Circumstances that Impelled Fertilization Treatment Research on Native Rangeland

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Nitrogen fertilization research projects were conducted in the Northern Plains in an attempt to find and develop cultural management practices that could be used to recover the degraded ecological condition, to return the natural botanical composition, and to restore the herbage biomass production of deteriorated native grassland ecosystems. The deterioration of the grassland resources was caused by an accumulation of antagonistic byproducts from naive land management practices that were implemented during the progressive stages of European settlement of the region.

European settlement of western North Dakota followed the railroad. In 1864, Congress passed the Federal Railroad Land Grant Act. Under that act, the Northern Pacific Railroad was given a grant of 39 million acres of land in a checkerboard pattern from Duluth, Minnesota to Puget Sound, Washington. Construction of the railroad started in 1870 at Superior, Wisconsin and reached Moorhead, Minnesota in December 1871. The tracks reached Bismarck, North Dakota in June 1873 and halted there until 1879. The Northern Pacific Railroad sold 4,352,000 acres in North Dakota between 1875 and 1895 for an average price of $3.90/acre. Construction of the tracks started again and reached Dickinson in 1880 and reached the Montana border in 1881. During the early stages of the settlement process, the railroad was used to move people west and to ship regional resources east.

The railroad moved about 5,000 buffalo skinners to Bismarck by 1882 and shipped 1.5 million bison hides to eastern markets between 1880 and 1884. This activity eliminated the northern bison herds west of the Missouri River in western North Dakota and eastern Montana. The last carload of hides containing the skins from the last herd of 300 free roaming bison was shipped from Dickinson, North Dakota in 1884.

While the bison herds were being removed, cattle outfits were trailing livestock from Texas into western North Dakota and eastern Montana to be fattened on the open range grass and then shipped to eastern markets by rail. Several large herds of mostly light weight 2-4 year old steers and dry cows were trailed north in 1882 and 1883. The first regional roundup in western North Dakota was conducted in the spring of 1884. The estimated population of cattle was 30 to 40,000 head in a district that was 100 by 50 miles, with Medora, North Dakota near the center. The stocking level at that time was 80 to 100 acres per head for a year of grazing. In western North Dakota, a 1200 pound cow needs 55.4 acres for a year of forage dry matter. During the fall of 1886, the stockman in western North Dakota and eastern Montana declared the district to be fully stocked and that no new outfits would be permitted to bring in cattle or horses.

The winter of 1886-1887 was very severe with numerous blizzards, very strong winds, and long spells of bitter sub-zero temperatures. By spring, 50% to 75% of the cattle were lost. Most of the absentee owner outfits pulled out. A few locally owned and operated outfits remained. The herd sizes stayed small and the numbers of grazing animals were not intensified because the financial backers considered the business of fattening cattle on western open range grass to be too risky. The cattle numbers were greatly reduced again during the drought of 1891 to 1893. The period of open range grazing of Texas cattle was not long and the grasslands were not heavily stocked. Had the grazing practices that were being developed during the open range period been permitted to progress, land management strategies in the semiarid regions of North America would have been based on low intensity pastoral philosophies similiar to the other grazing regions of the world that did not have homestead activity.

The human population of western North Dakota greatly increased between 1898 to 1915 with the peak period of activity between 1900 and 1910. Title to land was transferred from the US Government to private citizens through the Homestead Act and its many revisions. The Homestead Act provided that a person could claim 160 acres of public domain lands after filing and “prove up” on it for five years. During the period that much of North Dakota was settled, there was a provision in the Homestead Act that allowed a person to commute the homestead by a preemption right and pay the regular price of $1.25 or $2.50 per acre anytime after six months from the date of filing. About half of the acreage changing from public domain to private ownership in North Dakota after 1900 and before 1929 were commuted acres. The proceeds from a single crop of wheat or flax produced on 5 or 10 acre fields could pay for the purchase price. The Taylor Grazing Act of 1934 removed all unappropriated public domain lands from homestead, which included 68,442 acres in North Dakota.

The Homestead Act had many revisions in attempts to adjust the law to meet the needs of the people and the natural resources. None of the many revisions to the Homestead Act met the needs of the country west of the 100th Meridian. Failure of the lawmakers to address the requirements of natural resource management in semiarid regions created numerous long-lasting problems. This predicament was aggravated by the degradation of the grassland resources caused by the exceptionally high stocking rates suggested for use during the homestead period.

The heavy stocking rates used for cattle grazing in western North Dakota until 1934 (Whitman et al. 1943) were the suggested stocking rates ascertained from initial grassland research investigations in North Dakota. A grazing intensity study conducted from 1916 to 1929 by J.T. Sarvis at the Northern Great Plains Research Center, Mandan, North Dakota, examined 5.0-month seasonlong grazing at stocking rates that removed 75% to 80% of the total annual production and left 20% to 25% of the vegetation standing at the end of each season (Lorenz 1970). Sarvis (1941) determined these stocking rates to be neither over nor undergrazed. Whitman et al. (1943) considered the rangelands of western North Dakota to be heavily overstocked and that the livestock grazing pressure was around 67.5% heavier than the grasslands' carrying capacity that had been determined from the then recent range surveys conducted in western North Dakota by the Agricultural Adjustment Administration Office.

This widespread heavy overgrazing of Northern Plains grasslands greatly intensified the damaging effects caused by the drought conditions of 1934 and 1936. The drought damage to the grassland vegetation was severe, resulting in a 57% decrease in total cover density and a 56% reduction in plant height (Whitman et al. 1943). With cessation of the drought conditions, the favorable precipitation and a reduction of more than 60% in the stocking rates were responsible for the recovery of the vegetation in four years, with a return to the predrought densities and no change in composition of the major dominant species (Whitman et al. 1943). After 1936, the Northern Plains prairie and its soil were no longer considered to be inexhaustible.

The severe droughts of the 1930's combined with the economic depressions of the 1920's and 1930's and the low agricultural commodity prices received after 1929 created extreme hardships for the homesteaders in semiarid regions. These struggling people did not have sufficient productivity or financial income from the degraded natural resources on 160 acres to support their families. The homesteaders living on lands declared to be submarginal were given the option to sell their land back to the federal government. The Land Utilization Project was established in 1935 and a resettlement plan was completed that same year. The Bankhead-Jones Farm Tenant Act was passed by Congress on 22 July 1937. Under these legislative acts, 1,104,789 acres were purchased by the US Government in North Dakota. Most of these repurchased lands were managed with a follow up program of land conservation and a utilization plan. The homesteaders living on marginal or better lands did not have the option to sell to the federal government and were faced with abandonment of their land or finding a private buyer with sufficient credit.

Agricultural operations that survived the calamities of the 1930's had painfully discovered that eastern farming and grazing practices did not work west of the 20 inch rainfall line; regardless of these hard lessons, the problems of low productivity from the resulting poor condition of the cropland and grazingland continued. Major efforts to develop agricultural management practices suitable for semiarid lands were started in the 1930's but had to be postponed until after World War II. Tree shelterbelts, crop rotation, and contour strip farming methods were introduced to improve the croplands. Reduced stocking rates and deferred rotation grazing management were introduced to improve the grazinglands. The stocking rate problems were solved when Crider (1955) determined that proper stocking rates removed less than 50% of the herbage and that grass tillers with 50% or more of the aboveground leaf material removed reduced root growth, root respiration, and root nutrient absorption. However, the grazing management problems had not been solved because the deferred method of grazing was found to negatively affect grassland ecosystems. After 12 years of grazing deferment research, Sarvis (1941) was unable to determine any improved benefit to grass plant density from reseeding of the grasses with deferred grazing. Manske et al. (1988), in a three year study, found that total grass basal cover decreased significantly after one year of deferred grazing treatment. Grazing management practices that were beneficial for grassland ecosytems would not be developed until the early 1980's after scientists were able to describe and understand the complex physiological mechanisms and biogeochemical processes of the herbivore-grass-soil organism symbiotic system.

Consequently, those were the circumstances leading up to the 1950's that impelled grassland ecologists and rangeland scientists to investigate fertilization treatments for possible improvement in the deteriorated grassland ecosystems of the Northern Plains.

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Evaluation of Nitrogen Fertilization Treatments on Native Rangeland

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Fertilization treatments on native rangeland were evaluated as potential cultural practices to reverse the declining and deteriorating ecological condition of Northern Plains mixed grass prairie communities resulting from the unmanaged negative aspects of livestock defoliation caused by inappropriate season of use and/or too heavy use over a prolonged period of time (Goetz 1984). The objectives of the research treatments were to improve the nutrient cycles of the ecosystem, to return the natural balance of the botanical species composition, and to restore the productivity of the total herbage biomass of deteriorated native rangelands.

Procedure

Four fertilization treatment plot studies were conducted between 1957 and 1978 at the Dickinson Research Extension Center.

Nitrogen fertilization of native rangeland plot study I (1957)

Nitrogen fertilization of native rangeland plot study I (1957) was conducted by Dr. Warren C. Whitman on a heavily grazed pasture located at the original site of the livestock farm of the Dickinson Research Extension Center. The fertilized strip plots were arranged in a randomized block design with three replications. The ammonium nitrate fertilizer (33-0-0) was broadcast applied 24 April 1957 at three rates: 50 lbs N/ac, 100 lbs N/ac, and 150 lbs N/ac. Plots with no fertilizer applied were used as control checks. Dry matter weight of aboveground herbage was sampled by the clipping method at the end of the active growing season (around early to mid August). Herbage protected from grazing by two 4 X 4 foot movable steel cages was clipped at a height of one-quarter inch and separated into three categories: mid grasses, short grasses, and forbs. The plant material was oven dried and weighed (Whitman 1957).

Nitrogen fertilization of native rangeland plot study II (1962-1963)

Nitrogen fertilization of native rangeland plot study II (1962-1963) was conducted by Dr. Warren C. Whitman on two sites, a creek terrace and a west facing upland slope, located in a west pasture at the original site of the livestock farm of the Dickinson Research Extension Center. The 10 X 40 foot plots were arranged in a randomized block design with four replications. The treatments included a check 0 lbs N/ac, 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac. The ammonium nitrate fertilizer (33-0-0) was broadcast applied in the spring of each year. Dry matter weight of aboveground herbage was sampled by the clipping method at the end of the active growing season (around early to mid August). Herbage was clipped at a height of one-quarter inch and separated into three categories: mid grasses, short grasses, and forbs. The plant material was oven dried and weighed (Whitman 1962, 1963). Differences between yearly means were analyzed for this report by a standard paired-plot t-test (Mosteller and Rourke 1973).

Nitrogen fertilization of native rangeland plot study III (1964-1969)

Nitrogen fertilization of native rangeland plot study III (1964-1969) was conducted by Dr. Warren C. Whitman and Dr. Harold Goetz on four different range sites located within a 35 mile radius of Dickinson, ND. These four sites were representative of the important soils on a major portion of the grazinglands in the region. The soils were: Havre, Manning, Vebar, and Rhoades (Goetz 1969a).

The Havre silt loam soil, Frigid Ustic Torrifluvent, comprised a deep, light colored alluvium that occupied creek bottom floodplains in the Badlands. This overflow range site was located in the Pyramid Park pasture portion of the Dickinson Research Extension Center south of Fryburg, ND. During the study, this site was grazed during the summer and was in near excellent condition. The most important plants were western wheatgrass, plains reedgrass, green needlegrass, and silver sagebrush (Goetz 1969a).

The Manning silt loam soil, Typic Haploboroll, developed on a high river terrace underlain by a gravel layer at about 18-24 inches below the surface. This silty range site was located on private land along the Heart River near Taylor, ND. During the study this site was grazed heavily during early summer and was in low good condition. The most important plants were western wheatgrass, needle and thread, blue grama, threadleaf sedge, and fringed sagebrush (Goetz 1969a).

The Vebar fine sandy loam soil, Typic Haploboroll, developed from weathered weakly-cemented tertiary sandstone and was associated with gently undulating to moderately steep topography. This sandy range site was located in a north pasture at the original site of the livestock farm of the Dickinson Research Extension Center. During the study, this site was grazed heavily during late fall and was in low good condition. The most important plants were western wheatgrass, needle and thread, plains reedgrass, blue grama, threadleaf sedge, and white sagebrush (Goetz 1969a).

The Rhoades silty loam, high sodium, solonetz soil, Leptic Natriboroll, comprised a near impervious layer of dispersed clay particles in the profile varying in depth from the soil surface to approximately 20 inches. This thin claypan range site was studied at two places with both located south of Fryburg, ND; site A was used from 1964 to 1966 and site B was used from 1968 to 1969. During the study, these two sites were grazed during summer and were in low good condition. Because of the numerous claypans and barren panspots and low herbage production, these sites had reduced grazing capacity. The most important plants were western wheatgrass, blue grama, Sandberg bluegrass, and brittle prickly pear (Goetz 1969a).

The 30 X 100 foot plots were arranged in a randomized block design with four replications separated by 6 foot wide alleyways. The treatments included a check 0 lbs N/ac, 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac. Application of phosphorus alone and with nitrogen were treatments also included with this study but not included in this report. The ammonium nitrate fertilizer (33-0-0) was broadcast applied in granular form early in the spring of each year between 10 and 15 April, except in 1967 when a late snowstorm delayed application until 10 May (Whitman 1964, 1967).

The vegetation on each plot was protected from grazing by three steel wire quonset type cages measuring 3 X 7 foot. Dry matter weight of aboveground herbage was sampled by the clipping method at the end of the active growing period (around early to mid August). Herbage was clipped to ground level from three 2.5 X 5 foot steel frames per plot and separated into five categories: tall grasses, mid grasses, short grasses, perennial forbs, and annual forbs. The plant material was oven dried and weighed (Whitman 1964, Goetz 1969a). Differences between yearly means were analyzed for this report by a standard paired-plot t-test (Mosteller and Rourke 1973).

Quantitative species composition was determined by percent basal cover sampled with the ten-pin point frame method. The point frame was placed at 10 foot intervals in 5 lines of 10 sets. The 5 lines were placed 5 feet apart. A total of 2000 points was taken in each treatment, on each site, during three years (1964-1966) (Goetz 1969a).

Root development and distribution in the soil profile were determined from dry matter weight of root material per soil sample depth. Soil samples were collected with a tractor-mounted hydraulic soil probe using a 1.4059 inch diameter soil tube. Eight samples per plot (32 per treatment) were taken from 0-6, 6-12, 12-18, 18-24, 24-36, and 36-48 inch depths at the end of the growing season, 1966. The root cores were washed over a 60-mesh screen, oven dried at 147.2° F, and weighed. Data were statistically analyzed with the Duncan's multiple range test (Goetz 1969b).

Plant growth in height was determined for major species by measuring to the nearest 1 cm the leaves and stems of 20 plants at approximately 7 to10 day intervals during the growing season from mid April to late August. Only plants protected from grazing by steel cages were measured. Leaf heights were measured from ground level to the tips of extended leaves for species in which leaves and stalks were distinctly separate. For single stalked species where the leaves are attached to a calm, height measurements were made of the extended uppermost leaf. The fruiting stalk measurements were begun immediately following evidence of thickening of culms, and stalk heights were measured from ground level to the tip of the stalk or to the tip of the inflorescence after it had developed. Data were statistically analyzed with the Duncan's multiple range test (Goetz 1970). Phenological data of grass developmental stages were determined by recording observation dates of fruiting stalk initiation, anthesis, seed development, seed maturity, and earliest observed date of seed shedding. Leaf senescence by date was determined as an estimation of percentage of dry leaf in relation to total leaf area (Goetz 1970).

Available mineral nitrogen was determined from soil samples collected with a 1 inch diameter soil tube from 0-6, 6-12, 12-24, 24-36, and 36-48 inch depths at 1 month intervals during early spring and late summer and at 15 day intervals from mid May to late July, 1964 to 1969. Individual samples from each depth were immediately frozen and kept frozen until analysis could be made. The analysis for available mineral nitrogen were made by the Department of

Soils, North Dakota State University, using standard analysis techniques (Goetz 1975a).

Available soil water was determined by the gravimetric procedure from soil samples collected with a 1 inch diameter soil tube from 0-6, 6-12, 12-24, 24-36, and 36-48 inch depths at weekly intervals from mid April to early October, 1964-1969. Data were composited into monthly values (Goetz 1975a).

Crude protein content of major grasses and sedges was determined from a composite of 10 samples of each species collected systematically every 3 paces or from inside areas protected from grazing by wire cages at biweekly intervals from mid May to early September, 1964-1969. Plant material was oven dried at 105° F. Analysis of samples were made by the Cereal Technology Department, North Dakota State University, using standard crude protein determinations (Goetz 1975a).

Nitrogen fertilization of native rangeland plot study IV (1970-1978)

Nitrogen fertilization of native rangeland plot study IV (1970-1978) was conducted by Dr. Harold Goetz and Dr. Warren C. Whitman, with collaboration from Paul Nyren during 1976 to 1978, on a well drained Vebar sandy loam soil on an upland range site located approximately three miles northwest of Dickinson, ND, in a pasture of the Dickinson Research Extension Center. The 30 X 100 foot plots were arranged in a randomized block design with three replications. The treatments included a check 0 lbs N/ac; annual 67 lbs N/ac and 100 lbs N/ac applied every year (EY); biennial 67 lbs N/ac and 100 lbs N/ac applied every other year (EOY); and high rates of 200 lbs, 300 lbs, and 400 lbs N/ac applied one time (OT). Application of phosphorus and potassium alone and with nitrogen were treatments also included with this study but not included in this report. The ammonium nitrate fertilizer (33-0-0) was broadcast applied in the spring. Dry matter weight of aboveground herbage was sampled by the clipping method at the end of the active growing season (around early to mid August) and separated into four categories: mid grasses, short grasses, perennial forbs, and annual forbs. The plant material was oven dried and weighed (Whitman 1970, 1972).

Quantitative species composition was determined by percent basal cover sampled with the ten-pin point frame method at the end of the growing season (Whitman 1976). Each year 500 points were taken for each treatment in each replication for a total of 1500 points per treatment (Goetz et al. 1978).

Available soil water was determined weekly and available mineral nitrogen was determined biweekly from soil samples collected from 0-6, 6-12, 12-24, 24-36, and 36-48 inch depths throughout the growing season (Whitman 1971, 1972). Crude protein content of selected major species was determined from samples collected biweekly (Whitman 1971). The same techniques used during the nitrogen fertilization plot study III were presumably used during the nitrogen fertilization plot study IV.

Results

Nitrogen fertilization plot study I

The 1957 growing season precipitation (table 1) was greater than normal (20.17 inches, 148.86% of LTM). April, June, July, September, and October were wet months and each received 181.12%, 186.20%, 155.86%, 148.87%, and 204.21% of LTM precipitation, respectively. May received normal precipitation at 89.74% of LTM. August was a dry month and received 86.13% of LTM precipitation. Perennial plants were under water stress conditions during August, 1957 (Manske 2008).

Herbage production on the heavily grazed pasture site was considered to be greatly reduced and at quantities considerably below potential as a result of the long-term grazing management practices used. The average dry weight of herbage biomass production had been only 995 lbs/ac during the previous 11 years (Whitman 1957). The total yield of herbage biomass on the 50 lbs N/ac, 100 lbs N/ac, and 150 lbs N/ac fertilization treatments was 37.9%, 111.4%, and 80.8% greater than the total yield produced on the unfertilized treatments (Whitman 1957) (table 2).

The mid grass category consisted mostly of cool season grasses. The herbage weight of mid grasses on the 50 lbs N/ac, 100 lbs N/ac, and 150 lbs N/ac fertilization treatments was 71.1%, 134.8%, and 30.7% greater than the mid grass weight produced on the unfertilized treatment, respectively (Whitman 1957) (table 2). Herbage production and percent composition of mid grasses greatly increased on the 50 lbs N/ac and 100 lbs N/ac rates. The heavy rate of 150 lbs N/ac apparently caused some damage to the cool season mid grasses (Whitman 1957) (tables 2 and 3).

The short grass category consisted mostly of warm season grasses. The herbage weight of short grasses on the 50 lbs N/ac, 100 lbs N/ac, and 150 lbs N/ac fertilization treatments was 29.3%, 105.8%, and 106.1% greater than the short grass weight produced on the unfertilized treatment, respectively (Whitman 1957) (table 2). The high herbage production of short grasses on the 100 lbs N/ac and 150 lb N/ac treatments could be attributed to the above normal precipitation (Whitman 1957) (table 1). The percent composition of short grasses decreased 6.2% and 2.6% on the 50 lbs N/ac and 100 lbs N/ac treatments, respectively (table 3).

This early fertilization treatment study showed that herbage production on previously heavily grazed native grass pastures could be increased by application of nitrogen fertilizer (Whitman 1957). This study also showed the beginnings of the species composition shift in plant communities caused by nitrogen fertilization treatments resulting in an increase in cool season mid grasses and a decrease in warm season short grasses. This study eliminated the 150 lbs N/ac rate from future trials.

Whitman (1957) acknowledged that this study did not have sufficient data to determine if nitrogen fertilization of native rangeland could be economically justified, however, he did submit a predication; that based on the then current price of nitrogen fertilizer, additional benefits would be necessary to make the practice of nitrogen fertilization profitable.

Nitrogen fertilization plot study II

The precipitation during the growing seasons of 1962 and 1963 was greater than normal (table 4). During 1962 and 1963, 16.41 inches (121.11% of LTM) and 16.17 inches (119.34% of LTM) of precipitation were received, respectively. May, July, and August of 1962 were wet months and each received 264.10%, 145.05%, and 145.66% of LTM precipitation, respectively. April received normal precipitation at 78.32% of LTM. June, September, and October were dry months and each received 58.31%, 56.39%, and 57.89% of LTM precipitation, respectively. Perennial plants were under water stress conditions during September and October, 1962 (Manske 2008). April and May of 1963 were wet months and each received 265.03% and 157.69% of LTM precipitation, respectively. June, July and September received normal precipitation at 119.44%, 83.78%, and 101.50% of LTM. August and October were dry and very dry months and each received 60.12% and 21.05% of LTM precipitation, respectively. Perennial plants were under water stress conditions during August and October, 1963 (Manske 2008).

The two year mean (1962-1963) herbage biomass total yield on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac fertilization treatments was 27.1%, 60.4%, and 59.9% greater than the mean total yield produced on the unfertilized treatment on the creek terrace site and was 34.4%, 64.4%, and 66.4% greater than the mean total yield produced on the unfertilized treatment on the upland slope site, respectively (Whitman 1963) (tables 5 and 7). The herbage biomass produced on the 100 lbs N/ac rate was not much different than that produced on the 67 lbs N/ac rate (tables 5 and 7).

The mean herbage weight of mid grasses on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac fertilization treatments was 40.6%, 66.0%, and 34.1% greater than the mean mid grass weight produced on the unfertilized treatment on the creek terrace site and was 61.0%, 21.6%, and 201.9% greater than the mean mid grass weight produced on the unfertilized treatment on the upland slope site, respectively (tables 5 and 7).

The greatest increase in herbage production during 1963 was the mid grass component. The increase in mid grass production was greater on the creek terrace site than on the upland slope site (Whitman 1963). Herbage weight of mid grasses produced in 1963 on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments was 412.4%, 214.2%, and 36.1% greater than that produced on the creek terrace site in 1962 and was 169.6%, 130.9%, and 50.6% greater than that produced on the upland slope site in 1962 for the respective treatments (tables 5 and 7).

Percent composition of herbage weight of mid grasses in 1963 on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments was 229.9%, 156.0%, and 36.1% greater than the percent composition on the creek terrace site in 1962 and was 127.5%, 91.7%, and 36.5% greater than the percent composition on the upland slope site in 1962 for the respective treatments (tables 6 and 8).

The mean herbage weight of short grasses on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac fertilization treatments was 20.7%, 58.3%, and 66.1% greater than the mean short grass weight produced on the unfertilized treatment on the creek terrace site and was 28.0%, 55.0%, and 43.7% greater than the mean short grass weight produced on the unfertilized treatment on the upland slope site, respectively (tables 5 and 7).

The short grass production in 1963 was greater for all treatments on both study sites than that produced in 1962. The increase in short grass production was greater on the upland slope site than on the creek terrace site (Whitman 1963). Herbage weight of short grasses produced in 1963 on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments was 50.8%, 6.9%, and 17.7% greater than that produced on the creek terrace site in 1962 and was 60.8%, 57.6%, and 59.1% greater than that produced on the upland slope site in 1962 for the respective treatments (tables 5 and 7).

Percent composition of herbage weight of short grasses did not change much on the creek terrace site and the upland slope site during the two years of this study (Whitman 1963). The percent composition of short grasses decreased 5.0% and 1.3% on the 33 lbs N/ac and 67 lbs N/ac treatments on the creek terrace site and decreased 4.5%, 5.7%, and 13.6% on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments on the upland slope site, respectively (tables 6 and 8).

The mean herbage weight of perennial forbs on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac fertilization treatments was 51.3%, 84.9%, and 24.8% greater than the mean perennial forb weight produced on the unfertilized treatment on the upland slope site, respectively (table 7). Dry matter weight of forbs on the unfertilized, 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments was 149.6%, 160.7%, 198.7%, and 127.0% greater on the upland slope site than on the creek terrace site for the respective treatments (tables 5 and 7). Much of this increased forb production on the upland slope site was due to the abundance of fringed sage and white sage (Whitman 1963). The upland slope site had shallower soil structure and less water holding capacity than the creek terrace site and the upland slope site had the problem with a great increase in undesirable perennial forbs on all three fertilization treatments.

This two year study showed that nitrogen fertilization of native rangeland resulted in greater total herbage yield than that produced on unfertilized rangeland. The response to nitrogen fertilization was not the same for different range sites. The plant species composition shift started during the first year of nitrogen fertilization treatments. The increase in herbage weight and percent composition for mid cool season grasses was much greater during the second year than the increase during the first year of fertilization treatments. The herbage weight of short warm season grasses increased during the first and second year of fertilization treatments, however, the percent composition decreased slightly during the two years. The increases in mid cool season grasses was greater than the decrease in short warm season grasses during the first two years of nitrogen fertilization treatments. A great increase in undesirable perennial forbs is a serious problem caused by nitrogen treatments on rangeland sites in poor condition.

Whitman (1962, 1963) considered that the most economical fertilization treatment on the creek terrace site was the 67 lbs N/ac rate based on the percent increase in total grass production, however, he also considered that all fertilization treatments on the upland slope site were uneconomical.

Nitrogen fertilization plot study III

The precipitation during the growing seasons of 1964 to 1969 was normal or greater than normal (table 4). During 1964, 1965, 1966, 1967, 1968, and 1969, 17.28 inches (127.53% of LTM), 20.08 inches (148.19% of LTM), 14.93 inches (101.92% of LTM), 12.51 inches (92.32% of LTM), 13.81 inches (101.92% of LTM), and 14.26 inches (105.24% of LTM) of precipitation were received, respectively. June, July, and August of 1964 were wet months and each received 172.39%, 199.10%, and 165.90% of LTM precipitation, respectively. April and May received normal precipitation at 96.50% and 79.79% of LTM. September and October were dry and very dry months and received 46.62%, and 1.05% of LTM precipitation, respectively. Perennial plants were under water stress conditions during September and October, 1964 (Manske 2008). April, May, and July of 1965 were wet months and each received 238.46%, 259.40%, and 138.74% of LTM precipitation, respectively. June, August, and September received normal precipitation at 119.72%, 94.80%, and 122.56% of LTM. October was extremely dry and received no precipitation. Perennial plants were under water stress conditions during October, 1965 (Manske 2008). June and August of 1966 were wet months and each received 139.15% and 197.11% of LTM precipitation, respectively. May and July received normal precipitation at 92.31% and 98.65% of LTM. April, September, and October were dry months and received 57.34%, 69.92%, and 50.53% of LTM precipitation, respectively. Perennial plants were under water stress conditions during September and October, 1966 (Manske 2008). April and September of 1967 were wet months and each received 270.63% and 186.47% of LTM precipitation, respectively. May received normal precipitation at 119.23% of LTM. October was a dry month and received 64.21% of LTM precipitation. June, July, and August were very dry months and received 45.92%, 32.43%, and 23.70% of LTM precipitation, respectively. Perennial plants were under water stress conditions during July and August, 1967 (Manske 2008). July and August of 1968 were wet months and each received 127.48% and 230.64% of LTM precipitation, respectively. June and October received normal precipitation at 95.21% and 95.79% of LTM. April and May were dry months and received 71.33% and 53.42% of LTM precipitation, respectively. September was a very dry month and received 32.33% of LTM precipitation. Perennial plants were under water stress conditions during September, 1968 (Manske 2008). June and July of 1969 were wet months and each received 172.68% and 198.20% of LTM precipitation, respectively. October received normal precipitation at 90.53% of LTM. April and May were dry months and received

50.35% and 56.41% of LTM precipitation. August and September were very dry months and received 30.06% and 23.31% of LTM precipitation, respectively. Perennial plants were under water stress conditions during August and September, 1969 (Manske 2008).

The mean herbage biomass total yield on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac fertilization treatments was 5.6%, 34.0%, and 22.5% greater than the mean total yield produced on the unfertilized treatment on the Havre overflow range site; 13.7%, 61.6%, and 89.7% greater than the mean total yield produced on the unfertilized treatment on the Manning silty range site; 25.1%, 71.7%, and 75.0% greater than the mean total yield produced on the unfertilized treatment on the Vebar sandy range site; and 23.6%, 45.8%, and 50.7% greater than the mean total yield produced on the unfertilized treatment on the Rhoades thin claypan range site, respectively (tables 9, 11, 13, and 15). The herbage biomass produced on the 100 lbs N/ac rate was not much different than that produced on the 67 lbs N/ac rate (tables 9, 11, 13, and 15). The Havre overflow range site was the highest producing site followed in sequence by the Manning silty range site, the Vebar sandy range site, and the Rhoades thin claypan range site was the least productive site (Whitman 1969).

The plant species composition shift with an increase of mid grasses and a decrease of short grasses occurred during this 6 year study. The mid grass component increased as a result of the fertilization treatments. The mean herbage weight of mid grasses on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac fertilization treatments was 10.4%, 42.8%, and 36.2% greater than the mean mid grass weight produced on the unfertilized treatment on the Havre overflow range site; 10.0%, 57.4%, and 96.5% greater than the mean mid grass weight produced on the unfertilized treatment on the Manning silty range site; 13.5% lower, and 55.3% and 63.6% greater than the mean mid grass weight produced on the unfertilized treatment on the Vebar sandy range site; and 40.9%, 63.6%, and 71.1% greater than the mean mid grass weight produced on the unfertilized treatment on the Rhoades thin claypan range site for the respective treatments (tables 9, 11, 13, and 15).

These increases in the mean herbage weight of the mid grasses were not as great as would be expected because of the reductions in herbage weight produced by mid cool season grasses on all four range sites caused by cool, dry early spring weather conditions of 1966 and 1967 (Whitman 1966, 1967) and caused by a shortage of moisture early in the growing season of 1968 (Whitman 1968). The application of the fertilization treatments was delayed about a month in 1967 because of adverse weather conditions (Whitman 1967). The reductions in production of mid grass weight were greatest on the Vebar sandy range site. The reduced mid grass herbage weight on the 33 lbs N/ac treatment for 1966, 1967, and 1968 caused a reduction in the six year mean mid grass yield that was lower than the mean mid grass yield on the unfertilized treatment. The herbage weight of the mid grasses, however, did increase an average of 26.4 lbs/ac each year for the 33 lbs N/ac rate on the Vebar sandy range site.

The short grass component decreased as a result of the fertilization treatments. The weight of short grass composes less than 2% of the total herbage weight produced on the Havre overflow range site (table 10). The herbage weight of short grass increased slightly on the unfertilized and 33 lbs N/ac treatments and decreased slightly on the 67 lbs N/ac and 100 lbs N/ac treatments on the Havre overflow range site. The mean herbage weight of short grasses on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac fertilization treatments was greater than the mean short grass weight produced on the unfertilized treatment of the Manning silty range site, the Vebar sandy range site, and the Rhoades thin claypan range site (tables 11, 13, and 15). The percent composition of short grasses decreased 1.5%, 4.2%, and 10.9% on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments on the Manning silty range site; decreased 0.2% on the 100 lbs N/ac treatment on the Vebar sandy range site; and decreased 5.6%, 7.6%, and 12.6% on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments on the Rhoades thin claypan range site, respectively (tables 12, 14, and 16). The percent composition for short grasses on the Vebar sandy range site was substantially increased in 1966 as a result of the great reduction in mid grass herbage production caused by the cool, dry conditions that occurred during the early spring of that year. This increased percent composition of short grasses resulted in a 6 year mean percent composition for short grasses on the three fertilization treatments to be about equal to or greater than that on the unfertilized treatment (table 14) indicating a small increase in the means. The annual percent composition of the short grasses, however, did decrease an average of 5.2%, 5.5%, and 4.8% each year on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments on the Vebar sandy range site, respectively.

The mean herbage weight of perennial forbs on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac fertilization treatments was 27.3%, 100.2%, and 176.6% greater than the mean perennial forb weight produced on the unfertilized treatment on the Manning silty range site; and was 49.0%, 130.3%, and 131.6% greater than the mean perennial forb weight produced on the unfertilized treatment on the Vebar sandy range site, respectively (tables 11 and

13). The percent composition of herbage weight of perennial forbs on the Manning silty range site and the Vebar sandy range site was high (tables 12 and 14). The percent composition of perennial forbs ranged between 20% and 50% of the total herbage yield produced on the Manning silty range site during the first three years. Sometime between the third and fourth year, most of the fringed sage plants died and the percent composition ranged between 4% and 12% of the total yield during the fourth through the sixth years (Whitman 1965, 1967, 1969). The percent composition of perennial forbs ranged between 20% to 42% of the total herbage yield produced on the Vebar sandy range site during the six years of the study (Whitman 1967, 1969). The Manning silty range site and the Vebar sandy range site were both in relatively poor condition as a result of long-term antagonistic grazing management practices (Goetz 1969a) and both had the problem with a great increase in undesirable perennial forbs on all three fertilization treatments.

Total basal cover of grasses and forbs on the Havre overflow range site increased slightly, but not significantly (P<0.05), on all three nitrogen fertilization treatments compared to the unfertilized treatment during 1964 to 1966 (table 17). Western wheatgrass and green needlegrass increased in basal cover. Needle and thread and plains reedgrass decreased in basal cover. The basal cover of the two dominant shrubs, silver sagebrush and western snowberry, decreased resulting in a decreased total basal cover of shrubs, forbs, and grasses (Goetz 1969a).

Total basal cover on the Manning silty range site increased significantly (P<0.05) each year with the increased rates of all three nitrogen fertilization treatments compared to the unfertilized treatment during 1964 to 1966 (table 17). Western wheatgrass showed moderate, but significant (P<0.05), increases in basal cover with all three fertilization rates. Threadleaf sedge showed appreciable increases in basal cover on all three fertilization rates. Needle and thread decreased in basal cover. Blue grama did not change in basal cover. Fringed sage density increased significantly (P<0.05) each year with the increased rates of all three nitrogen fertilization treatments (Goetz 1969a) (table 17).

Total basal cover on the Vebar sandy range site decreased on all three nitrogen fertilization treatments compared to the unfertilized treatment during 1964 to 1966 (table 17). The decreased basal cover was significant (P<0.05) on the 67 lbs N/ac and 100 lbs N/ac fertilization treatments. Most of the reduction in total basal cover was the result of the decrease in basal cover of blue grama (table 17). Needle and thread had a slight decrease in basal cover. Plains reedgrass and threadleaf sedge had slight increases in basal cover with increased rates of nitrogen treatments. Prairie sandreed had increased basal cover on the 33 lbs N/ac and 67 lbs N/ac rates but had decreased basal cover on the 100 lbs N/ac treatment. Western wheatgrass, prairie Junegrass, needleleaf sedge, and sun sedge did not have significant (P<0.05) changes in basal cover. The dominant perennial forb, white sage, did not have significantly (P<0.05) increased basal cover (table 17) or plant density, however, the individual plants increased appreciably in size and weight (Goetz 1969a).

Total basal cover of grasses and forbs on the Rhoades thin claypan range site slightly decreased, but not significantly (P<0.05), on all three nitrogen fertilization treatments compared to the unfertilized treatment during 1964 to 1966 (table 17). Western wheatgrass had increased basal cover with increased rates of nitrogen fertilization (table 17). This increased basal cover was significant (P<0.05) on the 67 lbs N/ac treatment. Sandberg bluegrass had significantly (P<0.05) increased basal cover on the 33 lbs N/ac and 67 lbs N/ac treatments. Brittle prickly pear had increased basal cover and plant density with increased rates of nitrogen fertilization (Goetz 1969a).

Total root weight on the Havre overflow range site on the 67 lbs N/ac and 100 lbs N/ac fertilization treatments was 36.9% and 39.2% greater than the total root weight on the unfertilized treatment, respectively (table 18). The total root weight on the 100 lbs N/ac treatment was significantly (P<0.05) greater than that on the unfertilized treatment (Goetz 1969b) (table 18). The total root weight on the 33 lbs N/ac treatment was 12.0% less than that on the unfertilized treatment. All three nitrogen fertilization treatments had total root weight distribution in the soil profile with a greater percent at the 0-12 inch depth and a lower percent at the 12-48 inch depth than that of the unfertilized treatment. The root weights at the 0-6 inch depth were significantly (P<0.05) greater on the 67 lbs N/ac and 100 lbs N/ac treatments than that on the unfertilized treatment (Goetz 1969b) (table 18).

Total root weight on the Manning silty range site on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac fertilization treatments was 9.1%, 6.4%, and 6.9% greater than the total root weight on the unfertilized treatment, respectively (table 18). The greatest increase in total root weight on the Manning site was on the 33 lbs N/ac treatment (Goetz 1969b) (table 18). The 33 lbs N/ac and 67 lbs N/ac treatments had total root weight distribution in the soil profile with a greater percent at the 0-12 inch depth and a lower percent at the deeper depths than that of the unfertilized treatment. The root weight at the 6-12 inch depth was significantly (P<0.05) greater on the 100 lbs N/ac treatments than that on the unfertilized treatment (Goetz 1969b) (table 18).

Total root weight on the Vebar sandy range site on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac fertilization treatments was 68.8%, 0.9%, and 7.9% greater than the total root weight on the unfertilized treatment, respectively (table 18). The total root weight on the 33 lbs N/ac treatment was significantly (P<0.05) greater than that on the unfertilized treatment (Goetz 1969b) (table 18). The 67 lbs N/ac and 100 lbs N/ac treatments had total root weight distribution in the soil profile with a greater percent at the 0-12 inch depth and a lower percent at the 12-48 inch depth than that of the unfertilized treatment. The 33 lbs N/ac treatment had a greater percent of the total root weight at the 12-36 inch depth than that on the unfertilized treatment. The root weight at the 0-6 inch depth was significantly (P<0.05) greater on the 33 lbs N/ac treatment than that on the unfertilized treatment (Goetz 1969b) (table 18).

Total root weight on the Rhoades thin claypan range site on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac fertilization treatments was 30.8%, 87.8%, and 112.3% greater than the total root weight on the unfertilized treatment, respectively (table 18). The greatest increase in total root weight during this study was on the 100 lbs N/ac treatment (Goetz 1969b) (table 18). All three nitrogen fertilization treatments had total root weight distribution in the soil profile with a greater percent at the 0-12 inch depth and a lower percent at the 12-48 inch depth than that of the unfertilized treatment. The root weights at the 0-6 inch depth increased with each increase in rate of nitrogen fertilizer (Goetz 1969b). The root weights at the 0-6 inch depth were significantly (P<0.05) greater on the 67 lbs N/ac and 100 lbs N/ac treatments than that on the unfertilized treatment (Goetz 1969b) (table 18).

Western wheatgrass on the unfertilized treatment of the Havre overflow range site had active leaf growth in height during 70% of the growing season and reached maximum leaf height on 15 July at 15.47 inches. Western wheatgrass on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac fertilization treatments had greater rates of growth during 57.1%, 62.5%, and 75.0% of the unfertilized plant active leaf growth period and reached maximum leaf height on 15 July, 31 July, and 31 July that was 12.0%, 6.7%, and 14.3% greater than the leaf growth in height on the unfertilized treatment, respectively (table 19).

Needle and thread on the unfertilized treatment of the Havre overflow range site had active leaf growth in height during 70% of the growing season and reached maximum leaf height on 15 July at 11.30 inches. Needle and thread on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac fertilization treatments had greater rates of growth during 57.1%, 57.1%, and 75.0% of the unfertilized plant active leaf growth period and reached maximum leaf height on 15 July, 15 July, and 31 July that was 4.9% less than, and 3.5% and 20.2% greater than the leaf growth in height on the unfertilized treatment, respectively (table 19).

Green needlegrass on the unfertilized treatment of the Havre overflow range site had active leaf growth in height during 70% of the growing season and reached maximum leaf height on 15 July at 19.88 inches. Green needlegrass on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac fertilization treatments had greater rates of growth during 57.1%, 85.7%, and 75.0% of the unfertilized plant active leaf growth period and reached maximum leaf height on 15 July, 15 July, and 31 July that was 11.3%, 18.6%, and 17.1% greater than the leaf growth in height on the unfertilized treatment, respectively (table 19).

Western wheatgrass on the unfertilized treatment of the Manning silty range site had active leaf growth in height during 70% of the growing season and reached maximum leaf height on 15 July at 11.89 inches. Western wheatgrass on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac fertilization treatments had greater rates of growth during 42.9%, 50.0%, and 62.5% of the unfertilized plant active leaf growth period and reached maximum leaf height on 15 July, 31 July, and 31 July that was 1.7% less than, and 15.2% and 16.9% greater than the leaf growth in height on the unfertilized treatment, respectively (table 20).

Needle and thread on the unfertilized treatment of the Manning silty range site had active leaf growth in height during 70% of the growing season and reached maximum leaf height on 15 July at 11.30 inches. Needle and thread on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac fertilization treatments had greater rates of growth during 14.3%, 37.5%, and 37.5% of the unfertilized plant active leaf growth period and reached maximum leaf height on 15 July, 31 July, and 31 July that was 26.1%, 4.2%, and 7.7% less than the leaf growth in height on the unfertilized treatment, respectively (table 20).

Blue grama on the unfertilized treatment of the Manning silty range site had active leaf growth in height during 80% of the growing season and reached maximum leaf height on 31 July at 4.76 inches. Blue grama on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac fertilization treatments had greater rates of growth during 75.0%, 50.0%, and 62.5% of the unfertilized plant active leaf growth period and reached maximum leaf height on 31 July, 31 July, and 31 July that was 21.6%, 20.0%, and 52.1% greater than the leaf growth in height on the unfertilized treatment, respectively (table 20).

Threadleaf sedge on the unfertilized treatment of the Manning silty range site had active leaf growth in height during 60% of the growing season and reached maximum leaf height on 30 June at 4.61 inches. Threadleaf sedge on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac fertilization treatments had greater rates of growth during 57.1%, 33.3%, and 42.9% of the unfertilized plant active leaf growth period and reached maximum leaf height on 15 July, 30 June, and 30 June that was 11.9%, 11.9%, and 17.8% greater than the leaf growth in height on the unfertilized treatment, respectively (table 20).

Needleleaf sedge on the unfertilized treatment of the Manning silty range site had active leaf growth in height during 70% of the growing season and reached maximum leaf height on 15 July at 4.80 inches. Needleleaf sedge on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac fertilization treatments had greater rates of growth during 57.1%, 42.9%, and 71.4% of the unfertilized plant active leaf growth period and reached maximum leaf height on 15 July, 15 July, and 15 July that was 13.1%, 13.2%, and 23.8% greater than the leaf growth in height on the unfertilized treatment, respectively (table 20).

Western wheatgrass on the unfertilized treatment of the Vebar sandy range site had active leaf growth in height during 80% of the growing season and reached maximum leaf height on 31 July at 8.98 inches. Western wheatgrass on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac fertilization treatments had greater rates of growth during 50.0%, 77.8%, and 62.5% of the unfertilized plant active leaf growth period and reached maximum leaf height on 15 July, 15 August, and 31 July that was 0.9% less than, and 22.3% and 43.3% greater than the leaf growth in height on the unfertilized treatment, respectively (table 21).

Needle and thread on the unfertilized treatment of the Vebar sandy range site had active leaf growth in height during 70% of the growing season and reached maximum leaf height on 15 July at 10.43 inches. Needle and thread on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac fertilization treatments had greater rates of growth during 28.6%, 28.6%, and 62.5% of the unfertilized plant active leaf growth period and reached maximum leaf height on 15 July, 15 July, and 31 July that was 1.5%, 8.0%, and 6.4% greater than the leaf growth in height on the unfertilized treatment, respectively (table 21).

Blue grama on the unfertilized treatment of the Vebar sandy range site had active leaf growth in height during 80% of the growing season and reached maximum leaf height on 31 July at 4.57 inches. Blue grama on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac fertilization treatments had greater rates of growth during 50.0%, 62.5%, and 62.5% of the unfertilized plant active leaf growth period and reached maximum leaf height on 31 July, 15 July, and 15 July that was 7.7%, 33.5%, and 36.1% greater than the leaf growth in height on the unfertilized treatment, respectively (table 21).

Threadleaf sedge on the unfertilized treatment of the Vebar sandy range site had active leaf growth in height during 50% of the growing season and reached maximum leaf height on 15 June at 5.67 inches. Threadleaf sedge on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac fertilization treatments had greater rates of growth during 42.9%, 57.1%, and 42.9% of the unfertilized plant active leaf growth period and reached maximum leaf height on 30 June, 15 July, and 15 July that was 17.3%, 14.6%, and 10.4% greater than the leaf growth in height on the unfertilized treatment, respectively (table 21).

Needleleaf sedge on the unfertilized treatment of the Vebar sandy range site had active leaf growth in height during 70% of the growing season and reached maximum leaf height on 15 July at 5.08 inches. Needleleaf sedge on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac fertilization treatments had greater rates of growth during 42.9%, 57.1%, and 42.9% of the unfertilized plant active leaf growth period and reached maximum leaf height on 15 July, 15 July, and 15 June that was 0.8% and 13.2% greater than, and 8.5% less than the leaf growth in height on the unfertilized treatment, respectively (table 21).

Western wheatgrass on the unfertilized treatment of the Rhoades thin claypan range site had active leaf growth in height during 70% of the growing season and reached maximum leaf height on 15 July at 8.78 inches. Western wheatgrass on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac fertilization treatments had greater rates of growth during 57.1%, 71.4%, and 57.1% of the unfertilized plant active leaf growth period and reached maximum leaf height on 15 July, 15 July, and 15 July that was 1.8% less than, and 12.1% and 15.7% greater than the leaf growth in height on the unfertilized treatment, respectively (table 22).

Blue grama on the unfertilized treatment of the Rhoades thin claypan range site had active leaf growth in height during 80% of the growing season and reached maximum leaf height on 31 July at 3.58 inches. Blue grama on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac fertilization treatments had greater rates of growth during 25.0%, 75.0%, and 62.5% of the unfertilized plant active leaf growth period and reached maximum leaf height on 31 July, 31 July, and 30 June that was 2.2%, 31.8%, and 33.0% greater than the leaf growth in height on the unfertilized treatment, respectively (table 22).

Sandberg bluegrass on the unfertilized treatment of the Rhoades thin claypan range site had active leaf growth in height during 70% of the growing season and reached maximum leaf height on 15 July at 3.19 inches. Sandberg bluegrass on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac fertilization treatments had greater rates of growth during 42.9%, 57.1%, and 57.1% of the unfertilized plant active leaf growth period and reached maximum leaf height on 15 July, 30 June, and 15 July that was 8.5%, 5.0%, and 13.5% greater than the leaf growth in height on the unfertilized treatment, respectively (table 22).

