about 700 feet of fine textured clay Tertiary sediments during a period when the river had a relatively steep gradient. The Sand Hills region in Nebraska is located south of the Niobrara River and north of the Platte River. Wind deposited sand covers the Tertiary sediments of the region and forms a sand dune topography. Small areas have active dune movement, however, most of the region has been stabilized by grassland vegetation. Some of the sand hills are several hundred feet high. Lakes, ponds, or wetlands form in the depressions. The Loess Plain in north central Nebraska is located east of the Sand Hills region. Wind deposited silt (loess) about 100 feet thick covers the Tertiary sediments of the area and forms a gently rolling topography (Fenneman 1931).

Central Lowland Province

The Small Lakes Section and the Dissected Till Plains Section of the Central Lowland Province are separated by the age of the glacial till and the degree of development of integrated drainage systems. The Small Lakes Section is located in the northwestern part of the Central Lowland Province and extends eastward from the escarpment of the Missouri Coteau to the Great Lakes Section (Hunt 1974). However, for this report, the Small Lakes Section description extends eastward only to the transition between the Tall Grass Prairie and the Oak Forest in western Minnesota.

Small Lakes Section

The Small Lakes Section has a mantle of Wisconsin Age glacial till and glacial lake deposits. The Saskatchewan Plain between the Missouri Coteau Escarpment and the Manitoba Escarpment in Canada and the Glaciated Plains (Drift Prairie) east of the Missouri Coteau in North and South Dakota extending into western Minnesota are an undulating plain of ground moraine forming a knob and kettle topography with low to moderate relief (Hunt 1974). Water collects in the lower portions of the landscape forming lakes and ponds or marshes with the size decreasing westward with the decrease in annual precipitation (Hunt 1974). The Small Lakes Section does have a few river systems, however, these rivers are still at the early stages of developing complex integrated drainage systems. Thick glacial deposits forming a hummocky collapsed topography (Bluemle 2000) cover Moose Mountain in Saskatchewan and the Turtle Mountains in Manitoba and North Dakota as a result of shear stress planes developing in the ice as the glaciers advanced over preexisting high relief erosional remnant hills.

Glacial Lake Plains of relatively flat fine sediments and reworked till were formed by glacial lakes that developed when meltwater collected in landscape depressions, along the edge of receding glaciers, or as a result from ice damming drainage routes (Ojakangas and Matsch 1982, Bluemle 2000). Lakes Agassiz, Aitkin, Dakota, Duluth, Minnewaukan, Regina, Souris, and Upham were major glacial lakes that existed for periods sometime between 12,200 and 7,500 years ago. Lake Agassiz was, by far, the largest of the glacial lakes and its western edge is defined by the Manitoba-Pembina Escarpment. This escarpment was formed during the highly erosional period of the Pliocene when artesian ground water from the Cretaceous Dakota sandstone formation and overland water from the Grand, Cheyenne, and White Rivers flowed into the ancestral Red River, cut through the relatively soft Cretaceous sediments down to the west sloping Precambrian igneous rock of the Canadian Shield, and progressively shifted the erosional face westward (Bluemle 2000). These erosional surfaces were later covered with thick layers of glacial till and lake sediments during the Pleistocene glaciation. The exceptionally flat surface of Glacial Lake Agassiz sediments east of the Manitoba-Pembina Escarpment form the Manitoba Plain in Canada and the Red River Valley Plain in eastern North Dakota and western Minnesota.

Dissected Till Plains Section

The Dissected Till Plains Section was not glaciated during the Wisconsin Age. The glacial till of this section is from older glacial advances. The old dissected till deposits extend westward from the Mississippi River across southern Iowa and northern Missouri and narrows northward into southwestern Minnesota and southeastern South Dakota (Fenneman 1946, Raisz 1957). The western limit of the old glacial till occurs in eastern Nebraska. The drainage systems on older till have had longer to develop a complex integrated pattern with closely spaced deep valleys and rounded uplands. There are few lakes and ponds in this section and a younger mantle of about 30 feet of wind blown loess (silt) covers the region (Hunt 1974).

Soil Characteristics

Soil development is effected by climate, parent material, topography, living organisms, and time (Brady 1974). The main climatic factors that affect soil development are temperature and precipitation. Climate determines the type and rate of weathering that occurs. The rates of biogeochemical processes in soil are effected by soil temperature and soil moisture. Climate determines the type of native vegetation and the quantity of biomass production. There is a relationship between the type of native vegetation and the kind of soil that develops. Increases in soil moisture, increase the biomass production and tend to increase organic content of soils. Increases in soil temperature, increase the rate of decomposition and tend to decrease organic content of soils (Brady 1974).

The Northern Plains has a continental climate with cold winters and hot summers. Mean air temperatures increase from north to south changing from about 35° - 40° F (1.7° - 4.4° C) in the north to about 48° - 51° F (8.9° - 10.6° C) in the south. Most of the precipitation occurs during the early portion of the growing season. Total annual precipitation fluctuates greatly from year to year. Periods of water deficiency during the growing season occur more frequently than growing seasons without deficiencies. Drought conditions are common. Mean annual precipitation increases from west to east and increases from north to south. In the northern portion, precipitation ranges from about 12 inches (304.8 mm) in the west to about 24 inches (609.6 mm) in the east. In the southern portion, precipitation ranges from about 14 inches (355.6 mm) in the west to about 32 inches (812.8 mm) in the east.

Evapotranspiration affects the quantity of moisture in the soil and the duration infiltrated water remains available for plant growth. The potential evapotranspiration for most of the Northern Plains is greater than annual precipitation. Potential evapotranspiration demand increases from north to south, and increases from east to west. Along the eastern edge of the Northern Plains, the precipitation is greater than potential evapotranspiration during most years. The region also has several local areas where the combination of stored soil water, precipitation, plus water runin is greater than evapotranspiration. Subirrigated soils where the rooting zone is moist for most of the growing season would be comparable to conditions with greater precipitation than evapotranspiration.

The properties of the parent material that affect soil development include texture and structure, and chemical and mineral composition. The texture and structure of parent material varies from fine to coarse and is related to the type of source material and the degree of weathering. The texture of the parent material determines the texture of the soil and the relative content of clay, silt, sand, and gravel. The texture of the soil controls the downward movement of water. The chemical and mineral composition of the parent material strongly influences the growth of the native vegetation and determines the effectiveness of the weathering forces. Parent material influences the quantity and type of clay minerals that develop (Brady 1974). The parent material on the Northern Plains is eroded Tertiary fluvial sedimentary deposits, unsorted glacial till, sorted glacier related deposits of outwash and lake sediments, and wind deposited sand and silt.

Landform topography modifies soil development by influencing the quantity of precipitation absorbed and retained in the soil, determines aspect to solar radiation, and influences the rate of soil removal by erosion. Water, organic matter, mineral matter, and soluble salts move down slope, whether over the surface or internally. The steeper the gradient, the greater the movement. Soil temperature changes with slope aspect. Increases in soil temperature, increase evapotranspiration and decomposition rates. Upper slope soils tend to have lower soil moisture, less organic matter, and thinner horizon development than lower slope soils from similar parent material (Brady 1974).

Living organisms (including plants, animals, and soil microorganisms) affect soil development by influencing organic matter accumulation, profile mixing, nutrient cycling, and structural stability. The source of soil organic matter is the dead tissue and waste from organisms, decomposition is performed by soil organisms, nutrient cycles are complex processes involving living organisms, burrowing critters mix soil material, and soil aggregation is a result of soil organism secretions (Brady 1974).

Time is required for soils to develop and mature. However, soils do not all develop at the same rate. Conditions that increase soil development are warm humid climate, parent material highly permeable by water, unconsolidated material, low lime content, depression or level topography, good drainage, and forest vegetation. Conditions that retard soil development are cold dry climate, parent material not permeable by water, consolidated material, high lime content, steeply sloping topography, poor drainage, and grassland vegetation (Brady 1974). Some very old soils in the Northern Plains show little or no evidence of horizon development because they exist in dry regions, on steep, actively eroding slopes where the rate of soil removal is as great or greater than the rate of soil development.

The soils that are developing in the Northern Plains fit into the order classification descriptions of Mollisols, Aridisols, and Entisols.

Mollisols are mineral soils that develop under grassland vegetation with a thick mollic epipedon that is "soft", high in organic matter, and dark colored. The limited leaching results in a high base saturation with a concentration of positively charged exchangeable cations other than hydrogen. Most Mollisols in the Northern Plains have, or are developing, an argillic (clay) layer in an upper subhorizon and have an accumulation of calcium carbonate (lime) at some level of the profile (Soil Survey Staff 1975).

Aridisols are mineral soils that develop in aridic (dry) or torric (hot and dry) climates with a thin ochic epipedon that is low in organic matter and light colored. Soil water is not available to plants for long periods during the growing season. In the Northern Plains, the Aridisols have an argillic (clay) layer in an upper subhorizon and as a result of limited leaching, soluble salts, like calcium carbonate, accumulate in a zone that marks the average depth of moisture penetration (Soil Survey Staff 1975).

Entisols are mineral soils that show little or no evidence of horizon development and have a thin ochic epipedon that is low in organic matter and light colored. In the Northern Plains, considerable retardation of soil development produces Entisols where dry and/or salty medium to fine textured sediments with sparse grass or shrub vegetation are located on gentle to steep, actively eroding slopes with the rate of soil removal as great as the rate of soil development, or where coarse textured, well sorted, wind deposited sand with low water holding capacity and thin grass vegetation become dry and are easily moved by wind (Soil Survey Staff 1975).

Classification of soils into principal suborders is based on differences caused by climate and associated native vegetation. The biological processes in soil are effected by soil temperature and soil moisture. The different climatic characteristics important in soil development are separated into specific soil temperature regimes and soil moisture regimes.

The Northern Plains has two soil temperature regimes based on mean annual soil temperature. The mean annual soil temperature is considered to be the mean annual air temperature plus 1.8° F (1° C) (Soil Survey Staff 1975). The Frigid soil temperature regime has mean annual soil temperatures of less than 47° F (8° C). The Mesic soil temperature regime has mean annual soil temperatures higher than 47° F (8° C) and lower than 59° F (15° C) (Soil Survey Staff 1975). The separation between the Frigid and Mesic soil temperature regimes occurs along a wide irregular belt that extends eastward from central Wyoming along its north border with Montana and continues to north central South Dakota just south of its north border with North Dakota, then extends at a southeasterly diagonal to about the center of South Dakota's east border with Minnesota, and then extends at a northeasterly angle to the boundary of the Oak Forest.