Needleleaf sedge on the unfertilized treatment of the Rhoades thin claypan range site had active leaf growth in height during 70% of the growing season and reached maximum leaf height on 15 July at 3.39 inches. Needleleaf sedge on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac fertilization treatments had greater rates of growth during 71.4%, 42.9%, and 57.1% of the unfertilized plant active leaf growth period and reached maximum leaf height on 15 July, 15 July, and 15 July that was 16.2%, 21.8%, and 44.0% greater than the leaf growth in height on the unfertilized treatment, respectively (table 22).

Western wheatgrass, a mid cool season grass, was a major species on the Havre overflow, Manning silty, Vebar sandy, and Rhoades thin claypan range sites and unfertilized plants had an active leaf growth period during 72.5% of the growing season. Maximum leaf height was increased an average of 14.1% and 22.6%, respectively, on the 67 lbs N/ac and 100 lbs N/ac fertilization treatments of all four range sites; and was reduced an average of 1.5% on the 33 lbs N/ac treatment of the Manning silty, Vebar sandy, and Rhoades thin claypan range sites. Leaf growth rates of western wheatgrass on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac fertilization treatments were greater than the leaf growth rates on the unfertilized treatment during 51.8%, 65.4%, and 64.3% of the unfertilized plant active leaf growth period, respectively. Maximum leaf height was greatest on the Havre overflow range site and least on the Rhoades thin claypan range site (Goetz 1970).

Needle and thread, a mid cool season grass, was a major species on the Havre overflow, Manning silty, and Vebar sandy range sites and unfertilized plants had an active leaf growth period during 70.0% of the growing season. Maximum leaf height was increased an average of 1.5% on the 33 lbs N/ac treatment of the Vebar sandy range site; increased an average of 5.7% and 13.3%, respectively, on the 67 lbs N/ac and 100 lbs N/ac fertilization treatments of the Havre overflow and Vebar sandy range sites; reduced an average of 15.5% on the 33 lbs N/ac treatment of the Havre overflow and Manning silty range sites; and reduced an average of 4.2% and 7.7%, respectively, on the 67 lbs N/ac and 100 lbs N/ac treatments of the Manning silty range site. Leaf growth rates of needle and thread on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments were greater than the leaf growth rates on the unfertilized treatment during 33.3%, 41.1%, and 58.3% of the unfertilized plant active leaf growth period , respectively. Maximum leaf height was greatest on the Havre overflow range site.

Green needlegrass, a mid cool season grass, was a major species on the Havre overflow range site and unfertilized plants had an unfertilized plant active leaf growth period during 70.0% of the growing season. Maximum leaf height was increased 11.3%, 18.6%, and 17.1%, on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments, respectively. Leaf growth rates of green needlegrass on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments were greater than the leaf growth rates on the unfertilized treatment during 57.1%, 85.7%, and 75.0% of the unfertilized plant active leaf growth period, respectively. Maximum leaf height was greatest on the 67 lbs N/ac treatment (Goetz 1970).

Blue grama, a short warm season grass, was a major species on the Manning silty, Vebar sandy, and Rhoades thin claypan range sites and unfertilized plants had an active leaf growth period during 80.0% of the growing season. Maximum leaf height was increased an average of 10.5%, 28.4%, and 40.4% on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments, respectively. Leaf growth rates of blue grama on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments were greater than the leaf growth rates on the unfertilized treatment during 50.0%, 62.5%, and 62.5% of the unfertilized plant active leaf growth period, respectively. Maximum leaf height was greatest on the Manning silty range site and least on the Rhoades thin claypan range site (Goetz 1970).

Sandberg bluegrass, an early short cool season grass, was a major species on the Rhoades thin claypan range site and unfertilized plants had an active leaf growth period during 70.0% of the growing season. Maximum leaf height was increased 8.5%, 5.0%, and 13.5%, on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments, respectively. Leaf growth rates of sandberg bluegrass on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments were greater than the leaf growth rates on the unfertilized treatment during 42.9%, 57.1%, and 57.1% of the unfertilized plant active leaf growth period, respectively. Maximum leaf height was greatest on the 100 lbs N/ac treatment (Goetz 1970).

Threadleaf sedge, an early short cool season upland sedge, was a major species on the Manning silty and Vebar sandy range sites and unfertilized plants had an active leaf growth period during 55.0% of the growing season. Maximum leaf height was increased an average of 14.6%, 13.3%, and 14.1% on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac fertilization treatments, respectively. Leaf growth rates of threadleaf sedge on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments were greater than the leaf growth rates on the unfertilized treatment during 45.2%, 45.2%, and 42.9% of the unfertilized plant active leaf growth period, respectively. Maximum leaf height was greatest on the 33 lbs N/ac treatment (Goetz 1970).

Needleleaf sedge, an early short cool season upland sedge, was a major species on the Manning silty, Vebar sandy, and Rhoades thin claypan range sites and unfertilized plants had an active leaf growth period during 70.0% of the growing season. Maximum leaf height was increased an average of 10.1% and 16.1%, respectively, on the 33 lbs N/ac and 67 lbs N/ac treatments of the three range sites; increased an average of 33.9% on the 100 lbs N/ac treatment of the Manning silty and Rhoades thin claypan range sites; and reduced 8.5% on the 100 lbs N/ac treatment of the Vebar sandy range site. Leaf growth rates of needleleaf sedge on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments were greater than the leaf growth rates on the unfertilized treatment during 57.1%, 47.6%, and 57.1% of the unfertilized plant active leaf growth period, respectively.

Most of the phenological development of the various species was not appreciably affected by the different rates of nitrogen fertilization (Goetz 1970) (tables 23-26). The dates of flowering (anthesis) were not changed by the nitrogen fertilization treatments. Most of the dates of anthesis occurred within the normal range of variation which was determined by Stevens (1956) to be plus or minus 3 days from an average calculated date based on 10 years of data.

The rates of leaf drying on the fertilization treatments were a little different than those on the unfertilized treatments. Initiation of leaf tip drying began at an earlier date and the beginning stages of leaf drying progressed more rapidly early in the growing season on the unfertilized treatments. As the growing season progressed, this situation was reversed with the rate of leaf drying becoming more rapid on the fertilization treatments and the advanced stages of leaf drying were reached earlier than those on the unfertilized treatments (Goetz 1970).

The lengths of the early and late stages of leaf drying for western wheatgrass on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments were 1 day longer, and 6 and 7 days shorter during the beginning stages and were 1, 1, and 15 days shorter during the latter stages than the number of days of the leaf drying stages on the unfertilized treatments, respectively.

The lengths of the early and late stages of leaf drying for needle and thread on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments were 7, 2, and 4 days longer during the beginning stages and were 4, 15, and 2 days shorter during the latter stages than the number of days of the leaf drying stages on the unfertilized treatments, respectively.

The lengths of the early and late stages of leaf drying for green needlegrass on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments were 18, 12, and 17 days longer during the beginning stages and were 21, 12, and 24 days shorter during the latter stages than the number of days of the leaf drying stages on the unfertilized treatments, respectively.

The lengths of the early and late stages of leaf drying for plains reedgrass on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments were 11, 1, and 7 days longer during the beginning stages and were 7 days longer, and 7 and 7 days shorter during the latter stages than the number of days of the leaf drying stages on the unfertilized treatments, respectively.

The lengths of the early and late stages of leaf drying for blue grama on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments were 1, 10, and 7 days longer during the beginning stages and were 1 day longer, and 4 and 4 days shorter during the latter stages than the number of days of the leaf drying stages on the unfertilized treatments, respectively.

The lengths of the early stages of leaf drying for prairie Junegrass on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments were 7, 6, and 7 days longer during the beginning stages than the number of days of the leaf drying stages on the unfertilized treatments, respectively.

The lengths of the early and late stages of leaf drying for Sandberg bluegrass on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments were 30, 22, and 17 days longer during the beginning stages and were 20 days longer, and 5 and 11 days shorter during the latter stages than the number of days of the leaf drying stages on the unfertilized treatments, respectively.

The lengths of the early and late stages of leaf drying for the upland sedges on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments were 5 days shorter, and 2 and 1 days longer during the beginning stages and were 4, 2, and 2 days shorter during the latter stages than the number of days of the leaf drying stages on the unfertilized treatments, respectively.

Application of nitrogen fertilizer at 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatment rates increased the amount of available mineral nitrogen in the soil during the early portion of the growing season (Goetz 1975a). The peak quantity of available nitrogen in the 0-6 inch depth was reached 30 to 35 days following fertilizer application. The increase was greater with the higher treatment rates. The applied nitrogen was carried down in the soil profile reaching the deeper depths successively later, with some of the added nitrogen reaching the full sampling depth of 48 inches in the latter part of the growing season. During the third year of the study, 1966, there appeared to be a slight accumulation of nitrogen at the deeper depths (Goetz 1975a).

Differences in the amounts of available mineral nitrogen at the various sample depths on the three fertilization treatments diminished rapidly early in the growing season because of nitrogen immobilization by the soil-plant system. Beginning in early June, the amounts of mineral nitrogen on the fertilization treatments were essentially similar to the amounts on the unfertilized treatments (Goetz 1975a).

The quantity of available mineral nitrogen at the various samples depths changed seasonally and occurred as peaks and low points. The available nitrogen during the peaks increased 25% to 50% greater than that available during the low points. Three peaks occurred during the growing season on the unfertilized treatments. The peaks on the four range sites did not coincide exactly with each other. Three peaks occurred on the fertilization treatments of the Manning silty and Rhoades thin claypan sites and two peaks occurred on the Havre overflow and Vebar sandy sites. The observed peaks in available mineral nitrogen appeared to coincide with the phenological events of the major species of the sites rather than with the amount of available soil water. The first peak was reached around 15 May at approximately the same time on the unfertilized and fertilized treatments of all four range sites and occurred while the soils were warming in the spring but prior to rapid plant growth. The second peak occurred at the end of the active growing season in mid to late July. The third peak occurred in late autumn following plant development for the subsequent year's growth (Goetz 1975a). The low points coincided with periods of active plant growth. The heaviest nitrogen use on all treatments on all sites consistently occurred at the 6 to 12 inch soil depth, corresponding to the most active root zone (Goetz 1975a).

Available soil water increased from early spring through July with the maximum amounts available in June on all sites. The lowest total amounts of available soil water were on the Rhoades thin claypan range site. Soil water use was greater on the fertilized treatments than on the unfertilized treatments. Considerably greater amounts of soil water were extracted from the treatments with the heavier applications of nitrogen fertilizer (Goetz 1975a).

Application of nitrogen fertilizer to rangelands generally increased crude protein content on all species during early growth stages (tables 27-30). The magnitude and duration of the increase varied greatly with sites and species. Most species attained maximum crude protein content by mid May. The crude protein content decreased during the growing season and the decline was progressive with the advancement in maturity. Cool season species showed a more rapid loss of crude protein than warm season species. The rate of crude protein decline was accelerated by the nitrogen fertilization treatments and by the seasonal decline in soil moisture (Goetz 1975b).

Western wheatgrass was a major species on the Havre overflow, Manning silty, and Rhoades thin claypan range sites (tables 27, 28, and 30). Nitrogen fertilization increased the crude protein content during the early portion (early June to mid July) of the growing season. Crude protein content of the early growth stages of western wheatgrass on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments was 2.2% lower, and 4.9% and 15.2% greater on the Havre overflow site; 7.7%, 16.3%, and 25.2% greater on the Manning silty site; and 5.3%, 11.3%, and 14.5% greater on the Rhoades thin claypan site than the crude protein content on the unfertilized treatment, respectively. Crude protein content decreased progressively throughout the growing season as the plants matured. The rate of decline was greater on the fertilization treatments than on the unfertilized treatments. A statistically significant decrease in crude protein was evident by mid June on the Manning silty and Rhoades thin claypan range sites and by early July on the Havre overflow range site (Goetz 1975b). Fertilization treatments generally maintained a slightly higher crude protein level than the unfertilized treatment until early August when the differences became quite small. No significant differences were found between treatment means on the Havre overflow, Manning silty, and Rhoades thin claypan range sites (Goetz 1975b).

Needle and thread was a major species on the Manning silty and Vebar sandy range sites (tables 28 and 29). Nitrogen fertilization increased the crude protein content during the early portion of the growing season. Crude protein content of the early growth stages of needle and thread on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments was 3.8%, 22.0%, and 25.0% greater on the Manning silty site; and 3.6%, 16.5%, and 23.7% greater on the Vebar sandy site than the crude protein content on the unfertilized treatment, respectively. Crude protein content decreased progressively throughout the growing season as the plants matured. The rate of decline was greater on the fertilization treatments than on the unfertilized treatments. A statistically significant decrease in crude protein was evident by early July on the Manning silty and Vebar sandy range sites (Goetz 1975b). Fertilization treatments generally maintained a slightly higher crude protein level than the unfertilized treatment until early August when the differences became quite small. The mean percent crude protein on the 100 lbs N/ac treatment was significantly greater than that on the unfertilized treatment on the Vebar sandy range site. There was no significant differences between the 33 lbs N/ac and 67 lbs N/ac treatments and the unfertilized treatment. No significant differences were found between treatment means on the Manning silty range site (Goetz 1975b).

Green needlegrass was a major species on the Havre overflow range site (table 27). Nitrogen fertilization increased the crude protein content during the early portion of the growing season. Crude protein content of the early growth stages of green needlegrass on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments was 0.9% lower, and 8.8% and 23.2% greater on the Havre overflow site than the crude protein content on the unfertilized treatment, respectively. Crude protein content decreased progressively throughout the growing season as the plants matured. The rate of decline was greater on the fertilization treatments than on the unfertilized treatments. A statistically significant decrease in crude protein was evident by early July on the Havre overflow range site (Goetz 1975b). Fertilization treatments generally maintained a slightly higher crude protein level than the unfertilized treatment until early August when the differences became quite small. No significant differences were found between treatment means on the Havre overflow range site (Goetz 1975b).

Blue grama was a major species on the Manning silty, Vebar sandy, and Rhoades thin claypan range sites (tables 28, 29, and 30). Nitrogen fertilization increased the crude protein content during the early portion of the growing season. Crude protein content of the early growth stages of blue grama on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments was 15.9%, 27.5%, and 33.3% greater on the Manning silty site; 5.2%, 25.0%, and 31.0% greater on the Vebar sandy site; and 7.6%, 20.4%, and 32.2% greater on the Rhoades thin claypan site than the crude protein content on the unfertilized treatment, respectively. Crude protein content decreased progressively throughout the growing season as the plants matured. The rate of decline was greater on the fertilization treatments than on the unfertilized treatments. The decline in crude protein content was slower for blue grama, a warm season grass, than for the cool season grasses (Goetz 1975b). The mean percent crude protein on the 67 lbs N/ac and 100 lbs N/ac treatments was significantly greater than that on the unfertilized treatments on the Manning silty and Vebar sandy range sites. There was no significant differences between the 33 lbs N/ac treatments and the unfertilized treatments. No significant differences were found between treatment means on the Rhoades thin claypan range site (Goetz 1975b).

Sandberg bluegrass was a major species on the Rhoades thin claypan range site (table 30). Nitrogen fertilization increased the crude protein content during the early portion of the growing season. Early season response to nitrogen fertilization was high (Goetz 1975b). Crude protein content of the early growth stages of sandberg bluegrass on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments was 22.4%, 43.4%, and 47.7% greater on the Rhoades thin clypan site than the crude protein content on the unfertilized treatment, respectively. Crude protein content decreased rapidly because of the extremely short life span of the leaf material. Differences in crude protein content between the fertilization treatments and the unfertilized treatment were small by early July. No significant differences were found between treatment means on the Rhoades thin claypan range site (Goetz 1975b).

Threadleaf sedge was a major species on the Vebar sandy range site (table 29). Nitrogen fertilization increased the crude protein content during the early portion of the growing season.

Crude protein content of the early growth stages of threadleaf sedge on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments was 8.7%, 27.0%, and 32.3% greater on the Vebar sandy site than the crude protein content on the unfertilized treatment, respectively. Crude protein content decreased progressively throughout the growing season as a result of severe leaf drying. The rate of decline was greater on the fertilization treatments than on the unfertilized treatment. A statistically significant decrease in crude protein was evident by early July on the Vebar sandy range site (Goetz 1975b). Differences in crude protein content between the fertilization treatments and the unfertilized treatment were small before early August because of the high loss of leaf material. The mean percent crude protein on the 67 lbs N/ac and 100 lbs N/ac treatments was significantly greater than that on the unfertilized treatment on the Vebar sandy range site. There was no significant differences between the 33 lbs N/ac treatment and the unfertilized treatment (Goetz 1975b).

This six year study showed that nitrogen fertilization of native rangeland resulted in greater total herbage yield than that produced on unfertilized rangeland. The response to nitrogen fertilization was not the same for different range sites. Nitrogen fertilization caused a shift in plant species composition with an increase in herbage weight, percent composition, and basal cover of mid grasses and a decrease in percent composition and basal cover of short grasses. Nitrogen fertilization caused an increase in herbage weight, percent composition, and basal cover of undesirable perennial forbs and increases in individual forb plant size. Root weight increased slightly as a result of nitrogen fertilization with the percent root weight increasing greatly in the shallow soil depths and decreasing in the deeper soil depths.

Nitrogen fertilization increased leaf height about 13%. Unfertilized plants of most major species had active growth during 70% of the growing season. Fertilized plants had faster growth rates for about 55% of this unfertilized plant active growth period and unfertilized plants had faster growth rates for about 45% of the time. Fertilized plants had a greater rate of growth in leaf height during a short period in the early portion of the growing season. Unfertilized plants had a longer period of leaf height growth; during the early portion, the rate of growth in leaf height was slower than that of fertilized plants, and during the latter portion of the growing season, the rate of growth in leaf height was greater than that of fertilized plants. Phenological development was not affected by nitrogen fertilization. Flowering dates occurred within the normal range. Rates of leaf drying on the fertilization treatments were a little different than those on the unfertilized treatments. The early stages of leaf drying were started about 6.3 days later by plants on fertilized treatments than by plants on the unfertilized treatments. Plants on the fertilized treatments reached the advanced stages of leaf drying about 5 days earlier than the unfertilized plants.

Nitrogen fertilization increased the available mineral nitrogen in soil during the early portion of the growing season. The quantity of increase was greater with the higher rates. Peak available mineral nitrogen was reached 30 to 35 days after fertilizer application at the same time the first peak was reached on the unfertilized treatment around mid May prior to rapid plant growth. The quantity of available mineral nitrogen decreased quickly during rapid spring plant growth. Beginning in early June, the quantity of mineral nitrogen on the fertilized treatments was the same as that on the unfertilized treatment. The second peak occurred at the end of the active growing season in mid to late July. The third peak occurred in late autumn following plant development for the subsequent year's growth. The low points in available mineral nitrogen occurred during periods of active plant growth. The quantity of soil water use was greater on the fertilized treatments than on the unfertilized treatment with greater quantities of soil water extracted from the heavier application rates.

Nitrogen fertilization increased the crude protein content of aboveground plant material about 18.3% during early growth stages. Crude protein content decreased with advancement in plant maturity. The rate of decline was greater on the fertilized treatments than on the unfertilized treatment and the crude protein content was not different on unfertilized and fertilized treatments in early August. After which, the rate of decline in crude protein accelerated on the fertilized treatments.

Nitrogen fertilization plot study IV

The precipitation during the growing seasons of 1970 to 1978 was normal or greater than normal (table 31). During 1970, 1971, 1972, 1973, 1974, 1975, 1976, and 1978, 17.90 inches (132.10% of LTM), 18.58 inches (137.12% of LTM), 18.57 inches (137.05% of LTM), 11.83 inches (87.31% of LTM), 12.45 inches (91.88% of LTM), 15.26 inches (112.62% of LTM), 10.84 inches (80.00% of LTM), 18.65 inches (137.64% of LTM), and 15.17 inches (111.96% of LTM) of precipitation were received, respectively. April, May, and July of 1970 were wet months and each received 246.85%, 271.37%, and 173.87% of LTM precipitation, respectively. September received normal precipitation at 112.03% of LTM. June was a dry month and received 55.77% of LTM precipitation. August and October were very dry months and received 16.76% and 42.11% of the LTM precipitation, respectively. Perennial plants were under water stress conditions during August and October, 1970 (Manske 2008). April, June, September, and October of 1971 were wet months and each received 209.09%, 212.39%, 263.91%, and 334.74% of LTM precipitation, respectively. May, July, and August were very dry months and received 37.18%, 11.26%, and 13.87% of LTM precipitation, respectively. Perennial plants were under water stress conditions during May, July, and August, 1971 (Manske 2008). May, August, and October of 1972 were wet months and each received 217.52%, 167.63%, and 164.21% of LTM precipitation, respectively. April, June, and July received normal precipitation at 88.81%, 120.85%, and 122.52% of LTM. September was a dry month and received 55.64% of LTM precipitation. Perennial plants were under water stress conditions during September, 1972 (Manske 2008). April and September of 1973 were wet months and each received 224.48% and 167.67% of LTM precipitation, respectively. June received normal precipitation at 85.63% of LTM. May and October were dry months and received 55.56% and 70.53% of LTM precipitation. July and August were very dry months and received 40.99% and 27.17% of the LTM precipitation, respectively. Perennial plants were under water stress conditions during July, August, and October, 1973 (Manske 2008). April and May of 1974 were wet months and each received 197.20% and 177.35% of LTM precipitation, respectively. June, July, August, and October were dry months and received 56.34%, 67.57%, 52.02%, and 54.74% of LTM precipitation. September was a very dry month and received 42.11% of the LTM. Perennial plants were under water stress conditions during July, August, September, and October, 1974 (Manske 2008). April, May, and October of 1975 were wet months and each received 297.20%, 142.74%, and 149.47% of LTM precipitation, respectively. June received normal precipitation at 120.28% of LTM. September was a dry month and received 60.15% of LTM. July and August were very dry months and received 28.83% and 31.21% of LTM precipitation, respectively. Perennial plants were under water stress conditions during July, August, and September, 1975 (Manske 2008). April and September of 1976 were wet months and each received 147.55% and 133.08% of LTM precipitation, respectively. June received normal precipitation at 105.35% of LTM. May and October were dry months and received 60.68% and 68.42% of LTM. July and August were very dry months and received 33.78% and 23.12% of LTM precipitation, respectively. Perennial plants were under water stress conditions during July and August, 1976 (Manske 2008). June, September, and October of 1977 were wet months and each received 151.55%, 434.59%, and 227.37% of LTM precipitation, respectively. May and August received normal precipitation at 111.11% and 87.86 % of LTM. April and July were very dry months and received 9.09% and 48.65% of LTM precipitation, respectively. Perennial plants were under water stress conditions during April and July, 1977 (Manske 2008). April, May, and September of 1978 were wet months and each received 126.57%, 170.51%, and 192.48% of LTM precipitation, respectively. July and August received normal precipitation at 108.56% and 116.18% of LTM. June was a dry month and received 59.15% of LTM. October was a very dry month and received 30.53% of LTM precipitation. Perennial plants were under water stress conditions during October, 1978 (Manske 2008).

Total herbage biomass production increased on the fertilization treatments applied every other year (EOY), every year (EY), and one time (OT) (Whitman 1975, 1978). Mean herbage biomass total yield for the upland range site on the 67 lbs N/ac EOY, 67 lbs N/ac EY, 100 lbs N/ac EOY, 100 lbs N/ac EY, 200 lbs N/ac OT, 300 lbs N/ac OT, and 400 lbs N/ac OT fertitilization treatments was 12.1%, 32.1%, 27.3%, 38.5%, 7.7%, 27.2%, and 25.1% greater than the mean total herbage yield produced on the unfertilized treatment, respectively (table 32). The 100 lbs N/ac EY and 67 lbs N/ac EY treatments had the greatest increases in total herbage yield. The 200 lbs N/ac OT and 67 lbs N/ac EOY treatments had the lowest increases in total herbage yield. Nitrogen in combination with phosphorus produced slightly greater mean total herbage yield than the respective rate of nitrogen alone (Goetz 1984). Application of either phosphorus or potassium alone resulted in no appreciable change in total herbage yield, with no increase of cool season species and no decrease of short warm season species (Whitman 1976, Goetz et al. 1978).

The heavy one time application of 200 lbs N/ac, 300 lbs N/ac, and 400 lbs N/ac treatments had herbage yields 40.6%, 66.8%, and 59.2% greater than those on the unfertilized treatment, respectively, during the first 3 years after application (1970 to 1972) and had herbage yields 8.3% lower, and 5.6% and 9.6% greater than those on the unfertilized treatment, respectively, during the fourth through the ninth year after application (1973 to 1978) (Whitman 1978). One time application of heavy rates of nitrogen were regarded to be viable treatments during the early portions of the study (Whitman 1970, 1971, 1972). The mediocre production on the heavy one time treatments during the latter two thirds of the study resulted because of the rapid immobilization of nitrogen by the soil-plant system (Goetz 1975a). The solution to this problem was considered to be annually applied low rates of supplemental nitrogen fertilizer that would satisfy the needs of the existing plants for continuation of increased herbage yields (Whitman 1972).

The plant species composition shifted with an increase of mid grasses and a decrease of short grasses as a result of the nitrogen fertilization treatments during this nine year study (Whitman 1970, 1971, 1972, 1973, 1974, 1975, 1976, 1977, 1978). The mean herbage weight of mid grasses on the 67 lbs N/ac EOY, 67 lbs N/ac EY, 100 lbs N/ac EOY, 100 lbs N/ac EY, 200 lbs N/ac OT, 300 lbs N/ac OT, and 400 lbs N/ac OT fertilization treatments was 14.8%, 54.8%, 43.5%, 68.3%, 20.5%, 42.2%, and 39.1% greater than the mean mid grass weight produced on the unfertilized treatment, respectively, on the upland range site (table 32). The 100 lbs N/ac EY and 67 lbs N/ac EY treatments had the greatest increases in mid grass herbage yield. The 67 lbs N/ac EOY and 200 lbs N/ac OT treatments had the lowest increases in mid grass herbage yield.

The percent composition of weight yields for mid grasses was greater on the nitrogen fertilization treatments than those on the unfertilized treatments (Whitman 1978) (table 33). The percent composition for mid grasses on the 67 lbs N/ac EOY, 67 lbs N/ac EY, 100 lbs N/ac EOY, 100 lbs N/ac EY, 200 lbs N/ac OT, 300 lbs N/ac OT, and 400 lbs N/ac OT fertilization treatments increased 2.4%, 17.1%, 12.7%, 21.5%, 11.9%, 11.7%, and 11.2%, respectively. The 100 lbs N/ac EY and 67 lbs N/ac EY treatments had the greatest increases in percent composition of mid grasses. The 67 lbs N/ac EOY treatment had the lowest increase in percent composition of mid grasses.

The herbage weight produced by the mid grasses on all of the fertilization treatments was more than double the herbage weight produced by the short grasses (Whitman 1971). The mean herbage weight of short grasses for the upland range site on the 67 lbs N/ac EOY, 67 lbs N/ac EY, 100 lbs N/ac EOY, 100 lbs N/ac EY, 200 lbs N/ac OT, 300 lbs N/ac OT, and 400 lbs N/ac OT fertilization treatments was 15.2%, 26.6%, 29.5%, 27.2%, 20.2%, 7.4%, and 16.7% lower than the mean short grass weight produced on the unfertilized treatment, respectively (table 32). The 100 lbs N/ac EOY, 100 lbs N/ac EY, and 67 lbs N/ac EY treatments had the greatest decreases in short grass herbage yield. The 300 lbs N/ac OT, 67 lbs N/ac EOY, and 400 lbs N/ac OT treatments had the lowest decreases in short grass herbage yield.

The percent composition of weight yields for short grasses was lower on the nitrogen fertilization treatments than those on the unfertilized treatments (Whitman 1978) (table 33). The percent composition for short grasses on the 67 lbs N/ac EOY, 67 lbs N/ac EY, 100 lbs N/ac EOY, 100 lbs N/ac EY, 200 lbs N/ac OT, 300 lbs N/ac OT, and 400 lbs N/ac OT fertilization treatments decreased 24.4%, 44.5%, 44.6%, 47.4%, 25.9%, 27.2%, and 33.4%, respectively. The reductions in percent composition of short grasses was substantial on all nitrogen fertilization treatments. The reductions were greater on the 67 lbs N/ac EY, 100 lbs N/ac EOY, and 100 lbs N/ac EY treatments.

Herbage biomass production of perennial forbs increased on the fertilization treatments (Whitman 1978). Perennial forb dry matter weight produced on the 67 lbs N/ac EOY, 67 lbs N/ac EY, 100 lbs N/ac EOY, 100 lbs N/ac EY, 200 lbs N/ac OT, 300 lbs N/ac OT, and 400 lbs N/ac OT fertilization treatments was 101.6%, 117.9%, 133.3%, 110.7%, 34.4%, 75.3%, and 102.4% greater than the perennial forb weight produced on the unfertilized treatment, respectively (table 32) and percent composition of perennial forbs was 79.8%, 65.0%, 83.2%, 52.1%, 24.7%, 37.8%, and 61.5% greater than that on the unfertilized treatment, respectively (table 33). The 100 lbs N/ac EOY, 67 lbs N/ac EOY, and 100 lbs N/ac EY treatments had the greatest increases in perennial forb weight production. The 100 lbs N/ac EOY, 67 lbs N/ac EOY, and 67 lbs N/ac EY treatments had the greatest increases in percent composition of perennial forb weight. The 200 lbs N/ac OT treatment had the lowest increase in herbage biomass weight and percent composition of perennial forbs. Herbage weight of the perennial forb component greatly increased on all nitrogen fertilization treatments (Whitman 1975, 1978). Annual forb herbage weight did not contribute significantly to the total production yield on any of the nitrogen fertilization treatments (Whitman 1970, 1978).

Total basal cover decreased on the fertilization treatments (Whitman 1978, Goetz et al. 1978). Mean total basal cover of grasses and forbs for the upland range site on the 67 lbs N/ac EOY, 67 lbs N/ac EY, 100 lbs N/ac EOY, 100 lbs N/ac EY, 200 lbs N/ac OT, 300 lbs N/ac OT, and 400 lbs N/ac OT fertilization treatments was 9.1%, 21.5%, 16.0%, 19.8%, 15.2%, 25.9%, and 21.0% lower than the total basal cover on the unfertilized treatment, respectively (table 34). The 300 lbs N/ac OT, 67 lbs N/ac EY, 400 lbs N/ac OT, and 100 lbs N/ac EY treatments had the greatest decreases in total basal cover. The 67 lbs N/ac EOY treatment had the lowest decrease in total basal cover.

Basal cover of cool season grasses, including mid and short grasses, increased on the fertilization treatments (Whitman 1975, 1978; Goetz et al.1978). Cool season grass basal cover on the 67 lbs N/ac EOY, 67 lbs N/ac EY, 100 lbs N/ac EOY, 100 lbs N/ac EY, 200 lbs N/ac OT, 300 lbs N/ac OT, and 400 lbs N/ac OT fertilization treatments was 25.7%, 14.9%, 31.7%, 57.2%, 46.9%, 5.5%, and 34.6% greater than the cool season grass basal cover on the unfertilized treatment, respectively (table 34). The 100 lbs N/ac EY and 200 lbs N/ac OT treatments had the greatest increases in cool season grasses. Basal cover of the mid cool season grasses was not distinct on the biennial and most of the one time application fertilization treatments (Goetz et al. 1978). The 100 lbs N/ac EY, 200 lbs N/ac OT, and 67 lbs N/ac EY treatments had increases in mid cool season grass basal cover 25.2%, 20.8%, and 10.6% greater than those on the unfertilized treatment, respectively. Substantial increases in short cool season grass basal cover of 135.1%, 111.9%, 110.5%, 94.0%, and 92.9% occurred on the 100 lbs N/ac EY, 100 lbs N/ac EOY, 200 lbs N/ac OT, 400 lbs N/ac OT, and 67 lbs N/ac EOY treatments, respectively.

Basal cover of short warm season grasses decreased substantially on the fertilization treatments (Whitman 1975, 1978; Goetz et al. 1978). Short warm season grass basal cover on the 67 lbs N/ac EOY, 67 lbs N/ac EY, 100 lbs N/ac EOY, 100 lbs N/ac EY, 200 lbs N/ac OT, 300 lbs N/ac OT, and 400 lbs N/ac OT fertilization treatments was 42.1%, 67.6%, 51.2%, 77.7%, 46.9%, 49.1%, and 55.4% lower than the short warm season grass basal cover on the unfertilized treatment, respectively (table 34). The 100 lbs N/ac EY, 67 lbs N/ac EY, and 400 lbs N/ac OT treatments had the greatest decreases in short warm season grass basal cover.

Basal cover of domesticated and introduced grasses was low on the unfertilized treatment and was substantially increased on the fertilization treatments, except not on the 200 lbs N/ac OT treatment (table 34). Domesticated and introduced grass basal cover on the 67 lbs N/ac EOY, 67 lbs N/ac EY, 100 lbs N/ac EOY, 100 lbs N/ac EY, 300 lbs N/ac OT, and 400 lbs N/ac OT fertilization treatments was 655.6%, 988.9%, 211.1%, 288.9%, 544.4%, and 111.1% greater than the basal cover of domesticated and introduced grasses on the unfertilized treatment, respectively.

Basal cover of perennial forbs increased on the fertilization treatments with annual and biennial applications but decreased on the heavy one time application of fertilizer treatments (table 34). Perennial forb basal cover increased 75.0%, 66.4%, 47.1%, and 26.0% on the 100 lbs N/ac EY, 67 lbs N/ac EY, 100 lbs N/ac EOY, 67 lbs N/ac EOY treatments and decreased 23.1%, 16.4%, and 11.5% on the 300 lbs N/ac OT, 400 lbs N/ac OT, and 200 lbs N/ac OT treatments, respectively.

Available mineral nitrogen increased on the nitrogen fertilization treatments during the early portion of the growing season (Whitman 1975). The available mineral nitrogen was depleted quickly and was at low levels soon after active plant growth commenced in the spring (Whitman 1975). Quantities of mineral nitrogen increased and decreased in a cyclic phenomenon during the growing season. The first peak occurred in early spring ahead of active plant growth. The second peak occurred following the start of summer dormancy and before active initiation of new growth shortly before winter freeze up (Whitman 1975). The third peak occurred following plant development for the subsequent year's growth (Goetz 1975a).

Nitrogen fertilization treatments increased the crude protein content of grasses during early growth stages. The crude protein content declined with advancement in plant maturity. Crude protein content in warm season grasses decreased at a slower rate than that in cool season grasses. The rate of decline was more rapid on the fertilization treatments and the crude protein content dropped below livestock requirements earlier in the growing season than the crude protein content of grasses on the unfertilized treatment (Whitman 1975).

Whitman determined that the annual application of 67 lbs N/ac was the most productive treatment even though the 100 lbs N/ac EY treatment produced greater mean herbage weight. The 67 lbs N/ac EY treatment was the most efficient and used the lowest amount of nitrogen and the lowest amount of soil water for each pound of additional herbage produced beyond the herbage weight produced on the unfertilized treatment (Whitman 1970, 1971, 1972, 1975, 1976, 1978).

Whitman (1976) considered the application of nitrogen fertilizer to native rangeland to be a beneficial practice because, in a short period, it changed the plant composition from being dominated by short warm season grasses to being dominated by higher producing mid cool season grasses, it increased the annual herbage weight produced, it increased the crude protein content of grasses during early growth stages, and the water use efficiency was improved. The negative aspects of nitrogen fertilization treatments and the resulting shift in plant composition from multiple stemmed high cover species to single stalked low cover species were identified as decreased plant basal ground cover, reduced litter cover, increased soil erosion, increased undesirable perennial forbs and annual grasses, and greater fluctuations in individual plant numbers (Goetz et al. 1978).

This nine year study showed that nitrogen fertilization of native rangeland resulted in greater total herbage yield than that produced on unfertilized rangeland. Nitrogen fertilization caused a shift in plant species composition with an increase in herbage weight and percent composition of mid grasses and a decrease in herbage weight and percent composition of short grasses. Basal cover of mid and short cool season grasses increased and basal cover of short warm season grasses decreased on nitrogen fertilized treatments. Herbage weight and percent composition of undesirable perennial forbs greatly increased on all nitrogen fertilization treatments. Basal cover of perennial forbs increased on fertilization treatments with annual and biennial applications.

Nitrogen fertilization increased the available mineral nitrogen in soil during the early portion of the growing season. The available mineral nitrogen was depleted quickly and was at low levels soon after active plant growth commenced in the spring. A second peak occurred following the start of summer dormancy in mid to late July. The third peak occurred in late autumn. The low points in available mineral nitrogen occurred during the periods of active plant growth.

Nitrogen fertilization increased the crude protein content of grasses during early growth stages. Crude protein content decreased with advancement in plant maturity. The rate of decline was greater on the fertilized treatments than on the unfertilized treatment. The crude protein content of grasses on fertilized treatments dropped below livestock requirements earlier than that of grasses on unfertilized treatments.

The effectiveness of the nitrogen fertilization treatments evaluated during the fertilization plot studies conducted from 1957 to 1978 by Dr. Warren C. Whitman and Dr. Harold Goetz were not equal. The causes for some of the differences in treatment effectiveness were related to changes in available soil water during the numerous study years and variation in soil characteristics of the several study sites.

The effectiveness of the biennial application treatments was less than that of the annual application treatments. The every other year (EOY) application of 67 lbs N/ac and 100 lbs N/ac treatments had lower mean total herbage yield, lower herbage weight produced per pound of nitrogen, and greater cost for the additional treatment produced herbage than those on the 67 lbs N/ac EY treatment. However, the every other year treatments did slow the rate of change in plant composition. The increase in mid and short cool season grasses and the decrease in short warm season grasses were lower than that on the respective every year (EY) treatments.

The effectiveness of the single application treatments was less than that on the annual application treatments. The heavy one time (OT) applications of nitrogen treatments had lower mean total herbage yield than the 67 lbs N/ac EY treatment. The available mineral nitrogen was immobilized in the soil rapidly and the heavy one time treatments were not effective after the first three years following nitrogen application. During the first three years, the 300 lbs N/ac OT treatment was more effective than the 200 lbs N/ac OT and 400 lbs N/ac treatments.

Annual application of nitrogen fertilizer at low, medium, and high rates compared to unfertilized controls has been the primary objective of the nitrogen fertilization plot studies. The first study had a one year duration that produced a framework for what could be expected from further studies. The annually applied treatment rates in the next three studies were 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments. Generally, the heavier rates have produced greater herbage yield with an average increase of 22%, 53%, and 58% greater than the herbage yields produced on the unfertilized treatment, respectively. The relationships of these average increases in herbage production were not linear as would be expected if the effectiveness of the fertilizer treatments were equal. This means that total herbage yield data does not have diagnostic value to evaluate fertilizer treatment effectiveness. Effectiveness of fertilization treatments can be evaluated though comparisons of the mean pounds of herbage weight produced above that produced on the unfertilized treatment per pound of nitrogen applied per acre. The mean herbage weight produced per pound of nitrogen applied on the 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac treatments was 9.10 lbs, 12.23 lbs, and 8.76 lbs per pound of nitrogen applied on the fertilization plot study sites during 1962 to 1978 (table 35, figure 1). The descending order of treatment effectiveness was the 67 lbs N/ac, 33 lbs N/ac, and 100 lbs N/ac application rates. The 100 lbs N/ac treatment produced the greatest total herbage yield, however, it had the lowest treatment effectiveness and produced the lowest herbage weight per pound of nitrogen applied.

Related Results

Scientists at other research centers in the Northern Plains conducted studies that evaluated fertilization treatments on native rangeland for improvement of productivity and the botanical composition of grasslands and to determine the factors affecting nutrient uptake and distribution within the soil-plant system.

Rogler and Lorenz (1957) conducted a nitrogen fertilization on native rangeland plot study that evaluated changes in herbage production and plant species composition at the ARS Research Center, Mandan, ND from 1951 to 1957. Plots were replicated three times and were located in a heavily grazed pasture and a moderately grazed pasture. The treatments included 0 lbs N/ac, 30 lbs N/ac, and 90 lbs N/ac rates in ammonium nitrate applied annually in October. The mean total herbage dry matter production on the 30 lbs N/ac and 90 lbs N/ac rates were 77.3% and 203.6% greater than that on the unfertilized treatment in the heavily grazed pasture, respectively, and were 100.3% and 206.0% greater than that on the unfertilized treatment in the moderately grazed pasture, respectively. Plant species composition shifted with an increase in western wheatgrass basal cover and a decrease in blue grama basal cover.

Smika et al. (1961) conducted a nitrogen fertilization on native rangeland plot study that evaluated changes in chemical properties of the soil and moisture extraction at the ARS Research Center, Mandan, ND from 1951 to 1959. Plots were replicated three times. The treatments included 0 lbs N/ac, 30 lbs N/ac, and 90 lbs N/ac rates with ammonium nitrate applied annually in October. After 9 years of annual treatment, the proportion of the applied nitrogen remaining in the 6 foot soil profile was 88.9% and 69.1% for the 30 lbs N/ac and 90 lbs N/ac rates, respectively. The proportion of the applied nitrogen incorporated into the aboveground herbage was 11.1% and 18.8% for the 30 lbs N/ac and 90 lbs N/ac rates, respectively. During an average growing season, the dispersion of the applied nitrogen for the 30 lbs N/ac rate was 26.7 lbs N/ac immobilized in the soil and 3.3 lbs N/ac incorporated into the aboveground herbage; the dispersion of nitrogen for the 90 lbs N/ac rate was 62.2 lbs N/ac immobilized in the soil, 16.9 lbs N/ac incorporated into the aboveground herbage, and 10.9 lbs N/ac not accounted for that could have been incorporated into the root material or volatilized into the air. The greatest use of the applied nitrogen resulting from increased root activity occurred at the 24 to 36 inch soil depth. Ammonium nitrate and urea fertilizers increase soil acidity. The 30 lbs N/ac rate changed soil pH from 6.5 to 6.1 (a decrease of 6.2%) and the 90 lbs N/ac rate changed soil pH from 6.5 to 5.9 (a decrease of 9.2%) at the 0 to 6 inch soil depth. Phosphate solubility increases at soil pH values higher or lower than pH 7.0. The amount of available phosphorus in the surface soils increased with increases in soil acidity caused by nitrogen fertilization. The quantity of soil moisture withdrawal increased in all soil depths with the addition of nitrogen fertilizer.

Smika et al. (1965) conducted a nitrogen fertilization on native rangeland plot study that evaluated changes in herbage production, water use, water use efficiency, and recovery of nitrogen fertilizer by native grass at the ARS Research Center, Mandan, ND from 1958 to 1961. Plots were replicated three times. The treatments included 0 lbs N-35 lbs P/ac, 20 lbs N-35 lbs P/ac, 40 lbs N-35 lbs P/ac, 80 lbs N-0 lbs P/ac, 80 lbs N-35 lbs P/ac, and 160 lbs N-35 lbs P/ac rates with superphosphate applied one time the first year and ammonium nitrate applied annually in late fall. Aboveground herbage production increased with nitrogen fertilization. The mean total herbage dry matter production on the 20, 40, 80, and 160 pounds of nitrogen per acre rates were 51.3%, 120.5%, 184.6%, and 289.7% greater than that on the unfertilized treatment, respectively. Total water use was related to the available water supply. Under natural conditions, nearly all the available water was used on the unfertilized and fertilized treatments. A greater proportion of the water use on the unfertilized treatments may have been lost through evaporation. Under high moisture conditions, nitrogen fertilization treatments increased water use. Water use efficiency (pounds of herbage production per inch of water use) increased with increased rates of nitrogen fertilizer when sufficient water was available. The quantity of available water required for maximum water use efficiency for fertilizer rates greater than 40 lbs N/ac does not occur under natural conditions in the Northern Plains. The proportion of the applied nitrogen used by native plants under natural moisture conditions was low (17% to 25%). The proportion of the applied nitrogen incorporated into the aboveground herbage increased (27% to 35%) with greater amounts of available soil moisture. A high proportion of the applied nitrogen fertilizer was immobilized in the soil (40% to 53%). The remaining portions of the applied nitrogen were incorporated into the root material or volatilized into the air (27% to 42%).

Lorenz (1970) and Lorenz and Rogler (1972) conducted a nitrogen fertilization on native rangeland plot study that evaluated changes in herbage production and botanical composition at the ARS Research Center, Mandan, ND from 1958 to 1965. Plots were replicated three times and were located in a pasture that had previously been moderately grazed. The treatments included 0 lbs N-0 lbs P/ac, 0 lbs N-18 lbs P/ac, 0 lbs N-36 lbs P/ac, 40 lbs N-0 lbs P/ac, 40 lbs N-18 lbs P/ac, 40 lbs N-36 lbs P/ac, 80 lbs N-0 lbs P/ac, 80 lbs N-18 lbs P/ac, 80 lbs N-36 lbs P/ac, 160 lbs N-0 lbs P/ac, 160 lbs N-18 lbs P/ac, and 160 lbs N-36 lbs P/ac rates with ammonium nitrate and treble superphosphate applied annually in mid October. The mean total herbage dry matter production on the 40 lbs N/ac, 80 lbs N/ac and 160 lbs N/ac rates were 48.3%, 90.5%, and 105.5% greater than that on the unfertilized treatments, respectively. The response to fertilizer varied greatly from year to year as a result of variable effective precipitation, soil moisture supply, and other environmental factors. The response to phosphate applied without nitrogen was small. The response to phosphate increased as rate of nitrogen increased. Plant species composition shifted. Western wheatgrass density increased with increasing nitrogen rates and with phosphate applied with the 160 lbs N/ac rate. Blue grama basal cover decreased with increasing nitrogen rates.

Lorenz (1970) and Lorenz and Rogler (1973) conducted a nitrogen fertilization on native rangeland plot study that evaluated changes in growth rate at the ARS Research Center, Mandan, ND from 1958 to 1965. Plots were replicated three times. The treatments included 0 lbs N-0 lbs P/ac, 0 lbs N-18 lbs P/ac, 40 lbs N/ac, 80 lbs N/ac, 80 lbs N-18 lbs P/ac, and 160 lbs N/ac rates with ammonium nitrate and treble superphosphate applied annually in mid October. Herbage on the fertilized treatments had greater growth rates than that on the unfertilized treatments during the early portion of the growing season from early May to early July. The period with the greatest rate of growth for both the fertilized and unfertilized treatments occurred between 15 June and 1 July. Most treatments decreased in aboveground herbage weight between 15 July and 1 August.