Soil moisture regimes are based on the soil moisture conditions in the soil. The Northern Plains has four north-south zones of soil moisture regimes that increase in soil moisture from west to east. The soils in the Aridic and Torric soil moisture regime, typically of arid climates, are dry in all parts for more than half the time and the soils are never moist for as long as 90 days during the growing season (Soil Survey Staff 1975). The soils in the Ustic soil moisture regime, typically of semi arid climates, are dry in some or all parts for 90 or more days in most years, but not dry in all parts for more than half the time, and are not dry for as long as 45 days during the 4 months that follow the summer solstice in 6 or more years out of 10 years (Soil Survey Staff 1975). The soils in the Udic soil moisture regime, typically of sub humid climates, are not dry for as long as 90 days. During the summer, the amount of stored moisture plus rainfall is approximately equal to or exceeds the amount of evapotranspiration (Soil Survey Staff 1975). The soils in the Perudic soil moisture regime, typically of humid climates, are rarely dry. During the summer, the precipitation is greater than the evapotranspiration (Soil Survey Staff 1975).

The combination of four soil moisture regimes (Aridic, Ustic, Udic, and Perudic) and two soil temperature regimes (Frigid and Mesic) results in eight distinct soil moisture-temperature regimes in the

Northern Plains. The soils in the Aridic-Frigid soil moisture-temperature regime are primarily Aridic Borolls (arid cool Mollisols) and Torriorthents (hot dry recently eroded medium to fine textured Entisols) and support vegetation of short grasses with some mid grasses. The soils in the Ustic-Frigid soil moisture-temperature regime are primarily Typic Borolls (semi arid cool Mollisols) and support vegetation of mid and short grasses. The soils in the Udic-Frigid soil moisture-temperature regime are primarily Udic Borolls (sub humid cool Mollisols) and support vegetation of mid grasses with some tall grasses. The soils in the Perudic-Frigid soil moisture-temperature regime are primarily Aquolls (humid cool Mollisols that are saturated and absent of oxygen at times for unknown lengths) and support vegetation of tall grasses. The soils in the Aridic-Mesic soil moisture-temperature regime are primarily Argids (arid warm Aridisols with thin horizons, dry for long periods, and have a clay layer) and Aridic Ustolls (arid warm Mollisols) and support vegetation of short grasses. The soils in the Ustic-Mesic soil moisture-temperature regime are primarily Ustipsamments (semi arid warm Entisols that are well sorted wind deposited sands) and Typic Ustolls (semi arid warm Mollisols) and support vegetation of mid and short grasses with lower topographic slopes supporting tall grasses. The soils in the Udic-Mesic soil moisture-temperature regime are primarily Udic Ustolls (sub humid warm Mollisols) and support vegetation of mid grasses and tall grasses. The soils in the Perudic-Mesic soil moisture-temperature regime are primarily Udolls (humid warm Mollisols that do not have a calcium carbonate layer) and support vegetation of tall grasses.

Native Vegetation Types

Development of plant communities and vegetation types is effected by the climatic characteristics of temperature, precipitation, and evapotranspiration demand; the soil characteristics of texture, structure, and chemical and mineral composition; and the landform topographic characteristics of slope, aspect, and elevation. Vegetation of the Northern Plains separates into 10 grassland vegetation types and 7 grassland with woodland or forest vegetation types. The vegetation of the Northern Plains map (figure 1) developed by Dr. W.C. Whitman (Barker and Whitman 1989) is a compilation of information from several sources supplementary to the basic map of potential natural vegetation by Kuchler (1964). Modifications to vegetation type designations, distributions, and boundaries were conflated into the base map from state vegetation maps for Montana (Ross and Hunter 1976, Hacker and Sparks 1977), Nebraska (Kaul 1975, Bose 1977), North Dakota (Shaver 1977), South Dakota (Baumberger 1977), and Wyoming (Shrader 1977). Vegetation type designations and distributions from scientific papers were added for Canada (Clarke, Campbell, and Campbell 1942; Moss and Campbell 1947; Coupland and Brayshaw 1953; Coupland 1950, 1961). A new concept of a plains rough fescue mixture along a portion of the northern border of North Dakota was introduced to the map details by Whitman and Barker (1989).

No living plant species are known to have originated in the Northern Plains. All plant species considered to be native to the Northern Plains originated and developed in other regions and sometime later migrated into the Northern Plains. The plant communities and vegetation types, however, are relatively young and began development in place about 5,000 years ago when the current climate with cycles of wet and dry periods began. Nomenclature of plants in the vegetation types of the Northern Plains followed Flora of the Great Plains (1986) in Barker and Whitman (1989) and, in addition, nomenclature of grass plants follows Flora of North America (2003, 2007) in this report.

Tall Grass Prairie

The Tall Grass Prairie, Bluestem-Switchgrass-Indiangrass Type, exists on the eastern margin of the Northern Plains Grasslands and extends from southern Manitoba through eastern North and South Dakota and western Minnesota southward into northwestern Iowa and northeastern Nebraska to the Platte River. The physiography of the region consists of the Manitoba Plain and the Red River Valley Plain of the Small Lakes Section and extends into the Dissected Till Plains Section of the Central Lowland Province. The climate is humid with evapotranspiration lower than precipitation. The soil moisture regime is Perudic and the soil temperature regime is Frigid in the north and Mesic in the south. The soils are primarily Aquolls in the north and Udolls in the south. The major grasses of the Bluestem-Switchgrass-Indiangrass Type of the Tall Grass Prairie (table 1) are big bluestem, porcupinegrass, switchgrass, prairie dropseed, and indiangrass. Cool-season grass species increase towards the northern portions and warm-season grass species increase towards the southern portions. Big bluestem occupies the lower slopes and subirrigated soils in the north and increases in dominance in the south. Prominent forbs are prairie clover, tall blazing star, large beardtongue, stiff sunflower, scurf pea, white prairie aster, white sage, prairie goldenrods, and violets. Major shrubs are leadplant, white spiraea, wild roses, western snowberry, and willows. Most of this vegetation type has been converted to cropland, and only fragments of tall grass prairie vegetation remain. Plant communities with tall grass species exist in several other vegetation types where near equivalent environmental conditions develop from combinations of precipitation, stored soil water, and water runin that are greater than evapotranspiration.

Transition Mixed Grass Prairie

The Transition Mixed Grass Prairie, Wheatgrass-Bluestem-Needlegrass Type (figure 1), exists between the Tall Grass Prairie on the east and the Mixed Grass Prairie on the west and extends from east central Saskatchewan and southwestern Manitoba through east central North and South Dakota and east central Nebraska to the Platte River. The physiography of the region consists of the Saskatchewan Plain and the Glaciated Plains (Drift Prairie) of the Small Lakes Section of the Central Lowland Province and extends into the eastern portion of the High Plains Section of the Great Plains Province. The climate is sub humid with evapotranspiration greater than precipitation over most of the area except for subirrigated soils and topographic slope positions with water runin. The soil moisture regime is Udic and the soil temperature regime is Frigid in the north and Mesic in the south. The soils are primarily Udic Borolls in the north and Udic Ustolls in the south. The major grasses of the Wheatgrass-Bluestem-Needlegrass Type of the Transition Mixed Grass Prairie (table 2) are western wheatgrass, thickspike (northern) wheatgrass, little bluestem, porcupinegrass, needle and thread, and green needlegrass. Cool-season grass species increase towards the northern portions and warm-season grass species increase towards the southern portions. The needlegrasses and thickspike wheatgrass increase in the north. Little bluestem increases in the south. Prominent forbs are white prairie aster, scurf peas, prairie coneflower, purple coneflower, milkvetches, dotted blazing star, white sage, soft goldenrod, curlycup gumweed, hairy golden aster, and stiff sunflower. Major shrubs are wild roses, western snowberry, silverberry, leadplant, white spiraea, and willows. Plant communities change with topographic position. Wetland communities develop in nearly concentric rings around depressions. The salt-affected “pot holes” support saline plant communities. Wet meadow communities develop on subirrigated soils. Upland communities develop on well drained soils and xeric communities develop on shallow soils. Kentucky bluegrass and western snowberry communities have greatly increased in this region as a result of high stocking rates and too early of grazing starting dates.

Mixed Grass Prairie

The Mixed Grass Prairie has a high mid grass component with some short grasses and some tall grasses present and is separated into three vegetation types based on differences resulting from soil texture and soil temperature regime.

The Mixed Grass Prairie, Wheatgrass-Needlegrass Type (figure 1), exists on semi arid cool soils between the Transition Mixed Grass Prairie on the east and the Short Grass Prairie on the west and extends from mid Saskatchewan through western North Dakota and eastern Montana to north central and northwestern South Dakota. The physiography of the region consists of the eastern portions of the Glaciated and Unglaciated sections of the Missouri Plateau Section, including the Alberta Plain, of the Great Plains Province. The climate is semi arid with evapotranspiration greater than precipitation. The soil moisture regime is Ustic and the soil temperature regime is Frigid. The soils are primarily Typic Borolls. The major grasses of the Wheatgrass-Needlegrass Type of the Mixed Grass Prairie (table 3) are western wheatgrass, needle and thread, blue grama, prairie Junegrass, and green needlegrass. Prominent forbs are white prairie aster, scarlet gaura, scarlet globemallow, purple prairie clover, dotted blazing star, purple locoweed, fringed sage, white sage, hairy golden aster, curlycup gumweed, Hood’s spiny phlox, prairie smoke, green sage, and prairie chickweed. Major shrubs are silver sagebrush, buffaloberry, wild roses, western snowberry, broom snakeweed, and creeping juniper. This vegetation type grows in soils developed from glacial till north and east of the Missouri River and grows in soils developed from Tertiary sedimentary deposits south and west of the Missouri River. Soils in the unglaciated section are developing an argillic (clay) layer and accumulating soluble salts in a subhorizon at decreasing depths from east to west.

The Mixed Grass Prairie, Wheatgrass-Grama Type (figure 1), exists on semi arid warm clay soils south of the Wheatgrass-Needlegrass Type and is in southwestern South Dakota. The physiography of the region consists of the southeastern portion of the Unglaciated section of the Missouri Plateau

Section of the Great Plains Province. The climate is semi arid with evapotranspiration greater than precipitation. The soil moisture regime is Ustic and the soil temperature regime is Mesic. The soils are primarily clay textured Typic Ustolls. The major grasses of the Wheatgrass-Grama Type of the Mixed Grass Prairie (table 4) are western wheatgrass, blue grama, and buffalograss. This vegetation type is separated from the Wheatgrass-Needlegrass Type because the clay textured soils and warmer soil temperature regime result in near removal of needle and thread and in greatly increasing blue grama and buffalograss.

The Mixed Grass Prairie, Wheatgrass Type (figure 1), exists on semi arid warm dense clay soils south of the Wheatgrass-Needlegrass Type and is in northwestern South Dakota. The physiography of the region consists of the central portion of the Unglaciated section of the Missouri Plateau Section of the Great Plains Province. The climate is semi arid with evapotranspiration greater than precipitation. The soil moisture regime is Ustic and the soil temperature regime is Mesic. The soils are primarily dense clay textured Typic Ustolls. The major grasses of the Wheatgrass Type of the Mixed Grass Prairie (table 5) are western wheatgrass, green needlegrass, and thickspike wheatgrass. This vegetation type is separated from the Wheatgrass-Needlegrass Type because the dense clay textured soils and warmer soil temperature regime result in removal of blue grama and near removal of needle and thread.

Short Grass Prairie

The Northern Short Grass Prairie, Grama-Needlegrass-Wheatgrass Type (figure 1), exists on the western side of the Northern Plains Grasslands and extends from southeastern Alberta and southwestern Saskatchewan through central Montana and southward into northeastern Wyoming. The physiography of the region consists of the western portions of the Glaciated and Unglaciated sections of the Missouri Plateau Section of the Great Plains Province. The climate is arid with evapotranspiration greater than precipitation. The soil moisture regime is Aridic and the soil temperature regime is Frigid in the north and Mesic in the south. The soils are primarily Aridic Borolls and Torriorthents in the north and Argids and Aridic Ustolls in the south. The major grasses of the Grama-Needlegrass-Wheatgrass Type of the Northern Short Grass Prairie (table 6) are blue grama, needle and thread, small needlegrass, western wheatgrass, thickspike wheatgrass, green needlegrass, and buffalograss. Prominent forbs are fringed sage, green sage, milkvetches, Hood’s spiny phlox, curlycup gumweed, and prairie chickweed. Major shrubs are big sagebrush, silver sagebrush, rabbitbrush, broom snakeweed, plains prickly pear, greesewood, shadescale, saltbush, and winterfat. Dr. Whitman (Barker and Whitman 1989) continued the separation of this vegetation type from the Wheatgrass-Needlegrass Type because of the notable increase in the shortgrass component and the relative decrease of western wheatgrass and needle and thread. Cool-season grass species increase towards the northern portions and warm-season grass species increase towards the southern portions. The needlegrasses increase in the north. Blue grama and buffalograss increase in the south. Because of the presence of mid cool-season grasses, the Northern Shortgrass Prairie has sometimes been combined with the Northern Mixed Grass Prairie. However, these two vegetation types are distinct and should remain separated. The Grama-Needlegrass-Wheatgrass Type has the appearance of a shortgrass prairie and has an arid soil moisture regime, less soil horizon development, shallower soil depth to the accumulating soluble salts and developing argillic (clay) layer, shallower rooting depth, lower soil water holding capacity, greater evapotranspiration potential, and generally more xeric than the Wheatgrass-Needlegrass Type.

The Northern Short Grass Prairie, Saltgrass Type, exists on salt affected soils distributed in local areas across the Northern Short Grass Prairie region. The major grasses of the Saltgrass Type of the Northern Short Grass Prairie (table 7) are saltgrass, alkali cordgrass, basin wildrye, foxtail barley, little barley, and Nuttall’s alkali grass. Few plant species can tolerate the harsh environmental conditions of salt-affected areas. The tolerant species have mechanisms to exclude uptake of salts, or physiologically separate and discharge the undesired salts.

The Southern Short Grass Prairie, Blue grama-Buffalograss Type (figure 1), exists in northwestern Nebraska and extends into east central Wyoming north of the North Platte River. The physiography of the region consists of a small western portion of the High Plains Section of the Great Plains Province. The climate is arid with evapotranspiration greater than precipitation. The soil moisture regime is Aridic and the soil temperature regime is Mesic. The soils are primarily Argids and Aridic Ustolls. The major grasses of the Blue grama-Buffalograss Type of the Southern Short Grass Prairie (table 8) are blue grama and buffalograss. This vegetation type is separated from the Grama-Needlegrass-Wheatgrass Type because the arid soil moisture regime and mesic soil temperature regime severely reduce the mid cool-season grasses and greatly increase the short warm-season grasses. Only a small area of the Southern Short Grass Prairie extends into the Northern Plains.

Sandhills Prairie

The Sandhills Prairie, Bluestem-Sandreed-Grama-Needlegrass Type (figure 1), exists in the north central portion of Nebraska south of the Niobrara River and north of the Platte River. Other Sandhills Prairie areas exist scattered throughout the Northern Plains. Many areas are too small to map. A large area of Sandhills Prairie exists along the Sheyenne River in southeastern North Dakota and another large area exists near Swift Current, Saskatchewan. The physiography of the Nebraska Sandhills consists of the Sand Hills region of the High Plains Section of the Great Plains Province. The climate is semi arid with evapotranspiration greater than precipitation. The soil moisture regime is Ustic and the soil temperature regime is Mesic. The soils are primarily Ustipsamments. The major grasses of the Bluestem-Sandreed-Grama-Needlegrass Type of the Sandhills Prairie (table 9) are big bluestem, little bluestem, sand bluestem, prairie sandreed, sideoats grama, needle and thread, and switchgrass. Prominent forbs are purple prairie clover, silky prairie clover, scurf peas, goldenrods, sunflowers, white camas, and wild lily. Major shrubs are leadplant, wild roses, western snowberry, willows, creeping juniper, common juniper, eastern red cedar, and yucca. This vegetation type is fundamentally the Tall Grass Prairie vegetation on sand soils. The tall grass species occupy the lower slopes and subirrigated soils while the mid and short grasses occupy the dryer upper slopes. A unique assemblage of grasses grow in blowout areas with active wind erosion and deposition and are blowout grass, sandhill muhly, sand dropseed, indian ricegrass, and Schweinitz cyperus.

Foothills Prairie

The Foothills Prairie, Plains Rough Fescue Type (figure 1), exists as a fringe along the montane forest of the Rocky Mountain foothills from Alberta to south central Montana and along the aspen groveland and aspen parkland bordering the boreal forest zone in Alberta and Saskatchewan and the type mingles with the Wheatgrass-Bluestem-Needlegrass Type extending across Saskatchewan and southwestern Manitoba and into northern North Dakota. The physiography of the region consists of the northern portion of the Glaciated section of the Missouri Plateau Section of the Great Plains Province and the northern portion of the Small Lakes Section of the Central Lowland Province. The major grasses of the Plains Rough Fescue Type of the Foothills Prairie (table 10) are plains rough fescue, Parry's oatgrass, timber oatgrass, bluebunch wheatgrass, slender wheatgrass, western wheatgrass, thickspike wheatgrass, Nelson's needlegrass, and Richardson's needlegrass. Prominent forbs are lupines, tall larkspur, sticky-leaved geranium, and arrowleaf balsamroot. Major shrubs are shrubby cinquefoil and big sagebrush. This vegetation type consists of a high proportion of tussock-forming grass species that are now known to develop on other landforms than Rocky Mountain foothills.

Grassland with Woodland or Forest

The Pacific Bunchgrass Prairie, Bluebunch-Fescue Type (figure 1), exists in the south central portion of Montana. Numerous other areas too small to map exist within the Great Plains. The physiography of the region consists of the Unglaciated section of the Missouri Plateau Section of the Great Plains Province. The major grasses of the Bluebunch-Fescue Type of the Pacific Bunchgrass Prairie (table 11) are bluebunch wheatgrass, Idaho fescue, western wheatgrass, sideoats grama, and little bluestem. Prominent forbs are white prairie aster, western yarrow, American vetch, scarlet gaura, and fringed sage. Major shrubs are western snowberry, silver sagebrush, rabbitbrush, broom snakewood, and plains prickly pear. This vegetation type is commonly associated with big sagebrush and exists as open grasslands between savanna stands of ponderosa pine or Rocky Mountain juniper.

The Badlands and River Breaks, Woody Draw and Savanna Types (figure 1), exist in central Montana along the Missouri and Musselshell Rivers, in western North Dakota along the Little Missouri River, and in southwestern South Dakota along the White River. The physiography of the region consists of the Unglaciated section of the Missouri Plateau Section of the Great Plains Province. The major grasses of the Woody Draw and Savanna Types of the Badlands and River Breaks (table 12) are western wheatgrass, needle and thread, blue grama, green needlegrass, and prairie Junegrass. The grassland communities of this vegetation type exist as open grasslands or understory grasslands associated with thin stands of trees growing in highly eroded badland areas, on steep east and north facing slopes, or in steep, sharply eroded breaks along streams and rivers. The woodlands and savannas consist primarily of ponderosa pine and Rocky Mountain juniper, and the hardwood draws consist of green ash, American elm, boxelder, and hawthorn. Major shrubs are wild roses, Juneberry, chokecherry, skunk bush, western snowberry, and shrubby cinequefoil.

The Pine Savanna, Pine-Juniper-Bluebunch Type (figure 1), exists on rough uplands in south central and southeastern Montana, north central Wyoming, western South Dakota, and southwestern North Dakota. The physiography of the region is the Unglaciated section of the Missouri Plateau Section of the Great Plains Province. The major grasses of the Pine-Juniper-Bluebunch Type of the Pine Savanna (table 13) are bluebunch wheatgrass, western wheatgrass, thickspike wheatgrass, needle and thread, blue grama, green needlegrass, and little bluestem. The grassland communities of this vegetation type exist as open grasslands or understory grasslands associated with numerous disconnected savanna stands of ponderosa pine and Rocky Mountain juniper growing on eroded uplands with thin soils. Major shrubs are big sagebrush, bitterbrush, western snowberry, skunk bush, rabbitbrush, and common juniper.

The Black Hills Pine Forest, Pine-Spruce-Aspen Type (figure 1), exists in southwestern South Dakota and northeastern Wyoming. The physiography of the region consists of the Black Hills section of the Missouri Plateau Section of the Great Plains Province. The major grasses of the Pine-Spruce-Aspen Type of the Black Hills Pine Forest (table 14) are western wheatgrass, bluebunch wheatgrass, needle and thread, green needlegrass, prairie Junegrass, and blue grama. The grassland communities of this vegetation type exist as open grasslands or understory grasslands associated with the open park stands of ponderosa pine in the higher hills and with the savanna stands of ponderosa pine in the lower hills. Grassland communities are not important in the deep cool canyons with dense, nearly closed stands of white spruce and paper birch, in the dense secondary growth of aspen and paper birch, or in the dense deciduous forest stands of green ash, bur oak, American elm, boxelder, and hackberry along streams. Important shrubs are beaked hazelnut, Juneberry, chokecherry, willows, big sagebrush, sand sagebrush, and mountain mahogany.

The Montane Forest, Pine-Fir-Spruce Type (figure 1), exists on the Sweetgrass Hills, and the Highwood, Bearpaw, Little Rocky, Moccasin, Judith, and Big Snowy mountains in Montana and the Cypress Hills in Saskatchewan. The physiography of the region consists of the laccolithic domed mountains in the Unglaciated section and the erosional upland remnant in the Glaciated section of the Missouri Plateau Section of the Great Plains Province. The major grasses of the Pine-Fir-Spruce Type of the Montane Forest (table 15) are bluebunch wheatgrass, Idaho fescue, Nelson’s needlegrass, spike fescue, prairie Junegrass, needle and thread, and spike oatgrass. The grassland communities of this vegetation type exist as open grasslands and understory grasslands associated with open stands of ponderosa pine and Douglas fir on the lower elevations of the domed mountains. Prominent forbs are arrowleaf balsamroot, lupine, sticky-leaved geranium, bluebells, and prairie smoke. Major shrubs are western snowberry, white spiraea, and bearberry. Grassland communities are not important at the higher elevations with closed forest stands of subalpine fir, Douglas fir, and Engelmann spruce. Grassland communities are associated with the open forest stands of lodgepole pine, white spruce, paper birch, and aspen on the Cypress Hills.