Power (1970), Power and Alessi (1971), and Power (1972) conducted a nitrogen fertilization on native rangeland plot study that evaluated changes in mid summer cumulative aboveground herbage weight and nitrogen content, grass species abundance, annual spring soil mineral nitrogen content, and root weight and nitrogen content at the ARS Research Center, Mandan, ND from 1963 to 1968. Plots were replicated three times. The treatments included 0 lbs N/ac and total nitrogen rates of 30, 60, 120, 240, and 480 lbs N/ac applied in early spring as ammonium nitrate one time in the first year, one third of the total applied in each of three years, and one sixth of the total applied in each of six years. Cumulative 6 year aboveground herbage production increased with increased rates of nitrogen fertilization. Herbage production on treatments with a total of 30 lbs N/ac applied one, three, and six times was not significantly different from the herbage production on the unfertilized treatments. Year to year variations in herbage production existed as a result of variation in available water supply. The treatments with the same rates of total nitrogen applied one, three, and six times produced essentially the same total 6 year cumulative aboveground herbage dry matter with a slight lag on the treatments applied six times. Moderate and high nitrogen fertilization rates resulted in changes in plant species composition with an increased abundance of the mid cool season grasses, primarily western wheatgrass, and a decreased abundance of the short warm season grasses, primarily blue grama. The abundance of prairie Junegrass decreased. Mineral nitrogen (ammonium and nitrate) was available above the 3 foot soil depth in the spring at greater amounts than on the unfertilized treatments on only a few fertilization treatments: the 480 lbs N/ac and 240 lbs N/ac rates applied one time, the 160 lbs N/ac rate applied three times, and, after four treatments, the 80 lbs N/ac rate applied six times. Only about 17 to 28 lbs N/ac of fertilizer nitrogen from the high rates was assimilated into the aboveground herbage per year. About 178 lbs N/ac were immobilized or lost during the first year of treatment. The immobilized nitrogen was assimilated into grass roots, soil organic matter, and microbial tissue. The lost nitrogen was ammonium fixed by adsorption onto clay particles, or lost in gaseous form into the atmosphere by volatilization of ammonia, or by removing oxygen in denitrification forming nitrous oxide or N_2 gas. None of the nitrogen was lost by leaching. The immobilized quantity of nitrogen increased to around 285 lbs N/ac to 339 lbs N/ac within three or four years after the start of fertilization treatments and remained near that range thereafter. About half of the immobilized nitrogen was found in the grass roots. The nitrogen content of the grass roots on the high fertilization treatments was about 0.5% greater than that of unfertilized grass roots. The immobilized nitrogen in organic forms could be mineralized later by soil microorganisms and recirculated through the ecosystem. Mineralization is the enzymatic hydrolysis of the peptide bonds of organic materials which liberates and degrades amino acids into ammonia and carbon dioxide, or other low molecular weight carbon compounds. The ammonia released is oxidized to the nitrite form, then to the nitrate form, and is added to the plant available inorganic (mineral) nitrogen pool in the soil. The nitrogen immobilization capacity in grassland soils was somewhat variable and was influenced by soil texture, vegetation type, root growth, lignin content of organic matter, amount and minerology of clay material, and environmental parameters of soil temperature, soil oxygen, and soil water. An hypothesis on the operation of the nitrogen cycle in grassland soils was developed by Power along with implications for management. Considerable quantities of the fertilizer nitrogen were immobilized by components of the soil-plant system in addition to the amounts used for aboveground herbage growth. Once sufficient fertilizer nitrogen was applied to saturate the nitrogen immobilizing capacity of the soil-plant system, the excess quantity of fertilizer nitrogen remained in the soil in mineral form. Application of sufficient fertilizer nitrogen to grassland soils that saturated the immobilizing capacity would eliminate nitrogen as a growth limiting factor. As a result, semiarid grasslands would produce at the maximum level for whatever water was available if a small amount of annually applied fertilizer nitrogen plus the quantity of inorganic nitrogen mineralized by soil microorganisms equaled the amount of nitrogen immobilized and lost each growing season.

Wight and Black (1972) conducted a fertilization on native rangeland plot study that evaluated changes in herbage production, plant species composition, precipitation use efficiency, and energy fixation at the ARS Research Center, Sidney, MT from 1969 to 1970. Plots were arranged in a split plot design with two replicated blocks. Treatments included 0 lbs P/ac, 100 lbs P/ac, and 200 lbs P/ac as main plots and 0 lbs N/ac, 100 lbs N/ac, 300 lbs N/ac, and 900 lbs N/ac as subplots with superphosphate and ammonium nitrate applied one time in the early spring of 1969. Total herbage yield was greater on fertilized treatments than on unfertilized treatments. Herbage yield increased with increasing nitrogen on the 100 lbs N/ac and 300 lbs N/ac treatments. Herbage yield increased during the second year on the 900 lbs N and 200 lbs P/ac treatment. Phosphorus applied without nitrogen had no effect on herbage yield. Phosphorus increased total herbage production when applied with nitrogen. Herbage weight of western wheatgrass increased with increased rates of nitrogen when applied without phosphorus or with the 200 lbs P/ac rate. Stem density of western wheatgrass greatly increased during the second year on the treatments with high rates of nitrogen and phosphorus. Herbage weight of forbs increased on the 100 lbs N/ac and 300 lbs N/ac treatments. Threadleaf sedge herbage weight increased on the 100 lbs N/ac treatment. Needle and thread herbage weight increased on the 100 lbs N/ac and 300 lbs N/ac treatments. Herbage weights of blue grama and prairie Junegrass were not affected by the fertilization treatments. Fertilization treatments of high rates of nitrogen and phosphorus improved herbage precipitation use efficiency (pounds of herbage produced per inch of precipitation received). Total soil water use was greater on fertilized treatments than on unfertilized treatments. Energy fixation in native rangelands managed by traditional grazing practices captures low quantities of the sun's energy for use by man. The total amount of energy fixed by chlorophyllous plants on rangeland ecosystems is not limited by the availability of radiant energy from the sun or by the availability of atmospheric carbon dioxide (CO_2) but is limited by the low availability of mineral nitrogen and phosphorus. The availability of water, which is an essential requirement for plant growth and has a dominant role in physiological processes, does not limit herbage production on rangeland ecosystems to the extent that nutrient availability does. Nutrient cycling in Northern Plains rangeland ecosystems is inadequate to supply the nitrogen necessary for maximum herbage production. These rangelands are functioning at levels that cycle nitrogen at a rate of about 59 pounds of mineral nitrogen per acre per year or less (usually less) and produce only one half to one third of the potential quantity of herbage. Increasing herbage production to maximum yields would require nitrogen cycling at rates of about 100 to 165 pounds of available mineral nitrogen per acre per year.

Black and Wight (1972) conducted a fertilization on native rangeland plot study that evaluated changes in interactions of soil nitrogen and phosphorus at high fertilizations rates at the ARS Research Center, Sidney, MT from 1969 to 1970. Plots were arranged in a split plot design with two replicated blocks. Treatments included 0 lbs P/ac, 100 lbs P/ac, and 200 lbs P/ac as main plots and 0 lbs N/ac, 100 lbs N/ac, 300 lbs N/ac, and 900 lbs N/ac as subplots with superphosphate and ammonium nitrate applied one time in the early spring of 1969. Only 50% to 70% of the applied nitrogen was measured as nitrate during each of the two years. Nitrification of the ammonium form of nitrogen in the fertilizer may require more than one or two growing seasons. High rates of nitrogen fertilizer lowered soil pH an average of 7.6% in the top six inches. Soluble phosphorus increased greatly as a result of the decrease in pH caused by the applied nitrogen. Fertilization with high nitrogen rates increased the nitrogen content of aboveground plant material in mid July. The increase in the nitrogen content of the plant material was less the second year. Application of phosphorus had no influence on plant nitrogen content. The increased total herbage production and increased plant nitrogen content resulted in an increase in total production of crude protein. High nitrogen rates applied without phosphorus increased plant phosphorus uptake the first year but plant phosphorus content was below livestock requirements the second year. Phosphorus applied with nitrogen increased plant phosphorus content. The percentages of applied nitrogen and phosphorus recovered in aboveground plant material were extremely low. The quantities of soil available mineral nitrogen and soluble phosphorus were at very low levels. Plant-soil nutrient cycling systems of rangeland have a large proportion of the soil nitrogen and phosphorus required for plant growth tied up in the organic phase in relatively unavailable forms. This is corroborated by the low herbage yield and low quality of unfertilized range plants in this study. The effects of range management techniques on nutrient cycling and availability have not been fully determined.

Wight and Black (1979) conducted a fertilization on native rangeland plot study that evaluated the long-term effects on herbage yield and species composition at the ARS Research Center, Sidney, MT from 1967 to 1976. The treatments included low rates of ammonium nitrate and superphosphate applied annually for ten years in early spring on plots replicated four times. High rates of nitrogen and phosphorus were applied one time in early spring on split plots replicated two times with the treatments started during 1969, 1970, and 1971. Nitrogen was established as a major growth limiting factor in the Northern Plains. Nitrogen and phosphorus deficiencies on rangelands reduced potential herbage production around 44%. Applications of nitrogen and nitrogen plus phosphorus increased herbage yield. Magnitude of response varied with both the annual climate and application rate. Phosphorus increased yields only when applied with nitrogen and when nitrogen was nonlimiting. Most of the yield response to nitrogen occurred at the lower rates with only small increases in yield per added pound of nitrogen as nitrogen rate increased beyond 35 to 45 lbs N/ac rates. The most effective nitrogen fertilization treatments were the lower rates. Almost all of the nitrogen applied above the low rates remained in the soil profile, usually above the three foot depth, because very little water moves through soil profiles of semiarid rangelands under cover of perennial vegetation. Low rates of annually applied nitrogen may require four years to overcome the soil nitrogen-sink effect. Species composition varied considerably among years. The percent composition of perennial grasses varied inversely with forbs. The effects from nitrogen fertilization were relatively minor over the ten year study. Generally, the cool season species increased the most with nitrogen fertilization. Blue grama was not affected by low rates of nitrogen but the percent composition decreased as herbage yields of other species increased with nitrogen rates. High nitrogen rates caused blue grama herbage yields to decrease. Upland sedges responded little to fertilization treatments but the percent composition decreased as herbage yields of other species increased with nitrogen rates. During growing seasons with above normal precipitation, forbs like goatsbeard and fringed sage increased on nitrogen treatments and annual forbs like tansy mustard increased on high nitrogen and phosphorus treatments. Pounds of herbage produced per inch of precipitation received was called precipitation use efficiency. The pounds of herbage produced per inch of precipitation were greater on the nitrogen fertilized treatments than on the unfertilized treatments. Nitrogen fertilization effectively removed the nutrient induced limitations on herbage yield. The ten year annual precipitation during the study averaged 13% above the long-term mean and the ambient deficiency of available mineral nitrogen in the unfertilized rangeland ecosystems caused the weight of herbage production per inch of precipitation received to be reduced an average of 49.6% below the herbage produced per inch of precipitation in the fertilized rangeland ecosystems without a deficiency of available mineral nitrogen.

Black and Wight (1979) conducted a fertilization on native rangeland plot study that evaluated changes in plant uptake of nitrogen and phosphorus and recovery of the nutrients after eight years at the ARS Research Center, Sidney, MT from 1969 to 1976. Plots were arranged in a split plot design with two replicated blocks. Treatments included 0 lbs P/ac, 100 lbs P/ac, and 200 lbs P/ac as main plots and 0 lbs N/ac, 100 lbs N/ac, 300 lbs N/ac, and 900 lbs N/ac as subplots with superphosphate and ammonium nitrate applied one time in the early spring of 1969. Aboveground herbage samples were collected in mid July. Plant nitrogen content was not influenced by phosphorus fertilizer. Variations in plant nitrogen content were influenced by the applied rate of nitrogen and years (climate). By the third year after application, plant nitrogen content was no longer influenced by rate of nitrogen application and plant nitrogen content became more related to available water supplies and to the quantity of herbage produced. During wetter years with high herbage production, the plant nitrogen content decreased. During lower precipitation years with reduced herbage production, the plant nitrogen content increased. Plant phosphorus content in grasses decreased as nitrogen rates increased without phosphorus fertilization. The higher rates of nitrogen fertilization depressed plant phosphorus content far below the required levels for livestock. Plant phosphorus content in nongrasses was controlled by the applied rate of phosphorus and secondarily by years (climate). By the third year after application, plant phosphorus content was no longer influenced by rate of phosphorus application and was controlled by available water supplies. During wetter years, plant phosphorus content was relatively high. During lower precipitation years, plant phosphorus content was low. Plant nitrogen uptake was greater on nitrogen fertilization treatments than on the unfertilized treatments. Plant phosphorus uptake was not affected by the application rate of phosphorus. Plant phosphorus uptake increased with the increased rates of nitrogen fertilizer. Recovery of applied nitrogen in the harvested aboveground herbage during the eight years after application was 51.4%, 37.1%, and 19.6% without phosphorus added and was 48.6%, 50.5%, and 27.1% with phosphorus added for the 100 lbs N/ac, 300 lbs N/ac, and 900 lbs N/ac, respectively. Recovery of applied phosphorus in the harvested aboveground herbage during the eight years after application was 27% and 15% for the 100 lbs P/ac and 200 lbs P/ac rates, respectively. Five years after application of the 300 lbs N/ac rate, the distribution of accountable nitrogen (94%) was 34 lbs N/ac in the soil, 103 lbs N/ac in the roots, and 145 lbs N/ac in the aboveground herbage. The nitrogen not accounted for was 18 lbs N/ac, which may have volatilized into the air. The unfertilized treatments had 18,464 lbs/ac of root material in the top foot of soil. The 300 lbs N/ac with 200 lbs P/ac treatment had 21,685 lbs/ac of root material in the top foot of soil five years after application. The root material on the fertilized treatment contained 103 lbs/ac more nitrogen and 6.9 lbs/ac more phosphorus than the roots on the unfertilized treatment. This increased nutrient content of the root material showed that rangeland ecosystems have the potential to immobilize large quantities of nitrogen and phosphorus in the belowground root system.

Taylor (1976) conducted a nitrogen fertilization on native rangeland plot study that evaluated changes in herbage production, plant species composition, and effects from climatic factors at the ARS Research Center, Havre, MT from 1959 to 1973. Plots were replicated three times. The treatments included 0 lbs N/ac and 100 lbs N/ac rates with ammonium nitrate applied annually in late fall for three years, 1959, 1960, and 1961. Herbage samples separated into plant groups were clipped to ground level in early July, 1962 to 1969, 1972 to 1973. Herbage weight and percent composition increased for mid cool season grasses (primarily needle and thread) and herbage weight increased slightly and percent composition decreased for other grasses (primarily blue grama) on the nitrogen fertilization treatments. These changes were not significant because of the wide variations within the annual vegetation production. The climatic factors that explained the variation in plant productivity more than any other climatic factors was the January to peak herbage (June) available plant moisture index which integrated monthly precipitation and potential evapotranspiration. Even though this study was conducted over a 15 year period, the author considered the longevity of response monitoring to be too short because residual effects of nitrogen fertilization were still occurring 12 years after the treatments had stopped. Premature termination of rangeland research studies has contributed many incomplete and erroneous concepts to grassland resource management in the Northern Plains (Jack Taylor 1976).

Discussion

The grazingland natural resources in the Northern Plains had been degraded during the homestead period and beyond as a result of the persistently used naive traditional grazing management practices that repetitively grazed too early, too late, too long, and too heavy. Dr. Warren C. Whitman and Dr. Harold Goetz conducted four nitrogen fertilization of native rangeland plot studies at the Dickinson Research Extension Center from 1957 to 1978 to find and develop cultural management practices that could be used to correct the deteriorated condition of low productivity and botanical composition imbalance on the grazinglands in the Northern Plains. The major findings from these studies follow.

- Nitrogen fertilization of native rangeland resulted in greater total herbage yield than the aboveground herbage produced on unfertilized rangeland manged with traditional grazing practices. Annual applications of 33, 67, and 100 lbs N/ac increased herbage production 22%, 53%, and 58%, respectively. Biennial applications of 67 and 100 lbs N/ac increased herbage production 12% and 27%, respectively. Heavy one time applications of 200, 300, and 400 lbs N/ac were not effective after three years and increased herbage production 8%, 27%, and 25%, respectively. The vegetation responses to nitrogen fertilization were not the same on different range sites as a result of the variations in soil characteristics, soil water content, and plant health status.

- Nitrogen fertilization of native rangeland resulted in a shift in plant species composition. The transformation of the plant community started during the first year of treatment and progressed annually. Herbage weight and percent composition of mid grasses increased and herbage weight and percent composition of short grasses decreased. Basal cover of mid and short cool season grasses increased and basal cover of short warm season grasses decreased. Basal cover, herbage weight, and percent composition of undesirable perennial forbs increased and individual forb plant size greatly increased. The increases in undesirable perennial forbs were greater on range sites in poorer condition. The changes in plant composition were slower on biennially applied treatments. The increases in perennial forbs and the great reductions in blue grama were not beneficial for grassland ecosystems. This plant species shift was also a morphological change in plant community structure with an increase in single stalked low cover species and a decrease in multiple stemmed high cover species resulting in a decrease in total basal cover and an increase in the proportion of soil exposed to potential erosion and open to invasion by opportunistic "weedy" plant species. Basal cover of domesticated cool season grasses and introduced perennial and annual grasses increased slowly. The seriousness of the problems developing with these increasing intrusive grasses was not recognized during these early research projects because their density remained relatively low even after 6, 9, and 11 years of nitrogen fertilization treatments.

- Nitrogen fertilization of native rangeland resulted in an increase in average leaf height of about 13%. Unfertilized plants of most major grass species had active growth during 70% of the growing season. Fertilized plants had faster growth rates for about 55% of this unfertilized plant active growth period and unfertilized plants had faster growth rates for about 45% of the time. Fertilized plants had a greater rate of growth in leaf height during a short period in the early portion of the growing season. Unfertilized plants had a longer period of leaf height growth; during the early portion, the rate of growth in leaf height was slower than that of fertilized plants, and during the latter portion of the growing season, the rate of growth in leaf height was greater than that of fertilized plants. Development of phenological growth stages was not affected by nitrogen fertilization. Flowering (anthesis) occurred within the normal range of dates. Rate of leaf senescence was different for fertilized plants with the early stages of leaf drying starting a little later than for unfertilized plants. Once started, the rate of leaf drying was greater for fertilized plants and the leaves reached advanced stages of drying much earlier than for unfertilized plants.

- Nitrogen fertilization of native rangeland resulted in an increase in the crude protein content of aboveground plant material of about 18% during early growth stages. Crude protein content decreased with advancement in plant maturity. The rate of decline was greater for fertilized plants than for unfertilized plants. The crude protein content of grasses on fertilized treatments dropped below livestock requirements earlier in the growing season than the crude protein content of grasses on unfertilized treatments.

- Nitrogen fertilization of native rangeland resulted in a slight increase in total root weight with the percent root weight increasing greatly in the shallow soil depths and decreasing in the deeper soil depths.

- Nitrogen fertilization of native rangeland resulted in some improvement in soil water use efficiency with a slightly greater amount of herbage weight produced from an inch of soil water. The quantity of total soil water use was greater on the fertilized treatments than on the unfertilized treatments with considerably greater quantities of soil water extracted by the heavier nitrogen application rates.

- Nitrogen fertilization of native rangeland resulted in an increase in available mineral nitrogen in soil during the early portion of the growing season. The quantity of increase was greater with the heavier rates. The quantity of available mineral nitrogen is not at a constant level during the growing season. Low points in available mineral nitrogen occurred during periods of active plant growth and peaks occurred during periods of low plant growth. The first peak in available mineral nitrogen was reached 30 to 35 days after fertilizer application at the same time around mid May that the first peak was reached on the unfertilized treatment prior to rapid plant growth. The quantity of available mineral nitrogen was depleted quickly and was at low levels soon after active plant growth commenced in the spring. Beginning in early June, the quantity of mineral nitrogen on the fertilized treatments was the same as that on the unfertilized treatments. The second peak occurred at the end of the active growing season in mid to late July. The third peak occurred in late autumn following development of fall tillers and fall tiller buds that produce the plant growth during the subsequent growing season.

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Table 1. Precipitation in inches for growing-season months and the annual total precipitation for 1957, Dickinson, North Dakota.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Growing Season	Annual Total
Long-term mean 1892-2007	1.43	2.34	3.55	2.22	1.73	1.33	0.95	13.55	16.00
1957	2.59	2.10	6.61	3.46	1.49	1.98	1.94	20.17	22.15
% of LTM	181.12	89.74	186.20	155.86	86.13	148.87	204.21	148.86	138.44

Table 2. Dry matter weight in pounds per acre for fertilization treatments on a heavily grazed site, 1957.

Treatments	Tall Grasses	Mid Grasses	Short Grasses	Total Grasses	Perennial Forbs	Annual Forbs	Total Forbs	Total Yield
Unfertilized		540	1096	1636			145	1781
50 lbs N		924	1417	2341			115	2456
100 lbs N		1268	2255	3523			242	3765
150 lbs N		706	2259	2965			255	3220

Data from Whitman 1957.

Table 3. Percent composition of weight yield for fertilization treatments on a heavily grazed site, 1957.

Treatments	Tall Grasses	Mid Grasses	Short Grasses	Total Grasses	Perennial Forbs	Annual Forbs	Total Forbs	Total Yield
Unfertilized		30.3	61.5	91.9			8.1	1781
50 lbs N		37.6	57.7	95.3			4.7	2456
100 lbs N		33.7	59.9	93.6			6.4	3765
150 lbs N		21.9	70.2	92.1			7.9	3220

Data from Whitman 1957.

Table 4. Precipitation in inches for growing-season months and the annual total precipitation for 1962-1969, Dickinson, North Dakota.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Growing Season	Annual Total
Long-term mean 1892-2007	1.43	2.34	3.55	2.22	1.73	1.33	0.95	13.55	16.00
1962	1.12	6.18	2.07	3.22	2.52	0.75	0.55	16.41	18.34
% of LTM	78.32	264.10	58.31	145.05	145.66	56.39	57.89	121.11	114.63
1963	3.79	3.69	4.24	1.86	1.04	1.35	0.20	16.17	18.94
% of LTM	265.03	157.69	119.44	83.78	60.12	101.50	21.05	119.34	118.38
1964	1.38	1.86	6.12	4.42	2.87	0.62	0.01	17.28	18.74
% of LTM	96.50	79.49	172.39	199.10	165.90	46.62	1.05	127.53	117.13
1965	3.41	6.07	4.25	3.08	1.64	1.63	0.00	20.08	21.63
% of LTM	238.46	259.40	119.72	138.74	94.80	122.56	0.00	148.19	135.19
1966	0.82	2.16	4.94	2.19	3.41	0.93	0.48	14.93	16.69
% of LTM	57.34	92.31	139.15	98.65	197.11	69.92	50.53	110.18	104.31
1967	3.87	2.79	1.63	0.72	0.41	2.48	0.61	12.51	14.24
% of LTM	270.63	119.23	45.92	32.43	23.70	186.47	64.21	92.32	89.00
1968	1.02	1.25	3.38	2.83	3.99	0.43	0.91	13.81	15.73
% of LTM	71.33	53.42	95.21	127.48	230.64	32.33	95.79	101.92	98.31
1969	0.72	1.32	6.13	4.40	0.52	0.31	0.86	14.26	16.37
% of LTM	50.35	56.41	172.68	198.20	30.06	23.31	90.53	105.24	102.31
1962-1969	2.02	3.17	4.10	2.84	2.05	1.06	0.45	15.68	17.59
% of LTM	141.26	135.47	115.49	127.93	118.50	79.70	47.37	115.72	109.94

Table 5. Dry matter weight in pounds per acre for fertilization treatments on a creek terrace site, 1962-1963.

Treatments	Tall Grasses	Mid Grasses	Short Grasses	Total Grasses	Perennial Forbs	Annual Forbs	Total Forbs	Total Yield
Unfertilized		385.50a	943.00a	1328.50a	67.00a	125.50a	192.50a	1521.00a
33 lbs N		542.00a	1138.50a	1680.50a	32.50b	219.50a	252.00a	1932.50ab
67 lbs N		640.00a	1493.00a	2133.00a	101.00c	206.00a	307.00a	2440.00ab
100 lbs N		517.00a	1566.50a	2083.50a	70.50a	277.50a	348.00a	2431.50b

Means in the same column and followed by the same letter are not significantly different ($P<0.05$).
Data from Whitman 1962, 1963.

Table 6. Percent composition of weight yield for fertilization treatments on a creek terrace site, 1962-1963.

Treatments	Tall Grasses	Mid Grasses	Short Grasses	Total Grasses	Perennial Forbs	Annual Forbs	Total Forbs	Total Yield
Unfertilized		25.35	62.00	87.34	4.40	8.25	12.66	1521.00
33 lbs N		28.05	58.91	86.96	1.68	11.36	13.04	1932.50
67 lbs N		26.23	61.19	87.42	4.14	8.44	12.58	2440.00
100 lbs N		21.26	64.43	85.69	2.90	11.41	14.31	2431.50

Data from Whitman 1963.

Table 7. Dry matter weight in pounds per acre for fertilization treatments on an upland slope site, 1962-1963.

Treatments	Tall Grasses	Mid Grasses	Short Grasses	Total Grasses	Perennial Forbs	Annual Forbs	Total Forbs	Total Yield
Unfertilized		132.00a	745.50a	877.50a	280.50a	200.00a	480.50a	1358.00a
33 lbs N		212.50ab	954.50a	1167.00a	424.50a	233.50b	658.00ab	1825.00ab
67 lbs N		160.50a	1155.50a	1316.00a	518.50a	398.50c	917.00b	2233.00bc
100 lbs N		398.50b	1071.50a	1470.00a	350.00a	440.00c	790.00b	2260.00c

Means in the same column and followed by the same letter are not significantly different ($P<0.05$).
Data from Whitman 1962, 1963.

Table 8. Percent composition of weight yield for fertilization treatments on an upland slope site, 1962-1963.

Treatments	Tall Grasses	Mid Grasses	Short Grasses	Total Grasses	Perennial Forbs	Annual Forbs	Total Forbs	Total Yield
Unfertilized		9.72	54.90	64.62	20.66	14.73	35.38	1358.00
33 lbs N		11.64	52.30	63.95	23.26	12.79	36.00	1825.00
67 lbs N		7.19	51.75	58.93	23.22	17.85	41.07	2233.00
100 lbs N		17.63	47.41	65.04	15.49	19.47	34.96	2260.00

Data from Whitman 1963.

Table 9. Dry matter weight in pounds per acre for fertilization treatments on the Havre overflow range site, 1964-1969.

Treatments	Tall Grasses	Mid Grasses	Short Grasses	Total Grasses	Perennial Forbs	Annual Forbs	Total Forbs	Total Yield
Unfertilized		2068.50a	17.33a	2085.83a	424.50a	3.90a	428.50a	2514.33a
33 lbs N		2284.50a	15.67ab	2300.17a	351.33a	4.00a	355.33a	2655.50a
67 lbs N		2953.83a	5.00a	2959.00a	407.83a	1.17a	409.00a	3368.00a
100 lbs N		2817.83a	43.17b	2861.00a	215.00a	3.17a	218.17a	3079.17a

Means in the same column and followed by the same letter are not significantly different (P<0.05).
Data from Whitman 1964, 1965, 1966, 1967, 1968, 1969.

Table 10. Percent composition of weight yield for fertilization treatments on the Havre overflow range site, 1964-1969.

Treatments	Tall Grasses	Mid Grasses	Short Grasses	Total Grasses	Perennial Forbs	Annual Forbs	Total Forbs	Total Yield
Unfertilized		82.65a	0.72ab	83.37a	16.47a	0.15a	16.63a	2514.33a
33 lbs N		85.73a	0.57ab	86.28a	13.57a	0.13a	13.72a	2655.50a
67 lbs N		87.15a	0.13a	87.33a	12.63a	0.05a	12.67a	3368.00a
100 lbs N		90.93a	1.47b	92.42a	7.50a	0.08a	7.58a	3079.17a

Means in the same column and followed by the same letter are not significantly different (P<0.05).
Data from Whitman 1964, 1965, 1966, 1967, 1968, 1969.

Table 11. Dry matter weight in pounds per acre for fertilization treatments on the Manning silty range site, 1964-1969.

Treatments	Tall Grasses	Mid Grasses	Short Grasses	Total Grasses	Perennial Forbs	Annual Forbs	Total Forbs	Total Yield
Unfertilized		306.17a	946.67a	1252.67a	248.67a	30.50a	279.17a	1533.50a
33 lbs N		336.83a	1058.67a	1395.33a	316.50a	31.50a	348.00a	1743.17a
67 lbs N		482.00a	1451.83b	1933.83b	497.83a	45.83a	543.67a	2477.33b
100 lbs N		601.67a	1577.83b	2179.50b	687.83a	42.17a	730.00a	2909.33b

Means in the same column and followed by the same letter are not significantly different (P<0.05).
Data from Whitman 1964, 1965, 1966, 1967, 1968, 1969.

Table 12. Percent composition of weight yield for fertilization treatments on the Manning silty range site, 1964-1969.

Treatments	Tall Grasses	Mid Grasses	Short Grasses	Total Grasses	Perennial Forbs	Annual Forbs	Total Forbs	Total Yield
Unfertilized		20.03a	61.98a	82.00a	15.95a	1.93a	17.90a	1533.50a
33 lbs N		19.88a	61.05a	80.93a	17.13a	1.93a	19.08a	1743.17a
67 lbs N		20.38a	59.35a	79.73a	18.17a	2.05a	20.28a	2477.33b
100 lbs N		22.02a	55.22a	77.22a	21.20a	1.65a	22.78a	2909.33b

Means in the same column and followed by the same letter are not significantly different (P<0.05).
Data from Whitman 1964, 1965, 1966, 1967, 1968, 1969.

Table 13. Dry matter weight in pounds per acre for fertilization treatments on the Vebar sandy range site, 1964-1969.

Treatments	Tall Grasses	Mid Grasses	Short Grasses	Total Grasses	Perennial Forbs	Annual Forbs	Total Forbs	Total Yield
Unfertilized	44.67a	266.67a	696.67a	1007.83a	246.33a	77.50a	323.83a	1331.67a
33 lbs N	58.83a	230.67a	968.00a	1257.67a	367.00ab	41.50a	408.50a	1665.83a
67 lbs N	29.33a	414.17a	1232.50a	1676.17a	567.33b	47.00a	614.33a	2287.00a
100 lbs N	80.67a	436.17a	1221.67a	1738.33a	570.50b	22.00a	592.50a	2331.00a

Means in the same column and followed by the same letter are not significantly different (P<0.05).
Data from Whitman 1964, 1965, 1966, 1967, 1968, 1969.

Table 14. Percent composition of weight yield for fertilization treatments on the Vebar sandy range site, 1964-1969.

Treatments	Tall Grasses	Mid Grasses	Short Grasses	Total Grasses	Perennial Forbs	Annual Forbs	Total Forbs	Total Yield
Unfertilized	3.53a	20.08a	51.65a	75.30a	19.82a	4.88a	24.70a	1331.67a
33 lbs N	3.65a	17.83a	57.33a	75.17a	22.47a	2.40a	24.87a	1665.83a
67 lbs N	1.47a	18.22a	51.90a	71.58a	25.93a	2.73a	28.65a	2287.00a
100 lbs N	3.32a	18.40a	51.57a	73.28a	25.63a	1.07a	26.72a	2331.00a

Means in the same column and followed by the same letter are not significantly different (P<0.05).
Data from Whitman 1964, 1965, 1966, 1967, 1968, 1969.

Table 15. Dry matter weight in pounds per acre for fertilization treatments on the Rhoades thin claypan range site, 1964-1969.

Treatments	Tall Grasses	Mid Grasses	Short Grasses	Total Grasses	Perennial Forbs	Annual Forbs	Total Forbs	Total Yield
Unfertilized		429.60a	447.80a	877.20a	47.20a	86.60a	132.00a	1011.20a
33 lbs N		605.20a	516.00ab	1121.20ab	42.60a	85.80a	128.40a	1249.60a
67 lbs N		702.80a	605.00b	1307.60ab	115.00a	51.40a	166.40a	1474.00a
100 lbs N		735.00a	590.00ab	1324.80b	70.80a	128.60a	199.40a	1524.20a

Means in the same column and followed by the same letter are not significantly different (P<0.05).
Data from Whitman 1964, 1965, 1966, 1967, 1968, 1969.

Table 16. Percent composition of weight yield for fertilization treatments on the Rhoades thin claypan range site, 1964-1969.

Treatments	Tall Grasses	Mid Grasses	Short Grasses	Total Grasses	Perennial Forbs	Annual Forbs	Total Forbs	Total Yield
Unfertilized		41.18a	46.80a	87.98a	4.48a	7.54a	11.88a	1011.20a
33 lbs N		45.78a	44.16a	89.92a	3.28a	6.78a	10.08a	1249.60a
67 lbs N		45.84a	43.26a	89.12a	7.20a	3.72a	10.88a	1474.00a
100 lbs N		46.26a	40.90a	87.14a	4.74a	8.12a	12.86a	1524.20a

Means in the same column and followed by the same letter are not significantly different (P<0.05).
Data from Whitman 1964, 1965, 1966, 1967, 1968, 1969.

Table 17. Average basal cover of plant categories for fertilization treatments on native rangeland sites, 1964-1966.

Range Sites Treatments	Tall Grasses	Mid Grasses	Short Grasses	Sedge	Total Grasses	Perennial Forbs	Annual Forbs	Total Forbs	Total Basal Cover
Havre overflow range site									
unfertilized		18.55	2.33		20.88	0.68		0.68	22.26
33 lbs N		21.99	1.85		23.84	1.11		1.11	26.06
67 lbs N		24.28	2.16		26.44	2.58		2.58	28.36
100 lbs N		21.92	1.56		23.48	0.74		0.74	25.55
Manning silty range site									
unfertilized		1.58	35.33	7.04	43.95	0.73	0.0	0.73	44.88
33 lbs N		1.35	35.13	8.97	45.45	0.82	0.0	0.82	46.38
67 lbs N		1.39	35.33	8.21	44.93	1.04	0.03	1.07	46.20
100 lbs N		1.51	35.60	9.57	46.68	1.70	0.0	1.70	48.62
Vebar sandy range site									
unfertilized	0.17	2.15	33.30	3.84	39.46	0.36	0.07	0.43	40.15
33 lbs N	0.22	2.04	32.10	4.55	38.91	0.34	0.02	0.36	39.33
67 lbs N	0.37	2.94	29.92	4.34	37.57	0.37	0.0	0.37	38.22
100 lbs N	0.33	2.25	29.73	4.70	37.01	0.34	0.0	0.34	37.47
Rhoades thin claypan range site									
unfertilized		1.50	36.36	0.43	38.29	0.50	0.13	0.63	39.37
33 lbs N		1.60	33.57	0.67	35.84	0.65	0.05	0.70	36.70
67 lbs N		2.43	34.35	0.63	37.41	0.18	0.0	0.18	37.98
100 lbs N		2.22	34.58	0.60	37.40	0.13	0.10	0.23	38.48

Data from Goetz 1969a.

Table 18. Root weight in grams per soil sample depth for fertilization treatments on native rangeland sites, 1964-1966.

Range Site Treatment	Soil Depth in inches 0-6	6-12	12-18	18-24	24-36	36-48	Total root weight
Havre overflow range site							
unfertilized	0.885a	0.411a	0.251a	0.219ab	0.490a	0.172a	2.428a
33 lbs N	0.946a	0.245a	0.269a	0.140a	0.297a	0.240a	2.137ab
67 lbs N	1.559b	0.446a	0.349a	0.241a	0.444a	0.285a	3.324ab
100 lbs N	1.483b	0.517a	0.270a	0.264b	0.442a	0.403a	3.379b
Manning silty range site							
unfertilized	1.448a	0.247a	0.153a				1.848a
33 lbs N	1.603a	0.275a	0.138a				2.016a
67 lbs N	1.559a	0.249a	0.158a				1.966a
100 lbs N	1.429a	0.363b	0.184a				1.976a
Vebar sandy range site							
unfertilized	1.783a	0.254a	0.206a	0.148a	0.109ab	0.070a	2.570a
33 lbs N	2.881b	0.530a	0.398b	0.299b	0.143b	0.088a	4.339b
67 lbs N	1.964a	0.300a	0.157a	0.057c	0.080b	0.034a	2.592a
100 lbs N	1.819a	0.454a	0.178a	0.104ac	0.126ab	0.092a	2.773a
Rhoades thin claypan range site							
unfertilized	0.830a	0.161a	0.330a	0.009a	0.002a	0.001a	1.333a
33 lbs N	1.414ab	0.260a	0.045ab	0.016a	0.006a	0.002a	1.743a
67 lbs N	2.162b	0.244a	0.068b	0.025a	0.003a	0.001a	2.503a
100 lbs N	2.474b	0.267a	0.064b	0.019a	0.005a	0.001a	2.830a

Means in the same column of each range site and followed by the same letter are not significantly different (P<0.05).
Data from Goetz 1969b.

Table 19. Average leaf height in inches for fertilization treatments on the Havre overflow range site, 1964-1966.

Grasses Treatments	15 Apr	30 Apr	15 May	31 May	15 Jun	30 Jun	15 Jul	31 Jul	15 Aug	31 Aug	Maximum Average Height
Western wheatgrass											
unfertilized	2.05	2.99	5.51	8.27	10.63	13.39	15.47	11.81	11.02	11.02	15.47
33 lbs N	1.18	2.83	5.51	9.06	10.51	12.91	17.32	15.35	14.57	14.96	17.36
67 lbs N	1.73	3.27	5.91	8.54	12.24	14.17	16.34	16.50	14.13	14.13	16.50
100 lbs N	2.01	3.35	5.91	9.45	11.65	14.76	17.60	17.68	17.32	16.97	17.68
Needle and thread											
unfertilized	1.14	2.01	4.33	6.30	8.39	9.29	11.30	10.24	9.65	9.65	11.38
33 lbs N	1.22	2.24	4.72	6.30	9.57	10.12	10.75	9.45	9.06	9.06	10.79
67 lbs N	1.57	2.52	4.57	6.30	9.65	10.98	11.69	9.06	8.66	8.66	11.77
100 lbs N	1.22	2.28	4.37	6.61	11.61	12.60	13.50	13.58	13.54	13.54	13.58
Green needlegrass											
unfertilized	1.54	3.54	5.12	10.24	14.49	17.24	19.88	17.72	17.32	17.32	19.88
33 lbs N	1.93	3.66	5.51	11.02x	14.02	16.73x	22.13x	19.69x	18.90	19.29	22.17x
67 lbs N	2.20	3.82	5.51	11.42x	16.30	20.47x	23.58x	22.83x	22.83	22.83	23.62x
100 lbs N	2.09	3.82	5.51	11.81x	14.84	18.11x	23.23x	23.27x	23.23	23.23	23.27x

Asterisk (x) indicates difference between unfertilized and fertilized treatments is significant (P<0.05).
Data from Goetz 1970.

Table 20. Average leaf height in inches for fertilization treatments on the Manning silty range site, 1964-1966.

Grasses Treatments	15 Apr	30 Apr	15 May	31 May	15 Jun	30 Jun	15 Jul	31 Jul	15 Aug	31 Aug	Maximum Average Height
Western wheatgrass											
unfertilized	2.56	2.91	4.33	5.91	9.09	10.28	11.89	11.85	11.73	11.73	11.93
33 lbs N	2.56	2.87x	4.33	5.91x	9.45x	10.71	11.69	11.69	11.61	11.61	11.85
67 lbs N	2.56	3.15x	5.12	7.83x	10.35x	11.22	11.69	13.70	12.13	13.70	13.70
100 lbs N	2.56	3.27x	5.87	7.09x	10.67x	11.93	12.48	13.90	13.07	13.07	13.90
Needle and thread											
unfertilized	1.18	2.01	4.33	6.30	8.39	9.29	11.30	10.24	9.65	9.65	11.38
33 lbs N	0.98	1.46x	2.76x	5.39x	6.93x	7.68x	8.35x	8.03x	8.07	8.07	8.58x
67 lbs N	0.98	1.50x	3.35x	5.55x	7.60x	8.54x	9.45x	10.83x	10.16	10.08	10.83x
100 lbs N	0.98	1.38x	3.35x	4.33x	7.80x	9.13x	9.57x	10.43x	9.69	9.69	10.43x
Blue grama											
unfertilized	0.39	0.47	0.79	2.44	2.95	3.43	4.69	4.76	4.69	4.69	4.76
33 lbs N	0.39	0.67	1.14	1.77x	3.15x	3.78x	5.59x	5.79x	5.00x	5.00x	5.79x
67 lbs N	0.39	0.39	1.54	2.05x	3.11x	4.61x	5.16x	5.71x	5.67x	5.67x	6.50x
100 lbs N	0.39	0.91	1.61	2.17x	2.91x	4.76x	5.55x	7.24x	6.22x	6.26x	7.24x
Threadleaf sedge											
unfertilized	1.18	1.50	1.97	3.58	4.61	4.61	4.57	4.53	4.53	4.53	4.65
33 lbs N	1.18	1.30	2.72	3.39x	4.57x	4.76x	5.16x	4.76x	4.72x	4.72x	5.43x
67 lbs N	1.18	1.46	2.87	3.94x	4.96x	5.16x	4.92x	5.00x	5.08x	5.08x	5.20x
100 lbs N	1.18	1.46	2.56	4.25x	5.16x	5.43x	5.20x	5.39x	5.43x	5.43x	5.55x
Needleleaf sedge											
unfertilized	0.79	1.69	2.76	3.82	4.25	4.57	4.80	4.76	4.69	4.69	4.80
33 lbs N	0.79	1.57	2.76	3.70x	4.45x	4.84	5.43	5.16	5.04	5.04	5.43
67 lbs N	0.79	1.77	2.76	3.54x	4.80x	5.31	5.47	5.39	5.35	5.35	5.59
100 lbs N	0.79	1.57	2.76	4.21x	5.00x	5.63	5.94	5.94	5.94	5.94	6.02

Asterisk (x) indicates difference between unfertilized and fertilized treatments is significant ($P<0.05$).
Data from Goetz 1970.

Table 21. Average leaf height in inches for fertilization treatments on the Vebar sandy range site, 1964-1966.

Grasses Treatments	15 Apr	30 Apr	15 May	31 May	15 Jun	30 Jun	15 Jul	31 Jul	15 Aug	31 Aug	Maximum Average Height
Western wheatgrass											
unfertilized	1.77	2.52	4.72	5.91	6.54	8.90	8.94	8.98	8.98	8.98	8.98
33 lbs N	1.77	2.76	4.72	6.61	7.56	8.11x	8.90x	8.90x	8.90x	8.90x	9.06x
67 lbs N	0.79	2.24	4.96	6.30	8.15	9.13x	9.41x	10.75x	10.98x	10.98x	10.98x
100 lbs N	1.77	3.19	4.53	6.69	8.46	8.86x	12.48x	12.87x	12.87x	12.87x	12.87x
Needle and thread											
unfertilized	0.98	1.57	2.36	3.54	6.46	7.83	10.43	10.43	10.43	10.43	10.51
33 lbs N	0.98	1.97x	2.76x	3.94x	7.52x	8.90x	10.59x	10.59x	10.59x	10.55x	10.63
67 lbs N	0.98	2.60x	3.15x	5.51x	8.35x	9.72x	11.26x	11.26x	11.26x	11.26x	11.46
100 lbs N	0.98	2.24x	3.15x	5.51x	8.86x	9.92x	10.83x	11.10x	11.10x	11.10x	11.10
Blue grama											
unfertilized	0.20	0.59	0.98	1.77	3.15	3.98	4.45	4.57	4.57	4.53	4.57
33 lbs N	0.20	0.51x	0.98	1.97x	3.27x	4.45x	3.90x	4.92x	4.92x	4.92x	4.92x
67 lbs N	0.20	0.51x	1.18	2.36x	3.78x	5.12x	6.10x	6.10x	6.10x	6.10x	6.42x
100 lbs N	0.20	0.59x	1.18	2.13x	3.86x	5.12x	6.22x	6.22x	6.18x	6.18x	7.01x
Threadleaf sedge											
unfertilized	0.98	1.85	2.99	4.33	5.67	5.16	5.12	5.12	5.12	5.12	5.71
33 lbs N	0.98	1.81	2.36x	5.16	5.55x	6.65	5.47x	5.67	5.67	5.63	6.65
67 lbs N	0.98	1.93	3.15x	4.96	6.26x	5.28	6.50x	6.50	6.50	6.46	6.54
100 lbs N	0.98	2.09	3.15x	4.96	6.14x	5.16	6.26x	6.26	6.22	6.22	6.93
Needleleaf sedge											
unfertilized	0.79	1.42	1.97	3.15	3.74	4.88	5.08	5.08	5.04	5.04	5.12
33 lbs N	0.79	1.26	2.95	3.90	4.96	2.91x	5.12x	5.12	5.12	5.12	5.20
67 lbs N	0.79	1.97	3.54	3.94	4.57	5.47x	5.75x	5.75	5.75	5.75	5.75
100 lbs N	0.79	1.69	2.76	3.62	4.65	3.62x	3.62x	3.62	3.58	3.58	4.84

Asterisk (x) indicates difference between unfertilized and fertilized treatments is significant ($P<0.05$).
Data from Goetz 1970.

Table 22. Average leaf height in inches for fertilization treatments on the Rhoades thin claypan range site, 1964-1966.

Grasses Treatments	15 Apr	30 Apr	15 May	31 May	15 Jun	30 Jun	15 Jul	31 Jul	15 Aug	31 Aug	Maximum Average Height
Western wheatgrass											
unfertilized	1.54	1.85	3.39	3.54	5.91	7.32	8.78	8.78	8.78	8.78	8.78
33 lbs N	1.02	1.89	3.58	3.94x	6.57x	7.48x	8.62x	8.62x	8.62x	8.62x	8.62x
67 lbs N	0.59	1.61	3.27	4.29x	6.77x	8.07x	9.84x	9.84x	9.84x	9.76x	9.84x
100 lbs N	0.83	2.28	3.50	4.37x	6.93x	7.48x	10.16x	10.16x	10.16x	10.16x	10.16x
Blue grama											
unfertilized	0.12	0.24	0.79	1.38	2.24	2.87	3.46	3.58	3.58	3.58	3.58
33 lbs N	-	-	0.79	1.38	2.09x	2.44x	3.54x	3.66x	3.66x	3.66x	3.66x
67 lbs N	0.04	0.20	0.79	1.57	2.48x	3.43x	4.65x	4.72x	4.72x	4.72x	4.72x
100 lbs N	0.04	0.79	1.57	2.64	3.58x	4.76x	4.76x	4.76x	4.76x	4.76x	4.88x
Sandberg bluegrass											
unfertilized	0.04	1.34	1.54	1.69	2.17	2.80	3.19	3.19	3.19	3.19	3.19
33 lbs N	0.04	1.34	1.61	1.77	2.48x	3.07x	3.46x	3.46x	3.46x	3.46x	3.46x
67 lbs N	0.47	1.54	1.73	1.97	2.56x	3.35x	3.03x	3.03x	2.95x	2.87x	3.78x
100 lbs N	0.63	1.54	1.77	1.97	2.95x	3.43x	3.62x	3.62x	3.58x	3.54x	3.78x
Needleleaf sedge											
unfertilized	0.79	1.42	2.09	2.52	3.19	3.27	3.39	3.39	3.39	3.39	3.39
33 lbs N	0.79	1.69	2.40	2.60x	3.35x	3.58x	3.94x	3.94x	3.94x	3.94x	4.25x
67 lbs N	0.63	1.22	2.76	2.76x	3.46x	4.06x	4.13x	4.13x	4.09x	4.06x	4.29x
100 lbs N	0.75	1.06	2.40	2.76x	3.94x	4.49x	4.88x	4.88x	4.84x	4.80x	4.88x

Asterisk (x) indicates difference between unfertilized and fertilized treatments is significant (P<0.05).
Data from Goetz 1970.

Table 23. Average date of first flowering and of leaf senescence percentage for fertilization treatments on the Havre overflow range site, 1964-1966

Grasses Treatments	Anthesis	Leaf Tip Dry	Leaf 0-25% Dry	Leaf 25-50% Dry	Leaf 50-75% Dry
Western wheatgrass					
unfertilized	11 Jul	10 Jun	9 Jul	7 Sep	1 Oct
33 lbs N	12 Jul	11 Jun	31 Jul	7 Sep	
67 lbs N	22 Jul	26 Jun	31 Jul	9 Sep	
100 lbs N	22 Jul	26 Jun	31 Jul	9 Sep	
Needle and thread					
unfertilized	24 Jun	26 Jun	6 Aug	17 Aug	9 Sep
33 lbs N	19 Jun	6 Jul	6 Aug	7 Sep	19 Sep
67 lbs N	19 Jun	30 Jun	31 Jul	24 Aug	9 Sep
100 lbs N	29 Jun	30 Jun	31 Jul	24 Aug	9 Sep
Green needlegrass					
unfertilized	29 Jun	7 Jun	1 Jul	23 Aug	12 Sep
33 lbs N	24 Jun	7 Jun	19 Jul	20 Aug	
67 lbs N	24 Jun	8 Jun	14 Jul	24 Aug	
100 lbs N	24 Jun	8 Jun	19 Jul	17 Aug	
Plains reedgrass					
unfertilized	7 Jul	2 Jul	30 Jul	9 Aug	
33 lbs N	7 Jul	21 Jun	14 Aug	23 Aug	
67 lbs N	7 Jul	2 Jul	27 Jul	2 Aug	
100 lbs N	7 Jul	2 Jul	2 Aug	24 Aug	
Blue grama					
unfertilized	23 Jul	10 Jul	14 Aug		
33 lbs N	23 Jul	6 Jul	14 Aug		
67 lbs N	27 Jul	7 Jul	30 Aug		
100 lbs N	27 Jul	22 Jun	16 Aug		

Data from Goetz 1970.