The Upland Woodlands, Aspen-Ash-Oak-Juniper Types (figure 1), exist as scattered areas with various types of trees, shrubs, and grasses in North Dakota, Manitoba, and Saskatchewan. The physiography of the region consists of upland positions of the Small Lakes Section of the Central Lowland Province and of upland positions of the Unglaciated section of the Missouri Plateau Section of the Great Plains Province. The major grasses of the Aspen-Ash-Oak-Juniper Types of the Upland Woodlands (table 16) are roughleaf ricegrass, little ricegrass, and long-beaked sedge. Grass plants of these vegetation types are part of the understory community. Prominent forbs are northern bedstraw, wild strawberry, violets, anise root, and black snakeroot. Major shrubs are beaked hazelnut, western snowberry, Juneberry, chokecherry, red raspberry, bittersweet, gooseberry, wild plum, and northern hawthorn. The aspen woodlands contain trembling aspen, balsam poplar, paper birch, green ash, and sometimes bur oak. The ash woodlands contain green ash, American elm, boxelder, and occasionally hackberry. The oak woodlands contain bur oak, green ash, American elm, boxelder, aspen, and occasionally ironwood. The juniper woodlands contain Rocky Mountain juniper.

The Riparian Woodlands, Cottonwood-Ash-Elm Type (figure 1), exists along the floodplains of the larger rivers and streams and as small groves along minor drainage ways located throughout the Northern Plains. The major grasses of the Cottonwood-Ash-Elm Type of the Riparian Woodlands (table 17) are Canada wildrye, slender wheatgrass, Virginia wildrye, prairie sandreed, needle and thread, green needlegrass, marsh muhly, reed canarygrass, prairie cordgrass, bottlebrush grass, and mountain ricegrass. The grassland communities of this vegetation type exist as understory grasslands associated with open woodlands and sometimes fairly dense forest stands of cottonwood, green ash, boxelder, American elm, hackberry, peach-leaved willow, and occasionally bur oak. Prominent forbs are false solomon's seal, dogbane, wild licorice, fringed loosestrife, and meadow rue. Major shrubs are western snowberry, wild roses, skunk bush, golden currant, gooseberry, dogwood, poison ivy, bittersweet, wild grape, thicket creeper, and western clematis.

The environmental and biological factors that affect development of plant communities and vegetation types are the same factors that affect soil development. Soil moisture regimes affect distribution of plant species affiliations. The species affiliations that are the major vegetation types in the Northern Plains; Tall Grass Prairie, Transition Mixed Grass Prairie, Mixed Grass Prairie, and Short Grass Prairie; coincide with the four soil moisture regimes; Perudic, Udic, Ustic, and Aridic; respectively. The four soil moisture regimes are further separated into two soil temperature regimes; Frigid in the northern portions and Mesic in the southern portions. Soil temperature regimes affect composition and distribution of cool-season and warm-season grasses within the vegetation types. In the northern Frigid temperature regime, warm-season grass species decrease and cool-season grass species increase. In the southern Mesic temperature regime, cool-season grass species decrease and warm-season grass species increase.

Changes in elevation, slope, and aspect resulting from the various physiographic landforms in the Northern Plains affect plant species topographic distribution and plant community productivity by causing differential distribution and retention of soil water. Lower slopes have greater soil water than upper slopes. East and north facing slopes retain more soil water longer than south and west facing slopes. Lowland landscape slopes have soil water in amounts greater than precipitation levels because of water runin from upper slopes. Upland landscape slopes have soil water in amounts similar to precipitation levels because water runin and water runoff occur in low quantities and are about the same. Xeric landscape slopes have soil water in amounts less than precipitation levels because of restricted water infiltration, low water holding capacity, high evapotranspiration demand, and/or high water runoff.

Some slope positions have sufficiently low evapotranspiration demand and/or receive sufficient quantities of water runin for woodland and forest plant communities to develop. Woodlands and forests also develop along rivers and streams and at higher elevation positions that receive greater quantities of precipitation.

Enhancement of the Land Natural Resources

Generating greater new wealth with livestock agriculture requires enhancement of the land natural resources. These essential changes are doable and not the herculean task that they first appear to be. A few small catalyzing changes correctly timed can have remarkable effects.

The forces that change hills into valleys, rocks into clay, and forests into grasslands work slowly over thousands and millions of years. The physiographic landform characteristics have changed little during the past 10,000 years. The current climate with wet and dry periods, and the current soil moisture and soil temperature regimes have been operational for about 5,000 years. The native plant species completed development of their physiological processes and defoliation resistance mechanisms in conjunction with early herbivore evolution millions of years ago.

By contrast, the soils, plant communities, and vegetation types in the Northern Plains are relatively young and their development is still ongoing. These developmental processes can be manipulated through implementation of biologically effective management that benefits all living and nonliving ecosystem components by meeting the biological requirements of the plants and soil organisms which causes improvements in the biogeochemical processes, ecosystem health, soil quality, plant community composition, and vegetation type affiliations. These important improvements enhance the quality and productivity of the land natural resources and result in generation of greater new wealth.

Acknowledgment

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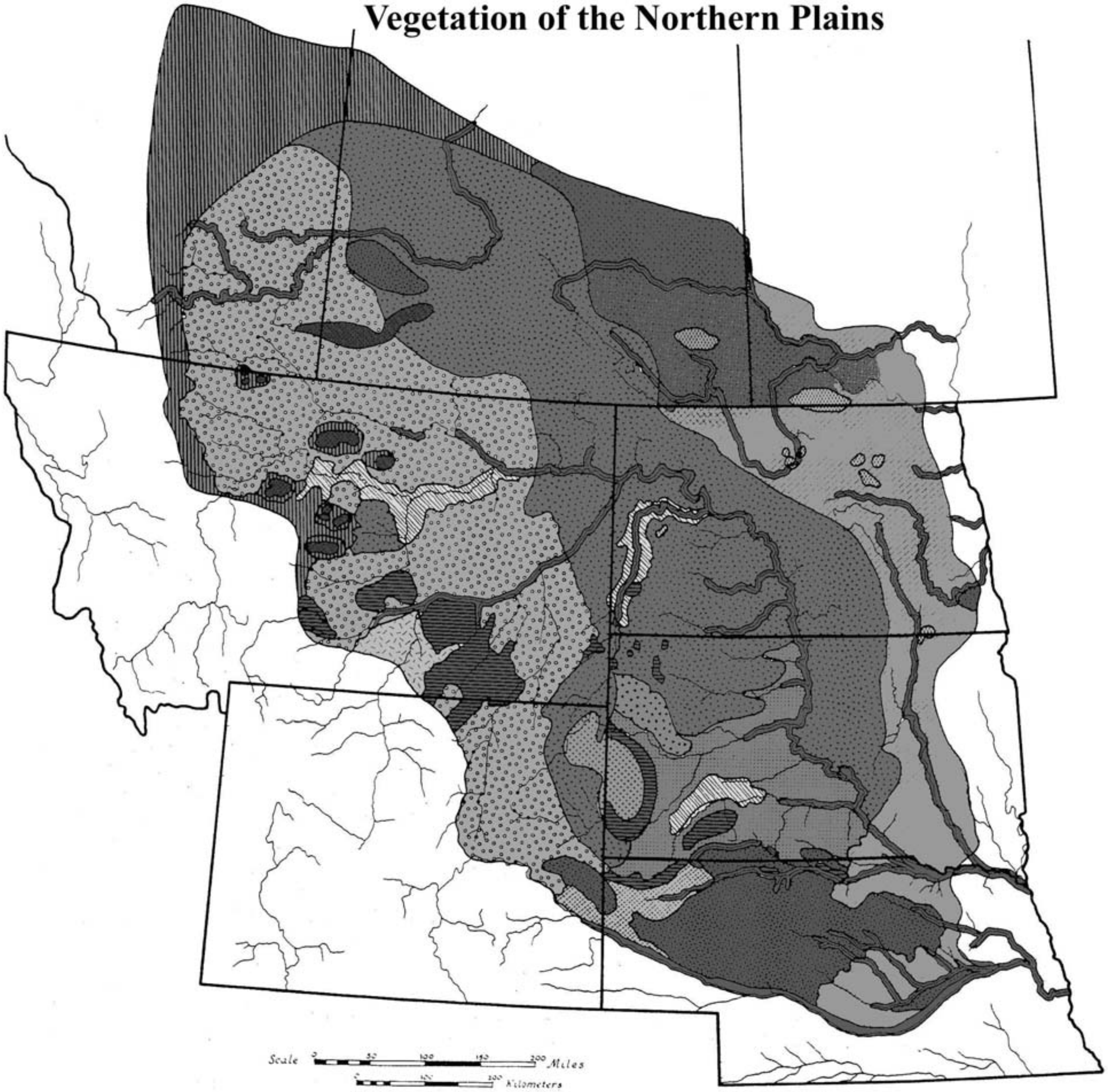
Vegetation of the Northern Plains



map from Barker and Whitman 1989

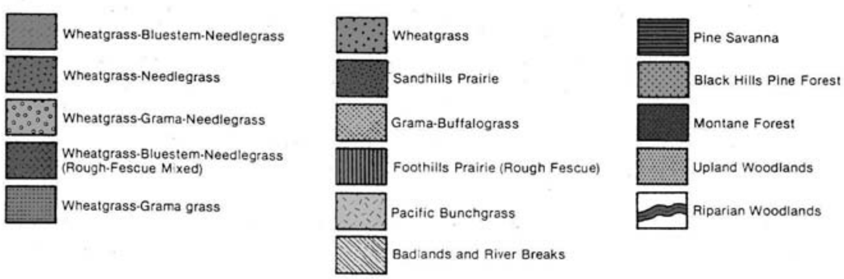


Table 1. Major Grasses of the Tall Grass Prairie; Bluestem-Switchgrass-Indiangrass Type.

Standardized Common Name	Flora of the Great Plains 1986	Flora of North America 2003, 2007
Big bluestem	Andropogon gerardii	Andropogon gerardii
Porcupinegrass	Stipa spartea	Hesperostipa spartea
Switchgrass	Panicum virgatum	Panicum virgatum
Prairie dropseed	Sporobolus heterolepis	Sporobolus heterolepis
Indiangrass	Sorghastrum nutans	Sorghastrum nutans
Northern reedgrass	Calamagrostis stricta	Calamagrostis stricta inexpansa
Prairie cordgrass	Spartina pectinata	Spartina pectinata
Sideoats grama	Bouteloua curtipendula	Bouteloua curtipendula
Slender wheatgrass	Agropyron caninum majus majus	Elymus trachycaulus trachycaulus
Bearded wheatgrass	Agropyron caninum majus unilaterale	Elymus trachycaulus subsecundus
Kentucky bluegrass	Poa pratensis	Poa pratensis
Needle and thread	Stipa comata	Hesperostipa comata
Little bluestem	Andropogon scoparius	Schizachyrium scoparium scoparium
Mat muhly	Muhlenbergia richardsonis	Muhlenbergia richardsonis
Needleleaf sedge	Carex eleocharis	Carex duriuscula
Sun sedge	Carex heliophila	Carex inops heliophila
Woolly sedge	Carex lanuginosa	Carex pellita

Table 2. Major Grasses of the Transition Mixed Grass Prairie; Wheatgrass-Bluestem-Needlegrass Type.

Standardized Common Name	Flora of the Great Plains 1986	Flora of North America 2003, 2007
Western wheatgrass	Agropyron smithii	Pascopyrum smithii
Thickspike wheatgrass	Agropyron dasystachyum	Elymus lanceolatus
Little bluestem	Andropogon scoparius	Schizachyrium scoparium scoparium
Porcupinegrass	Stipa spartea	Hesperostipa spartea
Needle and thread	Stipa comata	Hesperostipa comata
Green needlegrass	Stipa viridula	Nassella viridula
Bearded wheatgrass	Agropyron caninum majus unilaterale	Elymus trachycaulus subsecundus
Slender wheatgrass	Agropyron caninum majus majus	Elymus trachycaulus trachycaulus
Sideoats grama	Bouteloua curtipendula	Bouteloua curtipendula
Blue grama	Bouteloua gracilis	Bouteloua gracilis
Prairie Junegrass	Koeleria pyramidata	Koeleria macrantha
Prairie sandreed	Calamovilfa longifolia	Calamovilfa longifolia
Big bluestem	Andropogon gerardii	Andropogon gerardii
Kentucky bluegrass	Poa pratensis	Poa pratensis
Needleleaf sedge	Carex eleocharis	Carex duriuscula
Threadleaf sedge	Carex filifolia	Carex filifolia
Sun sedge	Carex heliophila	Carex inops heliophila

Table 3. Major Grasses of the Mixed Grass Prairie; Wheatgrass-Needlegrass Type.

Standardized Common Name	Flora of the Great Plains 1986	Flora of North America 2003, 2007
Western wheatgrass	Agropyron smithii	Pascopyrum smithii
Needle and thread	Stipa comata	Hesperostipa comata
Blue grama	Bouteloua gracilis	Bouteloua gracilis
Prairie Junegrass	Koeleria pyramidata	Koeleria macrantha
Green needlegrass	Stipa viridula	Nassella viridula
Plains reedgrass	Calamagrostis montanensis	Calamagrostis montanensis
Little bluestem	Andropogon scoparius	Schizachyrium scoparium scoparium
Prairie sandreed	Calamovilfa longifolia	Calamovilfa longifolia
Sandberg bluegrass	Poa sandbergii	Poa secunda
Thickspike wheatgrass	Agropyron dasystachyum	Elymus lanceolatus
Slender wheatgrass	Agropyron caninum majus majus	Elymus trachycaulus trachycaulus
Small needlegrass	Stipa curtiseta	Hesperostipa curtiseta
Bluebunch wheatgrass	Agropyron spicatum	Pseudoroegneria spicata
Buffalograss	Buchloe dactyloides	Buchloe dactyloides
Kentucky bluegrass	Poa pratensis	Poa pratensis
Threadleaf sedge	Carex filifolia	Carex filifolia
Sun sedge	Carex heliophila	Carex inops heliophila

Table 4. Major Grasses of the Mixed Grass Prairie on Clay Soils; Wheatgrass-Grama Type.		
Standardized Common Name	Flora of the Great Plains 1986	Flora of North America 2003, 2007
Western wheatgrass	Agropyron smithii	Pascopyrum smithii
Blue grama	Bouteloua gracilis	Bouteloua gracilis
Buffalograss	Buchloe dactyloides	Buchloe dactyloides
Thickspike wheatgrass	Agropyron dasystachyum	Elymus lanceolatus
Green needlegrass	Stipa viridula	Nassella viridula

Table 5. Major Grasses of the Mixed Grass Prairie on Dense Clay Soils; Wheatgrass Type.		
Standardized Common Name	Flora of the Great Plains 1986	Flora of North America 2003, 2007
Western wheatgrass	Agropyron smithii	Pascopyrum smithii
Green needlegrass	Stipa viridula	Nassella viridula
Thickspike wheatgrass	Agropyron dasystachyum	Elymus lanceolatus
Associated Grass		
Needle and thread	Stipa comata	Hesperostipa comata

Table 6. Major Grasses of the Northern Short Grass Prairie; Grama-Needlegrass-Wheatgrass Type.		
Standardized Common Name	Flora of the Great Plains 1986	Flora of North America 2003, 2007
Blue grama	Bouteloua gracilis	Bouteloua gracilis
Needle and thread	Stipa comata	Hesperostipa comata
Small needlegrass	Stipa curtiseta	Hesperostipa curtiseta
Western wheatgrass	Agropyron smithii	Pascopyrum smithii
Thickspike wheatgrass	Agropyron dasystachyum	Elymus lanceolatus
Green needlegrass	Stipa viridula	Nassella viridula
Buffalograss	Buchloe dactyloides	Buchloe dactyloides
Associated Grasses		
Red threeawn	Aristida purpurea robusta	Aristida purpurea longiseta
Indian ricegrass	Oryzopsis hymenoides	Achnatherum hymenoides
Plains muhly	Muhlenbergia cuspidata	Muhlenbergia cuspidata
Bluebunch wheatgrass	Agropyron spicatum	Pseudoroegneria spicata
Threadleaf sedge	Carex filifolia	Carex filifolia
Deteriorated Grassland		
Cheatgrass	Bromus tectorum	Bromus tectorum
Japanese brome	Bromus japonicus	Bromus japonicus

Table 7. Major Grasses of the Northern Short Grass Prairie on Salty Soils; Saltgrass Type.		
Standardized Common Name	Flora of the Great Plains 1986	Flora of North America 2003, 2007
Saltgrass	Distichlis spicata stricta	Distichlis spicata
Alkali cordgrass	Spartina gracilis	Spartina gracilis
Basin wildrye	Elymus cinereus	Leymus cinereus
Foxtail barley	Hordeum jubatum	Hordeum jubatum jubatum
Little barley	Hordeum pusillum	Hordeum pusillum
Nuttall's alkali grass	Puccinellia nuttalliana	Puccinellia nuttalliana
Common squirreltail	Sitanion hystrix	Elymus elymoides elymoides
Tumblegrass	Schedonnardus paniculatus	Schedonnardus paniculatus

Table 8. Major Grasses of the Southern Short Grass Prairie; Blue grama-Buffalograss Type.		
Standardized Common Name	Flora of the Great Plains 1986	Flora of North America 2003, 2007
Blue grama	Bouteloua gracilis	Bouteloua gracilis
Buffalograss	Buchloe dactyloides	Buchloe dactyloides
Associated Grasses		
Western wheatgrass	Agropyron smithii	Pascopyrum smithii
Needle and thread	Stipa comata	Hesperostipa comata

Table 9. Major Grasses of the Sandhills Prairie; Bluestem-Sandreed-Grama-Needlegrass Type.		
Standardized Common Name	Flora of the Great Plains 1986	Flora of North America 2003, 2007
Big bluestem	Andropogon gerardii	Andropogon gerardii
Little bluestem	Andropogon scoparius	Schizachyrium scoparium scoparium
Sand bluestem	Andropogon hallii	Andropogon hallii
Prairie sandreed	Calamovilfa longifolia	Calamovilfa longifolia
Sideoats grama	Bouteloua curtipendula	Bouteloua curtipendula
Needle and thread	Stipa comata	Hesperostipa comata
Switchgrass	Panicum virgatum	Panicum virgatum
Blue grama	Bouteloua gracilis	Bouteloua gracilis
Blowout Areas		
Blowout grass	Redfieldia flexuosa	Redfieldia flexuosa
Sandhill muhly	Muhlenbergia pungens	Muhlenbergia pungens
Sand dropseed	Sporobolus cryptandrus	Sporobolus cryptandrus
Indian ricegrass	Oryzopsis hymenoides	Achnatherum hymenoides
Schweinitz cyperus	Cyperus schweinitzii	Cyperus schweinitzii

Table 10. Major Grasses of the Foothills Prairie; Plains Rough Fescue Type.

Standardized Common Name	Flora of the Great Plains 1986	Flora of North America 2003, 2007
Plains rough fescue	Festuca scabrella	Festuca hallii
Parry's oatgrass	Danthonia parryi	Danthonia parryi
Timber oatgrass	Danthonia intermedia	Danthonia intermedia
Bluebunch wheatgrass	Agropyron spicatum	Pseudoroegneria spicata
Slender wheatgrass	Agropyron caninum majus majus	Elymus trachycaulus trachycaulus
Western wheatgrass	Agropyron smithii	Pascopyrum smithii
Thickspike wheatgrass	Agropyron dasystachyum	Elymus lanceolatus
Nelson's needlegrass	Stipa columbiana	Achnatherum nelsonii nelsonii
Richardson's needlegrass	Stipa richardsonii	Achnatherum richardsonii
Needle and thread	Stipa comata	Hesperostipa comata
Prairie Junegrass	Koeleria pyramidata	Koeleria macrantha
Idaho fescue	Festuca idahoensis	Festuca idahoensis
Spike oatgrass	Helictotrichon hookeri	Avenula hookeri
Kentucky bluegrass	Poa pratensis	Poa pratensis
Threadleaf sedge	Carex filifolia	Carex filifolia
Deteriorated Grassland		
Cheatgrass	Bromus tectorum	Bromus tectorum
Japanese brome	Bromus japonicus	Bromus japonicus

Table 11. Major Grasses of the Pacific Bunchgrass Prairie; Bluebunch-Fescue Type.		
Standardized Common Name	Flora of the Great Plains 1986	Flora of North America 2003, 2007
Bluebunch wheatgrass	Agropyron spicatum	Pseudoroegneria spicata
Idaho fescue	Festuca idahoensis	Festuca idahoensis
Western wheatgrass	Agropyron smithii	Pascopyrum smithii
Sideoats grama	Bouteloua curtipendula	Bouteloua curtipendula
Little bluestem	Andropogon scoparius	Schizachyrium scoparium scoparium
Red threeawn	Aristida purpurea robusta	Aristida purpurea longiseta
Needle and thread	Stipa comata	Hesperostipa comata
Plains muhly	Muhlenbergia cuspidata	Muhlenbergia cuspidata
Prairie Junegrass	Koeleria pyramidata	Koeleria macrantha
Blue grama	Bouteloua gracilis	Bouteloua gracilis
Thickspike wheatgrass	Agropyron dasystachyum	Elymus lanceolatus

Table 12. Major Grasses of the Badlands and River Breaks; Woody Draw and Savanna Types.