Table 24. Average date of first flowering and of leaf senescence percentage for fertilization treatments on the Manning silty range site, 1964-1966.

Grasses Treatments	Anthesis	Leaf Tip Dry	Leaf 0-25% Dry	Leaf 25-50% Dry	Leaf 50-75% Dry
Western wheatgrass					
unfertilized	17 Jul	7 Jun	31 Jul		1 Oct
33 lbs N	17 Jul	7 Jun	31 Jul		1 Oct
67 lbs N	17 Jul	7 Jun	25 Jul	9 Sep	25 Sep
100 lbs N	17 Jul	7 Jun	25 Jul	29 Aug	9 Sep
Needle and thread					
unfertilized	6 Jul	7 Jun	11 Aug	15 Aug	1 Oct
33 lbs N	6 Jul	7 Jun	12 Aug	15 Aug	1 Oct
67 lbs N	6 Jul	15 Jun	15 Aug	29 Aug	
100 lbs N	17 Jul	7 Jun	25 Jul	29 Aug	9 Sep
Plains reedgrass					
unfertilized	18 Jun	9 Jun	13 Jul	9 Sep	1 Oct
33 lbs N	18 Jun	9 Jun	25 Jul	1 Oct	
67 lbs N	18 Jun	9 Jun	11 Jul	9 Sep	1 Oct
100 lbs N		9 Jun	11 Jul	9 Sep	
Prairie Junegrass					
unfertilized	23 Jun	24 Jun	27 Jul		
33 lbs N	23 Jun	24 Jun	27 Jul		
67 lbs N	21 Jun	24 Jun	27 Jul		
100 lbs N	23 Jun	26 Jun	27 Jul	1 Oct	
Blue grama					
unfertilized	20 Jul	22 Jun	6 Aug	6 Sep	9 Sep
33 lbs N	20 Jul	22 Jun	6 Aug	5 Sep	9 Sep
67 lbs N	20 Jul	20 Jun	28 Jul	25 Aug	9 Sep
100 lbs N	20 Jul	29 Jun	31 Jul	25 Aug	9 Sep
Threadleaf sedge					
unfertilized	5 May	26 May	9 Jun	30 Jul	31 Jul
33 lbs N	4 May	26 May	7 Jun	7 Jul	17 Jul
67 lbs N	4 May	22 May	7 Jun	1 Jul	6 Aug
100 lbs N	4 May	21 May	7 Jun	13 Jul	13 Aug
Needleleaf sedge					
unfertilized	5 May	31 May	7 Jun	30 Jun	13 Jul
33 lbs N	5 May	26 May	7 Jun	30 Jun	27 Jul
67 lbs N	5 May	22 May	7 Jun	6 Jul	27 Jul
100 lbs N	5 May	21 May	7 Jun	13 Jul	27 Jul

Data from Goetz 1970.

Table 25. Average date of first flowering and of leaf senescence percentage for fertilization treatments on the Vebar sandy range site, 1964-1966.

Grasses Treatments	Anthesis	Leaf Tip Dry	Leaf 0-25% Dry	Leaf 25-50% Dry	Leaf 50-75% Dry
Western wheatgrass					
unfertilized	17 Jul	14 Jun	6 Aug		1 Oct
33 lbs N	17 Jul	16 Jun	22 Aug		1 Oct
67 lbs N	11 Jul	14 Jun	19 Jul		1 Oct
100 lbs N	11 Jul	16 Jun	14 Jul	8 Sep	
Needle and thread					
unfertilized	26 Jun	25 Jun	19 Aug	9 Sep	1 Oct
33 lbs N	19 Jun	15 Jun	21 Jul	9 Sep	1 Oct
67 lbs N	30 Jun	10 Jun	1 Aug	21 Aug	
100 lbs N	3 Jul	10 Jun	18 Jul	21 Aug	
Plains reedgrass					
unfertilized	29 Jun	8 Jun	16 Jul	25 Aug	1 Oct
33 lbs N	29 Jun	22 Jun	22 Jul	25 Aug	1 Oct
67 lbs N	22 Jun	13 Jun	19 Jul	8 Sep	1 Oct
100 lbs N	26 Jun	15 Jun	19 Jul	8 Sep	1 Oct
Prairie Junegrass					
unfertilized	24 Jun	3 Jul	27 Jul	9 Sep	
33 lbs N	21 Jun	28 Jun	24 Jul	22 Aug	1 Oct
67 lbs N	24 Jun	28 Jun	22 Jul	9 Sep	
100 lbs N	16 Jun	29 Jun	28 Jul	9 Sep	
Blue grama					
unfertilized	16 Jul	19 Jun	4 Aug	29 Aug	1 Oct
33 lbs N	16 Jul	15 Jun	4 Aug	28 Aug	1 Oct
67 lbs N	16 Jul	15 Jun	26 Jul	25 Aug	
100 lbs N	16 Jul	15 Jun	1 Aug	27 Aug	
Threadleaf sedge					
unfertilized	4 May	5 Jun	19 Jun	30 Jun	27 Jul
33 lbs N	4 May	5 Jun	14 Jun	13 Jul	27 Jul
67 lbs N	4 May	2 Jun	11 Jun	13 Jul	2 Aug
100 lbs N	4 May	18 Jun	20 Jun	13 Jul	2 Aug
Needleleaf sedge					
unfertilized	4 May	1 Jun	15 Jun	3 Jul	25 Jul
33 lbs N	4 May	5 Jun	14 Jun	3 Jul	21 Jul
67 lbs N	4 May	5 Jun	13 Jun	26 Jul	22 Jul
100 lbs N	4 May	5 Jun	15 Jun	3 Jul	22 Jul

Data from Goetz 1970.

Table 26. Average date of first flowering and of leaf senescence percentage for fertilization treatments on the Rhoades thin claypan range site, 1964-1966.

Grasses Treatments	Anthesis	Leaf Tip Dry	Leaf 0-25% Dry	Leaf 25-50% Dry	Leaf 50-75% Dry
Western wheatgrass					
unfertilized	12 Jul	1 Jun	1 Jul	5 Aug	2 Sep
33 lbs N	12 Jul	1 Jun	4 Jul	2 Aug	2 Sep
67 lbs N	12 Jul	14 Jun	8 Jul	9 Aug	7 Sep
100 lbs N	15 Jul	22 Jun	23 Jul	9 Aug	23 Aug
Prairie Junegrass					
unfertilized	24 Jun	7 Jul	18 Jul	25 Aug	
33 lbs N			7 Jul	25 Aug	
67 lbs N	24 Jun		11 Jun	25 Aug	
100 lbs N			7 Jul	25 Aug	
Blue grama					
unfertilized	18 Jul	16 Jun	31 Jul	20 Aug	9 Sep
33 lbs N	16 Jul	16 Jun	1 Aug	20 Aug	9 Sep
67 lbs N	15 Jul	16 Jun	18 Jul	11 Sep	
100 lbs N	18 Jul	16 Jun	7 Aug	11 Sep	
Sandberg bluegrass					
unfertilized	21 Jun	10 Jun	14 Jun	18 Jun	6 Jul
33 lbs N	8 Jun	12 Jun	4 Jun	10 Jul	6 Jul
67 lbs N	21 Jun	12 Jun	29 Jun	12 Jul	16 Jul
100 lbs N	21 Jun	12 Jun	5 Jul	7 Jul	16 Jul
Needleleaf sedge					
unfertilized	5 May	22 May	6 Jun	28 Jun	27 Jul
33 lbs N	4 May		8 Jun	16 Jun	13 Jul
67 lbs N	4 May		9 Jun	7 Jul	27 Jul
100 lbs N	30 May		6 Jun	24 Jun	27 Jul

Data from Goetz 1970.

Table 27. Percent crude protein of grass species for fertilization treatments on the Havre overflow range site, 1964-1969.

Treatments	1 Jun	15 Jun	1 Jul	15 Jul	1 Aug	15 Aug	1 Sep	Mean
Western wheatgrass								
unfertilized	17.1	15.7	12.2	11.7	10.1	9.0	8.8	12.1
33 lbs N	17.6	14.9	11.7	11.4	9.8	7.8	8.9	11.7
67 lbs N	19.3	16.2	11.7	12.6	9.0	8.4	8.8	12.3
100 lbs N	19.7	17.7	13.7	14.1	8.2	8.5	9.9	13.1
Green Needlegrass								
unfertilized	14.9	12.5	9.7	9.1	6.8	7.1	7.3	9.6
33 lbs N	15.6	12.5	8.9	9.1	6.8	6.4	7.6	9.6
67 lbs N	15.7	14.6	10.2	9.8	7.7	7.5	7.6	10.4
100 lbs N	19.3	15.6	11.4	11.0	8.2	8.0	8.2	11.7

Data from Goetz 1975b.

Table 28. Percent crude protein of grass species for fertilization treatments on the Manning silty range site, 1964-1969.

Treatments	1 Jun	15 Jun	1 Jul	15 Jul	1 Aug	15 Aug	1 Sep	Mean
Western wheatgrass								
unfertilized	15.2	11.7	12.3	9.7	8.3	6.5	6.3	10.0
33 lbs N	16.2	13.2	11.0	10.6	8.6	6.5	6.2	10.3
67 lbs N	18.1	15.5	12.6	10.8	8.9	7.0	6.2	11.3
100 lbs N	20.0	16.3	13.2	11.9	9.4	7.4	7.2	12.2
Needle and thread								
unfertilized	12.3	9.9	7.7	7.9	6.9	6.7	6.1	8.2
33 lbs N	12.5	10.2	8.6	7.8	6.6	6.3	6.1	8.3
67 lbs N	15.3	13.9	9.0	8.4	6.6	6.8	6.7	9.5
100 lbs N	16.5	12.6	10.0	8.6	7.5	6.9	7.3	9.9
Blue grama								
unfertilized	12.0	10.9	8.8	8.9	9.2	6.7	7.1	9.1
33 lbs N	11.0	11.6	12.8	10.7	8.6	7.1	7.3	9.9
67 lbs N	13.6	13.4	13.9	10.3	10.0	8.2	7.9	11.0
100 lbs N	15.6	15.0	11.5	12.0	9.7	10.1	8.8	11.8

Data from Goetz 1975b.

Table 29. Percent crude protein of grass species for fertilization treatments on the Vebar sandy range site, 1964-1969.

Treatments	1 Jun	15 Jun	1 Jul	15 Jul	1 Aug	15 Aug	1 Sep	Mean
Needle and Thread								
unfertilized	14.2	13.8	7.9	8.1	6.7	6.4	5.9	9.0
33 lbs N	14.8	12.4	9.5	8.1	6.8	6.8	6.4	9.3
67 lbs N	17.1	14.2	10.1	9.3	7.3	7.2	7.8	10.4
100 lbs N	18.2	15.4	10.3	10.1	9.5	8.7	7.9	11.4
Blue grama								
unfertilized	11.5	11.2	10.0	9.2	8.2	7.6	7.2	9.3
33 lbs N	12.8	12.7	9.5	9.3	8.8	7.7	8.4	9.9
67 lbs N	15.0	14.8	12.1	10.7	10.2	8.7	7.5	11.3
100 lbs N	15.4	16.0	13.4	10.4	10.8	9.2	8.5	12.0
Threadleaf sedge								
unfertilized	12.4	11.2	8.8	8.5	7.4	6.4	7.0	8.8
33 lbs N	13.6	12.6	9.4	9.0	6.9	6.9	8.0	9.5
67 lbs N	15.3	14.1	11.8	10.6	9.2	8.6	10.6	11.5
100 lbs N	15.7	14.8	12.4	11.0	10.1	8.8	11.3	12.0

Data from Goetz 1975b.

Table 30. Percent crude protein of grass species for fertilization treatments on the Rhoades thin claypan range site, 1964-1969.

Treatments	1 Jun	15 Jun	1 Jul	15 Jul	1 Aug	15 Aug	1 Sep	Mean
Western wheatgrass								
unfertilized	16.2	13.3	14.6	12.9	8.0	8.6	8.7	11.8
33 lbs N	17.1	15.3	12.4	14.9	9.5	10.2	8.0	12.5
67 lbs N	19.0	15.8	13.9	14.7	9.8	10.1	8.6	13.1
100 lbs N	21.0	15.0	14.6	14.9	11.5	6.6	9.9	13.4
Blue grama								
unfertilized	11.7	14.1	11.6	11.1	10.0	10.3	9.2	11.1
33 lbs N	14.1	13.9	10.4	13.5	12.4	10.0	9.1	11.9
67 lbs N	15.2	15.7	14.5	12.8	13.5	9.9	10.4	13.1
100 lbs N	15.9	16.2	17.4	14.2	16.6	9.8	11.0	14.4
Sandberg bluegrass								
unfertilized	11.5	9.4	7.3				4.9	8.3
33 lbs N	15.2	12.7	7.3	5.7			5.6	9.3
67 lbs N	17.5	14.8	8.8	8.8			5.7	11.1
100 lbs N	18.0	16.0	8.5	14.2			5.7	12.5

Data from Goetz 1975b.

Table 31. Precipitation in inches for growing-season months and the annual total precipitation for 1970-1978, Dickinson, North Dakota.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Growing Season	Annual Total
Long-term mean 1892-2007	1.43	2.34	3.55	2.22	1.73	1.33	0.95	13.55	16.00
1970	3.53	6.35	1.98	3.86	0.29	1.49	0.40	17.90	20.16
% of LTM	246.85	271.37	55.77	173.87	16.76	112.03	42.11	132.10	126.00
1971	2.99	0.87	7.54	0.25	0.24	3.51	3.18	18.58	21.25
% of LTM	209.09	37.18	212.39	11.26	13.87	263.91	334.74	137.12	132.81
1972	1.27	5.09	4.29	2.72	2.90	0.74	1.56	18.57	20.76
% of LTM	88.81	217.52	120.85	122.52	167.63	55.64	164.21	137.05	129.75
1973	3.21	1.30	3.04	0.91	0.47	2.23	0.67	11.83	13.53
% of LTM	224.48	55.56	85.63	40.99	27.17	167.67	70.53	87.31	84.56
1974	2.82	4.15	2.00	1.50	0.90	0.56	0.52	12.45	14.15
% of LTM	197.20	177.35	56.34	67.57	52.02	42.11	54.74	91.88	88.44
1975	4.25	3.34	4.27	0.64	0.54	0.80	1.42	15.26	17.71
% of LTM	297.20	142.74	120.28	28.83	31.21	60.15	149.47	112.62	110.69
1976	2.11	1.42	3.74	0.75	0.40	1.77	0.65	10.84	12.68
% of LTM	147.55	60.68	105.35	33.78	23.12	133.08	68.42	80.00	79.25
1977	0.13	2.60	5.38	1.08	1.52	5.78	2.16	18.65	23.13
% of LTM	9.09	111.11	151.55	48.65	87.86	434.59	227.37	137.64	144.56
1978	1.81	3.99	2.10	2.41	2.01	2.56	0.29	15.17	17.63
% of LTM	126.57	170.51	59.15	108.56	116.18	192.48	30.53	111.96	110.19
1970-1978	2.46	3.23	3.82	1.57	1.03	2.16	1.21	15.47	17.89
% of LTM	172.03	138.03	107.61	70.72	59.54	162.41	127.37	114.17	111.81

Table 32. Dry matter weight in pounds per acre for fertilization treatments on the upland range site, 1970-1978.

Treatments	Tall Grasses	Mid Grasses	Short Grasses	Total Grasses	Perennial Forbs	Annual Forbs	Total Forbs	Total Yield
Unfertilized		1254.23	746.33	2000.56	207.00	45.00	252.00	2252.56
67 lbs N EOY		1439.50	633.13	2072.63	417.25	35.75	453.00	2525.63
67 lbs N EY		1940.89	547.67	2488.56	451.00	36.33	487.33	2975.89
100 lbs N EOY		1799.71	525.86	2325.57	482.86	59.57	542.43	2868.00
100 lbs N EY		2111.00	543.56	2654.56	436.22	28.56	464.78	3119.34
200 lbs N OT		1511.56	595.56	2107.12	278.11	41.33	319.44	2426.56
300 lbs N OT		1782.89	691.11	2474.00	362.78	28.89	391.67	2865.67
400 lbs N OT		1745.11	621.44	2366.55	418.22	33.56	451.78	2818.33

Data from Annual Reports 1970-1978.

Table 33. Percent composition of weight yield for fertilization treatments on the upland range site, 1970-1978.

Treatments	Tall Grasses	Mid Grasses	Short Grasses	Total Grasses	Perennial Forbs	Annual Forbs	Total Forbs	Total Yield
Unfertilized		55.68	33.13	88.81	9.19	2.00	11.19	2252.56
67 lbs N EOY		57.00	25.06	82.06	16.52	1.42	17.94	2525.63
67 lbs N EY		65.22	18.40	83.62	15.16	1.22	16.38	2975.89
100 lbs N EOY		62.75	18.34	81.09	16.84	2.07	18.91	2868.00
100 lbs N EY		67.67	17.43	85.10	13.98	0.92	14.90	3119.34
200 lbs N OT		62.30	24.54	86.84	11.46	1.70	13.16	2426.56
300 lbs N OT		62.21	24.12	86.33	12.66	1.01	13.67	2865.67
400 lbs N OT		61.92	22.05	83.97	14.84	1.19	16.03	2818.33

Data from Annual Reports 1970-1978.

Table 34. Basal cover of plant categories for fertilization treatments on the upland range site, 1970-1976.

Treatments	Mid Warm	Short Warm	Western Wheatgrass	Mid Cool	Short Cool	Sedge	Domesticated and Introduced Grasses	Total Grass	Total Forbs	Total Basal Cover
Unfertilized	0.03	14.15	2.47	4.07	2.68	5.71	0.09	29.20	1.04	30.25
67 lbs N EOY	0.10	8.20	1.86	4.56	5.17	5.61	0.68	26.18	1.31	27.49
67 lbs N EY	0.08	4.58	3.61	3.62	3.36	5.78	0.98	22.01	1.73	23.74
100 lbs N EOY	0.02	6.90	1.55	4.91	5.68	4.54	0.28	23.88	1.53	25.41
100 lbs N EY	0.04	3.16	2.91	5.28	6.30	4.41	0.35	22.45	1.82	24.27
200 lbs N OT	0.02	7.51	1.36	6.54	5.64	3.65	0.01	24.73	0.92	25.65
300 lbs N OT	0.02	7.20	2.60	4.43	2.70	4.09	0.58	21.62	0.80	22.42
400 lbs N OT	0.07	6.31	1.50	5.71	5.20	4.04	0.19	23.02	0.87	23.89

Data from Goetz et al. 1978, Goetz 1984.

Table 35. Herbage weight in pounds per acre per pound of nitrogen fertilizer applied, 1962-1978.

	Nitrogen Fertilization Rates		
Study Sites	33 lbs N/ac	67 lbs N/ac	100 lbs N/ac
Creek terrace site	12.47	13.72	9.11
Upland slope site	14.15	13.06	9.02
Havre overflow range site	4.28	12.74	5.65
Manning silty range site	6.35	14.09	13.76
Vebar sandy range site	10.13	14.26	9.99
Rhoades thin claypan range site	7.22	6.91	5.13
Upland range site		10.80	8.67
Mean lbs herbage/lb nitrogen	9.10	12.23	8.76

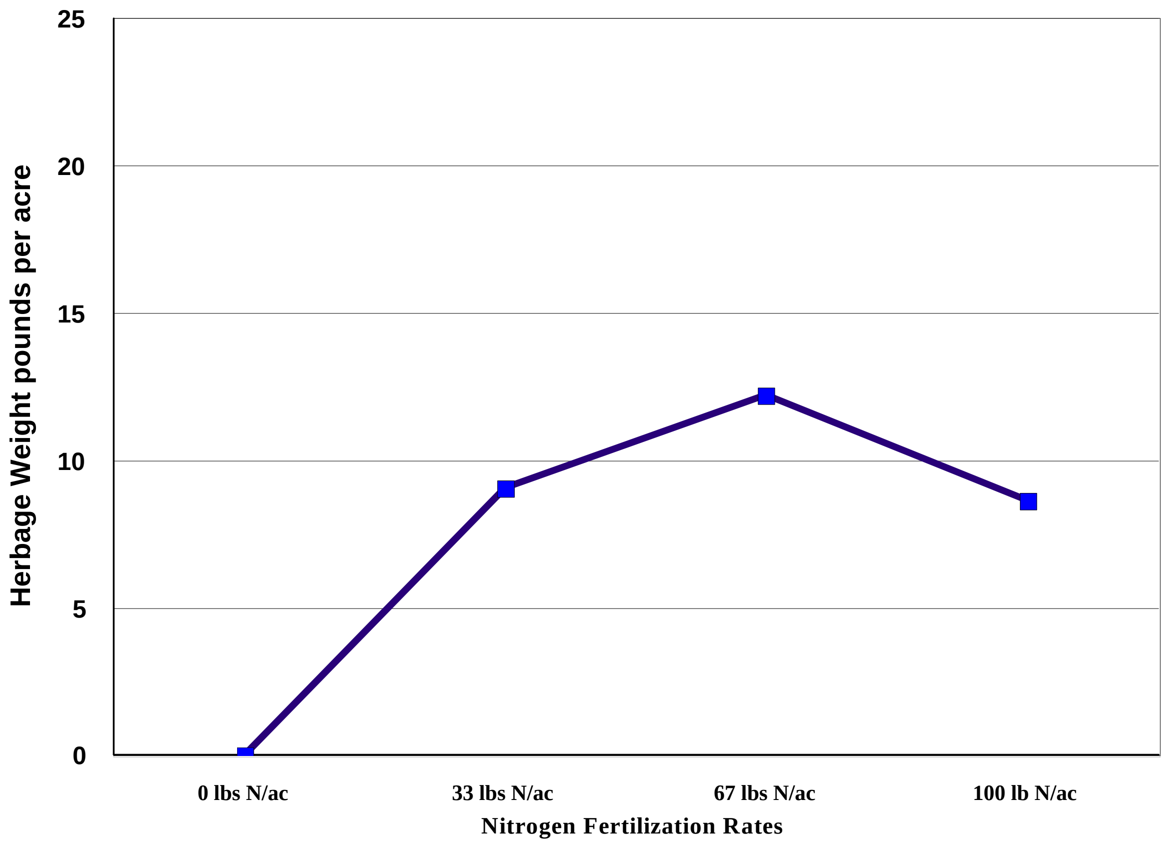

Figure 1. Herbage weight in pounds per acre per pound nitrogen fertilizer applied.

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Nitrogen Fertilization on Native Rangeland with Ammonium Nitrate and Urea

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Numerous nitrogen fertilization of native rangeland plot studies were conducted in the Northern Plains during the 1950's through the 1970's. The source of the fertilizer nitrogen for these studies was usually ammonium nitrate. Reductions in its availability had occurred as a result of serious problems with the manufacture and storage of ammonium nitrate fertilizer. During the manufacture of ammonium nitrate, emissions of nitrous oxides were released into the atmosphere and the high costs for industrial controls of these pollutants were prohibitive (Power 1974). Moreover, ammonium nitrate had explosive characteristics that presented potentially dangerous problems for fertilizer suppliers to handle and store this type of fertilizer.

Urea rapidly overtook ammonium sulfate as the predominant replacement source of fertilizer nitrogen. In order to be able to predict the usefulness of urea for cultural practices on native rangeland, the effects of the replacement fertilizer needed to be compared to the effects determined for ammonium nitrate fertilizer during the previous three decades of research projects.

Presumably, each pound of mineral (inorganic) nitrogen in the soil should yield similar results regardless of source. However, when urea is hydrolyzed to ammonia and carbon dioxide, usually some of the ammonia is volatilized into the atmosphere (Power 1974). The quantity of lost ammonia increases when soil conditions have neutral or alkaline pH, limited water supply, warm temperatures, and/or the presence of organic mulches. In a review of the literature, Power (1974) found that urea at higher rates greater than 100 lbs N/ac was not as effective as ammonium nitrate and that production of aboveground herbage on grasslands was generally from 5% to 40% less on the high rates of urea treatments than on the same rates of ammonium nitrate. This lower effectiveness and the greater proportions of the applied urea nitrogen not accounted for in the ecosystem was attributed to greater volatilization of ammonia from surface broadcast application of high rates of urea than with ammonium nitrate. The relationships of effectiveness at lower rates of ammonium nitrate and urea were not evaluated but were considered to be similar (Power 1974).

Previous studies determined that nitrogen fertilization of native rangeland caused a shift in plant species composition with an increase in mid cool season grasses, primarily western wheatgrass, and a decrease in short warm season grasses, primarily blue grama. Early studies considered these changes to be beneficial (Rogler and Lorenz 1957; Lorenz and Rogler 1972; Whitman 1957, 1976). Later studies (Goetz et al. 1978) found these shifts in plant composition to be undesirable because the resulting reduction in ground cover increased the amount of soil exposed to erosion and increased the amount of open spaces available for invasion by undesirable perennial forbs, domesticated cool season grasses, and introduced annual and perennial grasses.

The objectives of the nitrogen fertilization of native rangeland plot study V were to evaluate the effectiveness of similar low rates of ammonium nitrate and urea and to evaluate the degree of differences in annual and biennial applications of ammonium nitrate and urea fertilizers (Manske and Goetz 1985b).

Procedure

Nitrogen fertilization of native rangeland plot study V (1982-1987) was conducted by Dr. Harold Goetz and Dr. Llewellyn L. Manske on 2.6 acres located on the SW¼, SW¼, NW¼, sec. 16, T. 143 N., R. 96 W., at the Dickinson Research Extension Center ranch near Manning, ND. The 30 X 60 foot plots were arranged in a randomized block design with three replications separated by 10 foot wide alleyways. The soil was Moreau silty clay, Typic Haploboroll, with a loam texture in the top 12 inches and a silty clay loam texture from the 12 inch to 48 inch depths. This clayey range site was enclosed with a barbed wire fence constructed to exclude cattle grazing on the plots until after all of the data for that season had been collected. The treatments included controls of 0 lbs N/ac and fertilization rates of 40 lbs N/ac and 60 lbs N/ac applied annually (EY) and biennially (EOY) and 100 lbs N/ac applied biennially (EOY). For each treatment rate, ammonium nitrate and urea fertilizers were surface broadcast applied in granular form in early spring on 4 May, 1982 to 1985 for the annual treatments and on 4 May, 1982 and 1984 for the biennial treatments (Goetz and Manske 1982, 1983, 1984; Manske and Goetz 1985a). The total four year weight of applied nitrogen was 80, 120, 160, 200, and

240 lbs N/ac for the 40 lbs N/ac EOY, 60 lbs N/ac EOY, 40 lbs N/ac EY, 100 lbs N/ac EOY, and 60 lbs N/ac EY treatments, respectively. The annual spring application of 60 lbs N/ac of ammonium nitrate and urea were continued in 1986 and mid summer treatments of 60 lbs N/ac of ammonium nitrate and urea were applied on 15 August, 1985 and 1986 (Manske 1986, 1987). Results from these additive treatments were not included in this report.

Traditionally, values from single herbage clips at peak aboveground herbage biomass were compared in fertilization studies. Peak herbage biomass normally occurs during the latter portion of July. Aboveground herbage biomass production was sampled by the clipping method four times during late May through August, 1982 to 1987. Vegetation in six quarter-meter frames were hand clipped to ground level for each treatment on each sample period. Herbage was separated into seven biotype categories: cool short, warm short, cool mid, western wheatgrass, warm mid, sedges, and forbs. The plant material was oven dried and weighed (Goetz and Manske 1982, 1983, 1984; Manske and Goetz 1985a).

Quantitative species composition was determined by percent basal cover sampled with the ten-pin point frame method during the period of mid July to mid August, 1982 to 1987. A total of 1500 points were read annually for each treatment (Manske and Goetz 1985a). Forb and shrub densities were additionally sampled by the use of one-tenth meter square quadrats. Stems rooted within each frame were counted annually by species in 30 quadrats per treatment (Manske and Goetz 1985a).

Available soil water was determined by the gravimetric procedure from soil samples collected with the 1 inch Veihmeyer soil tube from 0-6, 6-12, 12-24, 24-36, and 36-48 inch depths at monthly intervals during June through August, 1982 to 1987. Two replications of soil core samples were collected at three locations, north, central, and south, with one set from each of the two alleyways (Manske and Goetz 1985a).

Available soil mineral nitrogen was determined from soil core samples collected on each plot with the 1 inch Veihmeyer soil tube from 0-6, 6-12, 12-24, 24-36, and 36-48 inch depths at monthly intervals during June through August, 1982 to 1985. Individual soil core samples from each depth were immediately frozen and kept frozen until analysis could be made by the soils laboratory at North Dakota State University (Manske and Goetz 1985a).

Results

The precipitation during the growing seasons of 1982 to 1985 was normal or greater than normal (table 1). During 1982, 1983, 1984, and 1985, 21.09 inches (150.97% of LTM), 13.59 inches (97.28% of LTM), 11.69 inches (83.68% of LTM), and 12.80 inches (91.62% of LTM) of precipitation were received, respectively. June, July, and October of 1982 were wet months and each received 133.96%, 142.17%, and 438.93% of LTM precipitation, respectively. April, May, August, and September received normal precipitation at 95.80%, 112.55%, 99.43%, and 122.46% of LTM. Perennial plants did not experience water stress conditions during 1982 (Manske 2008). August of 1983 was a wet month and received 252.84% of LTM precipitation. June and July received normal precipitation at 101.56% and 102.81% of LTM. May, September, and October were dry months and received 64.02%, 62.32%, and 54.96% of LTM precipitation, respectively. April was a very dry month and received 14.69% of LTM precipitation. Perennial plants were under water stress conditions during April and September, 1983 (Manske 2008). April and June of 1984 were wet months and each received 200.70% and 165.11% of LTM precipitation, respectively. August received normal precipitation at 109.09% of LTM. October was a dry month and received 73.28% of LTM precipitation. May, July, and September were very dry months and received 0.00%, 4.42%, and 38.41% of LTM precipitation, respectively. Perennial plants were under water stress conditions during May, July, and September, 1984 (Manske 2008). May and October of 1985 were wet months and each received 135.98% and 162.60% of LTM precipitation, respectively. April, August, and September received normal precipitation at 86.71%, 104.55%, and 122.46% of LTM. June and July were very dry months and received 49.22% and 42.97% of LTM precipitation, respectively. Perennial plants were under water stress conditions during July, 1985 (Manske 2008).

Mean January to July precipitation averaged 108.22% of LTM for 1982 and 1984 when both the annual and biennial fertilization treatments were applied and mean January to July precipitation averaged 75.07% of LTM (near drought conditions) for 1983 and 1985 when only the annual fertilization treatments were applied. These disproportional climatic conditions favored the biennially applied treatments and disfavored the annually applied treatments.

The period in days between application of fertilization treatments (4 May) and the first measurable precipitation was 3, 2, 33, and 9 days for 1982, 1983, 1984, and 1985, respectively. Volatilization of the ammonia from ammonium nitrate and urea fertilizers would be expected to be minor in 1982 and 1983, and possibly a little greater in 1985. Volatilization would be expected to be fairly substantial for both ammonium nitrate and urea fertilizers during 1984. The divergent conditions of 1982 and 1984 when both annual and biennial fertilization treatments were applied presented ideal circumstances in which to evaluate differences in volatilization characteristics of ammonium nitrate and urea fertilizers.

The available soil water in the top 24 inches decreased progressively from 1982 to 1985 (table 2) similar to the progressive decrease in the April to August precipitation from 1982 to 1985 (table 1). The available soil water from the 24 inch to 48 inch depths changed little during the study.

The available soil mineral nitrogen during June, July, and August was low at 62 lbs/ac on the unfertilized treatment (table 3). The available mineral nitrogen on the ammonium nitrate and urea fertilization treatments diminished to low levels during June, July and August and was not significantly different ($P<0.05$) than that on the unfertilized treatment, except the 100 lbs N EOY urea treatment had significantly greater ($P<0.05$) mineral nitrogen at the 0-48 inch soil core depth and at the 6-12 inch depth than that on the unfertilized treatment. Goetz (1975) also found that the available mineral nitrogen from similar fertilization treatment rates diminished rapidly because of nitrogen immobilization by the soil-plant system and that during the growing season from early June the amounts of mineral nitrogen on the fertilization treatments were essentially the same as the amounts on the unfertilized treatment.

Soil pH ranged between 6.8 and 8.0 in the top 6 inches of soil and was not significantly different ($P<0.05$) among any of the ammonium nitrate and urea fertilization treatments and the unfertilized treatment. Low rates of nitrogen fertilizer did not change soil pH in four years.

Herbage weight of mid and short warm season grasses were generally lower on the ammonium nitrate and urea fertilization treatments than on the unfertilized treatment (tables 4, 5, 6, and 7). Warm season grass herbage weight on the fertilization treatments were not significantly different ($P<0.05$) than that on the unfertilized treatment.

Percent composition for mid and short warm season grasses were generally lower on the ammonium nitrate and urea fertilization treatments than on the unfertilized treatment (tables 8, 9, 10, and 11). Percent composition on the fertilization treatments were significantly lower ($P<0.05$) for mid warm season grasses on the ammonium nitrate treatment of 60 lbs N EOY during July, and on the urea treatments of 60 lbs N EY and 100 lbs N EOY during May, and 40 lbs N EY and 60 lbs N EOY during August, and for short warm season grasses on the ammonium nitrate and urea treatments of 40 lbs N EY during June than on the unfertilized treatment.

Basal cover of mid and short warm season grasses were generally lower on the ammonium nitrate and urea fertilization treatments than on the unfertilized treatment (table 12). Mid warm season grass basal cover was significantly lower ($P<0.05$) on the ammonium nitrate treatment of 60 lbs N EOY and on the urea treatment of 40 lbs N EOY than on the unfertilized treatment. Short warm season grass basal cover on the fertilization treatments were not significantly different ($P<0.05$) from that on the unfertilized treatment.

Herbage weight of western wheatgrass and mid and short cool season grasses were generally greater on the ammonium nitrate and urea fertilization treatments than on the unfertilized treatment (tables 4, 5, 6, and 7). Herbage weight of western wheatgrass was significantly greater ($P<0.05$) on the urea treatment of 40 lbs N EY during May and June than on the unfertilized treatment. Herbage weight of mid cool season grasses was significantly greater ($P<0.05$) on the ammonium nitrate treatments of 40 lbs N EY, 60 lbs N EOY, and 60 lbs N EY during May and June, and on the urea treatments of 60 lbs N EY during May, 60 lbs N EOY during June, and 100 lbs N EOY during May, June, and July than on the unfertilized treatment. Herbage weight of short cool season grasses on the fertilization treatments were not significantly different ($P<0.05$) from that on the unfertilized treatment.

Percent composition for western wheatgrass and mid cool season grasses were generally greater and percent composition for short cool season grasses were generally lower on the ammonium nitrate and urea fertilization treatments than on the unfertilized treatment (tables 8, 9, 10, and 11). Percent composition for western wheatgrass was significantly greater ($P<0.05$) on the urea treatment of 40 lbs N EY during May and July than on the unfertilized treatment. Percent composition for mid cool season grasses was significantly greater ($P<0.05$) on the ammonium nitrate treatment of 40 lbs N EY during May, and on the urea treatments of 60 lbs N EOY and 60 lbs N EY during May than on the unfertilized treatment. Percent composition for short cool season grasses on the fertilization treatments was not significantly different ($P<0.05$) from that on the unfertilized treatment.

Basal cover of western wheatgrass and mid cool season grasses were generally greater and basal cover of short cool season grasses was generally lower on the ammonium nitrate and urea fertilization treatments than on the unfertilized treatment (table 12). Basal cover of western wheatgrass, and mid and short cool season grasses on the fertilization treatments were not significantly different ($P<0.05$) from that on the unfertilized treatment.

Herbage weight of upland sedges were generally greater on the ammonium nitrate and urea fertilization treatments than on the unfertilized treatment, except on the ammonium nitrate and urea treatments of 40 lbs N EY, the sedge herbage weight was consistently lower than the weight on the unfertilized treatment (tables 4, 5, 6, and 7). Herbage weight of sedges were significantly greater ($P<0.05$) on the ammonium nitrate treatments of 60 lbs N EY during June and 100 lbs N EOY during May, and on the urea treatments of 60 lbs N EOY and 60 lbs N EY during May, and 100 lbs N EOY during May and June than on the unfertilized treatment. Herbage weight of sedges were significantly lower ($P<0.05$) on the ammonium nitrate treatments of 40 lbs N EY during June, and on the urea treatment of 40 lbs N EY during May and June than on the unfertilized treatment.

Percent composition for upland sedges were generally greater on the ammonium nitrate and urea fertilization treatments than on the unfertilized treatment, except on the ammonium nitrate and urea treatments of 40 lbs N EY, percent composition was consistently lower than on the unfertilized treatment (tables 8, 9, 10, and 11). Percent composition for sedges was significantly greater ($P<0.05$) on the ammonium nitrate treatment of 60 lbs N EOY during August, and on the urea treatments of 60 lbs N EOY during August, and 100 lbs N EOY during May than on the unfertilized treatment. Percent composition for sedges was significantly lower ($P<0.05$) on the ammonium nitrate treatment of 40 lbs N EY during June and July, and on the urea treatment of 40 lbs N EY during May, June, July, and August than on the unfertilized treatment.

Basal cover of upland sedges were generally greater on the ammonium nitrate and urea fertilization treatments than on the unfertilized treatment, except on the ammonium nitrate and urea treatments of 40 lbs N EY, basal cover was consistently lower than on the unfertilized treatment (table 12). Sedge basal cover on the fertilization treatments were not significantly different ($P<0.05$) from that on the unfertilized treatment.

Herbage weight of forbs were generally greater on the ammonium nitrate and urea fertilization treatments than on the unfertilized treatment, except on the ammonium nitrate and urea treatments of 60 lbs N EOY, the forb herbage weight was consistently lower, but not significantly ($P<0.05$), than the forb weight on the unfertilized treatment (tables 4, 5, 6, and 7). Herbage weight of forbs was significantly greater ($P<0.05$) on the ammonium nitrate and urea treatments of 40 lbs N EY during May than on the unfertilized treatment.

Percent composition for forbs were generally lower on the ammonium nitrate and urea fertilization treatments than on the unfertilized treatment (tables 8, 9, 10, and 11). Percent composition for forbs was significantly lower ($P<0.05$) on the urea treatment of 60 lbs N EY during May than on the unfertilized treatment.

Basal cover of forbs were generally lower on the ammonium nitrate and urea fertilization treatments than on the unfertilized treatment (table 12). Forb basal cover on the fertilization treatments were not significantly different ($P<0.05$) from that on the unfertilized treatment.

Herbage weight, percent composition, and basal cover were generally lower for mid and short warm season grasses on the annual and biennial fertilization treatments than on the unfertilized treatment. Herbage weight, percent composition, and basal cover were generally greater for western wheatgrass and mid cool season grasses on the annual and biennial fertilization treatments than on the unfertilized treatment. Herbage weight was generally greater, and percent composition and basal cover were generally lower for short cool season grasses on the annual and biennial fertilization treatments than on the unfertilized treatment. Herbage weight, percent composition, and basal cover were generally greater for upland sedges on the annual and biennial fertilization treatments, except on the ammonium nitrate and urea treatments of 40 lbs N EY herbage weight, percent composition, and basal cover were lower, than on the unfertilized treatment. Herbage weight was generally greater; except on the ammonium nitrate and urea treatments of 60 lbs N EOY herbage weight was lower; and percent composition and basal cover were generally lower for forbs on the annual and biennial fertilization treatments than on the unfertilized treatment. General trends of the plant species shift on the annual and biennial fertilization treatments during the four years of this plot study V were the same as the shift in plant species composition found on previous nitrogen fertilization of native rangeland studies.

Peak aboveground herbage biomass usually occurs during the last two weeks in July. Most of the previous fertilization of native rangeland studies sampled herbage weight one time per year during late July or early August and compared these solitary herbage weights produced on the fertilization treatments. This study sampled aboveground herbage weight during May, June, July, and August to evaluate for differences in quantities and rates of herbage produced by plant categories on the fertilization treatments throughout the growing season.

Production of herbage weight by plant categories on the fertilization treatments did not occur in the same quantities during the growing season months as the quantity of herbage produced by plant categories on the unfertilized treatment (table 13 a, b, c). Peak herbage weights on the unfertilized treatment for cool season grasses, warm season grasses, total grasses, and total yield occurred during August, for sedges it occurred during May, and for forbs peak herbage occurred during July. During this four year study, peak herbage weight of total yield on the fertilized and unfertilized treatments occurred during July in 1982 and 1983 the same as peak herbage weight would occur during other typical growing seasons. During the growing seasons of 1984 and 1985, precipitation in July was well below normal (23.69% of long-term mean) followed by above average precipitation in August (106.82% of long-term mean) resulting in a shift in the occurrence of peak herbage biomass to August. The resulting four year mean herbage weight for total yield on the fertilization treatments were quite similar during July and August. Peak herbage weights on the fertilization treatments for cool season grasses, total grasses, and total yield occurred during July and August, for warm season grasses peak herbage occurred during August, for sedges it occurred during May, and for forbs peak herbage occurred during July or during August. The peak herbage weight of plant categories on fertilization treatments tended to occur earlier during the growing season than that on the unfertilized treatment (table 13 a, b, c).

Production of herbage weight by plant categories on the fertilization treatments did not occur at the same rates during the growing season months as the rate of herbage production by plant categories on the unfertilized treatment (table 14 a, b, c). Plant categories on the unfertilized treatment (0 lbs N) had greatest herbage weight for cool season grasses, warm season grasses, total grasses, and total yield during August, for sedges it occurred during May, and for forbs the greatest herbage weight occurred during July.

The urea treatment of 40 lbs N EOY (80 lbs N) had greater growth of warm season grasses, total grasses, and total yield during August. The ammonium nitrate treatment of 40 lbs N EOY (80 lbs N) and the ammonium nitrate and urea treatments of 60 lbs N EOY (120 lbs N) had greater growth of cool season grasses, total grasses, and total yield during July. The ammonium nitrate treatment of 40 lbs N EY (160 lbs N) had greater growth of warm season grasses, total grasses, and total yield during July. The urea treatment of 40 lbs N EY (160 lbs N) had greater growth of warm season grasses and total grasses during July and greater growth of cool season grasses and total yield during June. The ammonium nitrate and urea treatments of 100 lbs N EOY (200 lbs N) and 60 lbs N EY (240 lbs N) had greater growth of cool season grasses, total grasses, and total yield during June. Greater growth in herbage weight occurred earlier in the growing season with increases in total weight of nitrogen fertilizer applied (table 14 a, b, c).

Growth of herbage weight on the ammonium nitrate and urea fertilization treatments and on the unfertilized treatment occurred at different times and at different rates (table 15). The greatest herbage weight occurred during August on the unfertilized treatment. The greatest percent increase in herbage weight occurred during August on the urea treatment of 40 lbs N EOY. The greatest percent increase in herbage weight occurred during July on the ammonium nitrate treatments of 40 lbs N EOY, 60 lbs N EOY, and 40 lbs N EY, and on the urea treatment of 60 lbs N EOY. The greatest percent increase in herbage weight occurred during June on the ammonium nitrate treatments of 100 lbs N EOY and 60 lbs N EY, and on the urea treatments of 40 lbs N EY, 100 lbs N EOY, and 60 lbs N EY. The greatest percent increase in herbage weight occurred earlier in the growing season with increases in total weight of nitrogen fertilizer applied (table 15).

The ammonium nitrate treatments of 40 lbs N EOY and 60 lbs N EY consistently out performed the respective urea treatments during each of the growing season months, except the August percent herbage increase on the urea treatment of 40 lbs N EOY was greater than that on the ammonium nitrate treatment. The urea treatment of 100 lbs N EOY consistently out performed the respective ammonium nitrate treatment during each of the growing season months (table 15).

The urea treatments of 60 lbs N EOY, 40 lbs N EY, and 100 lbs N EOY had greater percent increases in herbage weight during the early portions of the growing season than the respective ammonium nitrate treatments, and the ammonium nitrate treatments of 60 lbs N EOY and 40 lbs N EY had greater percent increases in herbage weight during the latter portions of the growing season than the respective urea treatments. The urea treatment of 40 lbs N EY had greater percent increases in herbage weight of 21.75% and 41.94% during May and June than the May and June percent increases in herbage weight of 18.91% and 37.28% on the ammonium nitrate treatment of 40 lb N EY. The ammonium nitrate treatment of 40 lbs N EY had greater percent increases in herbage weight of 43.78% and 27.80% during July and August than the July and August percent increases in herbage weight of 33.43% and

19.41% on the urea treatment of 40 lbs N EY (table 15).

Peak herbage weight of plant categories tended to occur earlier during the growing season on fertilization treatments than on the unfertilized treatment. Greater growth in herbage weight occurred earlier in the growing season with increases in total weight of nitrogen fertilizer applied. The greatest percent increase in herbage weight occurred earlier in the growing season with increases in total weight of nitrogen fertilizer applied. The greatest percent increase in herbage weight did not occur at the same time as the greatest aboveground herbage biomass. The greatest percent increase in herbage weight on the urea treatments tended to occur during the early portions of the growing season and the greatest percent increase in herbage weight on the ammonium nitrate treatments tended to occur later in the growing season than on the urea treatments.

The quantity and rate of growth in herbage weight was differentially affected by the quantity and type of nitrogen applied, making impartial comparisons of treatments with multiple nitrogen sources difficult to accomplish from single herbage sample dates per year. The mean herbage weight data from the June, July, and August growing season sample dates were used to remove the unintentional bias that results from single herbage sample date data (table 16). Mean cool season grass herbage weight was 1.6% and 15.7% greater on the urea treatments of 40 lbs N EY and 100 lbs N EOY than on the respective ammonium nitrate treatments, and was 17.8%, 23.5%, and 0.3% greater on the ammonium nitrate treatments of 40 lbs N EOY, 60 lbs N EOY, and 60 lbs N EY than on the respective urea treatments. Mean warm season grass herbage weight was 5.2% greater on the urea treatment of 40 lbs N EOY than on the respective ammonium nitrate treatment, and was 9.5%, 17.3%, 17.6%, and 38.0% greater on the ammonium nitrate treatments of 60 lbs N EOY, 40 lbs N EY, 100 lbs N EOY, and 60 lbs N EY than on the respective urea treatments. The annual urea treatments of 40 lbs N/ac and 60 lbs N/ac were detrimental to warm season grass herbage production. Mean total yield herbage weight was 11.5% greater on the urea treatment of 100 lbs N EOY than on the respective ammonium nitrate treatment, and was 7.6%, 10.4%, 5.4%, and 15.0% greater on the ammonium nitrate treatments of 40 lbs N EOY, 60 lbs N EOY, 40 lbs N EY, and 60 lbs N EY than on the resepctive urea treatments. Generally, the herbage weight produced by the ammonium nitrate treatments was 5% to 38% greater than that produced by the respective urea treatments, except the urea treatment of 100 lbs N EOY out produced the respective ammonium nitrate treatment in cool season grasses, sedges, and total yield herbage weight consistently. The five ammonium nitrate treatments produced 4.9% greater mean cool season grass herbage weight, 15.5% greater mean warm season grass herbage weight, and 5.4% greater mean total yield herbage weight than the five urea treatments (table 16).