Standardized Common Name	Flora of the Great Plains 1986	Flora of North America 2003, 2007
Western wheatgrass	Agropyron smithii	Pascopyrum smithii
Needle and thread	Stipa comata	Hesperostipa comata
Blue grama	Bouteloua gracilis	Bouteloua gracilis
Green needlegrass	Stipa viridula	Nassella viridula
Prairie Junegrass	Koeleria pyramidata	Koeleria macrantha
Plains reedgrass	Calamagrostis montanensis	Calamagrostis montanensis
Kentucky bluegrass	Poa pratensis	Poa pratensis
Sandberg bluegrass	Poa sandbergii	Poa secunda
Buffalograss	Buchloe dactyloides	Buchloe dactyloides
Small needlegrass	Stipa curtiseta	Hesperostipa curtiseta
Thickspike wheatgrass	Agropyron dasystachyum	Elymus lanceolatus
Little bluestem	Andropogon scoparius	Schizachyrium scoparium scoparium
Bluebunch wheatgrass	Agropyron spicatum	Pseudoroegneria spicata
Saltgrass	Distichlis spicata stricta	Distichlis spicata

Table 13. Major Grasses of the Pine Savanna; Pine-Juniper-Bluebunch Type.

Standardized Common Name	Flora of the Great Plains 1986	Flora of North America 2003, 2007
Bluebunch wheatgrass	Agropyron spicatum	Pseudoroegneria spicata
Western wheatgrass	Agropyron smithii	Pascopyrum smithii
Thickspike wheatgrass	Agropyron dasystachyum	Elymus lanceolatus
Needle and thread	Stipa comata	Hesperostipa comata
Blue grama	Bouteloua gracilis	Bouteloua gracilis
Green needlegrass	Stipa viridula	Nassella viridula
Little bluestem	Andropogon scoparius	Schizachyrium scoparium scoparium

Table 14. Major Grasses of the Black Hills Pine Forest; Pine-Spruce-Aspen Type.

Standardized Common Name	Flora of the Great Plains 1986	Flora of North America 2003, 2007
Western wheatgrass	Agropyron smithii	Pascopyrum smithii
Bluebunch wheatgrass	Agropyron spicatum	Pseudoroegneria spicata
Needle and thread	Stipa comata	Hesperostipa comata
Green needlegrass	Stipa viridula	Nassella viridula
Prairie Junegrass	Koeleria pyramidata	Koeleria macrantha
Blue grama	Bouteloua gracilis	Bouteloua gracilis
Hairy grama	Bouteloua hirsuta	Bouteloua hirsuta
Buffalograss	Buchloe dactyloides	Buchloe dactyloides
Needleleaf sedge	Carex eleocharis	Carex duriuscula
Threadleaf sedge	Carex filifolia	Carex filifolia

Table 15. Major Grasses of the Montane Forest; Pine-Fir-Spruce Type.

Standardized Common Name	Flora of the Great Plains 1986	Flora of North America 2003, 2007
Bluebunch wheatgrass	Agropyron spicatum	Pseudoroegneria spicata
Idaho fescue	Festuca idahoensis	Festuca idahoensis
Nelson’s needlegrass	Stipa columbiana	Achnatherum nelsonii nelsonii
Spike fescue	Hesperochloa kingii	Leucopoa kingii
Prairie Junegrass	Koeleria pyramidata	Koeleria macrantha
Needle and thread	Stipa comata	Hesperostipa comata
Spike oatgrass	Helictotrichon hookeri	Avenula hookeri
Sandberg bluegrass	Poa sandbergii	Poa secunda

Table 16. Major Grasses of the Upland Woodlands; Aspen-Ash-Oak-Juniper Types.

Standardized Common Name	Flora of the Great Plains 1986	Flora of North America 2003, 2007
Roughleaf ricegrass	Oryzopsis asperifolia	Oryzopsis asperifolia
Little ricegrass	Oryzopsis micrantha	Piptatherum micranthum
Long-beaked sedge	Carex sprengelii	Carex sprengelii
Kentucky bluegrass	Poa pratensis	Poa pratensis
Associated Grasses		
Western wheatgrass	Agropyron smithii	Pascopyrum smithii
Bluebunch wheatgrass	Agropyron spicatum	Pseudoroegneria spicata
Thickspike wheatgrass	Agropyron dasystachyum	Elymus lanceolatus
Blue grama	Bouteloua gracilis	Bouteloua gracilis
Porcupinegrass	Stipa spartea	Hesperostipa spartea
Little bluestem	Andropogon scoparius	Schizachyrium scoparium scoparium

Table 17. Major Grasses of the Riparian Woodlands; Cottonwood-Ash-Elm Type.

Standardized Common Name	Flora of the Great Plains 1986	Flora of North America 2003, 2007
Canada wildrye	Elymus canadensis	Elymus canadensis
Slender wheatgrass	Agropyron caninum majus majus	Elymus trachycaulus trachycaulus
Virginia wildrye	Elymus virginicus	Elymus virginicus
Prairie sandreed	Calamovilfa longifolia	Calamovilfa longifolia
Needle and thread	Stipa comata	Hesperostipa comata
Green needlegrass	Stipa viridula	Nassella viridula
Marsh muhly	Muhlenbergia racemosa	Muhlenbergia racemosa
Reed canarygrass	Phalaris arundinacea	Phalaris arundinacea
Prairie cordgrass	Spartina pectinata	Spartina pectinata
Bottlebrush grass	Hystrix patula	Elymus hystrix
Mountain ricegrass	Oryzopsis racemosa	Piptatherum racemosum
Kentucky bluegrass	Poa pratensis	Poa pratensis
Yellow sedge	Carex pensylvanica	Carex pensylvanica
Long-beaked sedge	Carex sprengelii	Carex sprengelii

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Managing Drought Resistance into Grasslands

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

The percent reduction in herbage production during drought conditions on grasslands managed with traditional grazing management practices, like repeated seasonal, seasonlong, and deferred grazing, is greater than the percent reduction in precipitation (Manske 2002a, b). The shortage of rainfall is the most obvious detrimental factor occurring during a drought, however, it is not the only factor contributing to the reduction in herbage biomass production. The other primary factors responsible for this enhanced loss of herbage production are reductions in available mineral nitrogen and degradation of ecosystem health status.

Reductions in mineral nitrogen limit herbage production more often than water in temperate grasslands (Tilman 1990). Grasslands in the Northern Plains are not low in nitrogen. Grassland soils contain about 3 to 8 tons of organic nitrogen per acre. Plants, however, can not use organic nitrogen. The organic nitrogen must be converted into inorganic (mineral) nitrogen to be usable by plants. Soil microorganisms in the rhizosphere zone around perennial grass roots convert organic nitrogen into inorganic nitrogen. This process is symbiotic and mutually beneficial for both the plants and the rhizosphere organisms. Plants fix carbon and capture energy from the sun during photosynthesis. Organisms in the rhizosphere are low in carbon and receive a portion of the carbon fixed by the plants. Grassland plants are low in inorganic nitrogen which is a waste product from rhizosphere organism metabolism. Plants trade carbon to rhizosphere organisms for nitrogen and rhizosphere organisms trade nitrogen to plants for carbon (Manske 2007).

The quantity of organic nitrogen converted into inorganic nitrogen by rhizosphere organisms is dependent on the quantity of carbon released into the rhizosphere by plants. The quantity of carbon released by the plants is dependent on the type of grazing management practices used and the amount of leaf material removed by grazing at different plant phenological growth stages. Traditional grazing management practices that are not based on the biological requirements and the phenological growth stages of plants restrict the quantity of carbon released into the rhizosphere causing a reduction in rhizosphere organism volume and activity, resulting in a reduction in the quantity of available inorganic nitrogen. The quantity of available inorganic nitrogen gradually decreases each year. After several years of management with traditional grazing practices that are antagonistic to biogeochemical proceses, the accumulated reduction in available inorganic nitrogen results in a substantial reduction in herbage biomass production; generally around 25% to 50% of the grasslands' potential herbage biomass production during average growing seasons (Manske 2007).

Wight and Black (1979) conducted a fertilization on native rangeland plot study at the ARS Research Center, Sidney, MT from 1967 to 1976 and determined the precipitation use efficiency (pounds of herbage produced per inch of precipitation received) for unfertilized treatments deficient in available mineral nitrogen and fertilized treatments not deficient in available mineral nitrogen. The pounds of herbage produced per inch of precipitation were greater on rangeland ecosystems with adequate mineral nitrogen available compared to rangeland ecosystems that had insufficient quantities of available mineral nitrogen. During the eight study years with normal precipitation, the ambient deficiency in available mineral nitrogen on rangeland ecosystems caused the weight of herbage production per inch of precipitation to be reduced an average of 45.4% below the herbage produced per inch of precipitation on rangeland ecosystems without mineral nitrogen deficiencies.

The traditional grazing management practices of 6.0-month seasonlong (6.0-M SL) and 4.5-month seasonlong (4.5-M SL) caused decreases of 51.2% and 33.7% in rhizosphere volume after 20 years of treatment, respectively (figure 1) (Manske 2008b). A traditional deferred (DEF) grazing practice caused a 70.6% decrease in available mineral nitrogen after 35 years of treatment (figure 1) (Manske 2008b). During growing seasons with drought conditions, both inorganic nitrogen and soil water are greatly diminished in grasslands managed with traditional grazing practices and together low nitrogen and low water cause most of the reductions in herbage production and the resulting reductions in stocking rate.

The biologically effective twice-over rotation grazing management strategy (TOR) that is based on partial defoliation at beneficial phenological growth stages and on meeting the biological requirements of grass plants enhanced the biogeochemical processes in grassland ecosystems and caused a 67.7% increase in available inorganic nitrogen after six years of treatment and caused a 122.7% increase in rhizosphere volume after 20 years of treatment (figure 1) (Manske 2008b).

Biologically effective grazing management improves the biogeochemical processes in grassland ecosystems and activates the defoliation resistance mechanisms in grass plants. The increased rhizosphere organism volume and activity increases the quantity of available mineral nitrogen resulting in increases in herbage biomass production and beef weight production per acre. The increased ectomycorrhizal fungi in the rhizosphere improves the structure of the soil by increasing the quantity and depth of aggregation which increases the quantity of water infiltration and increases the water holding capacity of the soil. The increased plant density and increased litter cover shade the soil, lowering the soil temperature and decreasing the rate of soil water loss through evaporation (Manske 2007). Biologically effective grazing management improves the health status of grassland ecosystems (Manske 2001) and increases the drought resistance of grasslands.