Differences in the pounds of herbage biomass produced per pound of nitrogen applied were used to evaluate production differences between ammonium nitrate and urea fertilization treatments (table 17). The pounds of cool season grass weight produced per pound of nitrogen ranged from 6 to 16 pounds of herbage for ammonium nitrate treatments and from 6 to 11 pounds of herbage for urea treatments. The pounds of warm season grass weight produced per pound of nitrogen ranged from less than 1 pound to 3 pounds of herbage for ammonium nitrate treatments and from a loss of 0.5 pound to a gain of 1.7 pounds of herbage for urea treatments. The pounds of total herbage yield weight produced per pound of nitrogen ranged from 9.5 to 17 pounds of herbage for ammonium nitrate treatments and from 6 to 14 pounds of herbage for urea treatments (table 17).

The pounds of cool season grass herbage produced per pound of nitrogen was 0.3 and 2.0 pounds greater on the urea treatments of 40 lbs N EY and 100 lbs N EOY than on the respective ammonium nitrate treatments, and was 5.8, 5.1, and 0.03 pounds greater on the ammonium nitrate treatments of 40 lbs N EOY, 60 lbs N EOY, and 60 lbs N EY than on the respective urea treatments. The pounds of warm season grass herbage produced per pound of nitrogen was 0.9 pounds greater on the urea treatment of 40 lbs N EOY than on the respective ammonium nitrate treatment, and was 1.1, 1.4, 1.2, and 2.1 pounds greater on the ammonium nitrate treatments of 60 lbs N EOY, 40 lbs N EY, 100 lbs N EOY, and 60 lbs N EY than on the respective urea treatments. The pounds of total herbage yield produced per pound of nitrogen was 3.2 pounds greater on the urea treatment of 100 lbs N EOY than on the respective ammonium nitrate treatment, and was 5.2, 4.8, 1.9, and 3.4 pounds greater on the ammonium nitrate treatments of 40 lbs N EOY, 60 lbs N EOY, 40 lbs N EY, and 60 lbs N EY than on the respective urea treatments. Generally, the pounds of herbage biomass produced per pound of nitrogen by the ammonium nitrate treatments were 0.03 to 5.8 pounds of herbage greater than that produced by the respective urea treatments, except the urea treatment of 100 lbs N EOY produced 2.0 pounds greater cool season grass herbage and 3.2 pounds greater total herbage yield than the respective ammonium nitrate treatment. The five ammonium nitrate treatments produced 1.7 pounds of cool season grass herbage, 1.0 pound of warm season grass herbage, and 2.4 pounds of total herbage yield per pound of nitrogen applied greater than the five urea treatments (table 17).

Both the annual and biennial fertilization treatments were applied in 1982 and 1984. The April to June precipitation was 8.36 inches and 8.17 inches during 1982 and 1984, respectively. The period in days between application of fertilizer (4 May) and the first measurable precipitation was 3 days in 1982 and 33 days in 1984. These divergent conditions of 1982 and 1984 were used to evaluate differences in volatilization characteristics of ammonium nitrate and urea fertilizer (table 18). The difference in the percent herbage weight gain between 1982 and 1984 was considered to be the percent lost herbage weight due to volatilization of the ammonia from the ammonium nitrate and urea fertilizers resulting from the differences between 3 and 33 days with no precipitation following fertilizer application in 1982 and 1984, respectively. The mean percent lost herbage weight for the ammonium nitrate treatments was 72.9%, 27.4%, and 53.3% for cool season grasses, warm season grasses, and total herbage yield, respectively. The mean percent lost herbage weight for the urea treatments was 79.1%, 22.9%, and 56.1% for cool season grasses, warm season grasses, and total herbage yield, respectively (table 18).

The percent lost cool season grass herbage weight was 8.7% and 30.0% greater on the ammonium nitrate treatments of 40 lbs N EOY and 60 lbs N EY than on the respective urea treatments, and was 45.3%, 17.7%, and 6.8% greater on the urea treatments of 60 lbs N EOY, 40 lbs N EY, and 100 lbs N EOY than on the respective ammonium nitrate treatments. The percent lost warm season grass herbage weight was 38.7% and 1.2% greater on the ammonium nitrate treatments of 40 lbs N EY and 100 lbs N EOY than on the respective urea treatments, and was 0.7%, 10.6%, and 5.9% greater on the urea treatments of 40 lbs N EOY, 60 lbs N EOY, and 60 lbs N EY than on the respective ammonium nitrate treatments. The percent lost total yield herbage weight was 7.4%, 1.3%, and 15.1% greater on the ammonium nitrate treatments of 40 lbs N EOY, 100 lbs N EOY, and 60 lbs N EY than on the respective urea treatments, and was 29.2% and 8.7% greater on the urea treatments of 60 lbs N EOY and 40 lbs N EY than on the respective ammonium nitrate treatments. The five ammonium nitrate treatments had 4.5% greater percent lost warm season grass herbage weight than the five urea treatments. The five urea treatments had 6.2% greater percent lost cool season grass herbage weight and 2.8% greater percent lost total herbage yield weight than the five ammonium nitrate treatments (table 18). The percent lost herbage weight was generally similar for ammonium nitrate and urea fertilizers between 1982 and 1984.

Herbage growth during the monthly periods of the growing season was affected by the quantity and the source of nitrogen applied. Plants on the ammonium nitrate treatments had greater percent growth during monthly periods than unfertilized plants 48% of the growing season. Plants on the urea treatments had greater percent growth during monthly periods than unfertilized plants 49% of the growing season. Plants on the unfertilized treatment had greater percent growth during monthly periods than plants on the ammonium nitrate treatments 52% of the growing season and greater percent growth than plants on the urea treatments 51% of the growing season (table 19 a, b, c).

Fertilized cool season grasses had greater percent growth on the ammonium nitrate treatments of 40 lbs N EOY during June and July, 60 lbs N EOY during June and July, 40 lbs N EY during May and June, 100 lbs N EOY during June, and 60 lbs N EY during May and June, and on the urea treatments of 40 lbs N EOY during June and August, 60 lbs N EOY during May, June, and July, 40 lbs N EY during June, 100 lbs N EOY during May and June, and 60 lbs N EY during May and June than cool season grasses on the unfertilized treatment. Unfertilized cool season grasses had greater percent growth than fertilized cool season grasses on the ammonium nitrate treatments of 40 lbs N EOY during May and August, 60 lbs N EOY during May and August, 40 lbs N EY during July and August, 100 lbs N EOY during May, July, and August, and 60 lbs N EY during July and August, and on the urea treatments of 40 lbs N EOY during May and July, 60 lbs N EOY during August, 40 lbs N EY during May, July, and August, 100 lbs N EOY during July and August, and 60 lbs N EY during July and August (table 19 a, b, c). Figure 1 shows the greater percent growth of cool season grasses during May and June on the ammonium nitrate treatment of 60 lbs N EY and the greater percent growth during July and August on the unfertilized treatment.

Fertilized warm season grasses had greater percent growth on the ammonium nitrate treatments of 40 lbs N EOY during June, 60 lbs N EOY during June and July, 40 lbs N EY during June and July, 100 lbs N EOY during June, July, and August, and 60 lbs N EY during June, July, and August, and on the urea treatments of 40 lbs N EOY during June, July, and August, 60 lbs N EOY during June and August, 40 lbs N EY during July, 100 lbs N EOY during June and July, and 60 lbs N EY during July and August than warm season grasses on the unfertilized treatment. Unfertilized warm season grasses had greater percent growth than fertilized warm season grasses on the ammonium nitrate treatments of 40 lbs N EOY during May, July, and August, 60 lbs N EOY during May and August, 40 lbs N EY during May and

August, 100 lbs N EOY during May, and 60 lbs N EY during May, and on the urea treatments of 40 lbs N EOY during May, 60 lbs N EOY during May and July, 40 lbs N EY during May, June, and August, 100 lbs N EOY during May and August, and 60 lbs N EY during May and June (table 19 a, b, c).

Fertilized total grasses had greater percent growth on the ammonium nitrate treatments of 40 lbs N EOY during June and July, 60 lbs N EOY during June and July, 40 lbs N EY during June and July, 100 lbs N EOY during June, and 60 lbs N EY during May and June, and on the urea treatments of 40 lbs N EOY during June and August, 60 lbs N EOY during May, June, and July, 40 lbs N EY during June and July, 100 lbs N EOY during May and June, and 60 lbs N EY during May and June than total grasses on the unfertilized treatment. Unfertilized total grasses had greater percent growth than fertilized total grasses on the ammonium nitrate treatments of 40 lbs N EOY during May and August, 60 lbs N EOY during May and August, 40 lbs N EY during May and August, 100 lbs N EOY during May, July, and August, and 60 lbs N EY during July and August, and on the urea treatments of 40 lbs N EOY during May and July, 60 lbs N EOY during August, 40 lbs N EY during May and August, 100 lbs N EOY during July and August, and 60 lbs N EY during July and August (table 19 a, b, c).

Fertilized total herbage yield had greater percent growth on the ammonium nitrate treatments of 40 lbs N EOY during June and July, 60 lbs N EOY during June and July, 40 lbs N EY during June and July, 100 lbs N EOY during June and August, and 60 lbs N EY during May and June, and on the urea treatments of 40 lbs N EOY during June and August, 60 lbs N EOY during May, June, and July, 40 lbs N EY during May and June, 100 lbs N EOY during May and June, and 60 lbs N EY during May and June than total herbage yield on the unfertilized treatment. Unfertilized total herbage yield had greater percent growth than fertilized total herbage yield on the ammonium nitrate treatments of 40 lbs N EOY during May and August, 60 lbs N EOY during May and August, 40 lbs N EY during May and August, 100 lbs N EOY during May and July, and 60 lbs N EY during July and August, and on the urea treatments of 40 lbs N EOY during May and July, 60 lbs N EOY during August, 40 lbs N EY during July and August, 100 lbs N EOY during July and August, and 60 lbs N EY during July and August (table 19 a, b, c). Cool season grasses, warm season grasses, and upland sedges had greater percent growth during May on the urea treatments than on the ammonium nitrate treatments. Cool season grasses, warm season grasses, and upland sedges had greater percent growth during June on the ammonium nitrate treatments than on the urea treatments.

Fertilized plants had a greater rate of growth in herbage weight during a short period in the early portion of the growing season, usually May and June. The rapid growth period occurred earlier for plants fertilized with urea than with ammonium nitrate and the rapid growth period occurred earlier with increased quantities of nitrogen applied. Unfertilized plants had a longer period of herbage weight growth; during the early portion, the rate of growth in herbage weight was lower than that of fertilized plants, and during the latter portion of the growing season, usually July and August, the rate of growth in herbage weight was greater than that of fertilized plants.

Percent growth of cool season grasses during May and June on the ammonium nitrate and urea treatments was 10.6% and 10.8% greater, respectively, than that on the unfertilized treatment. Percent growth of cool season grasses during July and August on the unfertilized treatment was 15.1% and 13.9% greater than those on the ammonium nitrate and urea treatments, respectively. Percent growth of total grasses during May and June on the ammonium nitrate and urea treatments was 7.7% and 7.5% greater, respectively, than that on the unfertilized treatment. Percent growth of total grasses during July and August on the unfertilized treatment was 7.7% and 7.5% greater than those on the ammonium nitrate and urea treatments, respectively. Percent growth of total herbage yield during May and June on the ammonium nitrate and urea treatments was 5.5% and 6.5% greater, respectively, than that on the unfertilized treatment. Percent growth of total herbage yield during July and August on the unfertilized treatment was 6.5% and 6.5% greater than those on the ammonium nitrate and urea treatments, respectively (tables 20 and 21). Percent growth of total grasses and total herbage yield on the urea treatment of 40 lbs N EOY was lower during May and June and greater during July and August than those on the unfertilized treatment (tables 20 and 21). During May and June, percent growth of cool season grasses, total grasses, and total herbage yield was greater on the fertilized treatments than those on the unfertilized treatment, and during July and August, percent growth was greater on the unfertilized treatment than those on the fertilized treatments.

Discussion

Nitrogen fertilization of native rangeland plot study V (1982-1987) was conducted to evaluate the effectiveness of low rates of urea fertilizer compared to the same rates of ammonium nitrate and to determine the degree of differences in annual and biennial applications of ammonium nitrate and urea fertilizers. The major findings from this study follow.

- Nitrogen fertilization of native rangeland resulted in greater production of herbage weight than the quantity of aboveground herbage produced on unfertilized rangeland. Annual applications of 40 lbs N/ac and 60 lbs N/ac increased herbage production 35.7% and 41.4% on the ammonium nitrate treatments and 30.3% and 26.4% on the urea treatments, respectively. Biennial applications of 40 lbs N/ac, 60 lbs N/ac, and 100 lbs N/ac increased herbage production 21.2%, 37.1%, and 40.9% on the ammonium nitrate treatments, and 13.6%, 26.7%, and 52.4% on the urea treatments, respectively. The biennial applications of ammonium nitrate and urea fertilizers produced 74.5% and 73.0% of the total herbage weight produced on the annual applications of the respective fertilizers. The years when both the annual and biennial treatments were applied received 33% more precipitation than the years when only the annual treatments were applied causing disproportionally favorable results on the biennial treatments. The biennial applications of ammonium nitrate treatments in plot study IV (1970-1978) realistically produced 54.3% of the total herbage weight produced on the annual application treatments.

- Nitrogen fertilization of native rangeland caused general trends of a shift in plant species composition the same as the shift in plant species composition found on previous nitrogen fertilization of native rangeland studies. Composition of warm season grasses was reduced and composition of mid cool season grasses was increased on annual and biennial applications of ammonium nitrate and urea fertilization treatments.

- Native rangeland soils increase in available soil water during early spring to July under normal precipitation conditions and then decrease in soil water during July to the end of the growing season as a result of greater evapotranspiration demand than precipitation infiltration. Range plants experienced water stress during 25% of the growing season months during the study period of 1982 to 1985 which was lower than the normal long-term conditions with plants under water stress during 33% of the growing season months. Soil water below the 24 inch depth changed little during the study period indicating few grass roots in the lower depths of the soil profile, probably a result of the heavy seasonlong grazing management during past decades. Previous nitrogen fertilization of native rangeland studies have found that soil water use was greater on the fertilized treatments than on the unfertilized treatment and that greater amounts of soil water were used from the treatments with heavier rates of nitrogen fertilizer.

- Nitrogen fertilization of native rangeland with low rates of annual and biennial applications of ammonium nitrate and urea fertilizers did not change soil pH in four years, 1982 to 1985. Smika et al. (1961) found that annual applications of ammonium nitrate fertilizer could reduce soil pH 6% to 9% after 9 years and that the increase in soil acidity increased the solubility and availability of phosphate.

- Nitrogen fertilization of native rangeland with low rates of annual and biennial applications of ammonium nitrate and urea fertilizers did not increase available mineral nitrogen in soil from mid June to the end of the growing season, except the urea treatment of 100 lbs N EOY had significantly greater total available mineral nitrogen of 114 lbs N/ac in the soil profile to the 48 inch depth and consistently produced greater quantities of aboveground herbage throughout the study. Goetz (1975) found that as soil warmed in early spring, the available mineral nitrogen increased. This first peak in available mineral nitrogen occurred around mid May on unfertilized treatments and on fertilized treatments with nitrogen applications in early to mid April. Nitrogen applications in early May may shift the first peak to later in May. The quantity of available mineral nitrogen during the first peak was greater on the treatments with higher nitrogen rates. Differences in the amount of available mineral nitrogen diminished rapidly early in the growing season because of nitrogen immobilization by the soil-plant system. During the remainder of the growing season from early or mid June, the amounts of mineral nitrogen on the fertilization treatments was essentially the same as the amount available on the unfertilized treatment.

- Nitrogen fertilization of native rangeland resulted in the peak herbage weight of plant categories on fertilization treatments to occur earlier in the growing season than peak herbage on the unfertilized treatment. Peak herbage weight on unfertilized native rangeland usually occurs during the last two weeks in July. An exception to these standard conditions occurred during the growing seasons with below normal precipitation in July followed by above average precipitation in August. Peak herbage weights for cool season grasses, warm season grasses, total grasses, and total herbage yield occurred during August on the unfertilized treatment. Peak herbage weights for cool season grasses, total grasses, and total herbage yield occurred earlier during the growing season on the fertilization treatments than on the unfertilized treatment even with the changes in precipitation pattern. The increases in herbage weight occurred earlier in the growing season on the urea treatments than on the ammonium nitrate treatments.

- Nitrogen fertilization of native rangeland resulted in the greater rates of growth in herbage weight and the greatest percent increase in herbage weight to occur earlier in the growing season with increases in total weight of nitrogen fertilizer applied during the four years of the study. The greatest herbage weight on the unfertilized treatment occurred during August. Urea nitrogen applied at 80 lbs/ac resulted in greater herbage growth in August. Ammonium nitrate nitrogen applied at 80 lbs/ac and ammonium nitrate and urea nitrogen applied at 120 lbs/ac and 160 lbs/ac resulted in greater herbage growth in July. Ammonium nitrate and urea nitrogen applied at 200 lbs/ac and 240 lbs/ac resulted in greater growth in June. The greater the total weight of nitrogen fertilizer applied, the earlier in the growing season the greatest increase in herbage weight occurred. The greater rate of growth and the greatest percent increase in herbage weight did not occur at the same time as the greatest aboveground herbage biomass.

- Nitrogen fertilization of native rangeland reduced the time period of active growth. Fertilized plants had a high rate of growth in herbage weight during a short period in the early portion of the growing season and had a low rate of growth or a loss of weight during the latter portion of the growing season. Unfertilized plants had a longer period of active herbage weight growth. The rate of growth for unfertilized plants was lower than the growth rate for fertilized plants during the early portion of the growing season and the rate of growth was greater than the growth rate for fertilized plants during the latter portion of the growing season.

- Nitrogen fertilization of native rangeland resulted in greater herbage weight produced on the ammonium nitrate treatments than on the urea treatments. The herbage weight produced on the ammonium nitrate treatments with low rates of 100 lbs N/ac or less ranged from 5% to 38% greater than the herbage produced on urea treatments with the respective low rates. These differences in herbage production between ammonium nitrate and urea fertilizers at low rates were similar to the differences in herbage production at high rates greater than 100 lbs N/ac that were reported (Power 1974) to range from 5% to 40% greater on ammonium nitrate treatments than on the same rates of urea treatments. The five ammonium nitrate treatments produced a mean 5.4% greater herbage weight than the five urea treatments. Pounds of herbage weight produced per pound of nitrogen ranged from 9.5 to 17 pounds of herbage on the ammonium nitrate treatments and from 6 to 14 pounds of herbage on the urea treatments. The five ammonium nitrate treatments produced a mean 2.4 pounds of herbage weight per pound of nitrogen greater than the pounds of herbage produced per pound of nitrogen on the five urea treatments.

- Nitrogen fertilization of native rangeland resulted in a high loss of herbage weight from nitrogen volatilization that occurred during 33 days with no precipitation following broadcast application of ammonium nitrate and urea fertilizers in 1984. Hydrolyzed nitrogen fertilizers are broken down to ammonia and carbon dioxide. Under some conditions, a portion of the ammonia is volatilized into the atmosphere. This lost quantity of nitrogen is not available to plants for herbage growth. The greater the rate of volatilization, the greater the loss in herbage weight production. The amount of lost herbage weight on the ammonium nitrate and urea treatments was 72.9% and 79.1% of the cool season grasses, 27.4% and 22.9% of the warm season grasses, and 53.3% and 56.1% of the total herbage weight, respectively.

The urea treatments lost 1.5% greater herbage weight than the ammonium nitrate treatments as a result of volatilization of the ammonia.

- Nitrogen fertilization of native rangeland resulted in greater herbage growth rates during May and June on the fertilization treatments and greater herbage growth rates during July and August on the unfertilized treatment. Plants on the ammonium nitrate and urea treatments had greater percent herbage growth during 48% and 49% of the monthly periods than the plants on the unfertilized treatment, respectively, and plants on the unfertilized treatment had greater percent herbage growth during 52% and 51% of the monthly periods than the plants on the ammonium nitrate and urea treatments, respectively. Cool season grasses, warm season grasses, and upland sedges had greater percent herbage growth during May on the urea treatments than on the ammonium nitrate treatments, and had greater percent growth during June on the ammonium nitrate treatments than on the urea treatments. Percent growth of cool season grasses, total grasses, and total herbage weight was greater on the ammonium nitrate and urea fertilization treatments during May and June than on the unfertilized treatment, and percent herbage growth was greater on the unfertilized treatment during July and August than on the fertilization treatments.

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Table 1. Precipitation in inches for growing-season months and the annual total precipitation for 1982-1985, DREC Ranch, Manning, North Dakota.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Growing Season	Annual Total
Long-term mean 1982-2007	1.43	2.39	3.21	2.49	1.76	1.38	1.31	13.97	16.77
1982	1.37	2.69	4.30	3.54	1.75	1.69	5.75	21.09	25.31
% of LTM	95.80	112.55	133.96	142.17	99.43	122.46	438.93	150.97	150.92
1983	0.21	1.53	3.26	2.56	4.45	0.86	0.72	13.59	15.55
% of LTM	14.69	64.02	101.56	102.81	252.84	62.32	54.96	97.28	92.73
1984	2.87	T	5.30	0.11	1.92	0.53	0.96	11.69	12.88
% of LTM	200.70	0.00	165.11	4.42	109.09	38.41	73.28	83.68	76.80
1985	1.24	3.25	1.58	1.07	1.84	1.69	2.13	12.80	14.78
% of LTM	86.71	135.98	49.22	42.97	104.55	122.46	162.60	91.62	88.13
1982-1985	1.42	1.87	3.61	1.82	2.49	1.19	2.39	14.79	17.13
% of LTM	99.30	78.24	112.46	73.09	141.48	86.23	182.44	105.87	102.15

Table 2. Mean soil water in inches per sample depth for fertilization treatments on the Moreau clayey range site, 1982-1985.

	Soil Depth in inches					
Years	0-6	6-12	12-24	24-36	36-48	0-48
1982	1.22a	1.10a	2.10a	1.71ab	1.54a	7.66a
1983	1.06b	0.87b	1.90b	1.94a	1.81a	7.59a
1984	0.89c	0.86b	1.32c	1.51b	1.70a	6.29b
1985	0.65d	0.61c	1.14c	1.29b	1.59a	5.28c

Means in the same column and followed by the same letter are not significantly different (P<0.05).

Table 3. Mean soil mineral nitrogen content in pounds per acre for fertilization treatments on the Moreau clayey range site, 1982-1985.

	Soil Depth in inches					
Treatments	0-6	6-12	12-24	24-36	36-48	0-48
Unfertilized	8.34ab	7.05a	12.77ab	15.84ab	17.62a	61.61a
Ammonium nitrate						
40 lbs N EOY	9.29ab	6.41a	12.98a	14.53ab	17.14a	60.35a
40 lbs N EY	9.77ab	7.03a	13.64ab	15.36ab	15.62a	61.41a
60 lbs N EOY	8.86a	6.39a	11.62a	12.42a	14.99a	54.28a
60 lbs N EY	15.21b	9.09a	13.82a	13.78ab	13.47a	65.37a
100 lbs N EOY	10.50ab	14.27ab	17.33ab	15.40ab	19.69a	77.18ab
Urea						
40 lbs N EOY	8.61a	6.21a	12.37a	12.29a	15.88a	55.35a
40 lbs N EY	11.05ab	7.67a	13.75a	13.57ab	12.69a	58.73a
60 lbs N EOY	9.28ab	6.16a	11.74a	13.64a	12.61a	53.42a
60 lbs N EY	15.98b	9.23a	14.84ab	15.52ab	16.52a	72.07ab
100 lbs N EOY	29.28ab	22.44b	20.73b	24.17b	17.24a	113.85b

Means in the same column and followed by the same letter are not significantly different ($P<0.05$).

Table 4. Dry matter weight in pounds per acre for fertilization treatments 30 May on the Moreau clayey range site, 1982-1985.

Treatments	Mid Warm	Short Warm	Western Wheatgrass	Mid Cool	Short Cool	Sedge	Total Grass	Total Forbs	Total Yield
Unfertilized	22.00a	179.10a	69.69a	149.21a	170.39a	140.35a	730.73a	150.75a	881.49a
Ammonium nitrate									
40 lbs N EOY	9.53a	145.49a	100.29ab	179.97a	177.22a	182.79abc	795.30a	146.71ab	942.01a
40 lbs N EY	4.36a	99.91a	170.27ab	256.31b	192.48a	105.46abc	828.79a	219.43bc	1048.22a
60 lbs N EOY	2.97a	124.31a	129.46ab	235.90b	189.91a	192.68ab	875.23a	130.65ab	1005.88a
60 lbs N EY	7.94a	172.26a	139.35ab	251.54b	263.44a	222.21ab	1056.74a	189.30abc	1246.04a
100 lbs N EOY	2.97a	123.50a	159.79ab	207.34ab	210.34a	246.19b	950.13a	147.27ab	1097.40a
Urea									
40 lbs N EOY	1.00a	178.59a	82.86a	173.04ab	180.55a	146.48a	762.53a	133.41ab	895.94a
40 lbs N EY	2.00a	130.84a	239.67b	193.88ab	183.35a	70.16c	819.89a	253.33c	1073.22a
60 lbs N EOY	6.53a	166.68a	166.94ab	261.87ab	138.95a	271.18b	1012.16a	124.46ab	1136.62a
60 lbs N EY	0.00a	155.42a	137.99ab	248.17b	207.36a	226.78b	975.72a	160.17abc	1135.89a
100 lbs N EOY	0.59a	121.11a	204.75ab	333.20b	200.22a	323.51b	1183.40a	189.72ab	1373.12a

Means in the same column and followed by the same letter are not significantly different (P<0.05).

Table 5. Dry matter weight in pounds per acre for fertilization treatments 23 June on the Moreau clayey range site, 1982-1985.

Treatments	Mid Warm	Short Warm	Western Wheatgrass	Mid Cool	Short Cool	Sedge	Total Grass	Total Forbs	Total Yield
Unfertilized	6.04a	262.18a	85.43a	217.95a	246.96a	147.07a	928.86a	217.85a	1146.70a
Ammonium nitrate									
40 lbs N EOY	10.85a	275.96a	124.16a	336.59ab	290.06a	236.96a	1215.33b	181.20a	1396.53b
40 lbs N EY	20.20a	175.44a	190.78a	497.62b	345.77a	103.06b	1307.10b	267.13a	1574.23b
60 lbs N EOY	5.05a	279.71a	220.79a	483.78b	303.15a	136.77a	1395.05b	195.03a	1590.08b
60 lbs N EY	22.31a	314.74a	189.90a	477.71b	316.33a	252.74c	1510.54b	237.42a	1747.96b
100 lbs N EOY	13.23a	296.77a	245.13a	360.83ab	345.04a	216.65ac	1423.49b	234.15a	1657.64b
Urea									
40 lbs N EOY	57.98a	228.46a	107.61a	299.71ab	268.34a	112.23ab	1046.26a	249.89a	1296.15a
40 lbs N EY	3.73a	167.96a	320.25a	436.45ab	290.62a	74.94b	1275.21a	352.37a	1627.58b
60 lbs N EOY	4.75a	263.14a	198.23a	445.42b	218.08a	224.57ac	1298.04b	211.56a	1509.59ab
60 lbs N EY	5.07a	212.34a	171.02a	422.83ab	345.33a	232.94ac	1331.30b	173.09a	1504.39ab
100 lbs N EOY	10.12a	294.93a	203.06a	573.98b	349.20a	266.79c	1631.38b	218.29a	1849.67b

Means in the same column and followed by the same letter are not significantly different (P<0.05).

Table 6. Dry matter weight in pounds per acre for fertilization treatments 23 July on the Moreau clayey range site, 1982-1985.

Treatments	Mid Warm	Short Warm	Western Wheatgrass	Mid Cool	Short Cool	Sedge	Total Grass	Total Forbs	Total Yield
Unfertilized	13.22a	277.57a	118.33a	289.98a	242.79a	171.28a	1070.35a	295.45a	1365.80a
Ammonium nitrate									
40 lbs N EOY	24.84a	280.58a	171.72ab	457.43ab	391.75a	178.00a	1459.81a	386.70a	1846.49a
40 lbs N EY	19.64a	382.98a	265.10ab	489.32ab	349.81a	91.42a	1575.41a	388.33a	1963.71a
60 lbs N EOY	0.60a	341.61a	301.22ab	557.20ab	334.61a	230.55a	1708.15a	235.49a	1943.66a
60 lbs N EY	98.73a	289.90a	136.03ab	580.23ab	388.72a	220.05a	1658.64a	319.03a	1977.67a
100 lbs N EOY	22.76a	357.84a	241.99ab	439.88ab	376.84a	252.94a	1629.01a	270.66a	1899.67a
Urea									
40 lbs N EOY	30.92a	292.74a	147.23a	335.42ab	296.69a	140.95a	1208.71a	309.66a	1518.37a
40 lbs N EY	25.44a	369.10a	341.66b	428.63ab	273.40a	69.98a	1490.71a	331.66a	1822.38a
60 lbs N EOY	13.69a	248.88a	238.60ab	588.12ab	259.43a	224.58a	1517.15a	284.57a	1801.74a
60 lbs N EY	1.34a	287.64a	265.47ab	512.29ab	299.54a	164.14a	1489.39a	244.70a	1734.09a
100 lbs N EOY	19.78a	406.91a	247.49ab	592.43b	328.90a	264.63a	1793.97a	314.74a	2108.70a

Means in the same column and followed by the same letter are not significantly different (P<0.05).

Table 7. Dry matter weight in pounds per acre for fertilization treatments 23 August on the Moreau clayey range site, 1982-1985.

Treatments	Mid Warm	Short Warm	Western Wheatgrass	Mid Cool	Short Cool	Sedge	Total Grass	Total Forbs	Total Yield
Unfertilized	65.94a	363.79a	155.28a	303.08a	290.27a	184.94a	1317.06a	294.27a	1611.33a
Ammonium nitrate									
40 lbs N EOY	37.75a	408.54a	217.83a	397.39a	325.57a	192.26a	1531.27a	224.00a	1755.27a
40 lbs N EY	100.22a	393.67a	291.68a	482.73a	345.49a	118.94a	1703.00a	356.24a	2059.24a
60 lbs N EOY	38.20a	426.87a	271.79a	526.26a	389.78a	269.39a	1854.94a	266.45a	2121.39a
60 lbs N EY	38.95a	568.65a	154.49a	431.89a	360.52a	272.37a	1758.77a	346.54a	2105.32a
100 lbs N EOY	73.73a	506.01a	403.01a	456.70a	315.78a	233.11a	1930.06a	322.74a	2252.80a
Urea									
40 lbs N EOY	59.02a	421.08a	232.92a	307.88a	369.12a	222.01a	1556.52a	313.80a	1870.32a
40 lbs N EY	5.36a	349.65a	381.65a	518.70a	298.81a	87.59a	1619.86a	304.15a	1924.02a
60 lbs N EOY	0.00a	467.29a	308.49a	416.84a	258.09a	259.06a	1645.01a	269.11a	1914.12a
60 lbs N EY	38.35a	412.88a	252.04a	455.79a	306.11a	284.05a	1678.20a	295.67a	1973.87a
100 lbs N EOY	62.29a	445.37a	283.33a	561.69a	358.30a	246.00a	1895.47a	430.07a	2325.54a

Means in the same column and followed by the same letter are not significantly different (P<0.05).

Table 8. Percent composition of weight yield for fertilization treatments 30 May on the Moreau clayey range site, 1982-1985.

Treatments	Mid Warm	Short Warm	Western Wheatgrass	Mid Cool	Short Cool	Sedge	Total Grass	Total Forbs	Total Yield
Unfertilized	2.49a	20.05a	7.88a	16.84a	19.11a	16.19a	82.56a	17.44a	881.49
Ammonium nitrate									
40 lbs N EOY	1.05ab	15.69a	10.27a	19.12ab	17.97a	20.22abc	84.31a	15.69a	942.01
40 lbs N EY	0.46ab	10.41a	14.95ab	24.96b	16.39a	11.71abc	78.88a	21.12a	1048.22
60 lbs N EOY	0.35ab	13.34a	12.79a	24.49ab	16.95a	19.02a	86.94a	13.06a	1005.88
60 lbs N EY	0.73ab	15.22a	10.36a	21.29ab	18.52a	19.15ac	85.27a	14.73a	1246.04
100 lbs N EOY	0.35ab	12.60a	13.93ab	18.95ab	17.64a	23.66ac	87.12a	12.88a	1097.40
Urea									
40 lbs N EOY	0.12a	21.06a	8.67a	19.58ab	18.86a	16.98abc	85.28a	14.72a	895.94
40 lbs N EY	0.22a	12.79a	22.14b	17.40ab	15.31a	7.06b	74.92a	25.08a	1073.22
60 lbs N EOY	0.59ab	16.01a	14.23a	22.68b	11.15a	24.34ac	89.06a	10.94a	1136.62
60 lbs N EY	0.00b	15.17a	11.91a	21.87b	16.14a	21.17ac	86.25a	13.75a	1135.89
100 lbs N EOY	0.03b	9.13a	13.95ab	25.02ab	12.61a	24.06c	84.79a	15.21a	1373.12

Means in the same column and followed by the same letter are not significantly different (P<0.05).

Table 9. Percent composition of weight yield for fertilization treatments 23 June on the Moreau clayey range site, 1982-1985.

Treatments	Mid Warm	Short Warm	Western Wheatgrass	Mid Cool	Short Cool	Sedge	Total Grass	Total Forbs	Total Yield
Unfertilized	0.55a	22.89a	7.68a	18.86a	21.68a	12.36a	80.92a	19.08a	1146.70
Ammonium nitrate									
40 lbs N EOY	0.82a	19.74a	8.77a	24.32a	20.21a	17.88ab	87.27ab	12.73ab	1396.53
40 lbs N EY	1.37a	11.45b	11.61a	32.84a	21.11a	6.78b	83.46ab	16.54ab	1574.23
60 lbs N EOY	0.34a	17.78ab	13.92a	31.02a	18.30a	8.99ab	88.10ab	11.90ab	1590.08
60 lbs N EY	1.30a	18.86ab	10.87a	28.12a	16.75a	14.78a	86.98ab	13.02ab	1747.96
100 lbs N EOY	1.16a	17.90ab	14.43a	22.56a	19.13a	14.99ab	86.43ab	13.58ab	1657.64
Urea									
40 lbs N EOY	4.76a	17.74a	7.94a	24.00a	19.79a	9.39ab	81.27ab	18.74ab	1296.15
40 lbs N EY	0.31a	10.62b	18.21a	29.56a	16.30a	5.00b	78.76ab	21.25ab	1627.58
60 lbs N EOY	0.28a	17.86ab	12.58a	29.74a	13.32a	17.05a	86.57ab	13.43ab	1509.59
60 lbs N EY	0.45a	14.81ab	11.11a	27.95a	21.37a	17.31a	88.65b	11.35b	1504.39
100 lbs N EOY	0.77a	16.12ab	11.11a	31.17a	17.78a	15.77a	88.79ab	11.21ab	1849.67

Means in the same column and followed by the same letter are not significantly different ($P<0.05$).

Table 10. Percent composition of weight yield for fertilization treatments 23 July on the Moreau clayey range site, 1982-1985.

Treatments	Mid Warm	Short Warm	Western Wheatgrass	Mid Cool	Short Cool	Sedge	Total Grass	Total Forbs	Total Yield
Unfertilized	0.89a	21.04a	8.25a	21.10a	18.33a	12.49a	78.97a	21.04a	1365.80
Ammonium nitrate									
40 lbs N EOY	1.27ab	15.04a	9.37a	24.64a	21.66a	11.75a	80.79a	19.21a	1846.49
40 lbs N EY	1.24a	20.45a	13.12ab	26.22a	17.44a	5.61bc	82.67a	17.33a	1963.71
60 lbs N EOY	0.03b	18.02a	15.62ab	28.93a	16.16a	13.51a	88.88a	11.12a	1943.66
60 lbs N EY	5.66ab	15.15a	6.63a	30.31a	17.63a	13.06a	85.18a	14.82a	1977.67
100 lbs N EOY	1.56ab	19.98a	12.42a	23.85a	17.53a	15.45a	86.91a	13.09a	1899.67
Urea									
40 lbs N EOY	1.76ab	19.88a	9.48a	22.37a	18.85a	10.40ab	80.13a	19.87a	1518.37
40 lbs N EY	1.43ab	21.02a	18.32b	25.57a	13.88a	3.97c	83.18a	16.82a	1822.38
60 lbs N EOY	1.10ab	14.87a	13.14ab	32.96a	12.70a	16.04a	86.79a	13.21a	1801.74
60 lbs N EY	0.07ab	17.07a	14.24ab	31.29a	16.17a	10.26a	86.55a	13.45a	1734.09
100 lbs N EOY	0.84ab	19.02a	11.11ab	30.39a	13.80a	15.12a	86.51a	13.50a	2108.70

Means in the same column and followed by the same letter are not significantly different (P<0.05).

Table 11. Percent composition of weight yield for fertilization treatments 23 August on the Moreau clayey range site, 1982-1985.

Treatments	Mid Warm	Short Warm	Western Wheatgrass	Mid Cool	Short Cool	Sedge	Total Grass	Total Forbs	Total Yield
Unfertilized	3.63a	23.61a	8.78a	19.05a	19.93a	9.00a	81.86a	18.14a	1611.33
Ammonium nitrate									
40 lbs N EOY	2.19ab	21.39a	11.57a	22.74a	20.49a	9.77abc	87.54a	12.46a	1755.27
40 lbs N EY	4.41ab	20.59a	13.60a	24.69a	17.01a	5.01ac	84.05a	15.95a	2059.24
60 lbs N EOY	1.17ab	20.09a	12.57a	25.72a	18.74a	13.48b	88.39a	11.61a	2121.39
60 lbs N EY	1.12ab	28.38a	6.55a	20.78a	17.57a	13.07ab	84.20a	15.80a	2105.32
100 lbs N EOY	2.73ab	22.84a	16.92a	20.68a	13.80a	11.60abc	85.66a	14.34a	2252.80
Urea									
40 lbs N EOY	3.21ab	23.73a	11.96a	16.25a	20.74a	10.96ab	84.09a	15.91a	1870.32
40 lbs N EY	0.38b	18.06a	19.40a	29.32a	14.89a	3.98c	85.02a	14.98a	1924.02
60 lbs N EOY	0.00b	22.23a	16.98a	21.55a	13.62a	14.29b	88.09a	11.91a	1914.12
60 lbs N EY	1.22ab	21.11a	12.88a	23.19a	15.89a	14.76ab	85.35a	14.66a	1973.87
100 lbs N EOY	2.57ab	20.68a	11.29a	24.30a	13.70a	10.60ab	80.50a	19.50a	2325.54

Means in the same column and followed by the same letter are not significantly different (P<0.05).

Table 12. Basal cover of plant categories for fertilization treatments on the Moreau clayey range site, 1982-1985.

Treatments	Mid Warm	Short Warm	Western Wheatgrass	Mid Cool	Short Cool	Sedge	Total Grass	Total Forbs	Total Basal Cover
Unfertilized	1.38a	15.80ab	1.39a	4.08a	3.97a	3.70a	30.31a	4.34a	34.65a
Ammonium nitrate									
40 lbs N EOY	1.18a	14.85ab	1.02a	4.47a	3.88a	4.37a	29.77a	3.37a	33.13a
40 lbs N EY	0.70a	14.00a	2.09a	5.39a	5.45a	3.45a	31.07a	4.40a	35.47a
60 lbs N EOY	0.25b	16.19ab	1.59a	5.37a	3.29a	3.97a	30.63a	3.70a	34.33a
60 lbs N EY	0.40ab	17.30ab	1.95a	4.28a	3.80a	5.65a	33.38a	3.79a	37.17a
100 lbs N EOY	0.82a	13.49a	2.49a	5.83a	4.00a	4.93a	31.55a	4.10a	35.65a
Urea									
40 lbs N EOY	0.45b	20.53b	1.98a	4.72a	3.93a	4.39a	36.01a	4.41a	40.41a
40 lbs N EY	0.39ab	15.02ab	3.08a	4.78a	4.82a	1.85a	29.93a	4.90a	34.84a
60 lbs N EOY	1.42a	13.23a	1.97a	5.42a	3.72a	6.15a	31.90a	4.36a	36.26a
60 lbs N EY	1.17a	15.47ab	1.97a	5.62a	5.39a	3.75a	33.35a	3.78a	37.13a
100 lbs N EOY	0.59ab	17.92b	2.20a	5.20a	2.97a	6.33a	35.20a	2.10a	37.30a

Means in the same column and followed by the same letter are not significantly different (P<0.05).

Table 13a. Mean herbage biomass in pounds per acre of plant categories for fertilization treatments on the Moreau clayey range site, 1982-1985.

Dates Treatments	Cool Season	Warm Season	Sedge	Total Native Grass	Forbs	Total Yield
Unfertilized						
30 May	389.29	201.10	140.35	730.73	150.75	881.49
23 Jun	550.34	268.22	110.30	928.86	217.85	1146.70
23 Jul	651.10	290.79	128.46	1070.35	295.45	1365.80
23 Aug	748.63	429.73	138.70	1317.06	294.27	1611.33
Ammonium nitrate 40 lbs N EOY						
30 May	457.48	155.02	182.79	795.30	146.71	942.01
23 Jun	750.81	286.81	177.71	1215.33	181.20	1396.53
23 Jul	1020.90	305.42	133.50	1459.82	386.70	1846.52
23 Aug	940.79	446.29	144.19	1531.27	224.00	1755.27
40 lbs N EY						
30 May	619.06	104.27	105.46	828.79	219.43	1048.22
23 Jun	1034.17	195.64	77.29	1307.10	267.13	1574.23
23 Jul	1104.23	402.62	68.57	1575.41	388.33	1963.74
23 Aug	1119.90	493.89	89.21	1703.00	356.24	2059.24
60 lbs N EOY						
30 May	555.27	127.28	192.68	875.23	130.65	1005.88
23 Jun	1007.72	284.76	102.57	1395.05	195.03	1590.08
23 Jul	1193.03	342.21	172.91	1708.15	235.49	1943.66
23 Aug	1187.83	465.07	202.04	1854.94	266.45	2121.39

Table 13b. Mean herbage biomass in pounds per acre of plant categories for fertilization treatments on the Moreau clayey range site, 1982-1985.

Dates Treatments	Cool Season	Warm Season	Sedge	Total Native Grass	Forbs	Total Yield
60 lbs N EY						
30 May	654.33	180.20	222.21	1056.74	189.30	1246.04
23 Jun	983.94	337.05	189.55	1510.54	237.42	1747.96
23 Jul	1104.98	388.63	165.03	1658.64	319.03	1977.67
23 Aug	946.90	607.60	204.28	1758.78	346.54	2105.32
100 lbs N EOY						
30 May	577.47	126.47	246.19	950.13	147.27	1097.40
23 Jun	951.00	310.00	162.49	1423.49	234.15	1657.64
23 Jul	1058.71	380.60	189.70	1629.01	270.66	1899.67
23 Aug	1175.49	579.74	174.83	1930.06	322.74	2252.80
Urea 40 lbs N EOY						
30 May	436.45	179.59	146.48	762.53	133.41	895.94
23 Jun	675.66	286.44	84.16	1046.26	249.89	1296.15
23 Jul	779.34	323.66	105.71	1208.71	309.66	1518.37
23 Aug	909.92	480.10	166.50	1556.52	313.80	1870.32
40 lbs N EY						
30 May	616.90	132.84	70.16	819.89	253.33	1073.22
23 Jun	1047.32	171.69	56.20	1275.21	352.37	1627.58
23 Jul	1043.69	394.54	52.49	1490.72	331.66	1822.38
23 Aug	1199.16	355.01	65.69	1619.86	304.15	1924.02

Table 13c. Mean herbage biomass in pounds per acre of plant categories for fertilization treatments on the Moreau clayey range site, 1982-1985.

Dates Treatments	Cool Season	Warm Season	Sedge	Total Native Grass	Forbs	Total Yield
60 lbs N EOY						
30 May	567.76	173.22	271.18	1012.16	124.46	1136.62
23 Jun	861.73	267.89	168.42	1298.04	211.56	1509.59
23 Jul	1086.15	262.57	168.43	1517.15	284.57	1801.74
23 Aug	983.42	467.29	194.30	1645.01	269.11	1914.12
60 lbs N EY						
30 May	593.52	155.42	226.78	975.72	160.17	1135.89
23 Jun	939.18	217.41	174.71	1331.30	173.09	1504.39
23 Jul	1077.30	288.98	123.11	1489.39	244.70	1734.09
23 Aug	1013.94	451.23	213.03	1678.20	295.67	1973.87
100 lbs N EOY						
30 May	738.18	121.71	323.51	1183.40	189.72	1373.12
23 Jun	1126.24	305.05	200.09	1631.38	218.29	1849.67
23 Jul	1168.82	426.69	198.46	1793.97	314.73	2108.70
23 Aug	1203.32	507.66	184.49	1895.47	430.07	2325.54

Table 14a. Percent increase or decrease in herbage production of plant categories for fertilization treatments different than for the unfertilized treatment on the Moreau clayey range site, 1982-1985.

Dates Treatments	Cool Season	Warm Season	Sedge	Total Native Grass	Forbs	Total Yield
Unfertilized						
30 May	389.29	201.10	140.35	730.73	150.75	881.48
23 Jun	550.34	268.22	110.30	928.86	217.85	1146.70
23 Jul	651.10	290.79	128.46	1070.35	295.45	1365.80
23 Aug	748.63	429.73	138.70	1317.06	294.27	1611.33
Ammonium nitrate 40 lbs N EOY						
30 May	17.52	-22.91	30.24	8.84	-2.68	6.87
23 Jun	36.43	6.93	61.12	30.84	-16.82	21.79
23 Jul	56.80	5.03	3.92	36.39	30.89	35.20
23 Aug	25.67	3.85	3.96	16.26	-23.88	8.93
40 lbs N EY						
30 May	59.02	-48.15	-24.86	13.42	45.56	18.91
23 Jun	87.91	-27.06	-29.93	40.72	22.62	37.28
23 Jul	69.59	38.46	-46.62	47.19	31.44	43.78
23 Aug	49.59	14.93	-35.68	29.30	21.06	27.80
60 lbs N EOY						
30 May	42.64	-36.71	37.29	19.77	-13.33	14.11
23 Jun	83.11	6.17	-7.01	50.19	-10.47	38.67
23 Jul	83.23	17.68	34.60	59.59	-20.29	42.31
23 Aug	58.67	8.22	45.67	40.84	-9.45	31.65

Table 14b. Percent increase or decrease in herbage production of plant categories for fertilization treatments different than for the unfertilized treatment on the Moreau clayey range site, 1982-1985.

Dates Treatments	Cool Season	Warm Season	Sedge	Total Native Grass	Forbs	Total Yield
60 lbs N EY						
30 May	68.08	-10.39	58.33	44.61	25.57	41.36
23 Jun	78.79	25.66	71.85	62.62	8.98	52.43
23 Jul	69.71	33.65	28.47	54.96	7.98	44.80
23 Aug	26.48	41.39	47.28	33.54	17.76	30.66
100 lbs N EOY						
30 May	48.34	-37.11	75.41	30.02	-2.31	24.49
23 Jun	72.80	15.58	47.32	53.25	7.48	44.56
23 Jul	62.60	30.88	47.67	52.19	-8.39	39.09
23 Aug	57.02	34.91	26.05	46.54	9.67	39.81
Urea 40 lbs N EOY						
30 May	12.11	-10.70	4.37	4.35	-11.50	1.64
23 Jun	22.77	6.79	-23.70	12.64	14.71	13.03
23 Jul	19.70	11.30	-17.71	12.93	4.81	11.17
23 Aug	21.54	11.72	20.04	18.18	6.64	16.07
40 lbs N EY						
30 May	58.47	-33.94	-50.01	12.20	68.05	21.75
23 Jun	90.30	-35.99	-49.05	37.29	61.75	41.94
23 Jul	60.30	35.68	-59.14	39.27	12.26	33.43
23 Aug	60.18	-17.39	-52.64	22.99	3.36	19.41

Table 14c. Percent increase or decrease in herbage production of plant categories for fertilization treatments different than for the unfertilized treatment on the Moreau clayey range site, 1982-1985.