Drought resistance in grasslands is directly related to the ecosystem health status and depends on the effectiveness of the grazing management to meet the biological requirements of grass plants, to enhance the ecosystems biogeochemical processes, to cause improvements in soil aggregation, water infiltration, water holding capacity, vegetative reproduction, plant density, litter cover, rhizosphere volume and microorganism activity, and to increase the quantity of available mineral nitrogen converted from soil organic nitrogen.

The antagonistic effects of traditional grazing management practices on the living and nonliving (abiotic) ecosystem components degrade ecosystem health status and decrease drought resistance over time in grasslands by causing deterioration of soil characteristics, reduction of plant physiological mechanisms, decrease of rhizosphere volume and activity, suppression of ecosystem biogeochemical processes, and reduction of the quantity of available mineral nitrogen. The level of ecosystem health status and drought resistance determines the severity of the reduction in herbage biomass production and the reduction in stocking rate during drought conditions, and determines the length of time needed for ecosystem recovery following a drought.

Grasslands with low health status managed by heavy stocking or by starting dates too early and/or ending dates too late with traditional grazing practices, like repeated seasonal, 6.0-month seasonlong, and deferred grazing, require 2 years of recovery with reduced stocking rates for moderate drought conditions and 4 years of recovery with greatly reduced stocking rates for severe drought conditions (Whitman et al. 1943; Manske 1989, 1990).

Grasslands with moderate health status managed with moderately stocked traditional grazing practices, like 4.5-month seasonlong, require 1 year of recovery with reduced stocking rates for moderate drought conditions and 2 years of recovery with reduced stocking rates for severe drought conditions (Manske 1989, 1990).

Grasslands with high health status managed with biologically effective twice-over rotation grazing strategies have sufficient resistance to moderate drought conditions that reduction in stocking rate is not necessary during 1 season of moderate drought, however, if 2 growing seasons with moderate drought conditions occur successively, stocking rates need to be reduced during the second season. High health status grasslands require less than 1 growing season with no reduction in stocking rates to recover from moderate drought conditions and require 1 year with reduced stocking rates to recover from severe drought conditions (Manske 1989, 1990).

Periods with rainfall shortage are normal weather conditions for the Northern Plains. Average 6 month perennial plant growing seasons, mid April to mid October, have water deficiency or drought conditions during 32.8% of the period, amounting to 2 months per growing season, and occur during 78.5% of the years. Growing seasons with drought conditions that receive less than 75% of the long-term mean precipitation occur during 15.5% of the years. Moderate drought conditions, that have growing season precipitation at less than 75% and greater than 50% of the long-term mean, occur during 12.1% of the years. Severe drought conditions, that have growing season precipitation at less than 50% of the long-term mean, occur during 3.5% of the years. Nondrought conditions are actually the abnormal phenomenon and occur during only 6.0% of the growing seasons (table 1) (Manske 2008a).

During a hypothetical 48 year career in agriculture (table 1), a beef producer in the Northern Plains experiences 3 growing seasons with no drought conditions, 37 growing seasons each with an average of 2 months with water deficiencies, 6 growing seasons with moderate drought conditions that have precipitation at less than 75% but greater than 50% of the long-term mean, and 2 growing seasons with severe drought conditions that have precipitation at less than 50% of the long-term mean.

Grasslands with low health status and low drought resistance have a total of 28 years during a 48 year career (58.3%) with reduced herbage production and reduced stocking rates; 8 years caused by drought conditions and 20 years caused by recovery from drought conditions; and have 20 years (41.7%) in which the grasslands are properly stocked at full capacity (table 1).

Grasslands with moderate health status and moderate drought resistance have a total of 18 years during a 48 year career (37.5%) with reduced herbage production and reduced stocking rates; 8 years caused by drought conditions and 10 years caused by recovery from drought conditions; and have 30 years (62.5%) in which the grasslands are properly stocked at full capacity (table 1).

Grasslands with high health status and high drought resistance have a total of 4 years during a 48 year career (8.3%) with reduced herbage production and reduced stocking rates; 2 years caused by drought conditions and 2 years caused by recovery from drought conditions; and have 44 years (91.7%) in which the grasslands are properly stocked at full capacity (table 1).

The shortage of rainfall is not the only factor that causes reductions in herbage production and reductions in stocking rate during drought conditions. Deteriorated soil characteristics, reduced plant physiological mechanisms, decreased rhizosphere volume and activity, suppressed ecosystem biogeochemical processes, and reduced available mineral nitrogen on grasslands with low or moderate health status are the additional negative factors that intensify the severity of the problems that develop during drought conditions. These living and nonliving (abiotic) ecosystem components can be improved with biologically effective grazing management and changed into beneficial factors that diminish the detrimental effects from drought conditions on grasslands with high health status. Implementation of twice-over rotation grazing management can improve the drought resistance in grasslands.

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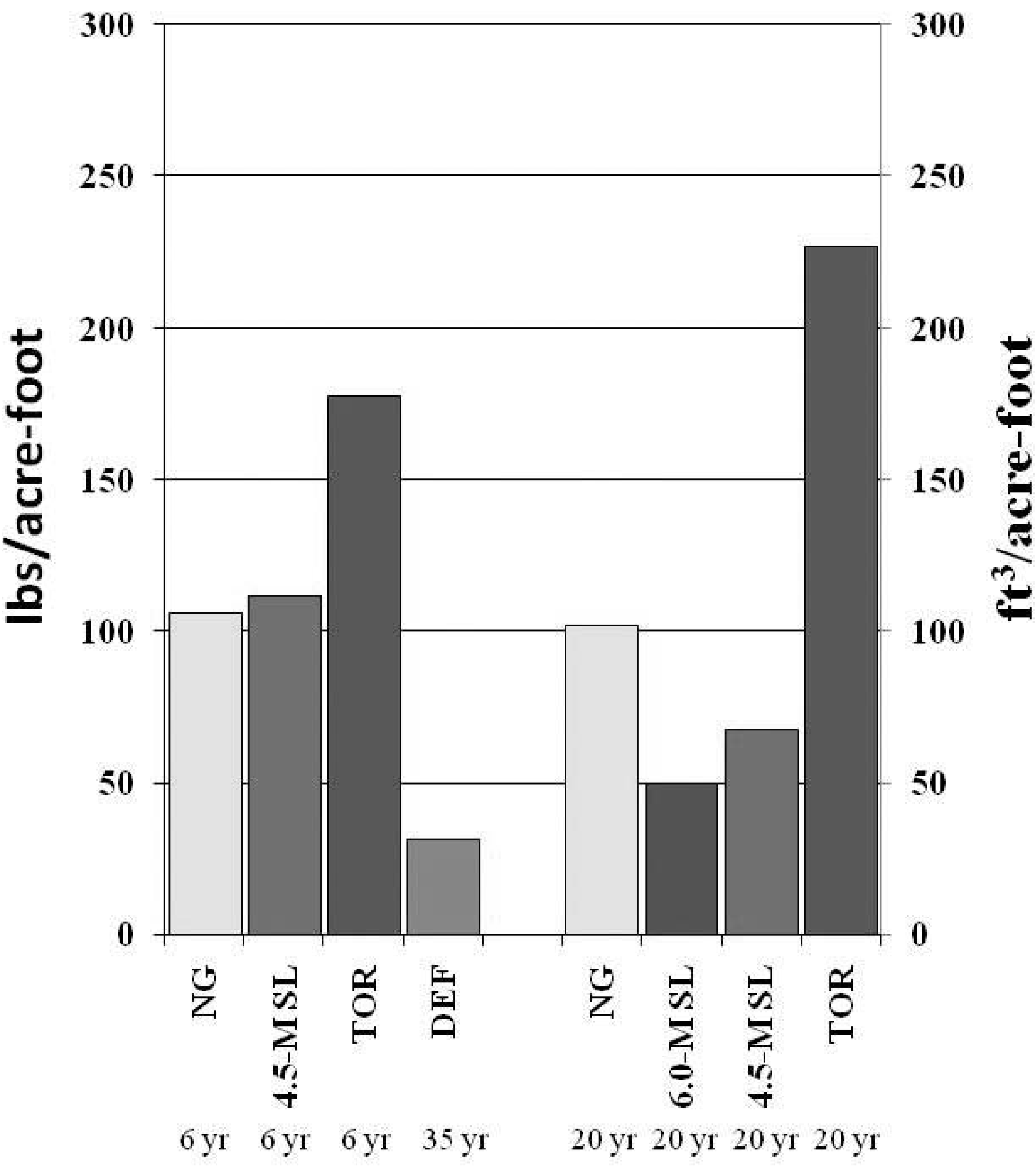

Mineral nitrogen (lbs/ac-ft) and rhizosphere volume (ft^3/ac-ft) for 6, 20, and 35 years of grazing treatments.

Table 1. Effects from drought conditions and length of recovery time on the number of years with reduced stocking rates on grasslands with different managed health status.

			Healthy Grasslands	Moderately Healthy Grasslands	Low Health Grasslands
Ag Career		yrs	48	48	48
No Drought	(6.0%)	yrs	3	3	3
Drought for 2 mo/yr	(78.5%)	yrs	37	37	37
Moderate Drought Growing Seasons	(12.1%)	yrs	6	6	6
Recovery Time		yrs	0	6	12
Severe Drought 1936-1988 levels	(3.5%)	yrs	2	2	2
Recovery Time		yrs	2	4	8
Reduced Stocking for Droughts		yrs	2	8	8
Reduced Stocking for Recovery Time		yrs	2	10	20
Total Time with Reduced Stocking		yrs	4	18	28
Fully Stocked		yrs	44	30	20

Drought frequency data from Manske 2008a.
Recovery time data from Whitman et al. 1943 and Manske 1989, 1990.

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Environmental Factors that Affect Range Plant Growth, 1892-2008

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

Environmental factors affect range plant growth. 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. 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 (Manske 2009).

Light is the most important ecological factor affecting plant growth. 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. 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 changes during the growing season, increasing from about 13 hours in mid April to nearly 16 hours in mid June, then decreasing to around 11 hours in mid October (Fig. 1).

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. Most plant biological activity and growth occur within only a narrow range of temperatures, between 32° F (0° C) and 122° F (50° C). The long-term (117-year) mean annual temperature in the Dickinson, North Dakota, area is 40.9° F (4.9° C) (Table 1). January is the coldest month, with a mean temperature of 11.5° F (-11.4° C). July and August are the warmest months, with mean temperatures of 68.8° F (20.4° C) and 67.0° F (19.5° 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). Perennial grassland plants are capable of growing for longer than the frost-free period, but to continue active growth, they require temperatures above the level that freezes water in plant tissue and soil. Winter dormancy in perennial plants is not total inactivity but reduced activity.