Dates Treatments	Cool Season	Warm Season	Sedge	Total Native Grass	Forbs	Total Yield
60 lbs N EOY						
30 May	45.84	-13.86	93.22	38.51	-17.44	28.94
23 Jun	56.58	-0.12	52.69	39.75	-2.89	31.65
23 Jul	66.82	-9.70	31.11	41.74	-3.68	31.92
23 Aug	31.36	8.74	40.09	24.90	-8.55	18.79
60 lbs N EY						
30 May	52.46	-22.72	61.58	33.53	6.25	28.86
23 Jun	70.65	-18.94	58.40	43.33	-20.55	31.19
23 Jul	65.46	-0.62	-4.16	39.15	-17.18	26.97
23 Aug	35.44	5.00	53.59	27.42	0.48	22.50
100 lbs N EOY						
30 May	89.62	-39.48	130.50	61.95	25.85	55.77
23 Jun	104.64	13.73	81.41	75.63	0.20	61.30
23 Jul	79.51	46.73	54.49	67.61	6.53	54.39
23 Aug	60.74	18.13	33.01	43.92	46.15	44.32

Table 15. Herbage weight (lbs/ac) for total yield category and percent difference from unfertilized treatment during growing season months on the Moreau clayey range site, 1982-1985.

Treatments	Total Nitrogen lbs/ac		30 May	23 Jun	23 Jul	23 Aug
Unfertilized	0	lbs/ac	881.49	1146.70	1365.80	1611.33
Ammonium nitrate						
40 lbs N EOY	80	lbs/ac	942.01	1396.53	1846.49	1755.27
		%	6.87	21.79	35.19	8.93
60 lbs N EOY	120	lbs/ac	1005.88	1590.08	1943.66	2121.39
		%	14.11	38.67	42.31	31.65
40 lbs N EY	160	lbs/ac	1048.22	1574.23	1963.71	2059.24
		%	18.91	37.28	43.78	27.80
100 lbs N EOY	200	lbs/ac	1097.40	1657.64	1899.67	2252.80
		%	24.49	44.56	39.09	39.81
60 lbs N EY	240	lbs/ac	1246.04	1747.96	1977.67	2105.32
		%	41.36	52.43	44.80	30.66
Urea						
40 lbs N EOY	80	lbs/ac	895.91	1296.15	1518.37	1870.32
		%	1.64	13.03	11.17	16.07
60 lbs N EOY	120	lbs/ac	1136.62	1509.59	1801.74	1914.12
		%	28.94	31.65	31.92	18.79
40 lbs N EY	160	lbs/ac	1073.22	1627.58	1822.38	1924.02
		%	21.75	41.94	33.43	19.41
100 lbs N EOY	200	lbs/ac	1373.12	1849.67	2108.70	2325.54
		%	55.77	61.30	54.39	44.32
60 lbs N EY	240	lbs/ac	1135.89	1504.39	1734.09	1973.87
		%	28.86	31.19	26.97	22.50

Table 16. Four year mean June, July, and August herbage weight (lbs/ac) for fertilization treatments and percent difference from unfertilized treatment on the Moreau clayey range site, 1982-1985.

Treatments	Total Nitrogen lbs/ac	Cool Season		Warm Season		Total Yield	
Unfertilized	0						
lbs/ac		650.02		329.58		1374.61	
Fertilized		Ammonium nitrate	Urea	Ammonium nitrate	Urea	Ammonium nitrate	Urea
40 lbs N EOY	80						
lbs/ac		904.16	788.31	346.17	363.40	1666.11	1561.66
% difference		39.10	21.27	5.03	10.26	21.21	13.61
60 lbs N EOY	120						
lbs/ac		1129.53	977.10	364.01	332.58	1885.04	1741.81
% difference		73.77	50.32	10.45	0.91	37.13	26.71
40 lbs N EY	160						
lbs/ac		1086.10	1096.73	364.05	307.08	1865.74	1791.33
% difference		67.09	68.72	10.46	-6.83	35.73	30.32
100 lbs N EOY	200						
lbs/ac		1061.73	1163.62	471.26	413.13	1936.70	2094.64
% difference		63.33	79.01	42.99	25.35	40.89	52.38
60 lbs N EY	240						
lbs/ac		1011.94	1010.14	444.42	319.21	1943.65	1737.45
% difference		55.68	55.40	34.85	-3.15	41.40	26.40

Table 17. Herbage weight difference (lbs/ac) for fertilization treatments from unfertilized treatment and pounds of herbage per pound of nitrogen on the Moreau clayey range site, 1982-1985.

Treatments	Total Nitrogen lbs/ac	Cool Season		Warm Season		Total Yield	
Unfertilized	0						
lbs/ac		650.02		329.58		1374.61	
Fertilized		Ammonium nitrate	Urea	Ammonium nitrate	Urea	Ammonium nitrate	Urea
40 lbs N EOY	80						
lbs/ac difference		254.14	138.29	16.59	33.82	291.50	187.05
lbs/lb N		12.71	6.91	0.83	1.69	14.58	9.35
60 lbs N EOY	120						
lbs/ac difference		479.51	327.08	34.43	3.00	510.43	367.20
lbs/lb N		15.98	10.90	1.15	0.10	17.01	12.24
40 lbs N EY	160						
lbs/ac difference		436.08	446.71	34.47	-22.50	491.13	416.72
lbs/lb N		10.90	11.17	0.86	-0.56	12.28	10.42
100 lbs N EOY	200						
lbs/ac difference		411.71	513.60	141.68	83.55	562.09	720.03
lbs/lb N		8.23	10.27	2.83	1.67	11.24	14.40
60 lbs N EY	240						
lbs/ac difference		361.92	360.12	114.84	-10.37	569.04	362.84
lbs/lb N		6.03	6.00	1.91	-0.17	9.48	6.05

Table 18. Percent difference of mean June, July, and August herbage weight for fertilization treatments from unfertilized treatment produced in 1982 and 1984 and percent lost from 33 days with no precipitation in 1984 on the Moreau clayey range site.

Treatments	Total Nitrogen lbs/ac	Cool Season		Warm Season		Total Yield	
Unfertilized							
1982 lbs/ac		624.10		276.93		1184.23	
1984 lbs/ac		930.07		480.53		2054.43	
Fertilized		Ammonium nitrate	Urea	Ammonium nitrate	Urea	Ammonium nitrate	Urea
40 lbs N EOY	80						
1982 %		77.86	63.03	20.22	20.46	51.35	39.63
1984 %		15.69	9.55	10.72	10.23	10.43	6.06
% Lost		-62.17	-53.48	-9.50	-10.23	-40.92	-33.57
60 lbs N EOY	120						
1982 %		104.71	120.97	31.77	25.35	65.33	79.58
1984 %		45.27	16.28	15.20	-1.86	22.67	7.71
% Lost		-59.44	-104.69	-16.57	-27.21	-42.66	-71.87
40 lbs N EY	160						
1982 %		91.32	93.71	55.26	15.91	72.03	68.66
1984 %		40.05	24.76	0.33	-0.29	21.01	8.97
% Lost		-51.27	-68.95	-54.93	-16.20	-51.02	-59.69
100 lbs N EOY	200						
1982 %		147.14	160.73	63.28	63.46	100.27	110.57
1984 %		26.60	33.40	30.92	32.33	20.40	31.99
% Lost		-120.54	-127.33	-32.36	-31.13	-79.87	-78.58
60 lbs N EY	240						
1982 %		103.46	75.92	57.19	19.26	80.02	46.96
1984 %		32.21	34.70	33.58	-10.24	27.99	10.02
% Lost		-71.25	-41.22	-23.61	-29.50	-52.03	-36.94

Table 19a. Percent herbage growth and senescence of plant categories for fertilization treatments on the Moreau clayey range site, 1982-1985.

Dates Treatments	Cool Season	Warm Season	Sedge	Total Native Grass	Forbs	Total Yield
Unfertilized						
30 May	52.00	46.80	83.17	55.48	51.02	54.71
23 Jun	21.51	15.62	-17.81	15.04	22.71	16.46
23 Jul	13.46	5.25	10.76	10.74	26.27	13.60
23 Aug	13.03	32.33	6.07	18.73	-0.40	15.24
Ammonium nitrate 40 lbs N EOY						
30 May	44.81	34.74	94.47	51.94	37.94	51.02
23 Jun	28.73	29.53	-2.63	27.43	8.92	24.62
23 Jul	26.46	4.17	-22.85	15.97	53.14	24.37
23 Aug	-7.85	31.56	5.53	4.67	-42.07	-4.94
40 lbs N EY						
30 May	55.28	21.11	83.63	48.67	56.51	50.90
23 Jun	37.07	18.50	-22.34	28.09	12.28	25.54
23 Jul	6.26	41.91	-6.92	15.76	31.21	18.91
23 Aug	1.40	18.48	16.37	7.49	-8.26	4.64
60 lbs N EOY						
30 May	46.54	27.37	65.95	47.18	49.03	47.42
23 Jun	37.92	33.86	-30.84	28.02	24.16	27.54
23 Jul	15.53	12.35	24.08	16.88	15.18	16.67
23 Aug	-0.44	26.42	9.97	7.91	11.62	8.38

Table 19b. Percent herbage growth and senescence of plant categories for fertilization treatments on the Moreau clayey range site, 1982-1985.

Dates Treatments	Cool Season	Warm Season	Sedge	Total Native Grass	Forbs	Total Yield
60 lbs N EY						
30 May	59.22	29.66	84.99	60.08	54.63	59.19
23 Jun	29.83	25.81	-12.49	25.80	13.89	23.84
23 Jul	10.95	8.49	-9.38	8.42	23.55	10.91
23 Aug	-14.31	36.04	15.01	5.69	7.94	6.06
100 lbs N EOY						
30 May	49.13	21.81	90.05	49.23	45.63	48.71
23 Jun	31.78	31.66	-30.61	24.53	26.92	24.87
23 Jul	9.16	12.18	9.95	10.65	11.31	10.74
23 Aug	9.93	34.35	-5.44	15.60	16.14	15.68
Urea 40 lbs EOY						
30 May	47.97	37.41	64.02	48.99	42.51	47.90
23 Jun	26.29	22.26	-27.24	18.23	37.12	21.40
23 Jul	11.39	7.75	9.42	10.44	19.05	11.88
23 Aug	14.35	32.58	26.56	22.34	1.32	18.82
40 lbs N EY						
30 May	51.29	33.67	84.17	50.61	71.89	55.78
23 Jun	35.79	9.85	-16.75	28.11	28.11	28.81
23 Jul	-0.30	56.48	-4.45	13.30	-5.88	10.12
23 Aug	12.93	-10.02	15.83	7.97	-7.81	5.28

Table 19c. Percent herbage growth and senescence of plant categories for fertilization treatments on the Moreau clayey range site, 1982-1985.

Dates Treatments	Cool Season	Warm Season	Sedge	Total Native Grass	Forbs	Total Yield
60 lbs N EOY						
30 May	52.27	36.65	91.29	61.53	43.74	59.38
23 Jun	27.07	20.03	-34.59	17.38	30.61	19.49
23 Jul	20.66	-1.13	0.00	13.32	25.66	15.26
23 Aug	-9.46	43.32	8.71	7.77	-5.43	5.87
60 lbs N EY						
30 May	55.09	34.44	71.61	58.14	54.17	57.55
23 Jun	32.09	13.74	-16.44	21.19	4.37	18.67
23 Jul	12.82	15.86	-16.30	9.42	24.22	11.64
23 Aug	-5.88	35.96	28.39	11.25	17.24	12.15
100 lbs N EOY						
30 May	61.34	23.97	100.00	62.43	44.11	59.05
23 Jun	32.25	36.12	-38.15	23.63	6.64	20.49
23 Jul	3.54	23.96	-0.50	8.58	22.43	11.14
23 Aug	2.87	15.95	-4.32	5.35	26.82	9.32

Table 20. Percent herbage growth occurring during May and June for fertilization treatments on the Moreau clayey range site, 1982-1985.

Treatments	Cool Season Grass		Total Native Grass		Total Yield	
Unfertilized	73.5		70.5		71.2	
Fertilized	Ammonium nitrate	Urea	Ammonium nitrate	Urea	Ammonium nitrate	Urea
40 lbs N EOY	73.5	74.3	79.4	67.2	75.6	69.3
40 lbs N EY	92.4	87.1	76.8	78.7	76.4	84.6
60 lbs N EOY	84.5	79.3	75.2	78.9	75.0	78.9
60 lbs N EY	89.1	87.2	85.9	79.3	83.0	76.2
100 lbs N EOY	80.9	93.6	73.8	86.1	73.6	79.5

Table 21. Percent herbage growth occurring during July and August for fertilization treatments on the Moreau clayey range site, 1982-1985.

Treatments	Cool Season Grass		Total Native Grass		Total Yield	
Unfertilized	26.5		29.5		28.8	
Fertilized	Ammonium nitrate	Urea	Ammonium nitrate	Urea	Ammonium nitrate	Urea
40 lbs N EOY	18.6	25.7	20.6	32.8	19.4	30.7
40 lbs N EY	7.7	12.6	23.3	21.3	23.6	15.4
60 lbs N EOY	15.1	11.2	24.8	21.1	25.1	21.1
60 lbs N EY	-3.4	6.9	14.1	20.7	17.0	23.8
100 lbs N EOY	19.1	6.4	26.3	13.9	26.4	20.5

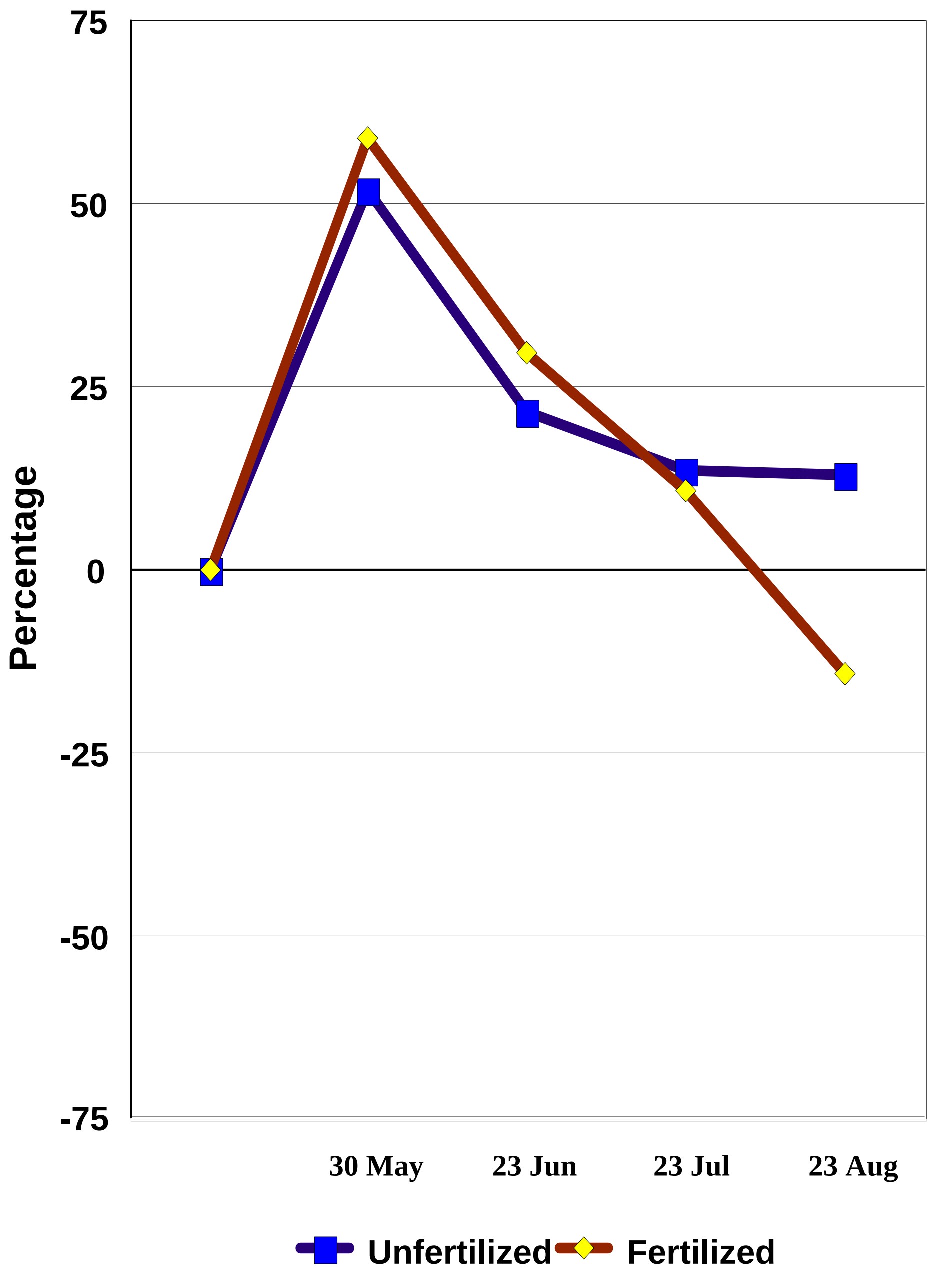

Figure 1. Percent herbage growth and senescence of cool season grasses for 60 lbs N EY and unfertilized treatments on the Moreau clayey range site, 1982-1985.

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Cost of Herbage Weight for Nitrogen Fertilization Treatments on Native Rangeland

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All of the nitrogen fertilization of native rangeland treatments increased total aboveground herbage weight to some degree. The nitrogen treatments increased herbage weight of mid cool season grasses and decreased herbage weight of warm season grasses. Native rangeland response to nitrogen fertilization was differentially affected by the quantity and source of nitrogen applied, and the vegetative communities on different range sites were affected by variation in soil characteristics, soil water content, plant species composition, and health status of the ecosystem. The fertilization treatments with the greatest production of total herbage weight may not be the treatments that are the most effective or lowest cost. This report evaluates the nitrogen fertilization treatments from five native rangeland plot studies for treatment effectiveness and herbage costs.

Procedure

Five nitrogen fertilization of native rangeland plot studies were conducted at the Dickinson Research Extension Center between 1957 and 1987. Plot study I (1957) was conducted on a heavily grazed site with an unfertilized control and ammonium nitrate treatments of 50 lbs N/ac, 100 lbs N/ac, and 150 lbs N/ac applied annually. Plot study II (1962-1963) was conducted on a creek terrace site and an upland slope site with an unfertilized control and ammonium nitrate treatments of 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac applied annually. Plot study III (1964-1969) was conducted on a Havre overflow, Manning silty, Vebar sandy, and Rhoades thin claypan range sites with an unfertilized control and ammonium nitrate treatments of 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac applied annually. Plot study IV (1970-1978) was conducted on an upland range site with an unfertilized control and ammonium nitrate treatments of 67 lbs N/ac and 100 lbs N/ac applied annually, 67 lbs N/ac and 100 lbs N/ac applied biennially, and 200 lbs N/ac, 300 lbs N/ac, and 400 lbs N/ac applied one time. Plot study V (1982-1987) was conducted on a Moreau clayey range site with an unfertilized control and ammonium nitrate and urea treatments of 40 lbs N/ac and 60 lbs N/ac applied annually, and 40 lbs N/ac, 60 lbs N/ac, and 100 lbs N/ac applied biennially.

Nitrogen fertilizer costs were the actual costs paid during plot study V with ammonium nitrate at $0.24 per pound of nitrogen, and urea at $0.25 per pound of nitrogen. Land rent value for grazinglands in North Dakota taken from the North Dakota Agricultural Statistics Service, 1998, was the mean rent in fifteen western counties at $8.76 per acre.

Herbage cost was compared and evaluated from the cost of herbage weight per ton. Herbage cost per ton on the unfertilized treatments was determined first, by dividing the grazingland rent cost per acre by the mean total herbage weight produced on the unfertilized treatment to derive cost per pound of herbage; then, cost per pound was multiplied by 2000 pounds to derive cost per ton of unfertilized herbage. Herbage cost per ton on the fertilized treatments was determined in three stages: first, the nitrogen cost per acre was determined by multiplying the nitrogen cost per pound by the quantity of nitrogen applied annually (or half the biennial rate); next, the nitrogen cost per acre was divided by the weight difference in mean total herbage weight produced on the fertilization treatments from the mean total herbage weight produced on the unfertilized treatments to derive cost per pound of herbage; then, cost per pound was multiplied by 2000 pounds to derive cost per ton for the additional herbage produced by the nitrogen treatments.

Treatment effectiveness was compared and evaluated from the herbage weight produced per pound of nitrogen applied. Pounds of herbage per pound of nitrogen was determined by dividing the quantity of nitrogen applied annually (or half the biennial rate) by the weight difference in mean total herbage weight produced on the fertilization treatments from the mean total herbage weight produced on the unfertilized treatments.

Results and Discussion

The mean total herbage weight produced on the fertilization treatments was 594.80 pounds greater than the mean total herbage weight produced on the unfertilized treatments. The weight difference in mean total herbage weight produced on the fertilization treatments was 300.3 lbs, 819.0 lbs, and

876.0 lbs greater for ammonium nitrate annually applied at treatment rates of 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac, respectively, and this increase in herbage weight on the fertilization treatments was 21.6%, 52.9%, and 57.5% greater, respectively, than the total herbage weight produced on the unfertilized treatments. Ammonium nitrate treatments applied biennially produced about 54.3% of the total herbage weight produced on the annually applied treatments. Ammonium nitrate treatments produced a mean 5.4% greater total herbage weight than produced on the urea treatments (tables 1-6).

Cost of unfertilized herbage weight per ton on plot study I, plot study II, III, and IV, and plot study V was $9.84, $11.59, and $12.75 per ton of herbage, respectively. The mean cost of herbage weight on the fertilization treatments was $51.39 per ton. Cost of fertilized herbage weight on most of the plot study sites and fertilization treatment rates ranged between $32.00 and $84.00 per ton, with the lowest cost at $24.19 per ton, and the highest cost at $112.21 per ton. The mean cost of herbage weight on the ammonium nitrate annually applied treatment rates of 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac was $62.34, $41.58, and $60.40 per ton, respectively. The cost of herbage weight on the ammonium nitrate treatments applied biennially were in the same range of costs per ton as the costs of herbage weight on the annually applied treatments. The cost of herbage weight on the urea treatments was about $13.23 per ton greater than the cost of herbage weight on the ammonium nitrate treatments (tables 7-8).

The mean percent increase in cost of fertilized herbage weight was 373.56% greater than the cost of herbage weight on the unfertilized treatments. The percent increase in the cost of fertilized herbage weight for most of the fertilization treatments ranged between 160% and 600% greater than the cost of unfertilized herbage weight. More than 80% of the fertilization treatments had herbage weight costs that were greater than 200% of the unfertilized herbage cost. None of the fertilization treatments had herbage weight costs that were less than 120% greater then the herbage weight costs on the unfertilized treatments. The mean percent increase in cost of fertilized herbage weight on the ammonium nitrate annually applied treatment rates of 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac was 502.01%, 279.06%, and 471.28% greater, respectively, than the cost of unfertilized herbage weight. The biennially applied ammonium nitrate treatments had an increase of 184.76% on the 67 lbs N/ac rate and had a reduction of 138.41% on the 100 lbs N/ac rate in cost of herbage weight from the cost of herbage weight on the respective annually applied treatments. The percent increase in the cost of herbage weight on the urea treatments was 104.18% greater than the percent increase in the cost of herbage weight on the ammonium nitrate treatments (tables 9-10).

On native rangeland grazinglands, about 50% of the produced herbage is required by the plants to remain healthy and productive and about 50% of the produced herbage is not needed by the plants and is expendable. About 50% of the plant expendable herbage is lost from the plant by leaf senescence and by grazing of insects and wildlife. The other 50% of the plant expendable herbage is ingested as forage by grazing livestock. About 25% of the produced herbage weight is captured through grazing by livestock as forage. The cost of forage weight is four times greater than the cost of herbage weight. Fertilization treatments with herbage weight costs of $32.00 and $84.00 per ton would have forage weight costs of $128.00 and $336.00 per ton, respectively.

Cost of herbage weight per ton on all of the annual and biennial ammonium nitrate and urea fertilization treatments were too great to be cost effective. More than 62% of the fertilization treatments had herbage weight costs greater than $40 per ton, or forage weight costs greater than $160 per ton. Only one fertilization treatment had herbage weight costs less than $30 per ton or forage weight costs of less than $120 per ton.

Unfertilized treatments with herbage weight costs of $11.59 per ton would have forage weight costs of $46.36 per ton. Cost of herbage weight per ton on unfertilized treatments were not excessive and could be cost effective.

The primary reason for the high herbage weight costs on the fertilization treatments was low pounds of herbage produced per pound of nitrogen applied. The mean weight of herbage produced per pound of nitrogen applied was 10.55 pounds of herbage. The herbage weight produced per pound of nitrogen on most of the fertilization treatments ranged between 8.0 and 14.6 pounds of herbage, with the lowest at 4.3 pounds of herbage and the greatest at 17.0 pounds of herbage. The mean pounds of herbage per pound of nitrogen on the ammonium nitrate annually applied treatment rates of 33 lbs N/ac, 67 lbs N/ac, and 100 lbs N/ac was 9.1 lbs, 12.2 lbs, and 8.8 lbs of herbage. The pounds of herbage per pound of nitrogen on the ammonium nitrate treatments applied biennially were in the same range of pounds of herbage per pound of nitrogen as on the annually applied treatments. The ammonium nitrate treatments produced 2.43 pounds of herbage per pound nitrogen greater than that produced on the urea treatments (tables 11-12).

With few pounds of herbage produced per pound of nitrogen, each pound of herbage had a high cost and each ton of herbage produced on the fertilization treatments cost substantially more than the cost of herbage produced on the unfertilized treatments. Based on the cost of the additional herbage weight produced on the fertilization treatments, the practice of nitrogen fertilization of native rangeland will not be profitable.

Acknowledgment

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Table 1. Mean nitrogen costs and herbage costs of fertilization treatments on a heavily grazed site, plot study I, 1957.

Treatments	Total Yield lbs/ac	Weight Difference from Unfertilized lbs/ac	Percent Difference from Unfertilized %	Herbage Weight per Pound of Nitrogen lbs	Nitrogen Cost @$0.24/lb $/ac	Herbage Cost $/ton
Unfertilized	1781.00					9.84
50 lbs N	2456.00	675.00	37.90	13.50	12.00	35.56
100 lbs N	3765.00	1984.00	111.40	19.84	24.00	24.19
150 lbs N	3220.00	1439.00	80.80	9.59	36.00	50.03

Table 2. Mean nitrogen costs and herbage costs of fertilization treatments on two range sites, plot study II, 1962-1963.

Treatments	Total Yield lbs/ac	Weight Difference from Unfertilized lbs/ac	Percent Difference from Unfertilized %	Herbage Weight per Pound of Nitrogen lbs	Nitrogen Cost @$0.24/lb $/ac	Herbage Cost $/ton
Creek terrace site						
Unfertilized	1521.00					11.52
33 lbs N	1932.50	411.50	27.05	12.47	7.92	38.49
67 lbs N	2440.00	919.00	60.42	13.72	16.08	34.99
100 lbs N	2431.50	910.50	59.86	9.11	24.00	52.72
Upland slope site						
Unfertilized	1358.00					12.90
33 lbs N	1825.00	467.00	34.39	14.15	7.92	33.92
67 lbs N	2233.00	875.00	64.43	13.06	16.08	36.75
100 lbs N	2260.00	902.00	66.42	9.02	24.00	53.22
Mean of two sites						
Unfertilized	1439.50					12.17
33 lbs N	1878.75	439.25	30.51	13.31	7.92	36.06
67 lbs N	2336.50	897.00	62.31	13.39	16.08	35.85
100 lbs N	2345.75	906.25	62.96	9.06	24.00	52.97

Table 3. Mean nitrogen costs and herbage costs of fertilization treatments on four range sites, plot study III, 1964-1969.

Treatments	Total Yield lbs/ac	Weight Difference from Unfertilized lbs/ac	Percent Difference from Unfertilized %	Herbage Weight per Pound of Nitrogen lbs	Nitrogen Cost @$0.24/lb $/ac	Herbage Cost $/ton
Havre overflow range site						
Unfertilized	2514.33					6.97
33 lbs N	2655.50	141.17	5.61	4.28	7.92	112.21
67 lbs N	3368.00	853.67	33.95	12.74	16.08	37.67
100 lbs N	3079.17	564.84	22.46	5.65	24.00	84.98
Manning silty range site						
Unfertilized	1533.50					11.42
33 lbs N	1743.17	209.67	13.67	6.35	7.92	75.55
67 lbs N	2477.33	943.83	61.55	14.09	16.08	34.07
100 lbs N	2909.33	1375.83	89.72	13.76	24.00	34.89
Vebar sandy range site						
Unfertilized	1331.67					13.16
33 lbs N	1665.83	334.16	25.09	10.13	7.92	47.40
67 lbs N	2287.00	955.33	71.74	14.26	16.08	33.66
100 lbs N	2331.00	999.33	75.04	9.99	24.00	48.03
Rhoades thin claypan range site						
Unfertilized	1011.20					17.33
33 lbs N	1249.60	238.40	23.58	7.22	7.92	66.44
67 lbs N	1474.00	462.80	45.77	6.91	16.08	69.49
100 lbs N	1524.20	513.00	50.73	5.13	24.00	93.57
Mean of four range sites						
Unfertilized	1597.68					10.97
33 lbs N	1828.53	230.85	14.45	7.00	7.92	68.62
67 lbs N	2401.58	803.90	50.32	12.00	16.08	40.00
100 lbs N	2460.93	863.25	54.03	8.63	24.00	55.60

Table 4. Mean nitrogen costs and herbage costs of fertilization treatments on the upland range site, plot study IV, 1970-1978.

Treatments	Total Yield lbs/ac	Weight Difference from Unfertilized lbs/ac	Percent Difference from Unfertilized %	Herbage Weight per Pound of Nitrogen lbs	Nitrogen Cost @$0.24/lb $/ac	Herbage Cost $/ton
Unfertilized	2252.56					7.81
67 lbs N EOY	2525.63	273.07	12.12	8.15	8.04	58.89
67 lbs N EY	2975.89	723.33	32.11	10.80	16.08	44.46
100 lbs N EOY	2868.00	615.44	27.32	10.77	13.71	44.57
100 lbs N EY	3119.34	866.78	38.48	8.67	24.00	55.38
200 lbs N OT	2426.56	174.00	7.72	7.83	5.33	61.26
300 lbs N OT	2865.67	613.11	27.22	18.40	8.00	26.10
400 lbs N OT	2818.33	565.77	25.12	12.73	10.67	37.72

Table 5. Mean nitrogen costs and herbage costs of ammonium nitrate fertilization treatments on the Moreau clayey range site, plot study V, 1982-1985.

Treatments	Total Yield lbs/ac	Weight Difference from Unfertilized lbs/ac	Percent Difference from Unfertilized %	Herbage Weight per Pound of Nitrogen lbs	Nitrogen Cost @$0.24/lb $/ac	Herbage Cost $/ton
Unfertilized	1374.61					12.75
Ammonium nitrate						
40 lbs N EOY	1666.11	291.50	21.21	14.58	4.80	32.93
40 lbs N EY	1865.74	491.13	35.73	12.28	9.60	39.09
60 lbs N EOY	1885.04	510.43	37.13	17.01	7.20	28.21
60 lbs N EY	1943.65	569.04	41.40	9.48	14.40	50.61
100 lbs N EOY	1936.70	562.09	40.89	11.24	12.00	42.70

Table 6. Mean nitrogen costs and herbage costs of urea fertilization treatments on the Moreau clayey range site, plot study V, 1982-1985.

Treatments	Total Yield lbs/ac	Weight Difference from Unfertilized lbs/ac	Percent Difference from Unfertilized %	Herbage Weight per Pound of Nitrogen lbs	Nitrogen Cost @$0.25/lb $/ac	Herbage Cost $/ton
Unfertilized	1374.61					12.75
Urea						
40 lbs N EOY	1561.66	187.05	13.61	9.35	5.00	53.46
40 lbs N EY	1791.33	416.72	30.32	10.42	10.00	47.99
60 lbs N EOY	1741.81	367.20	26.71	12.24	7.50	40.85
60 lbs N EY	1737.45	362.84	26.40	6.05	15.00	82.68
100 lbs N EOY	2094.64	720.03	52.38	14.40	12.50	34.72

Table 7. Cost of herbage weight per ton on annual and biennial ammonium nitrate fertilization treatments and on unfertilized treatments.

Study Sites	Treatment Rates 0 lbs N/ac $/ton	33 lbs N/ac $/ton	67 lbs N/ac $/ton	100 lbs N/ac $/ton
Annual Treatments				
Creek terrace site	11.52	38.49	34.99	52.72
Upland slope site	12.90	33.92	36.75	53.22
Havre overflow range site	6.97	112.21	37.67	84.98
Manning silty range site	11.42	75.55	34.07	34.89
Vebar sandy range site	13.16	47.40	33.66	48.03
Rhoades thin claypan range site	17.33	66.44	69.49	93.57
Upland range site	7.81	-	44.46	55.38
Mean	11.59	62.34	41.58	60.40
Biennial Treatments				
Upland range site	7.81	-	58.89	44.57

Table 8. Cost of herbage weight per ton on annual and biennial ammonium nitrate and urea fertilization treatments and on the unfertilized treatment.

Study Sites	Treatment Rates 0 lbs N/ac $/ton	40 lbs N/ac $/ton	60 lbs N/ac $/ton	100 lbs N/ac $/ton
Moreau clayey range site				
Annual Treatments				
Ammonium nitrate	12.75	39.09	50.61	-
Urea	12.75	47.99	82.68	-
Biennial Treatments				
Ammonium nitrate	12.75	32.93	28.21	42.70
Urea	12.75	53.46	40.85	34.72

Table 9. Percent increase in cost of herbage weight per ton on annual and biennial ammonium nitrate fertilization treatments and cost of herbage weight per ton on unfertilized treatments.

	Treatment Rates			
Study Sites	0 lbs N/ac $/ton	33 lbs N/ac %	67 lbs N/ac %	100 lbs N/ac %
Annual Treatments				
Creek terrace site	11.52	234.11	203.73	357.64
Upland slope site	12.90	162.95	184.88	312.56
Havre overflow range site	6.97	1509.90	440.46	1119.23
Manning silty range site	11.42	561.56	198.34	205.52
Vebar sandy range site	13.16	260.18	155.78	264.97
Rhoades thin claypan range site	17.33	283.38	300.98	439.93
Upland range site	7.81	-	469.27	609.09
Mean	11.59	502.01	279.06	471.28
Biennial Treatments				
Upland range site	7.81	-	654.03	470.68

Table 10. Percent increase in cost of herbage weight per ton on annual and biennial ammonium nitrate and urea fertilization treatments and cost of herbage weight per ton on the unfertilized treatment.

	Treatment Rates			
Study Sites	0 lbs N/ac $/ton	40 lbs N/ac %	60 lbs N/ac %	100 lbs N/ac %
Moreau clayey range site				
Annual Treatments				
Ammonium nitrate	12.75	206.59	296.94	-
Urea	12.75	276.39	548.47	-
Biennial Treatments				
Ammonium nitrate	12.75	158.27	121.25	234.90
Urea	12.75	319.29	220.39	172.31

Table 11. Herbage weight (in pounds per acre) per pound of nitrogen fertilizer applied and herbage weight on unfertilized treatments.

	Treatment Rates			
Study Sites	0 lbs N/ac lbs/ac	33 lbs N/ac lbs/ac/lb N	67 lbs N/ac lbs/ac/lb N	100 lbs N/ac lbs/ac/lb N
Annual Treatments				
Creek terrace site	1521.00	12.47	13.72	9.11
Upland slope site	1358.00	14.15	13.06	9.02
Havre overflow range site	2514.33	4.28	12.74	5.65
Manning silty range site	1533.50	6.35	14.09	13.76
Vebar sandy range site	1331.67	10.13	14.26	9.99
Rhoades thin claypan range site	1011.20	7.22	6.91	5.13
Upland range site	2252.56	-	10.80	8.67
Mean	1646.04	9.10	12.23	8.76
Biennial Treatments				
Upland range site	2252.56	-	8.15	10.77

Table 12. Herbage weight (in pounds per acre) per pound of nitrogen fertilizer applied and herbage weight on the unfertilized treatment.

	Treatment Rates			
Study Sites	0 lbs N/ac lbs/ac	40 lbs N/ac lbs/ac/lb N	60 lbs N/ac lbs/ac/lb N	100 lbs N/ac lbs/ac/lb N
Moreau clayey range site				
Annual Treatments				
Ammonium nitrate	1374.61	12.28	9.48	-
Urea	1374.61	10.42	6.05	-
Biennial Treatments				
Ammonium nitrate	1374.61	14.58	17.01	11.24
Urea	1374.61	9.35	12.24	14.40

Evaluation of Grazing Fertilized Native Rangeland Pastures

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Fertilization of native rangeland plot studies showed that application of nitrogen fertilizers increased total herbage yield (Rogler and Lorenz 1957; Whitman 1957, 1963, 1969, 1978; Smika et al. 1965; Power and Alessi 1971; Lorenz and Rogler 1972; Wight and Black 1972, 1979; Taylor 1976) and increased aboveground herbage crude protein content during the early portion of the growing season (Black and Wight 1972, Whitman 1975, Goetz 1975).

A fertilization of native rangeland grazing study with two grazing trials was conducted at the Dickinson Research Extension Center from 1972 to 1982 to test the performance of herbage and livestock on unfertilized native rangeland and fertilized rangeland pastures. Grazing trial I experimented with yearling steers and was conducted from 1972 to 1976 by Dr. Warren C. Whitman and Dr. Harold Goetz. Data from grazing trial I was reported by Nyren et al. 1983. A transition period occurred during 1977. Grazing trial II experimented with cow-calf pairs and was conducted from 1978 to 1981 by Paul E. Nyren and Dr. Harold Goetz and continued during 1981 to 1982 by Dr. Llewellyn L. Manske and Dr. Harold Goetz. Data from grazing trial II was reported by Nyren et al. 1984 and by Manske et al. 1984.

This report reevaluates the original data collected during grazing trials I and II and compares livestock weight gains, ungrazed and grazed total herbage production, and costs and returns on unfertilized and fertilized native rangeland pastures.

Procedure

The nitrogen fertilization of native rangeland grazing study was conducted from 1972 to 1982 as two grazing trials. The research pastures were located on the SW½, sec. 23, T. 140 N., R. 97 W., at the Dickinson Research Extension Center. The native rangeland plant community was strongly rolling upland mixed grass prairie. The soils were Vebar, Parshall, and Flasher fine sandy loams. The control pasture was 18 acres of untreated native rangeland. The fertilized pasture was 12 acres of native rangeland fertilized annually with ammonium nitrate fertilizer (33-0-0) broadcast applied in granular form at a rate of 50 lbs N/ac in early spring, usually around early to mid April, for eleven years from 1972 to 1982.

Steer performance during grazing trial I and cow and calf performance during grazing trial II were determined by mean weight gains or losses. The cattle were weighed upon entering and leaving each pasture.

Aboveground herbage biomass production was sampled by the clipping method. During grazing trial I, herbage samples were collected at the end of each grazing period and during grazing trial II, herbage samples were collected at the beginning and end of each grazing period. Vegetation was hand clipped to ground level in rectangular quadrats located both inside and outside exclosure cages. The plant material was oven dried and weighed. The difference between the aboveground herbage biomass values collected inside and outside the exclosure cages was the forage utilized. The forage use per acre included the forage ingested by the cattle, the loss in vegetation weight caused by senescence, and the loss in vegetation weight caused by parts broken from the plant, soiled by animal waste, consumed by insects and wildlife, and lost to other natural processes.

In 1982, the last year of the fertilization of native rangeland grazing study, the unfertilized and fertilized pasture herbage weight was sampled by clipping to ground level the vegetation from inside and outside exclosure cages during five monthly periods throughout the growing season. The plant material was separated into five categories: warm season grasses, cool season grasses, sedges, introduced grasses, and forbs.

Costs and returns for grazing trial I and grazing trial II were determined from total pasture and forage costs and value of steer and calf weight gain during the grazing periods and followed the methods developed by Manske et al. (2007). Nitrogen fertilizer costs were the actual costs paid during 1982-1985 with ammonium nitrate at $0.24 per pound of nitrogen. Land rent value for grazinglands in North Dakota taken from the North Dakota Agricultural Statistics Service, 1998, was the mean rent in fifteen western counties at $8.76 per acre. Differences between means from treatment years were analyzed by a standard paired-plot t-test (Mosteller and Rourke 1973).

Results

Grazing Trial I (1972-1976)

The precipitation during the growing seasons of 1972 to 1976 was normal or greater than normal (table 1). During 1972, 1973, 1974, 1975, and 1976, 18.57 inches (137.05% of LTM), 11.83 inches (87.31% of LTM), 12.45 inches (91.88% of LTM), 15.26 inches (112.62% of LTM), and 10.84 inches (80.00% of LTM) of precipitation were received, respectively. May, August, and October of 1972 were wet months and each received 217.52%, 167.63%, and 164.21% of LTM precipitation, respectively. April, June, and July received normal precipitation at 88.81%, 120.85%, and 122.52% of LTM, respectively. September was a dry month and received 55.64% of LTM precipitation . Perennial plants were under water stress conditions during September, 1972 (Manske 2009). April and September of 1973 were wet months and each received 224.48% and 167.67% of LTM precipitation, respectively. June received normal precipitation at 85.63% of LTM. May and October were dry months and received 55.56% and 70.53% of LTM precipitation, respectively. July and August were very dry months and received 40.99% and 27.17% of LTM precipitation, respectively. Perennial plants were under water stress conditions during July, August, and October, 1973 (Manske 2009). April and May of 1974 were wet months and each received 197.20% and 177.35% of LTM precipitation, respectively. June, July, August, and October were dry months and received 56.34%, 67.57%, 52.02%, and 54.74% of LTM precipitation, respectively. September was a very dry month and received 42.11% of LTM precipitation. Perennial plants were under water stress conditions during July, August, September, and October, 1974 (Manske 2009). April, May, and October of 1975 were wet months and each received 297.20%, 142.74%, and 149.47% of LTM precipitation, respectively. June received normal precipitation at 120.28% of LTM. September was a dry month and received 60.15% of LTM precipitation. July and August were very dry months and received 28.83% and 31.21% of LTM precipitation, respectively. Perennial plants were under water stress conditions during July, August, and September, 1975 (Manske 2009). April and September of 1976 were wet months and each received 147.55% and 133.08% of LTM precipitation, respectively. June received normal precipitation at 105.35% of LTM. May and October were dry months and received 60.68% and 68.42% of LTM precipitation, respectively. July and August were very dry months and received 33.78% and 23.12% of LTM precipitation, respectively. Perennial plants were under water stress conditions during July and August, 1976 (Manske 2009).

The native rangeland and fertilized rangeland pastures of steer grazing trial I were grazed during one period for an average of 59 days from 30 June to 27 August. The grazing periods varied from 46 to 71 days in length and occurred between 21 June and 3 September. The pastures were grazed by 12 yearling steers of which 50% were Hereford and 50% were Angus-Hereford. The mean stocking rate on the native rangeland pasture was 1.08 acres per animal unit equivalent month (AUEM) with a range from 0.88 acres to 1.24 acres per AUEM. The mean stocking rate on the fertilized pasture was 0.73 acres per AUEM with a range from 0.60 acres to 0.84 acres per AUEM. The stocking rate on the fertilized pasture was 48.9% greater than, and significantly different ($P<0.05$) from, the stocking rate on the native rangeland pasture (table 2).

Post study determination of hindsight stocking rates was made from measured standing herbage biomass and animal unit equivalent of the June steer live weight (table 3). The determined stocking rate on the native rangeland pasture was 0.92 acres per AUEM and was not significantly different ($P<0.05$) from the stocking rate used. The determined stocking rate on the fertilized pasture was 0.64 acres per AUEM and was not significantly different ($P<0.05$) from the stocking rate used (tables 2 and 3). The determined stocking rate on the fertilized pasture was 43.8% greater than, but not significantly different ($P<0.05$) from, the determined stocking rate on the native rangeland pasture (table 3).

Steer performance on the native rangeland and fertilized pastures managed with one grazing period on grazing trial I were compared using gain per head, gain per day, and gain per acre data (table 4). Steer gain per head on the fertilized pasture was 5.6% greater than, but not significantly different ($P<0.05$) from, steer gain per head on the native rangeland pasture. Steer gain per day on the fertilized pasture was 7.9% greater than, but not significantly different ($P<0.05$) from, steer gain per day on the native rangeland pasture. Steer gain per acre on the fertilized pastures was 58.6% greater than, but not significantly different (P<0.05) from, steer gain per acre on the native rangeland pasture (table 4).

Early growing season steer daily gain on the fertilized pasture was greater during mid June to late July than steer daily gain on the native rangeland pasture. Late growing season steer daily gain on the native rangeland pasture was greater during early August to mid September than steer daily gain on the fertilized pasture (table 5).

Aboveground herbage biomass on the native rangeland and fertilized pastures managed with one grazing period on grazing trial I was compared from ungrazed and grazed total herbage production sampled at the end of the grazing period, and by the quantity of forage used per acre during the grazing period (table 6). Ungrazed herbage biomass at the end of the grazing period on the fertilized pasture was 49.8% greater than, but not significantly different (P<0.05) from, the ungrazed herbage biomass at the end of the grazing period on the native rangeland pasture. Grazed herbage biomass remaining at the end of the grazing period on the fertilized pasture was 40.7% greater than, but not significantly different (P<0.05) from, the grazed herbage biomass remaining at the end of the grazing period on the native rangeland pasture. The forage used during the grazing period on the fertilized pasture was 64.7% greater than, but not significantly different (P<0.05) from, the quantity of forage used per acre on the native rangeland pasture (table 6).

Costs and returns on the native rangeland and fertilized pastures on grazing trial I were compared using pasture costs and value of steer weight gain (table 7). On the native rangeland pasture managed with one grazing period, a steer required 2.04 acres per period, at a cost of $17.87 for the 59-day period, or $0.30 per day. Steer weight gain was 1.40 lbs per day and 56.18 lbs per acre; accumulated weight gain was 85.70 lbs. When steer accumulated weight was assumed to have a value of $0.70 per pound, the gross return was $59.99 per steer, and the net returns after pasture costs were $42.12 per steer and $20.80 per acre. The cost of steer weight gain was $0.26 per pound. On the fertilized pasture managed with one grazing period, a steer required 1.38 acres per period, at a cost of $29.30 for the 59-day period, or $0.50 per day. Steer weight gain was 1.51 lbs per day and 89.10 lbs per acre; accumulated weight gain was 90.50 lbs. When steer accumulated weight was assumed to have a value of $0.70 per pound, the gross return was $63.35 per steer, and the net returns after pasture costs were $34.05 per steer and $25.10 per acre. The cost of steer weight gain was $0.40 per pound (table 7).

Pasture costs per grazing period on the fertilized pasture was 64.0% greater than, and significantly different (P<0.05) from, pasture costs on the native rangeland pasture. Value of steer weight gain on the fertilized pasture was 5.6% greater than, but not significantly different (P<0.05) from, steer weight gain value on the native rangeland pasture. Net returns per steer on the native rangeland pasture was 23.7% greater than, but not significantly different (P<0.05) from, net returns per steer on the fertilized pasture. Net returns per acre on the fertilized pasture was 20.7% greater than, but not significantly different (P<0.05) from, net returns per acre on the native rangeland pasture. Cost per pound of steer accumulated weight on the fertilized pasture was 53.8% greater than, but not significantly different (P<0.05) from, cost per pound of steer accumulated weight on the native rangeland pasture (table 7).