Water (precipitation) 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 biochemically important because it is a necessary component in physiological processes. Plant water stress limits growth. Water stress can vary in degree from a small decrease in water potential to the lethal limit of desiccation. The long-term (117-year) annual precipitation for the area of Dickinson, North Dakota, is 15.97 inches (405.67 mm). The growing season precipitation (April to October) is 13.50 inches (343.13 mm), 84.58% of the annual precipitation. June has the greatest monthly precipitation, at 3.54 inches (89.97 mm). The seasonal distribution of precipitation (Table 2) shows the greatest amount of precipitation occurring in the spring (7.29 inches, 45.70%) and the smallest amount occurring in winter (1.53 inches, 9.58%). Total precipitation received in November through March averages less than 2.5 inches (15.47%). The precipitation received in May, June, and July accounts for 50.66% of the annual precipitation (8.09 inches).

Of the past 117 years (1892 to 2008), 14 (11.97%) were drought years, receiving 75% or less of the long-term mean precipitation level. Fifteen (12.82%) were wet years, receiving 125% or more of the long-term mean precipitation level. Eighty-eight years (75.21%) received normal annual precipitation amounts, between 75% and 125% of the long-term mean. Of the past 117 growing seasons, 18 (15.38% were drought growing seasons, 20 (17.09%) were wet growing seasons, and 79 (67.52%) received precipitation at normal levels.

Temperature and precipitation act together to affect the physiological and ecological status of range plants. The balance between rainfall and potential evapotranspiration determines a plant's biological situation. When rainfall is lower than evapotranspiration demand, a water deficiency exists. The ombrothermic graph technique (Emberger et al. 1963), which plots mean monthly temperature and monthly precipitation on the same axis, was used to identify months with water deficiency conditions during 1892-2008 (Manske 2009). The long-term ombrothermic graph for the Dickinson area (Fig. 2) shows near water deficiency conditions for August, September, and October, a finding indicating that range plants generally may have difficulty growing and accumulating biomass during these 3 months. Favorable water relations occur during May, June, and July, a period during which range plants should be capable of growing and accumulating herbage biomass.

Drought years occurred during 12.0% of the past 117 years, and 15.4% of the growing seasons were drought growing seasons. The 117-year period (1892 to 2008) contained a total of 702 growing-season months. Water deficiency conditions occurred during 230.5 of these, a finding indicating that during 32.83% of the growing season months, or for an average of 2.0 months during every 6.0-month growing season, range plants were under water stress and therefore limited in growth and herbage biomass accumulation. Water deficiency occurred in May and June 13.7% and 10.3 % of the time, respectively. Water deficiency conditions occurred in July less than 40% of the time. Water deficiency conditions occurred in August, September, and October more than 50% of the time: 52.1% of the time in August, 50.4 % of the time in September, and 47.0% of the time in October. Water deficiency conditions lasting a month or more cause plants to experience water stress severe enough to reduce herbage production. These levels of water stress are a major factor limiting the quantity and quality of plant growth in western North Dakota and can limit livestock production if not considered during the development and implementation of long-term grazing management strategies.

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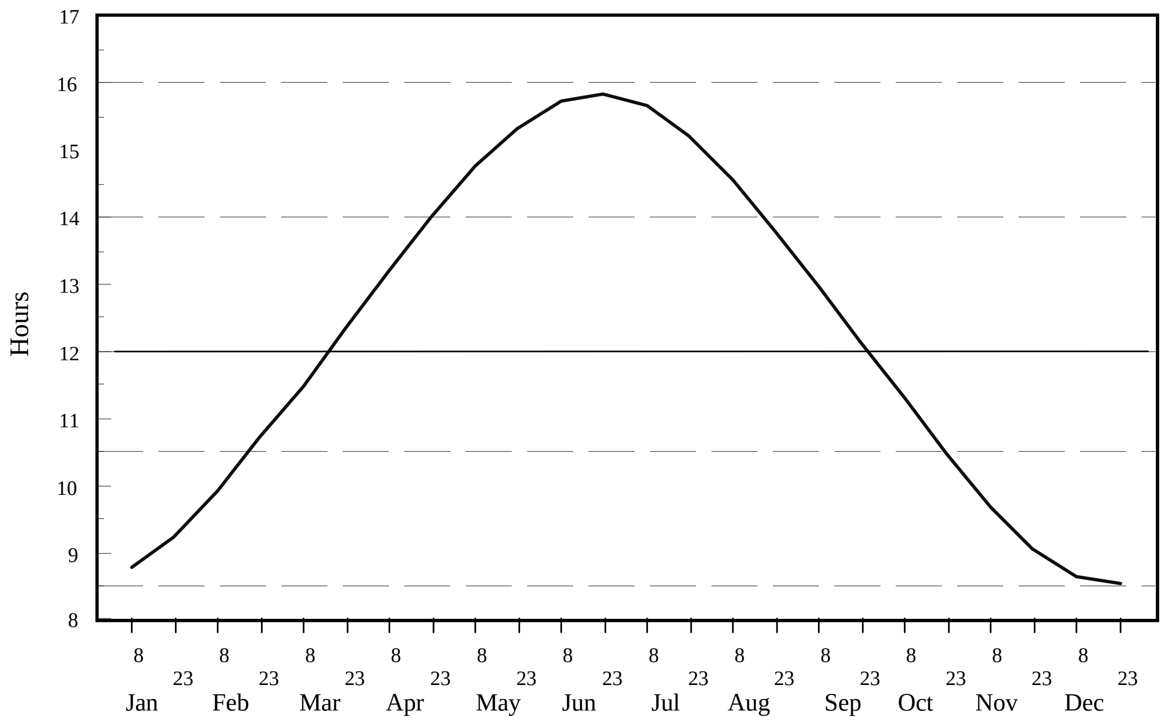

Fig. 1. Annual pattern of daylight duration at Dickinson, North Dakota.

Table 1. Long-term (1892-2008) mean monthly temperature and monthly precipitation at Dickinson, ND.

	° F	° C	in.	mm
Jan	11.48	-11.40	0.41	10.39
Feb	15.29	-9.28	0.40	10.15
Mar	26.20	-3.22	0.72	18.27
Apr	41.57	5.32	1.42	35.97
May	52.80	11.56	2.33	59.22
Jun	62.00	16.67	3.54	89.97
Jul	68.79	20.44	2.22	56.41
Aug	67.03	19.46	1.72	43.75
Sep	56.05	13.36	1.32	33.58
Oct	43.77	6.54	0.95	24.23
Nov	28.38	-2.01	0.54	13.62
Dec	17.01	-8.33	0.40	10.11
	MEAN		**TOTAL**	
	40.86	**4.93**	**15.97**	**405.67**

Table 2. Seasonal percentage of mean annual precipitation distribution (1892-2008).

Season	in.	%
Winter (Jan, Feb, Mar)	1.53	9.58
Spring (Apr, May, Jun)	7.29	45.70
Summer (Jul, Aug, Sep)	5.27	33.01
Fall (Oct, Nov, Dec)	1.89	11.82
TOTAL	15.97	

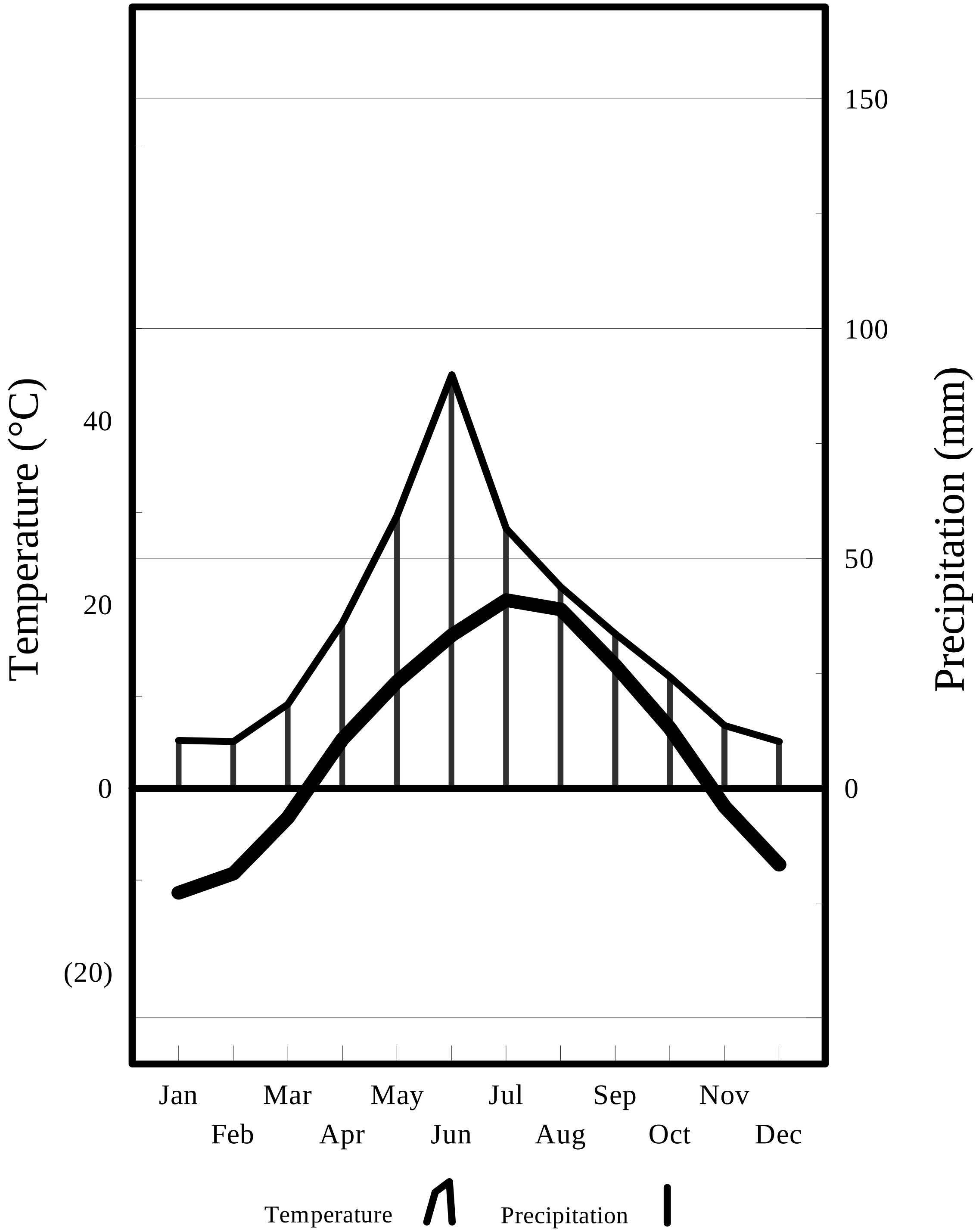

Fig. 2. Ombrothermic diagram of long-term (1892-2008) mean monthly temperature and monthly precipitation at Dickinson, North Dakota.

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