Grazing Trial II (1978-1982)

The precipitation during the growing seasons of 1978 to 1982 was normal or greater than normal (table 8). During 1978, 1979, 1980, 1981, and 1982, 15.17 inches (111.96% of LTM), 11.12 inches (82.07% of LTM), 10.73 inches (79.19% of LTM), 14.27 inches (105.31% of LTM), and 22.53 inches (166.27% of LTM) of precipitation were received, respectively. April, May, and September of 1978 were wet months and each received 126.57%, 170.51%, and 192.48% of LTM precipitation, respectively. July and August received normal precipitation at 108.56% and 116.18% of LTM, respectively. June was a dry month and received 59.15% of LTM precipitation. October was a very dry month and received 30.53% of LTM precipitation. Perennial plants were under water stress conditions during October, 1978 (Manske 2009). August of 1979 was a wet month and received 127.75% of LTM precipitation. April, June, July, and September received normal precipitation at 89.51%, 86.20%, 100.00%, and 95.49% of LTM, respectively. May and October were very dry months and received 33.89% and 17.89% of LTM precipitation, respectively. Perennial plants were under water stress conditions during October, 1979 (Manske 2009). August and October of 1980 were wet months and each received 191.33% and 253.68% of LTM precipitation, respectively. June received normal precipitation at 75.21% of LTM. July and September were dry months and received 64.41% and 57.14% of LTM precipitation, respectively. April and May were very dry months and received 2.10%

and 5.13% of LTM precipitation, respectively. The April through July precipitation received in 1980 was 44.5% of the LTM precipitation causing drought conditions. Perennial plants were under water stress conditions during April, May, July, and September, 1980 (Manske 2009). August and September of 1981 were wet months and each received 234.10% and 206.77% of LTM precipitation, respectively. June received normal precipitation at 104.51% of LTM. May and July were dry months and received 55.56% and 70.72% of LTM precipitation, respectively. April and October were very dry months and received 46.15% and 24.21% of LTM precipitation, respectively. Perennial plants were under water stress conditions during July and October, 1981 (Manske 2009). April, May, August, September, and October of 1982 were wet months and each received 129.37%, 184.62%, 152.02%, 133.08%, and 685.26% of LTM precipitation, respectively. June and July received normal precipitation at 96.62% and 90.99% of LTM, respectively. Perennial plants did not experience water stress conditions during 1982 (Manske 2009).

The native rangeland pasture of cow-calf grazing trial II was grazed during one period for an average of 45 days from 21 June to 5 August. The grazing periods varied from 28 to 60 days in length and occurred between 19 June and 20 August. The fertilized rangeland pasture of cow-calf grazing trial II was grazed during one period for an average of 51 days from 25 June to 15 August. The grazing periods varied from 28 to 67 days in length and occurred between 17 June and 15 September. The pastures were grazed by 10 commercial crossbred cow-calf pairs. The mean stocking rate on the native rangeland pasture was 1.38 acres per AUEM with a range from 0.91 acres to 1.90 acres per AUEM. The mean stocking rate on the fertilized pasture was 0.82 acres per AUEM with a range from 0.52 acres to 1.25 acres per AUEM. The stocking rate on the fertilized pasture was 67.1% greater than, but not significantly different ($P<0.05$) from, the stocking rate on the native rangeland pasture (table 9).

Post study determination of hindsight stocking rates was made from measured standing herbage biomass and animal unit equivalent of the June cow live weight (table 10). The determined stocking rate on the native rangeland pasture was 1.93 acres per AUEM which was 39.9% lower than, but not significantly different ($P<0.05$) from, the mean stocking rate used. The determined stocking rate on the fertilized pasture was 1.25 acres per AUEM which was 52.4% lower than, but not significantly different ($P<0.05$) from, the mean stocking rate used (tables 9 and 10). The determined stocking rate on the fertilized pasture was 54.4% greater than, but not significantly different ($P<0.05$) from, the determined stocking rate on the native rangeland pasture (table 10).

During the 1980 drought growing season of grazing trial II, the pastures were managed with one grazing period and the stocking rates were reduced greatly. The stocking rate used during drought conditions on the native rangeland pasture was 4.58 acres per AUEM, which was 231.9% lower than the mean stocking rate used during nondrought growing seasons. The determined stocking rate that could have been used during drought conditions on the native rangeland pasture was 2.64 acres per AUEM, which was 91.3% lower than the mean stocking rate used during nondrought growing seasons. The stocking rate used during drought conditions on the fertilized pasture was 3.12 acres per AUEM, which was 280.5% lower than the mean stocking rate used during nondrought growing seasons. The determined stocking rate that could have been used during drought conditions on the fertilized pasture was 2.42 acres per AUEM, which was 195.1% lower than the mean stocking rate used during nondrought growing seasons (tables 9 and 10).

Cow and calf performance on the native rangeland and fertilized pastures managed with one grazing period on grazing trial II were compared using gain per head, gain per day, and gain per acre data (tables 11, 12, and 13). Cow gain per head on the native rangeland pasture was 105.6% greater than, but not significantly different ($P<0.05$) from, cow gain per head on the fertilized pasture. Cow gain per day on the native rangeland pasture was 104.1% greater than, but not significantly different ($P<0.05$) from, cow gain per day on the fertilized pasture. Cow gain per acre on the native rangeland pasture was 109.4% greater than, but not significantly different ($P<0.05$) from, cow gain per acre on the fertilized pasture (tables 11 and 13). Calf gain per head on the native rangeland pasture was 8.4% greater than, but not significantly different ($P<0.05$) from, calf gain per head on the fertilized pasture. Calf gain per day on the native rangeland pasture was 25.2% greater than, but not significantly different ($P<0.05$) from, calf gain per day on the fertilized pasture. Calf gain per acre on the fertilized pasture was 36.8% greater than, but not significantly different ($P<0.05$) from, calf gain per acre on the native rangeland pasture (tables 12 and 13).

Cow and calf performance during the 1980 drought growing season on the native rangeland and fertilized pastures managed with one grazing period on grazing trial II were compared using gain per head, gain per day, and gain per acre data (tables 11, 12, and 13). Cow gain per head on the native rangeland pasture was 1528.6% greater than cow gain per head on the fertilized pasture. Cow gain per day on the native rangeland pasture was 1675.0% greater than cow gain per day on the fertilized pasture. Cow gain per acre on the native rangeland pasture was 2259.3% greater than cow gain per acre on the fertilized pasture (tables 11 and 13). Calf gain per head on the native rangeland pasture was 21.1% greater than calf gain per head on the fertilized pasture. Calf gain per day on the native rangeland pasture was 21.1% greater than calf gain per day on the fertilized pasture. Calf gain per acre on the fertilized pasture was 23.9% greater than calf gain per acre on the native rangeland pasture (tables 12 and 13).

Early growing season cow daily gain on the fertilized pasture was greater during early to mid July than cow daily gain on the native rangeland pasture. Late growing season cow daily gain on the native rangeland pasture was greater during early to late August than cow daily gain on the fertilized pasture. Calf daily gain on the native rangeland pasture was greater during mid to late June and during mid July to late August than calf daily gain on the fertilized pasture. Calf daily gain on the fertilized pasture was not greater during any biweekly period than calf daily gain on the native rangeland pasture (table 14).

Cow and calf daily gain during the 1980 drought growing season on the native rangeland pasture was greater during early and late July than cow and calf daily gain on the fertilized pasture (table 14).

Aboveground herbage biomass on the native rangeland and fertilized pastures managed with one grazing period on grazing trial II was compared from pregrazed total herbage biomass sampled at the start of the grazing period, ungrazed and grazed total herbage biomass sampled at the end of the grazing period, and by the quantity of forage used per acre during the grazing period (table 15). Pregrazed herbage biomass on the fertilized pasture was 49.6% greater than, but not significantly different ($P<0.05$) from, pregrazed herbage biomass on the native rangeland pasture. Ungrazed herbage biomass at the end of the grazing period on the fertilized pasture was 60.9% greater than, but not significantly different ($P<0.05$) from, ungrazed herbage biomass at the end of the grazing period on the native rangeland pasture. Grazed herbage biomass remaining at the end of the grazing period on the fertilized pasture was 29.8% greater than, but not significantly different ($P<0.05$) from, grazed herbage biomass remaining at the end of the grazing period on the native rangeland pasture. The forage used during the grazing period on the fertilized pasture was 113.4% greater than, but not significantly different ($P<0.05$) from, the quantity of forage used per acre on the native rangeland pasture (table 15).

Aboveground herbage biomass during the 1980 drought growing season on the native rangeland and fertilized pastures managed with one grazing period on grazing trial II were compared from pregrazed total herbage biomass sampled at the start of the grazing period, ungrazed and grazed total herbage biomass sampled at the end of the grazing period, and by the quantity of forage used per acre during the grazing period (table 15). Pregrazed herbage biomass on the fertilized pasture was 5.5% greater than pregrazed herbage biomass on the native rangeland pasture. Ungrazed herbage biomass at the end of the grazing period on the fertilized pasture was 8.7% greater than ungrazed herbage biomass at the end of the grazing period on the native rangeland pasture. Grazed herbage biomass remaining at the end of the grazing period on the native rangeland pasture was 29.0% greater than grazed herbage biomass remaining at the end of the grazing period on the fertilized pasture. The forage used during the grazing period on the fertilized pasture was 142.6% greater than the quantity of forage used per acre on the native rangeland pasture (table 15).

Costs and returns on the native rangeland and fertilized pastures on grazing trial II were compared using pasture costs and value of calf weight gain (table 16). On the native rangeland pasture managed with one grazing period, a cow and calf required 1.83 acres per period, at a cost of $16.01 for the 45-day period, or $0.36 per day. Calf weight gain was 1.89 lbs per day and 44.93 lbs per acre; accumulated weight gain was 83.98 lbs. When calf accumulated weight was assumed to have a value of $0.70 per pound, the gross return was $58.78 per calf, and the net returns after pasture costs were $42.77 per cow-calf pair and $23.74 per acre. The cost of calf weight gain was $0.21 per pound. On the fertilized pasture managed with one grazing period, a cow and calf required 1.23 acres per period, at a cost of $26.15 for the 51-day period, or $0.51 per day. Calf weight gain was 1.51 lbs per day and 61.45 lbs per acre; accumulated weight gain was 77.45 lbs. When calf accumulated weight was assumed to have a value of $0.70 per pound, the gross return was $54.22 per calf, and the net returns after pasture costs were $28.06 per cow-calf pair and $23.21 per acre. The cost of calf weight gain was $0.39 per pound (table 16).

Pasture costs per grazing period on the fertilized pasture was 63.3% greater than, and significantly different ($P<0.05$) from, pasture costs on the native rangeland pasture. Value of calf weight gain on the native rangeland pasture was 8.4% greater than, but not significantly different ($P<0.05$) from, calf weight gain value on the fertilized pasture. Net returns per cow-calf pair on the native rangeland pasture was 52.4% greater than, but not significantly different ($P<0.05$) from, net returns per cow-calf pair on the fertilized pasture. Net returns per acre on the native rangeland pasture was 2.3% greater than, but not significantly different ($P<0.05$) from, net returns per acre on the fertilized pasture. Cost per pound of calf accumulated weight on the fertilized pasture was 85.7% greater than, but not significantly different ($P<0.05$) from, cost per pound of calf accumulated weight on the native rangeland pasture (table 16).

Costs and returns during the 1980 drought growing season on the native rangeland and fertilized pastures on grazing trial II were compared using pasture costs and value of calf weight gain (table 16). On the native rangeland pasture managed with one grazing period, a cow and calf required 2.38 acres per period, at a cost of $20.85 for the 16-day period, or $1.30 per day. Calf weight gain was 2.01 lbs per day and 12.48 lbs per acre; accumulated weight gain was 32.10 lbs. When calf accumulated weight was assumed to have a value of $0.70 per pound, the gross return was $22.47 per calf, and the net returns after pasture costs were $1.62 per cow-calf pair and $0.68 per acre. The cost of calf weight gain was $0.65 per pound. On the fertilized pasture managed with one grazing period, a cow and calf required 1.62 acres per period, at a cost of $34.44 for the 16-day period, or $2.15 per day. Calf weight gain was 1.66 lbs per day and 15.46 lbs per acre; accumulated weight gain was 26.50 lbs. When calf accumulated weight was assumed to have a value of $0.70 per pound, the gross return was $18.55 per calf, and the net returns after pasture costs were a loss of $15.89 per cow-calf pair and a loss of $9.81 per acre. The cost of calf weight gain was $1.30 per pound (table 16).

Pasture costs per grazing period during the 1980 drought growing season on the fertilized pasture was 65.2% greater than pasture costs on the native rangeland pasture. Value of calf weight gain on the native rangeland pasture was 21.1% greater than calf weight gain value on the fertilized pasture. Net returns per cow-calf pair on the native rangeland pasture was 1080.9% greater than net returns per cow-calf pair on the fertilized pasture. Net returns per acre on the native rangeland pasture was 1542.6% greater than net returns per acre on the fertilized pasture. Cost per pound of calf accumulated weight on the fertilized pasture was 100.0% greater than cost per pound of calf accumulated weight on the native rangeland pasture (table 16).

Grazing fertilized native rangeland pastures with steers or with cow-calf pairs did not capture much wealth from the land natural resources because the animal performance responded to the quality of the vegetation. Fertilized plants produced herbage weight at a rapid growth rate over a short period of time that occurred during the early portion of the growing season. Unfertilized plants produced herbage weight at a slower growth rate over a long period of time that continued later into the growing season.

Steers on the fertilized pasture had greater daily gain during mid June to late July than steers on the unfertilized pasture. Steers on the unfertilized pasture had greater daily gain during early August to mid September than steers on the fertilized pasture (table 5).

Cows on the fertilized pasture had similar daily gain to cows on the unfertilized pasture during mid June to mid July. Cows on the fertilized pasture started to lose weight in mid July or early August and lost more weight during the latter portion of the grazing period than they gained during the early portion. Cows on the unfertilized pasture gained weight during mid June to mid August and lost a small amount of weight towards the end of the grazing period. Cows on the unfertilized pasture gained more weight per head than the cows on the fertilized pasture. During drought conditions, cows on the fertilized pasture lost weight and cows on the unfertilized pasture gained weight (table 14).

Calves on the fertilized pasture had similar daily gain to the calves on the unfertilized pasture during mid June to mid July. Calves on the fertilized pasture had lower daily gain after mid July than calves on the unfertilized pasture. Calves on the unfertilized pasture gained more weight per head than the calves on the fertilized pasture. During drought conditions, calves on the unfertilized pasture had greater daily gain than calves on the fertilized pasture (table 14).

Nitrogen fertilization of native rangeland increased the crude protein content of aboveground plant material during early growth stages. Most grass species attained maximum crude protein content in mid May. Crude protein content decreased with advancement of plant maturity. A significant decrease in crude protein was evident on the fertilized treatments during mid June to early July and was not different than that on the unfertilized treatments in early August (Goetz 1975). An accelerated rate of decline progressed rapidly on the fertilized treatments and the crude protein content dropped below livestock requirements earlier in the growing season than the crude protein content of grasses on the unfertilized treatments (Whitman 1975).

The growing season of 1982 was the eleventh year with an application of 50 lbs N/ac on the fertilized native rangeland pasture used during the steer grazing trial I (1972-1976) and the cow-calf grazing trial II (1978-1982). The effects from 11 years of fertilization on native rangeland vegetation were determined from herbage weight clipped during 5 monthly periodic dates and separated into 5 categories. Percent herbage growth and senescence of plants during the monthly periods of the growing season were affected by the fertilizer treatment. Fertilized plants have greater herbage growth during a short period in the early portion of the growing season. Unfertilized plants have active growth during about double the length of time of the fertilized plant growth period and have greater herbage growth during the latter portion. Greater total percent herbage senescence occurred during the latter portion of the growing season on the fertilized pasture than on the unfertilized pasture (table 18).

Cool season grasses and upland sedges on the unfertilized and fertilized pastures gained herbage weight during May, June, and July, and then lost aboveground biomass during August and September (table 17). Percent herbage growth of cool season grasses and upland sedges was greater during May and June on the fertilized pasture and was greater during July on the unfertilized pasture. Total percent cool season grass herbage senescence was greater on the fertilized pasture during August and September (table 18 and figure 1).

Warm season grasses on the unfertilized pasture gained herbage weight during May, June, July, and August, and then lost aboveground biomass during September. Warm season grasses on the fertilized pasture gained herbage weight during May, June, and July, and lost aboveground biomass during August and September (table 17). Percent herbage growth of warm season grasses was greater during May and July on the fertilized pasture and was greater during June and August on the unfertilized pasture. Total percent warm season grass herbage senescence was greater on the unfertilized pasture during September (table 18 and figure 2).

Total native grasses on the unfertilized pasture gained herbage weight during May, June, July, and August, and then lost aboveground biomass during September. Total native grasses on the fertilized pasture gained herbage weight during May, June, and July, and lost aboveground biomass during August and September (table 17). Percent herbage growth of total native grasses was greater during May and June on the fertilized pasture and was greater during July and August on the unfertilized pasture. Total percent herbage senescence of total native grasses was greater on the fertilized pasture during August and September (table 18 and figure 3).

Herbage growth of introduced and domesticated grasses occurred during June and July and herbage senescence occurred during August and September on the fertilized pasture and did not occur on the unfertilized pasture (table 18 and figure 4).

Forbs on the unfertilized pasture gained herbage weight during May, June, and July, and then lost aboveground biomass during August and September. Forbs on the fertilized pasture gained herbage weight during May, June, and July, and August, and lost aboveground biomass during September (table 17). Percent herbage growth of forbs was greater during May and June on the unfertilized pasture and was greater during July and August on the fertilized pasture. Almost all of the forb herbage weight on the fertilized pasture was fringed sage. Total percent forb herbage senescence was greater on the fertilized pasture during September (table 18 and figure 5).

Total herbage yield on the unfertilized pasture gained herbage weight during May, June, July, and August, and then lost aboveground biomass during September. Total herbage yield on the fertilized pasture gained herbage weight during May, June, and July, and lost aboveground biomass during August and September (table 17). Percent herbage growth of total herbage yield was greater during May and June on the fertilized pasture and was greater during July and August on the unfertilized pasture. Total percent herbage senescence of total herbage yield was greater on the fertilized pasture during August and September (table 18 and figure 6).

Discussion

Nitrogen fertilization of native rangeland does result in greater production of herbage weight, primarily mid cool season grasses, and a greater crude protein content during early growth stages. These “improvements” in the vegetation, however, do not translate into improved livestock performance throughout the grazing season.

Fertilized rangeland plants have a short period of rapid growth in leaf height and herbage weight during May and June. This rapid increase period is followed by a period of accelerated senescence, with a rapid decline in crude protein content, an increasing rate of leaf drying, and a high rate of loss in aboveground herbage weight during July, August, and September.

Livestock performance responds to the conditions of the vegetation. Yearling steers grazing fertilized rangeland have a high rate of gain during mid June to late July and a poor rate of gain after early August. Cows grazing fertilized rangeland have a good rate of gain during mid June to mid July and have a high loss of weight after mid July or early August. Calves with cows on fertilized rangeland have a good rate of gain during mid June to mid July, have reduced gains during mid July to early August, and have poor gains after early August.

Unfertilized rangeland plants have an active growth period for about 70% of the growing season, which is about double the length of the fertilized plant active growth period. Unfertilized plant growth in leaf height and herbage weight during May and June is slower than the growth rate of fertilized plants. Unfertilized plant growth during July and August is greater than the growth rate of fertilized plants. After mid August, unfertilized rangeland plants have a period of senescence that usually progresses at a slower rate than senescence of fertilized rangeland plants.

Yearling steers grazing unfertilized rangeland have a good rate of gain during mid June to mid September. After early August, the rate of gain by steers on unfertilized rangeland is greater than the rate of gain by steers on fertilized rangeland. Cows grazing unfertilized rangeland have a good rate of gain during mid June to mid August, and after mid August, cows lose a small amount of weight. Calves with cows on unfertilized rangeland have a good rate of gain during mid June to mid August and have a slightly reduced rate of gain after mid August.

Fertilization of native rangeland does produce a short period of rapid plant growth and greater herbage weight, however, fertilization of rangeland does not produce greater livestock performance and does not result in the capture of greater wealth from the native rangeland natural resources.

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Table 1. Precipitation in inches for growing-season months and the annual total precipitation for 1972-1976, Dickinson, North Dakota.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Growing Season	Annual Total
Long-term mean 1892-2007	1.43	2.34	3.55	2.22	1.73	1.33	0.95	13.55	16.00
1972	1.27	5.09	4.29	2.72	2.90	0.74	1.56	18.57	20.76
% of LTM	88.81	217.52	120.85	122.52	167.63	55.64	164.21	137.05	129.75
1973	3.21	1.30	3.04	0.91	0.47	2.23	0.67	11.83	13.53
% of LTM	224.48	55.56	85.63	40.99	27.17	167.67	70.53	87.31	84.56
1974	2.82	4.15	2.00	1.50	0.90	0.56	0.52	12.45	14.15
% of LTM	197.20	177.35	56.34	67.57	52.02	42.11	54.74	91.88	88.44
1975	4.25	3.34	4.27	0.64	0.54	0.80	1.42	15.26	17.71
% of LTM	297.20	142.74	120.28	28.83	31.21	60.15	149.47	112.62	110.69
1976	2.11	1.42	3.74	0.75	0.40	1.77	0.65	10.84	12.68
% of LTM	147.55	60.68	105.35	33.78	23.12	133.08	68.42	80.00	79.25
1972-1976	2.73	3.06	3.47	1.30	1.04	1.22	0.96	13.78	15.77
% of LTM	191.05	130.77	97.75	58.56	60.12	91.73	101.05	101.70	98.56

Table 2. Mean stocking rates for steers on native rangeland treatments, 1972-1976.

Treatments	Grazing Period Dates	Days in Period	Months in Period	Number of Steers	Number of AUEM	AUEM per Acre	Acres per AUEM
One grazing period 1972-1976							
Unfertilized	30 Jun-27Aug	59	1.92	12	16.95a	0.94a	1.08a
Fertilized	30 Jun-27 Aug	59	1.92	12	16.77a	1.40b	0.73b

Means in the same column and followed by the same letter are not significantly different (P<0.05).

Table 3. Stocking rates for steers determined from standing herbage biomass and June animal unit equivalent (AUE), 1972-1976.

Treatments	Mean Standing Herbage (lb/ac)	Mean Forage Available (lb/ac)	June AUE	Forage per Day (lbs)	Forage per Month (lbs)	AUEM per Acre	Acres per AUEM
One grazing period 1972-1976							
Unfertilized	2676.60a	669.15a	0.7657a	19.91a	607.17a	1.10a	0.92a
Fertilized	4010.00a	1002.50a	0.7574a	19.69a	600.65a	1.68a	0.64a

Means in the same column and followed by the same letter are not significantly different (P<0.05).

Table 4. Mean steer performance on native rangeland treatments, 1972-1976.

Treatments	Mean Steer initial weight (lbs)	Mean Steer final weight (lbs)	Mean Steer Gain per Head (lbs)	Mean Steer Gain per Day (lbs)	Mean Steer Gain per Acre (lbs)
One grazing period 1972-1976					
Unfertilized	700.92a	786.62a	85.70a	1.40a	56.18a
Fertilized	690.86a	781.36a	90.50a	1.51a	89.10a

Means in the same column and followed by the same letter are not significantly different (P<0.05).

Table 5. Biweekly average daily gain for steers on native rangeland treatments, 1972-1976.

Treatments	1-15 Jun	16-30 Jun	1-15 Jul	16-31 Jul	1-15 Aug	16-31 Aug	1-15 Sep	Mean gain per Day
One grazing period 1972-1976								
Unfertilized		1.28	1.51	1.56	1.40	1.49	1.58	1.40
Fertilized		1.75	1.78	1.67	1.28	1.24	1.31	1.51

Table 6. Herbage biomass production and forage utilization on native rangeland treatments, 1972-1976.

Treatments	Aboveground Herbage Biomass Pregrazed (lbs/acre)	Ungrazed (lbs/acre)	Grazed (lbs/acre)	Forage Utilized (lbs/acre)	Percent Utilization (%)	Forage per steer (lbs/day)
One grazing period 1972-1976						
Unfertilized		2676.60a	1660.60a	1016.00a	38.21a	27.26a
Fertilized		4010.00a	2337.20a	1672.80a	42.07a	29.48a

Means in the same column and followed by the same letter are not significantly different (P<0.05).

Table 7. Costs and returns after pasture costs for steers on native rangeland treatments, 1972-1976.

Treatments	Land Area per Period (acres)	Production Cost per Acre ($)	Cost per Period ($)	Steer Weight Gain per Period (lbs)	Steer Weight Value @ $0.70/lb ($)	Net Return per Steer ($)	Net Return per Acre ($)	Cost per Pound Steer Gain ($)
One grazing period 1972-1976								
Unfertilized	2.04a	8.76	17.87a	85.70a	59.99a	42.12a	20.80a	0.26a
Fertilized	1.38b	21.26	29.30b	90.50a	63.35a	34.05a	25.10a	0.40a

Means in the same column and followed by the same letter are not significantly different (P<0.05).

Table 8. Precipitation in inches for growing season months and the annual total precipitation for 1978-1982, Dickinson, North Dakota.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Growing Season	Annual Total
Long-term mean 1892-2007	1.43	2.34	3.55	2.22	1.73	1.33	0.95	13.55	16.00
1978	1.81	3.99	2.10	2.41	2.01	2.56	0.29	15.17	17.63
% of LTM	126.57	170.51	59.15	108.56	116.18	192.48	30.53	111.96	110.19
1979	1.28	0.91	3.06	2.22	2.21	1.27	0.17	11.12	12.81
% of LTM	89.51	38.89	86.20	100.00	127.75	95.49	17.89	82.07	80.06
1980	0.03	0.12	2.67	1.43	3.31	0.76	2.41	10.73	12.58
% of LTM	2.10	5.13	75.21	64.41	191.33	57.14	253.68	79.19	78.63
1981	0.66	1.30	3.71	1.57	4.05	2.75	0.23	14.27	15.76
% of LTM	46.15	55.56	104.51	70.72	234.10	206.77	24.21	105.31	98.50
1982	1.85	4.32	3.43	2.02	2.63	1.77	6.51	22.53	26.58
% of LTM	129.37	184.62	96.62	90.99	152.02	133.08	685.26	166.27	166.13
1978-1982	1.13	2.13	2.99	1.93	2.84	1.82	1.92	14.76	17.07
% of LTM	79.02	91.03	84.23	86.94	164.16	136.84	202.11	108.93	106.69

Table 9. Mean stocking rates for cow-calf pairs on native rangeland treatments, 1978-1982.

Treatments	Grazing Period Dates	Days in Period	Months in Period	Number of Cow-Calf Pairs	Number of AUEM	AUEM per Acre	Acres per AUEM
One grazing period 1978-1979, 1981-1982							
Unfertilized	21 Jun-5Aug	45a	1.47a	10a	14.61a	0.82a	1.38a
Fertilized	25 Jun-15 Aug	51a	1.68a	10a	16.49a	1.37a	0.82a
Drought Season 1980							
Unfertilized	7 Jul-23 Jul	16	0.52	7	3.93	0.22	4.58
Fertilized	7 Jul-23 Jul	16	0.52	7	3.84	0.32	3.12

Means in the same column and followed by the same letter are not significantly different (P<0.05).

Table 10. Stocking rates for cow-calf pairs determined from monthly standing herbage biomass and June animal unit equivalent (AUE), 1978-1982.

Treatments	Mean Monthly Standing Herbage (lb/ac)	Mean Forage Available (lb/ac)	June AUE	Forage per Day (lbs)	Forage per Month (lbs)	AUEM per Acre	Acres per AUEM
One grazing period 1978-1979, 1981-1982							
Unfertilized	1718.48a	429.62a	1.0433a	27.13a	827.36a	0.52a	1.93a
Fertilized	2824.41a	706.10a	1.0354a	26.92a	821.05a	0.86a	1.25a
Drought Season 1980							
Unfertilized	1296.45	324.11	1.0799	28.08	856.36	0.38	2.64
Fertilized	1386.85	346.71	1.0557	27.45	837.17	0.41	2.42

Means in the same column and followed by the same letter are not significantly different (P<0.05).

Table 11. Mean cow performance on native rangeland treatments, 1978-1982.

Treatments	Mean Cow initial weight (lbs)	Mean Cow final weight (lbs)	Mean Cow Gain per Head (lbs)	Mean Cow Gain per Day (lbs)	Mean Cow Gain per Acre (lbs)
One grazing period 1978-1979, 1981-1982					
Unfertilized	1058.53a	1087.75a	29.23a	0.74a	15.91a
Fertilized	1047.63a	1045.98a	-1.65a	-0.03a	-1.50a
Drought Season 1980					
Unfertilized	1107.90	1108.60	0.70	0.04	0.27
Fertilized	1075.00	1065.00	-10.00	-0.63	-5.83

Means in the same column and followed by the same letter are not significantly different (P<0.05).

Table 12. Mean calf performance on native rangeland treatments, 1978-1982.

Treatments	Mean Calf initial weight (lbs)	Mean Calf final weight (lbs)	Mean Calf Gain per Head (lbs)	Mean Calf Gain per Day (lbs)	Mean Calf Gain per Acre (lbs)
One grazing period 1978-1979, 1981-1982					
Unfertilized	217.60a	301.58a	83.98a	1.89a	44.93a
Fertilized	234.20a	311.65a	77.45a	1.51a	61.45a
Drought Season 1980					
Unfertilized	287.90	320.00	32.10	2.01	12.48
Fertilized	286.40	312.90	26.50	1.66	15.46

Means in the same column and followed by the same letter are not significantly different (P<0.05).

Table 13. Mean cow and calf performance on native rangeland treatments, 1978-1982.

	COW			CALF		
Treatments	Gain per Head (lbs)	Gain per Day (lbs)	Gain per Acre (lbs)	Gain per Head (lbs)	Gain per Day (lbs)	Gain per Acre (lbs)
One grazing period 1978-1979, 1981-1982						
Unfertilized	29.23a	0.74a	15.91a	83.98a	1.89a	44.93a
Fertilized	-1.65a	-0.03a	-1.50a	77.45a	1.51a	61.45a
Drought Season 1980						
Unfertilized	0.70	0.04	0.27	32.10	2.01	12.48
Fertilized	-10.00	-0.63	-5.83	26.50	1.65	15.46

Means in the same column and followed by the same letter are not significantly different (P<0.05).

Table 14. Biweekly average daily gain for cow-calf pairs on native rangeland treatments, 1978-1982.

Treatments	1-15 Jun	16-30 Jun	1-15 Jul	16-31 Jul	1-15 Aug	16-31 Aug	1-15 Sep	Mean gain per Day
One grazing period 1978-1979, 1981-1982								
Cow								
Unfertilized		1.23	1.23	0.22	0.25	-0.25		0.74
Fertilized		1.23	1.27	0.25	-0.88	-1.79	-2.52	-0.03
Calf								
Unfertilized		1.91	1.91	1.89	1.90	1.77		1.89
Fertilized		1.79	1.91	1.72	1.42	0.96	0.46	1.51
Drought Season 1980								
Cow								
Unfertilized			0.04	0.04				0.04
Fertilized			-0.63	-0.63				-0.63
Calf								
Unfertilized			2.01	2.01				2.01
Fertilized			1.65	1.65				1.65

Table 15. Herbage biomass production and forage utilization on native rangeland treatments, 1978-1982.

Treatments	Aboveground Herbage Biomass Pregrazed (lbs/acre)	Ungrazed (lbs/acre)	Grazed lbs/acre)	Forage Utilized (lbs/acre)	Percent Utilization (%)	Forage per Cow-Calf Pair (lbs/day)
One grazing period 1978-1979, 1981-1982						
Unfertilized	1608.18a	1828.78a	1147.63a	681.15a	36.23a	30.94a
Fertilized	2705.60a	2943.23a	1489.53a	1453.70a	51.53a	39.94a
Drought Season 1980						
Unfertilized	1389.10	1203.80	976.50	227.30	18.90	36.53
Fertilized	1465.30	1308.40	756.90	551.50	42.20	59.09

Means in the same column and followed by the same letter are not significantly different (P<0.05).

Table 16. Costs and returns after pasture costs for cow-calf pairs on native rangeland treatments, 1978-1982.

Treatments	Land Area per Period (acres)	Production Cost per Acre ($)	Cost per Period ($)	Calf Weight Gain per Period (lbs)	Calf Weight Value @ $0.70/lb ($)	Net Return per Cow-Calf Pair ($)	Net Return per Acre ($)	Cost per Pound Calf Gain ($)
One grazing period 1978-1979, 1981-1982								
Unfertilized	1.83a	8.76	16.01a	83.98a	58.78a	42.77a	23.74a	0.21a
Fertilized	1.23b	21.26	26.15b	77.45a	54.22a	28.06a	23.21a	0.39a
Drought Season 1980								
Unfertilized	2.38	8.76	20.85	32.10	22.47	1.62	0.68	0.65
Fertilized	1.62	21.26	34.44	26.50	18.55	-15.89	-9.81	1.30

Means in the same column and followed by the same letter are not significantly different (P<0.05).

Table 17. Monthly dry matter weight in pounds per acre for treatments on the evaluation of native rangeland pasture fertilization trial, 1982.

Plant Categories Treatments	15 May	15 Jun	15 Jul	15 Aug	15 Sep
Unfertilized					
cool season	429.6	834.9	1506.1	1232.0	1147.7
warm season	9.3	178.1	520.2	965.9	404.4
total native grass	438.9	1013.0	2026.3	2197.9	1552.1
introduced grass	0.0	0.0	0.0	0.0	0.0
forbs	31.4	199.5	231.6	222.6	203.4
total yield	470.3	1212.5	2257.9	2420.5	1755.5
Fertilized					
cool season	1085.4	2690.6	3260.0	2332.8	2233.6
warm season	54.2	71.0	229.8	162.7	126.1
total native grass	1139.6	2761.6	3489.8	2495.5	2359.7
introduced grass	0.0	201.2	895.9	707.1	264.0
forbs	10.7	205.5	480.3	638.0	133.2
total yield	1150.3	3168.3	4866.0	3840.6	2756.9

Table 18. Percent herbage growth and senescence of plant categories for treatments on the evaluation of native rangeland pasture fertilization trial, 1982.

Plant Categories Treatments	15 May	15 Jun	15 Jul	15 Aug	15 Sep
Unfertilized					
cool season	28.52	26.91	44.57	-18.20	-5.60
warm season	0.96	17.48	35.42	46.14	-58.13
total native grass	19.97	26.12	46.10	7.81	-29.38
introduced grass	0.0	0.0	0.0	0.0	0.0
forbs	13.56	72.58	13.86	-3.89	-8.29
total yield	19.43	30.66	43.19	6.72	-27.47
Fertilized					
cool season	33.29	49.24	17.47	-28.44	-3.04
warm season	23.59	7.31	69.10	-29.20	-15.93
total native grass	32.66	46.48	20.87	-28.49	-3.89
introduced grass	0.0	22.46	77.54	-21.07	-49.46
forbs	1.68	30.53	43.07	24.72	-79.12
total yield	23.64	41.47	34.89	-21.07	-22.27

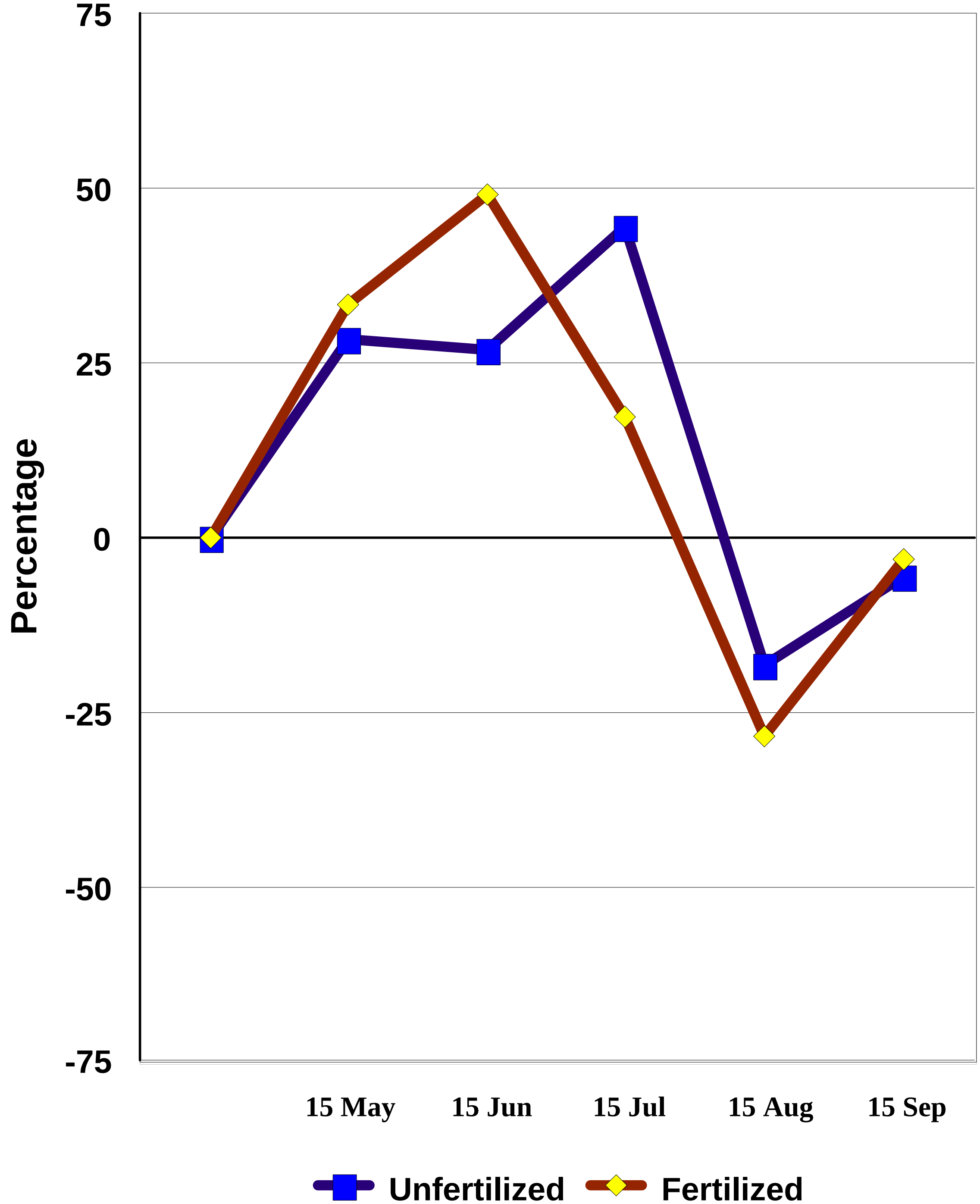

Figure 1. Percent herbage growth and senescence of cool season grasses for treatments on the evaluation of native rangeland pasture fertilization trial, 1982.

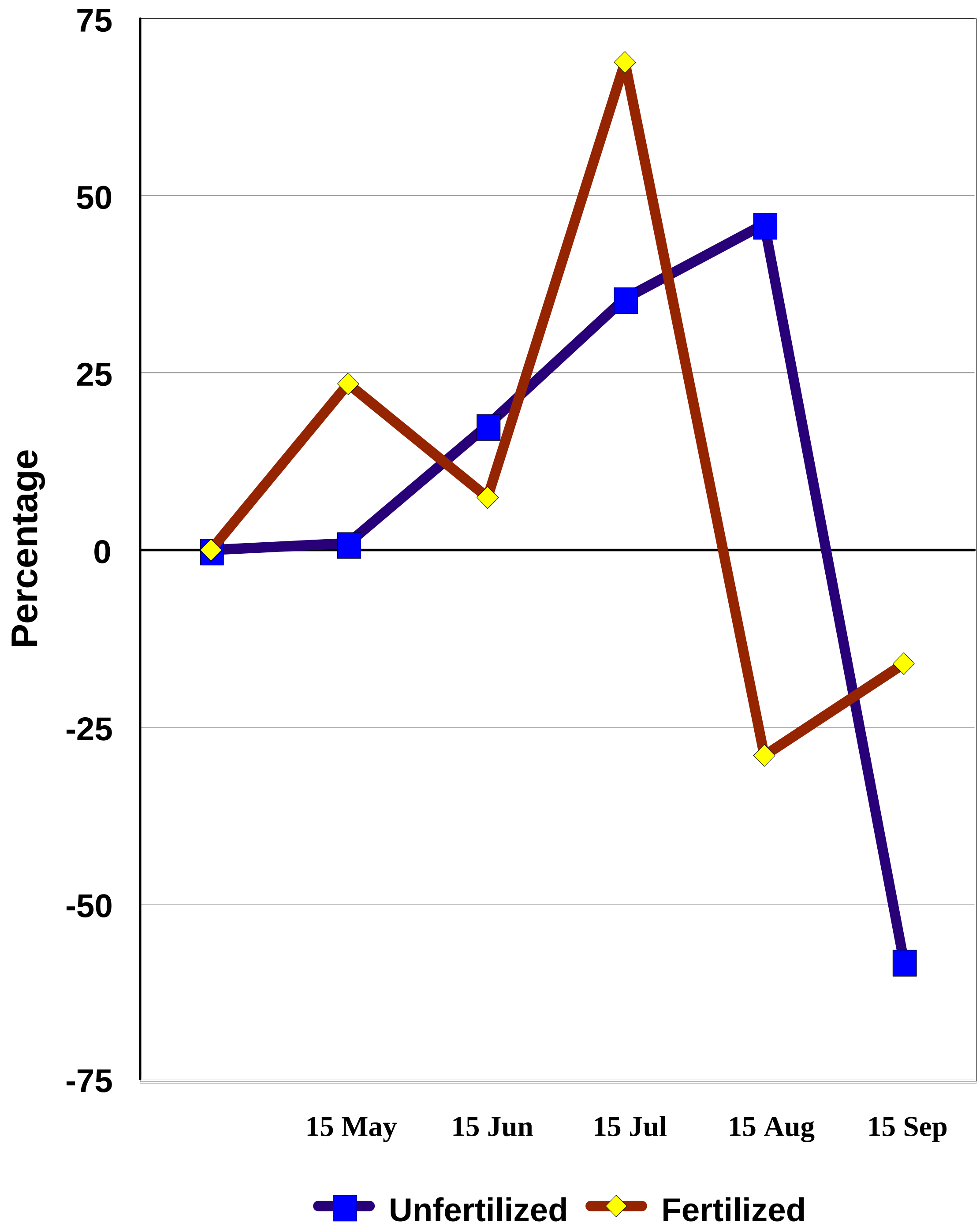

Figure 2. Percent herbage growth and senescence of warm season grasses for treatments on the evaluation of native rangeland pasture fertilization trial, 1982.

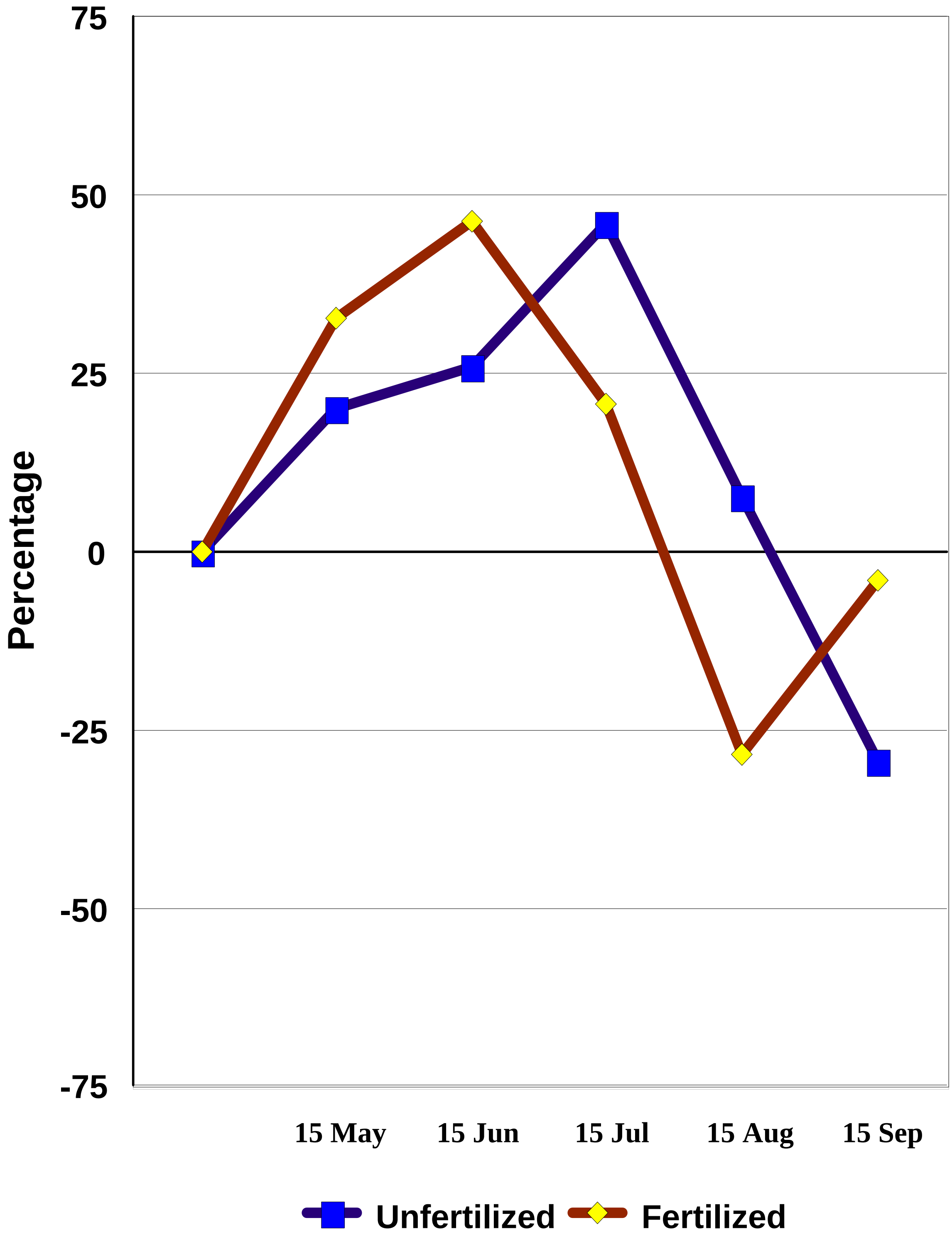

Figure 3. Percent herbage growth and senescence of total native grasses for treatments on the evaluation of native rangeland pasture fertilization trial, 1982.

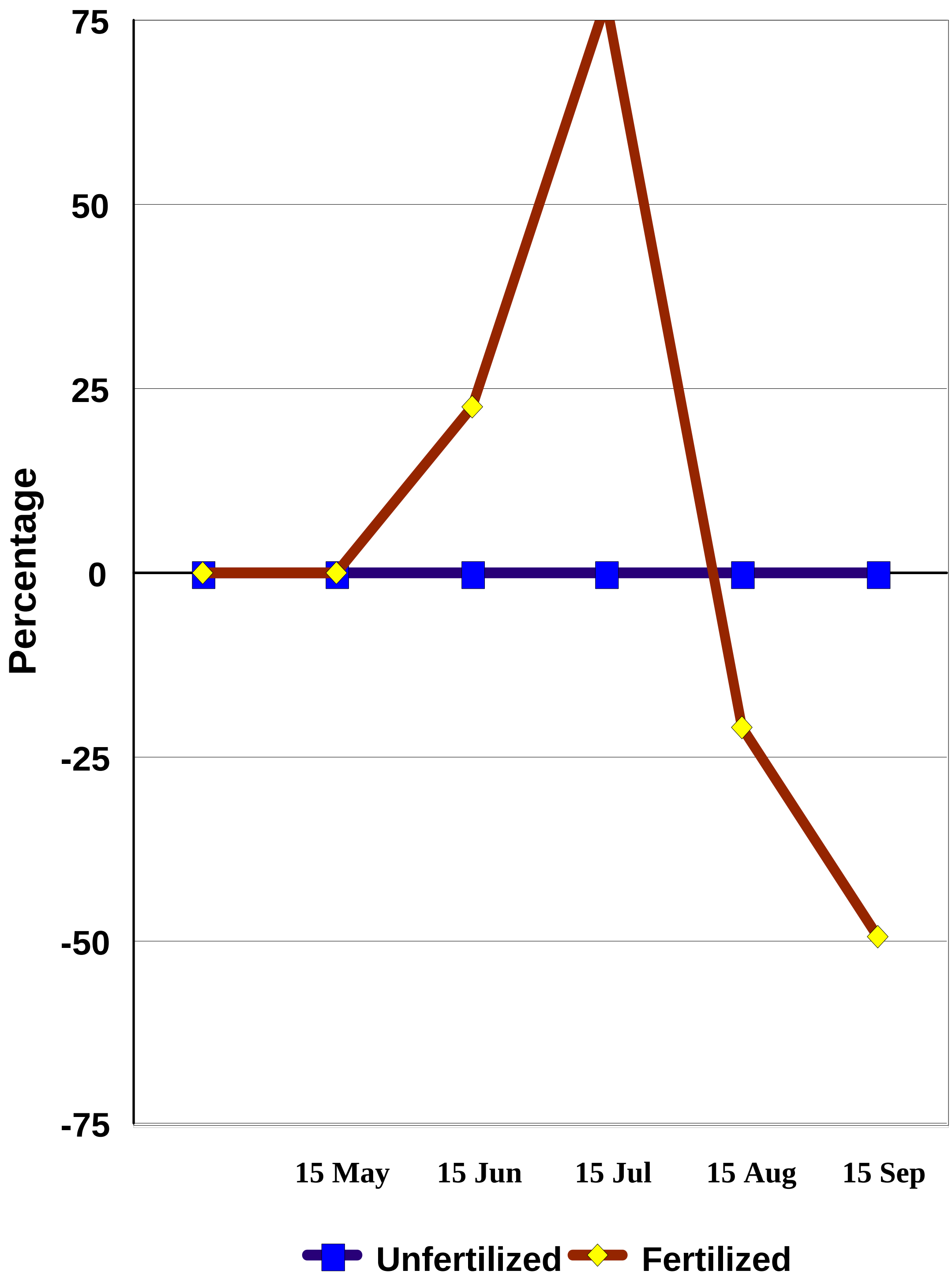

Figure 4. Percent herbage growth and senescence of introduced grasses for treatments on the evaluation of native rangeland pasture fertilization trial, 1982.

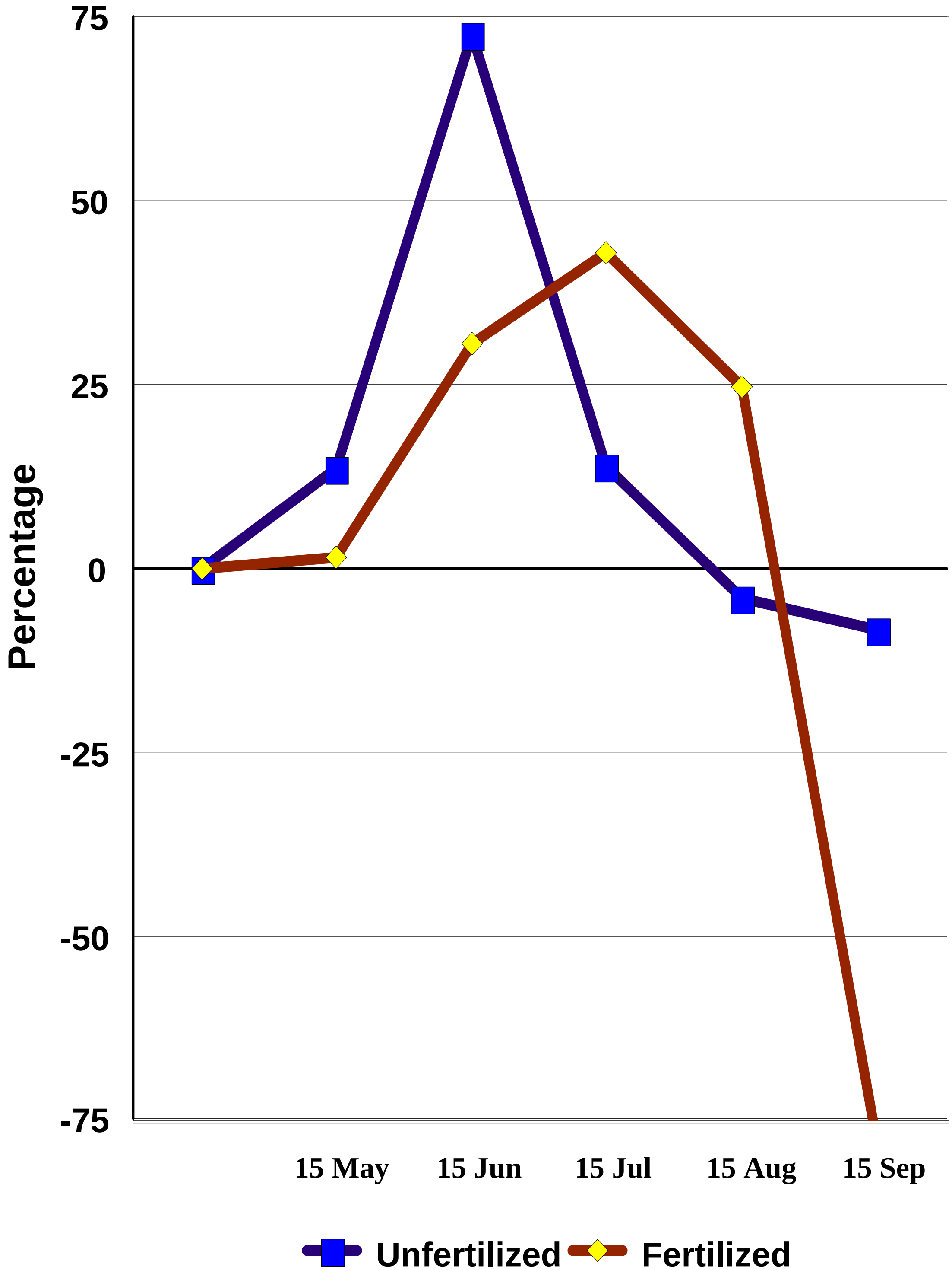

Figure 5. Percent herbage growth and senescence of forbs for treatments on the evaluation of native rangeland pasture fertilization trial, 1982.

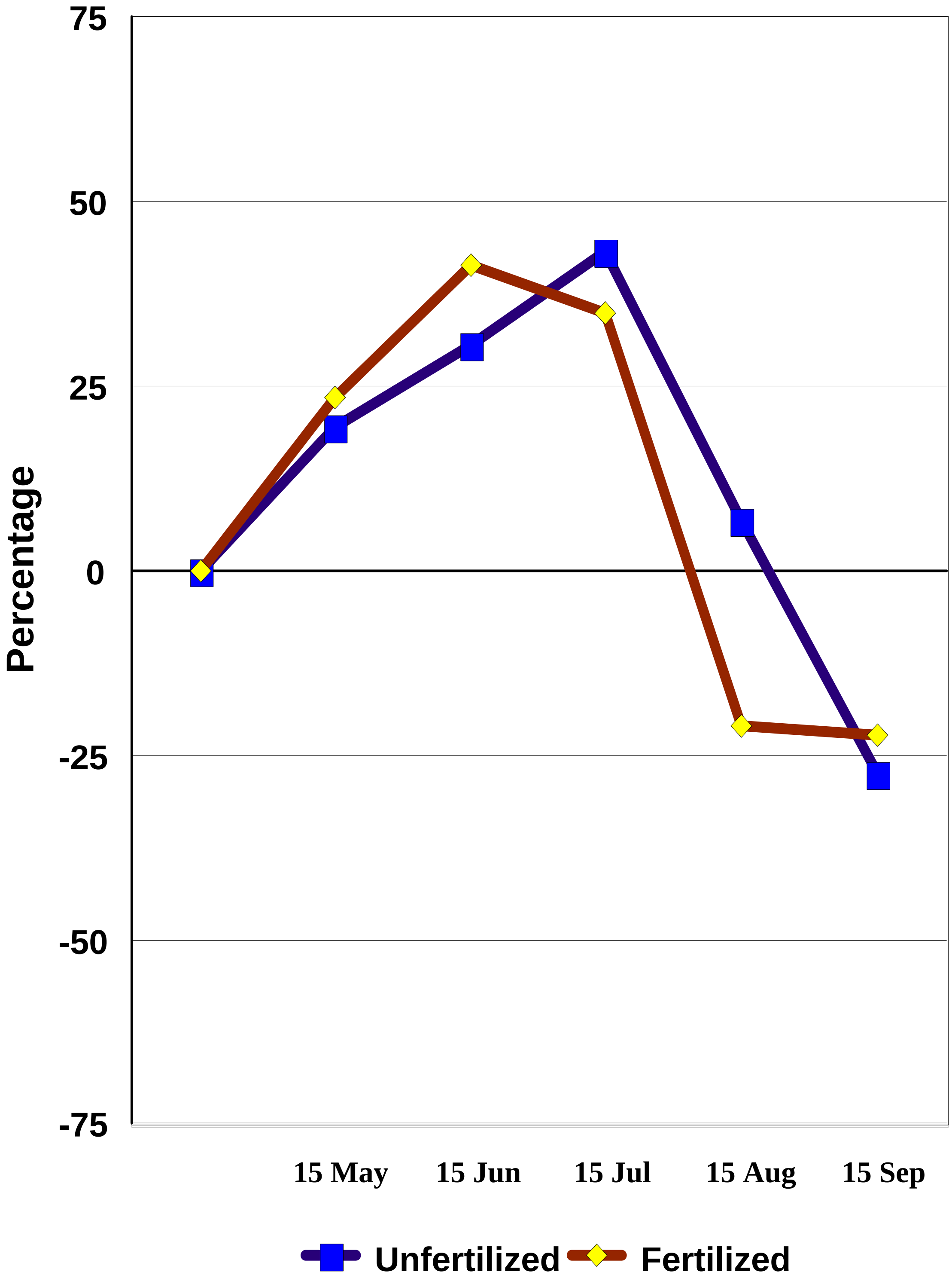

Figure 6. Percent herbage growth and senescence of total yield for treatments on the evaluation of native rangeland pasture fertilization trial, 1982.

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Fate of Applied Fertilizer Nitrogen on Native Rangeland

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Residual effects from nitrogen fertilizer in grasslands appear to be much more prolonged than for cultivated soils (Power and Alessi 1971).

The fate of applied fertilizer nitrogen on native rangeland ecosystems is dependent on the immobilization and mineralization of nitrogen by various biotic and abiotic factors called nitrogen sinks. Power (1977) determined the nitrogen content in the various sinks of a grazed semiarid native mixed grass prairie ecosystem near Mandan, ND that had been annually fertilized with 80 lbs N/ac for 11 years by G.A. Rogler and R.J. Lorenz. Power (1977) subtracted the nitrogen content of the various nitrogen sinks of the unfertilized pasture from the nitrogen content of the respective sinks of the fertilized pasture to determine the content and percentage of the applied fertilizer nitrogen in each nitrogen sink. The fate of nitrogen as a percent of applied fertilizer determined by Power (1977) is shown in the left column of table 1. The fate of applied fertilizer nitrogen during one year (50 lbs N/ac per year) and during eleven years (550 lbs N/ac per 11 years) of the fertilization of native rangeland grazing study conducted at the Dickinson Research Extension Center (1972-1982) are shown in the center and right columns of table 1, respectively.

The largest nitrogen sinks after eleven years of fertilization treatments were the soil mineral nitrogen (41%), grass root material (19%), and organic surface litter (16%). Fertilizer nitrogen remaining in the aboveground herbage and grass crowns was only 3% (Power 1977) (table 1). None of the fertilizer nitrogen was lost by leaching through the soil profile (Power 1970). The nitrogen not accounted for was 18%, of which other research suggests 5% was gaseous nitrogen lost to the atmosphere and 13% was immobilized in soil organic matter (Power 1975).

Black and Wight (1972) concluded that the plant-soil nutrient cycling systems of rangeland have a large portion of the soil nitrogen required for plant growth tied up in the organic phase in relatively unavailable forms. A large amount of fertilizer nitrogen was immobilized into grass roots, soil organic matter, and microbial tissue. About half of the immobilized nitrogen was found in the grass roots. The nitrogen immobilization capacity in grassland soils was somewhat variable and was influenced by soil texture, vegetation type, root growth, lignin content of organic matter, amount and mineralogy of clay material, and environmental parameters of soil temperature, soil oxygen, and soil water (Power 1972). The immobilized nitrogen in organic forms could be mineralized later by soil microorganisms and recirculated through the ecosystem. Mineralization breaks down organic materials into ammonia and carbon dioxide, or other low molecular weight carbon compounds. Most of the ammonia released is readily hydrolyzed to the ammonium form. Some of the ammonium is nitrified by oxidation to the nitrite form, then oxidized again to the nitrate form. The ammonium and nitrate produced by the mineralization and nitrification processes are added to the plant available inorganic (mineral) nitrogen pool in the soil (Power 1972).

Soil mineral nitrogen (ammonium NH_4 and nitrate NO_3) was available above the 3 foot soil depth in early spring the first year on high fertilization treatment rates greater than 160 lbs N/ac. Lower fertilization rates, greater than 40 lbs N/ac, required two to six years before increased inorganic nitrogen was available during early spring (Power 1972). Power (1977) determined after 11 years of annual applications of ammonium nitrate that 41% of the applied fertilizer nitrogen was available as soil mineral nitrogen with a small amount in the ammonium form (2%) and most in the nitrate form (39%) (table 1).

Only a small amount of fertilizer nitrogen was assimilated into the aboveground herbage per year. Smika et al. (1961) determined the fertilizer nitrogen fate after 9 years of annual applications of ammonium nitrate that 11.1% of the 30 lbs N/ac rate and that 18.8% of the 90 lbs N/ac rate had been incorporated into the aboveground herbage. Smika et al. (1965) determined the fertilizer nitrogen fate after 4 years of annual applications of ammonium nitrate that under natural moisture conditions 17% to 25% of the applied nitrogen was incorporated into the aboveground herbage. Power (1977) determined the aboveground fertilizer nitrogen fate at the end of the eleventh growing season of a grazed semiarid rangeland pasture with annual applications of ammonium nitrate to be at least a total of 18% and that 2% remained in the live aboveground herbage and 16% remained in the organic surface litter (table 1).

Livestock grazing removes only a small portion of the nitrogen from the aboveground herbage, leaving a significant part of the nitrogen in the remaining live aboveground herbage, the standing dead vegetation, and the litter. Most of the nitrogen consumed by grazing livestock is returned to the soil surface in urine and feces waste. Grazing livestock retain only a small amount of the nitrogen consumed, about 15% in a nonlactating animal and about 30% in a lactating animal (Russelle 1992). Power (1977) determined that about 3% of the applied nitrogen was removed from the grassland pasture as livestock product (table 1).

Some soil mineral nitrogen is immobilized when fixed by adsorption onto clay particles. The type of clay mineral affects the retention of ammonium. Clay materials with expanding lattices, such as montmorillonite, have greater surface area and adsorptive capacity for ammonium than clay minerals with nonexpanding lattices, such as kaolinite (Legg 1975).

Soil nitrogen is lost to the atmosphere through denitrification and ammonia volatilization. Denitrification is the reduction of the nitrite or nitrate mineral nitrogen to form nitrous oxide or dinitrogen gas. Denitrification probably accounts for only a small part of total nitrogen losses from pastures and rangeland because grass plants readily take up mineral nitrogen. Gaseous ammonia forms during mineralization of soil organic nitrogen to ammonium. Under some conditions the ammonia escapes into the atmosphere by volatilization. Ammonia volatilization losses generally increase with increasing aridity. Power (1977) estimated that about 5% of the applied nitrogen was lost to the atmosphere in gaseous form (table 1).

Fertilizer nitrogen applied to native rangeland soils is retained at greater quantities for considerably longer time periods than the same amount of fertilizer nitrogen applied to cropland soils because of the relatively rapid immobilization of mineral nitrogen into organic forms by perennial grass roots and soil microbial activity. These living components of grassland ecosystems can immobilize about 178 lbs N/ac in one growing season and around 285 lbs N/ac to 339 lbs N/ac within three or four years and the amount of nitrogen immobilized in live tissue can remain near that high range thereafter (Power 1972). The turnover rate of immobilized organic root material operates on a 3- to 4-year cycle (Power 1972). Mineralization of some of the organic nitrogen immobilized in perennial grass roots increases the supply of available mineral nitrogen (Power 1977). Rates of immobilization of mineral nitrogen to organic nitrogen and rates of mineralization of organic nitrogen to mineral nitrogen effect the quantity of available mineral nitrogen in grassland soils.

Cropland soils lack perennial grass roots and the ability to preserve a large portion of the mineral nitrogen as immobilized organic nitrogen. Mineral nitrogen in cropland soils is vulnerable to great losses through denitrification and ammonia volatilization.

Acknowledgment

I am grateful to Sheri Schneider for assistance in the production of this manuscript and for development of the table.

Table 1. Fate of applied fertilizer nitrogen on native rangeland pasture, 1972-1982, following first approximation percentages of fertilizer nitrogen fate in grazed semiarid rangeland developed by Power (1977).

Biotic and Abiotic Nitrogen Sinks	Fate of N as Percent of Applied Data from Power 1977 %			Fate of N from 50 lbs N/ac per year lbs N/yr			Fate of N from 550 lbs N/ac per 11 years lbs N/11 yrs		
Retained in Ecosystem			92%			46.0			506.0
Plants		22%			11.0			121.0	
aboveground herbage	2%			1.0			11.0		
crown	1%			0.5			5.5		
roots	19%			9.5			104.5		
Litter		16%			8.0			88.0	
Soil Mineral Nitrogen		41%			20.5			225.5	
ammonium NH_4	2%			1.0			11.0		
nitrate NO_3	39%			19.5			214.5		
Soil Organic Nitrogen unmeasured estimate		13%			6.5			71.5	
Lost to Ecosystem			8%			4.0			44.0
Beef Tissue		3%			1.5			16.5	
Gaseous Losses unmeasured estimate		5%			2.5			27.5	
Leaching		0%			0.0			0.0	

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Evaluation of Plant Species Shift on Fertilized Native Rangeland

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Nitrogen fertilization of native rangeland results in a plant species composition shift with an increase in mid cool season grasses and a decrease in short warm season grasses and these changes have been shown to occur from 30 and 90 lbs N/ac annually applied in fall and monitored for 7 years (Rogler and Lorenz 1957), from 33, 67, and 100 lbs N/ac annually applied to two range sites in spring and monitored for 2 years (Whitman 1963), from 33, 67, and 100 lbs N/ac annually applied to four range sites in spring and monitored for 6 years (Whitman 1969, Goetz 1969), from 30, 60, 120, 240, and 480 lbs N/ac applied over 1 year, 3 years, and 6 years in spring and monitored for 6 years (Power and Alessi 1971), from 40, 80, and 160 lbs N/ac annually applied with and without phosphate in fall and monitored for 8 years (Lorenz and Rogler 1972), from 100 lbs N/ac annually applied for 3 years in fall and monitored for 15 years (Taylor 1976), from 67 and 100 lbs N/ac annually and biennially applied in spring and 200, 300, and 400 lbs N/ac applied one time and monitored for 8 years (Whitman 1978, Goetz et al. 1978), and from low rates of less than 100 lbs N/ac annually applied in spring and high rates of greater than 100 lbs N/ac applied one time and monitored for 10 years (Wight and Black 1979). This shift in plant species composition was, at first, considered to be a beneficial change and a process to restore the natural balance in the botanical species composition of the Northern Plains mixed grass prairie.

The disruption of the natural species composition was caused during the homestead period between 1900 and 1936 by excessively heavy grazing with stocking rates greater than 60% heavier than the biological carrying capacity (Whitman et al. 1943). The resulting deterioration in the Northern Plains mixed grass prairie caused a decrease in herbage biomass production and a disproportional reduction of mid cool season grass species, such as western wheatgrass, and leaving a predominance of short warm season grass species, such as blue grama.

Heavy grazing damages grass species with long shoot tillers to a greater extent than grass species with short shoot tillers. Grass species with long shoots elevate the apical meristem a short distance above ground level by internode elongation while still in the vegetative phase (Dahl 1995) exposing the elevated apical meristem to removal by grazing prior to flowering. Grass species with short shoots do not produce significant internode elongation during vegetative growth and the apical meristem remains below grazing or cutting height until the flower stalk elongates during the sexual reproductive phase (Dahl 1995). Grass species with long shoots are nearly always decreased at greater rates than grass species with short shoots in pastures that are repeatedly grazed heavily (Branson 1953).

Application of nitrogen fertilizer to native rangeland in spring or fall, at low rates, high rates, annually, biennially, or one time all cause a shift in species composition with an increase in mid cool season grasses and a decrease in short warm season grasses. These multiple variables, however, do affect the rates of change differently and the shift in plant species composition does not occur at the same rate under different conditions. Cultural management practices of nitrogen fertilization that seemed to restore the natural species composition balance and appeared to correct existing problems were initially considered to be beneficial.

However, Goetz et al. (1978) found several undesirable aspects related to the changes in plant species composition that have implications of adverse consequences for mixed grass prairie communities. Detrimental complications could develop from synthetically induced changes in plant species because the increasing mid cool season grasses were primarily single stalked, low-cover, plants and the decreasing short warm season grasses were primarily multiple stemmed, high-cover, plants and the shift in plant species would cause a decrease in basal cover and a reduction in live plant material covering the soil and would open an otherwise closed community. The resulting reductions in ground cover would expose greater amounts of soil to erosion and to higher levels of solar radiation, and would create larger areas of open spaces available for potential invasion by undesirable perennial forbs, domesticated cool season grasses, and introduced annual and perennial grasses.

Eventhough, the nitrogen fertilization plot studies conducted in the Northern Plains from the early 1950's to the mid 1980's were comparatively long with 6 to 10 years of monitoring data, none of the studies were conducted long enough to fully document the undesirable changes proposed by Goetz et al. 1978. Taylor (1976) conducted a study for 15 years and found that residual effects from nitrogen fertilization of native rangeland were still occurring 12 years after the treatments had stopped.

This report uses compiled vegetation data from four studies to follow the plant species composition changes in a nitrogen fertilized mixed grass prairie community during 33 years from 1972 to 2004 and corroborates the adverse implications of nitrogen fertilization in native rangeland that were hypothesized to occur by Goetz et al. 1978.

Procedure

The changes in plant species composition evaluated during this investigation occurred in the mixed grass prairie communities of the unfertilized and nitrogen fertilized pastures of the fertilization of native rangeland grazing study. The research pastures were located on the SW½, sec. 23, T. 140 N., R. 97 W., at the Dickinson Research Extension Center. The native rangeland plant community was strongly rolling upland mixed grass prairie. The soils were Vebar, Parshall, and Flasher fine sandy loams. The control pasture was 18 acres of untreated native rangeland. The fertilized pasture was 12 acres of native rangeland fertilized annually with ammonium nitrate fertilizer (33-0-0) broadcast applied in granular form at a rate of 50 lbs N/ac in early spring, usually around early to mid April, for eleven years from 1972 to 1982. The growing season of 1982 was the last year of fertilizer application.

The unfertilized and fertilized native rangeland pastures were grazed by yearling steers from 1972 to 1976 and grazed by cow-calf pairs from 1977 to 1982 during mid June to late August or early September. The fertilized pasture grazing project was not conducted in 1983. A two grazing period study was conducted from 1984 to 1988 on the unfertilized pasture. The unfertilized pasture was grazed by cow-calf pairs for two periods per year with the first period during early to mid June and the second period during mid July to mid August. The fertilized pasture was not fertilized after 1982 and was grazed by cow-calf pairs from 1984 to 1988 one period during mid June to late August or early September. Grazing studies were terminated at this location and the pastures were grazed by cattle that were not in research projects. The pastures were used from 1989 to 2004 for one period usually during early June to late August.

Aboveground herbage biomass production was sampled on the unfertilized and fertilized native rangeland pastures by the clipping method from inside and outside exclosure cages in 1972 to 1982, on the unfertilized pasture from inside and outside exclosure cages in 1984 to 1988, and on the unfertilized and fertilized pastures in 1997 to 2004. The exclosures were steel wire quonset type cages measuring 3 X 7 foot. During 1972 to 1988, the exclosures were distributed in a systematic grid with an average of 20 exclosures per pasture. The exclosure cages were moved within the respective grids every spring. All of the herbage samples were oven dried and weighed. During 1972 to 1976, dry aboveground herbage biomass was sampled by hand clipping to ground level from 2.5 X 5.0 foot (0.75 X 1.5 meter) heavy steel frames with one clip per year at the end of the grazing period during mid August to mid September. The plant material was not separated into categories. During 1977 to 1981, dry aboveground herbage biomass was sampled by hand clipping to ground level from 0.82 X 3.28 foot (0.25 X 1.0 meter) light weight steel frames with two clippings per year at the beginning and end of the grazing period with the first clip during mid June to mid July and the second clip during late July to mid August. The plant material was not separated into categories. During 1982 to 1988, dry aboveground herbage biomass was sampled by hand clipping to ground level from 0.82 X 3.28 foot (0.25 X 1.0 meter) light weight steel frames with four clippings per year with the first clip during early to mid June, the second clip during mid June to mid July, the third clip during mid July to mid August, and the fourth clip during mid August to mid September. The plant material was separated into five categories: warm season grasses, cool season grasses, sedges, introduced grasses, and forbs. An additional clip was conducted during mid May in 1982. Herbage weight data were not collected in 1983.

Herbage samples were not collected between 1989 and 1996. During 1997 to 2004, the unfertilized and fertilized native rangeland pastures were each separated into three equal sized replicated sample zones; west, middle, and east. Dry aboveground herbage biomass was sampled by hand clipping to ground level from three to five 0.82 X 3.28 foot (0.25 X 1.0 meter) light weight steel frames from each of the three replicated zones with one clip per year during late June to mid August. The plant material was separated into five categories: warm season grasses, cool season grasses, sedges, introduced grasses, and forbs. The exclosure cages had been moved to other research pastures and the sites clipped were areas with no or low herbage removed by grazing livestock. Herbage weight data were not collected in 2003.

Quantitative species composition was determined by percent basal cover sampled with the ten-pin point frame method during the period of mid July to mid August, on the unfertilized and fertilized pastures in 1982, on the unfertilized pasture in 1985 to 1988, and on the unfertilized and fertilized pastures in 1998-2004.

Results

The precipitation during the growing seasons of 1972 to 1976 was normal or greater than normal (table 1). During 1972, 1973, 1974, 1975, and 1976, 18.57 inches (137.05% of LTM), 11.83 inches (87.31% of LTM), 12.45 inches (91.88% of LTM), 15.26 inches (112.62% of LTM), and 10.84 inches (80.00% of LTM) of precipitation were received, respectively. Perennial plants were under water stress conditions during September, 1972; July, August, and October, 1973; July, August, September, and October, 1974; July, August, and September, 1975; and July and August, 1976 (Manske 2009).

The precipitation during the growing seasons of 1977 to 1982 was normal or greater than normal (table 1). During 1977, 1978, 1979, 1980, 1981, and 1982, 18.65 inches (137.64% of LTM), 15.17 inches (111.96% of LTM), 11.12 inches (82.07% of LTM), 10.73 inches (79.19% of LTM), 14.27 inches (105.31% of LTM), and 22.53 inches (166.27% of LTM) of precipitation were received, respectively. Perennial plants were under water stress conditions during April and July, 1977; October, 1978; October, 1979; April, May, July, and September, 1980; and July and October, 1981. The April through July precipitation received in 1980 was 44.5% of the LTM causing drought conditions, and August and October of 1980 were wet months. Perennial plants did not experience water stress conditions during 1982 (Manske 2009).

The precipitation during the growing seasons of 1997 to 2004 was normal or greater than normal (table 2). During 1997, 1998, 1999, 2000, 2001, 2002, 2003, and 2004, 14.74 inches (108.78% of LTM), 20.51 inches (151.37% of LTM), 14.20 inches (104.80% of LTM), 11.91 inches (87.90% of LTM), 17.74 inches (130.92% of LTM), 15.47 inches (114.17% of LTM), 11.45 inches (84.50% of LTM), and 10.26 inches (75.77% of LTM) of precipitation were received, respectively. Perennial plants were under water stress conditions during August and September, 1997; July and October, 1999; August and September, 2000; August and October, 2001; September, 2002; July and August, 2003; and June and August, 2004. The April through August precipitation received in 2004 was 52.8% of the LTM causing mild drought conditions. Perennial plants did not experience water stress conditions during 1998 (Manske 2009).

Trial I (1972-1976)

The unfertilized and fertilized pasture herbage weight samples collected in 1972 to 1976 were clipped to ground level from inside and outside exclosure cages one time per growing season during the clip period of mid August to mid September. Some previous years standing dead were included in the samples collected from inside the exclosure cages. The herbage samples were not separated into categories. The reported data were mean total ungrazed herbage from the one clip period.

Mean aboveground total ungrazed herbage weight during 1972 to 1976 was 2676.60 lbs per acre on the unfertilized pasture and was 4010.00 lbs per acre on the fertilized pasture during the clip period of mid August to mid September (table 3). The total ungrazed herbage weight on the fertilized pasture was 49.8% greater than, but not significantly different ($P<0.05$) from, the total ungrazed herbage weight on the unfertilized native rangeland pasture.

Trial II (1977-1982)

The unfertilized and fertilized pasture herbage weight samples collected in 1977 to 1981 were clipped to ground level from inside and outside exclosure cages two times per growing season during the clip period of mid June to mid July and during the clip period of mid July to mid August. The herbage samples were not separated into categories. The reported data were mean total ungrazed herbage from the two clip periods.

Mean aboveground total ungrazed herbage weight during 1977 to 1979 and 1981 to 1982 was 1733.72 lbs per acre on the unfertilized pasture and was 2623.95 lbs per acre on the fertilized pasture during the two grazing season clip periods between early June and mid September (table 3). The mean total ungrazed herbage weight on the fertilized pasture was 51.3% greater than, but not significantly different ($P<0.05$) from, the mean total ungrazed herbage weight on the unfertilized native rangeland pasture. In 1980, drought conditions occurred from April through July with only 44.5% of the LTM precipitation received. The ungrazed herbage samples were collected 7 and 23 July after 2.67 inches of precipitation was received in June. Mean aboveground total ungrazed herbage weight during 1980 was 1296.45 lbs per acre on the unfertilized pasture and was 1386.85 lbs per acre on the fertilized pasture (table 3). The mean total ungrazed herbage weight on the fertilized pasture was 7.0% greater than, but not significantly different ($P<0.05$) from, the total ungrazed herbage weight on the unfertilized pasture.

The unfertilized and fertilized pasture herbage weight samples collected in 1982 were clipped to ground level from inside and outside exclosure cages five times per growing season. The first clip was during mid May before grasses were phenologically ready for grazing. After grasses were phenologically ready for grazing, the second clip was during the clip period of early to mid June, the third clip was during the clip period of mid June to mid July, the fourth clip was during the clip period of mid July to mid August, and the fifth clip was during the clip period of mid August to mid September. The herbage was separated into five categories: warm season grasses, cool season grasses, sedges, introduced and domesticated grasses, and forbs. The reported data was mean ungrazed herbage for each category and for the total yield of all categories from the four grazing season clip periods between early June and mid September.

The growing season of 1982 was the eleventh and last year with an application of 50 lbs N/ac on the fertilized native rangeland pasture. The effects from 11 years of fertilization on native rangeland vegetation were determined from herbage weight clipped during 5 periodic dates and separated into categories and from plant species composition determined by basal cover.

Cool season grasses on the unfertilized and fertilized pastures gained herbage weight during May, June, and July, and then lost aboveground biomass during August and September (table 4). Mean cool season grass herbage weight during the four grazing season clip periods between early June and mid September was 898.28 lbs per acre, composing 46.99%, on the unfertilized pasture and was 2392.55 lbs per acre, composing 65.41%, on the fertilized pasture. Mean cool season herbage weight on the fertilized pasture was 166.3% greater than mean cool season herbage weight on the unfertilized pasture. Mean sedge herbage weight on the unfertilized pasture was 281.90 lbs per acre, composing 14.75%, and was 236.70 lbs per acre, composing 6.47%, on the fertilized pasture. Mean sedge herbage weight on the fertilized pasture was 16.0% lower than that on the unfertilized pasture (tables 6 and 7).

Warm season grasses, total native grasses, and total yield on the unfertilized pasture gained herbage weight during May, June, July, and August, and lost aboveground biomass during September. Warm season grasses, total native grasses, and total yield on the fertilized pasture gained herbage weight during May, June, and July, and lost aboveground biomass during August and September (table 4). Mean warm season grass herbage weight during the four grazing season clip periods was 517.15 lbs per acre, composing 27.05%, on the unfertilized pasture and was 147.40 lbs per acre, composing 4.03%, on the fertilized pasture. Mean warm season grass herbage weight on the fertilized pasture was 71.5% lower than mean warm season grass herbage weight on the unfertilized pasture (tables 6 and 7).

Forbs on the unfertilized pasture gained herbage weight during May, June, and July, and lost aboveground biomass during August and September. Forbs on the fertilized pasture gained herbage weight during May, June, July, and August, and lost aboveground biomass during September (table 4). Mean forb herbage weight during the four grazing season clip periods was 214.27 lbs per acre, composing 11.21%, on the unfertilized pasture and was 364.25 lbs per acre, composing 9.96%, on the fertilized pasture. Almost all of the forb herbage weight on the fertilized pasture was fringed sage. Mean forb herbage weight on the fertilized pasture was 70.0% greater than mean forb herbage weight on the unfertilized pasture (tables 6 and 7).

Mean total native grass herbage weight on the fertilized pasture was 63.6% greater than mean total native grass herbage weight on the unfertilized pasture. Mean total yield herbage weight was 91.4% greater on the fertilized pasture than on the unfertilized pasture. The greater production of herbage weight on the fertilized pasture resulted from the increase in cool season grass and forb herbage weight and from the additional 517.05 lbs per acre of herbage weight produced by introduced and domesticated grasses that were not measured on the unfertilized pasture (tables 4 and 6).

Mean percent composition of herbage weight on the fertilized pasture was 39.2% greater for cool season grasses, and was 85.1% lower for warm season grasses, 56.1% lower for sedges, and 11.2%

lower for forbs than the percent composition of herbage weight of the respective categories on the unfertilized pasture (tables 5 and 7). Herbage weight of introduced and domesticated grasses, composed 14.1% of the mean total herbage yield on the fertilized pasture.

Mean percent total basal cover of the plant community during 1982 was 22.81% on the unfertilized pasture and was 17.47% on the fertilized pasture. Total basal cover on the fertilized pasture was 23.4% lower than total basal cover on the unfertilized pasture (table 8). Warm season grass basal cover was 9.94% on the unfertilized pasture and was 3.20% on the fertilized pasture. Warm season grass basal cover on the fertilized pasture was 67.8% lower than that on the unfertilized pasture. Basal cover of mid warm season grasses, primarily little bluestem and sideoats grama, had decreased 95.3% and basal cover of short warm season grasses, primarily blue grama, had decreased 65.9% on the fertilized pasture (table 13). Cool season grass basal cover was 4.47% on the unfertilized pasture and was 6.27% on the fertilized pasture. Cool season grass basal cover on the fertilized pasture was 40.3% greater than that on the unfertilized pasture. Basal cover of mid cool season grasses, primarily western wheatgrass and green needlegrass, had increased 94.3% and basal cover of short cool season grasses, primarily prairie Junegrass, had decreased 26.5% on the fertilized pasture (table 13). Sedge basal cover on the unfertilized pasture was 6.64% and was 5.70% on the fertilized pasture. Sedge basal cover on the fertilized pasture was 14.2% lower than that on the unfertilized pasture. Total native grass basal cover on the unfertilized pasture was 21.05% and was 15.17% on the fertilized pasture. Total native grass basal cover on the fertilized pasture was 27.9% lower than that on the unfertilized pasture. Domesticated grass basal cover was 0.36% on the unfertilized pasture and was 1.96% on the fertilized pasture. Domesticated grass basal cover on the fertilized pasture was 444.4% greater than that on the unfertilized pasture. The domesticated grasses were crested wheatgrass with a basal cover of 0.67% and smooth bromegrass with a basal cover of 0.63%. The introduced grasses were Kentucky bluegrass and Canada bluegrass with a combined basal cover of 0.66% (table 13). Forb basal cover on the unfertilized pasture was 1.40% and was 0.34% on the fertilized pasture. Forb basal cover on the fertilized pasture was 75.7% lower than that on the unfertilized pasture (table 8). The typical shift in plant species composition with an increase in mid cool season grasses and a decrease in short warm season grasses occurred as a result of eleven years of 50 lbs N/ac applied each spring. Total basal cover decreased 23.4% on the fertilized pasture because the increasing plants, consisting of native mid cool season grasses, domesticated mid cool season grasses, and introduced mid cool season grasses, were single stalked, low-cover plants and the decreasing plants, consisting of native mid and short warm season grasses, native short cool season grasses, and native upland sedges, were multiple stemmed, high-cover plants.

Trial III (1984-1988)

Herbage weight and basal cover samples were not collected on the fertilized pasture during 1984 to 1988. The unfertilized pasture herbage weight samples collected in 1984 to 1988 were clipped to ground level from inside and outside exclosure cages four times per growing season. The first clip was during the clip period of early to mid June, the second clip was during the clip period of mid June to mid July, the third clip was during the clip period of mid July to mid August, and the fourth clip was during the clip period of mid August to mid September. The herbage was separated into five categories: warm season grasses, cool season grasses, sedges, introduced and domesticated grasses, and forbs. The reported data for 1984 was mean ungrazed herbage for each category and for the total yield of all categories from two clip periods; the clip period of mid June to mid July, and the clip period of mid August and mid September. The reported data for 1985 to 1988 was mean ungrazed herbage for each category and for the total yield of all categories from the four grazing season clip periods conducted between early June and mid September.

Mean aboveground total ungrazed herbage weight during 1984 to 1987 was 1429.72 lbs per acre on the unfertilized pasture during the growing season periods between early June and mid September (tables 3 and 6). Mean warm season herbage weight was 293.45 lbs per acre and composed 20.3% of the total herbage weight. Mean cool season herbage weight was 416.35 lbs per acre and composed 29.1% of the total herbage weight. Mean sedge herbage weight was 581.99 lbs per acre and composed 41.1% of the total herbage weight. Mean total native grass herbage weight was 1291.78 lbs per acre and composed 90.5% of the total herbage weight. Mean forb herbage weight was 137.94 lbs per acre and composed 9.5% of the total herbage weight (tables 6 and 7). In 1988, severe drought conditions occurred during the entire growing season with only 48.4% of the LTM precipitation received from April through October. Mean aboveground total ungrazed herbage weight in 1988 was 451.23 lbs per acre on the unfertilized pasture during the growing season periods between early June and mid September (tables 3 and 6). Mean warm season herbage weight was 92.03 lbs per acre and composed 20.4% of the total herbage weight. Mean cool season herbage weight was 89.54 lbs per acre and composed 19.8% of the total herbage weight. Mean sedge herbage weight was 208.58 lbs per acre and composed 46.2% of the total herbage weight. Mean total native grass herbage weight was 390.15 lbs per acre and composed 86.5% of the total herbage weight. Mean forb herbage weight was 61.08 lbs per acre and composed 13.5% of the total herbage weight (tables 6 and 7).

Mean total basal cover during 1985 to 1987 was 30.59% on the unfertilized pasture (table 8). Mean warm season grass basal cover was 9.95%. Mean cool season grass basal cover was 6.20%. Mean sedge basal cover was 10.47%. Mean total native grass basal cover was 26.62%. Mean forb basal cover was 3.94% (table 8).

Mean total basal cover during the 1988 drought conditions was 26.83% on the unfertilized pasture (table 8). Mean warm season grass basal cover was 8.51%. Mean cool season grass basal cover was 5.21%. Mean sedge basal cover was 7.88%. Mean total native grass basal cover was 21.60%. Mean forb basal cover was 5.23% (table 8).

Trial IV (1997-2004)

The unfertilized and fertilized pasture herbage weight samples collected in 1997 to 2002 and 2004 were clipped to ground level one time per growing season during late June to mid August. The herbage was separated into five categories: warm season grasses, cool season grasses, sedges, introduced and domesticated grasses, and forbs. The pastures were grazed and the clipped herbage samples were collected from ungrazed or lightly grazed areas. The reported data were mean ungrazed herbage or lightly grazed herbage for each category and for the total yield of all categories from the one clip period on each of the three replicated pasture zones.

Mean aboveground total yield herbage weight during 1997 to 1999 and 2001 to 2002 was 1348.47 lbs per acre on the unfertilized pasture and was 2288.09 lbs per acre on the fertilized pasture during the growing season period of early June to mid August (tables 9 and 10). The total herbage weight on the fertilized pasture was 69.7% greater than, and significantly different ($P<0.05$) from, the total herbage weight on the unfertilized pasture. Mean warm season grass herbage weight was 236.77 lbs per acre, composing 18.96%, on the unfertilized pasture and was 71.31 lbs per acre, composing 3.39%, on the fertilized pasture. Warm season grass herbage weight on the fertilized pasture was 69.9% lower than, and significantly different ($P<0.05$) from, mean warm season grass herbage weight on the unfertilized pasture. Mean cool season grass herbage weight was 453.28 lbs per acre, composing 34.74%, on the unfertilized pasture and was 125.74 lbs per acre, composing 6.12%, on the fertilized pasture. Cool season grass herbage weight on the fertilized pasture was 72.3% lower than, and significantly different ($P<0.05$) from, that on the unfertilized pasture. Mean sedge herbage weight on the unfertilized pasture was 319.79 lbs per acre, composing 22.70%, and was 199.81 lbs per acre, composing 9.33%, on the fertilized pasture and were not significantly different ($P<0.05$). Mean total native grass herbage weight was 1009.84 lbs per acre, composing 76.41%, on the unfertilized pasture and was 396.86 lbs per acre, composing 18.83%, on the fertilized pasture. Total native grass herbage weight on the fertilized pasture was 60.7% lower than, and significantly different ($P<0.05$) from, that on the unfertilized pasture. Mean domesticated grass herbage weight was 108.94 lbs per acre, composing 7.53%, on the unfertilized pasture and was 1785.52 lbs per acre, composing 78.04%, on the fertilized pasture. Domesticated grass herbage weight on the fertilized pasture was 1539.0% greater than, and significantly different ($P<0.05$) from, domesticated grass herbage weight on the unfertilized pasture. Mean forb herbage weight on the unfertilized pasture was 229.68 lbs per acre, composing 16.06%, and was 105.71 lbs per acre, composing 4.90%, on the fertilized pasture and were not significantly different ($P<0.05$) (tables 10 and 11).

Mean percent composition of herbage weight for warm season grass, cool season grass, sedge, total native grass, and forbs were significanly lower ($P<0.05$) on the fertilized pasture than on the unfertilized pasture. Mean percent composition of herbage weight for domesticated grass were significantly greater ($P<0.05$) on the fertilized pasture than on the unfertilized pasture (table 11). The herbage weight samples of 2000 were collected from areas that were more than lightly grazed. In 2004, mild drought conditions occurred from April through August with 52.8% of the LTM precipitation received.

Mean percent total basal cover of the plant community during 1998 to 1999 and 2001 to 2003 was 26.37% on the unfertilized pasture and was

21.96% on the fertilized pasture and were not significantly different (P<0.05) (table 12). Mean warm season grass basal cover was 7.92% on the unfertilized pasture and was 2.56% on the fertilized pasture. Warm season grass basal cover on the fertilized pasture was 67.7% lower than, and significantly different (P<0.05) from, mean warm season grass basal cover on the unfertilized pasture. Basal cover of mid warm season grasses had decreased 80.0% and basal cover of short warm season grasses had decreased 63.5% on the fertilized pasture (table 13). Mean cool season grass basal cover was 5.42% on the unfertilized pasture and was 1.34% on the fertilized pasture. Cool season grass basal cover on the fertilized pasture was 75.3% lower than, and significantly different (P<0.05) from, that on the unfertilized pasture. Basal cover of mid cool season grasses had decreased 66.1% and basal cover of short cool season grasses had decreased 86.9% on the fertilized pasture (table 13). Mean sedge basal cover on the unfertilized pasture was 7.18% and was 4.45% on the fertilized pasture and were not significantly different (P<0.05). Mean total native grass basal cover on the unfertilized pasture was 20.52% and was 8.35% on the fertilized pasture. Total native grass basal cover on the fertilized pasture was 59.3% lower than, and significantly different (P<0.05) from, that on the unfertilized pasture. Mean domesticated grass basal cover was 2.45% on the unfertilized pasture and was 12.39% on the fertilized pasture. Domesticated grass basal cover on the fertilized pasture was 405.7% greater than, and significantly different (P<0.05) from, domesticated grass basal cover on the unfertilized pasture. Basal cover of crested wheatgrass had increased 577.6%, basal cover of smooth bromegrass had increased 568.3%, and basal cover of Kentucky bluegrass and Canada bluegrass had increased 451.5% from their respective basal cover in 1982 (table 13). The introduced and domesticated grasses had back filled 81.7% of the open spaces created in the plant community by the decrease in native grass basal cover on the fertilized pasture. Mean forb basal cover on the unfertilized pasture was 3.40% and was 1.22% on the fertilized pasture. Forb basal cover on the fertilized pasture was 64.1% lower than, and significantly different (P<0.05) from, that on the unfertilized pasture (table 12). The basal cover samples of 2000 were collected from areas that were more than lightly grazed. In 2004, mild drought conditions occurred from April through August with 52.8% of the LTM precipitation received.

Introduced and domesticated grasses are apparently capable of occupying open spaces created by native grass reductions in the plant community when soil mineral nitrogen is readily available. The plant community in the fertilized pasture would be expected to continue to change in plant species composition with a decrease in native warm season grasses, cool season grasses, upland sedges, and prairie forbs and an increase in domesticated and introduced mid cool season grasses until the quantity of applied fertilizer nitrogen was no longer readily available as soil mineral nitrogen. The duration of time that the applied fertilizer nitrogen would remain in the ecosystem could be estimated by determination of the fate of the applied fertilizer nitrogen according to the nitrogen fate percentages developed by Power (1977).

The fate of applied nitrogen fertilizer in native rangeland ecosystems is dependent on various biotic and abiotic factors called nitrogen sinks. Power (1977) determined the nitrogen content in the various sinks of a grazed native mixed grass prairie near Mandan, ND. Power (1977) subtracted the nitrogen content of the unfertilized pasture from the nitrogen content of the fertilized pasture to determine the content and percentage of the applied fertilizer nitrogen in each sink.

The fate of nitrogen as a percent of applied fertilizer determined by Power (1977) is shown in the left column of table 14. Power (1977) determined that 8% or 4.0 lbs per acre of the applied nitrogen was lost from the ecosystem per year. At a constant rate of loss at 4.0 lbs of applied nitrogen per acre per year, the applied nitrogen would be used up in 126.5 years from the last year fertilizer was applied and the ecosystem should be devoid of fertilizer nitrogen sometime during the growing season in the year 2109.

Discussion

Nitrogen fertilization of native rangeland with annual applications of 50 lbs N/ac caused the plant species composition to shift. Pasture fertilization increased total herbage weight 49.8% during 1972 to 1976, and increased mean total herbage weight 51.3% during 1977 to 1982. In 1982, after 11 years of fertilization treatments, total herbage weight had increased 91.4% and the plant species composition had changed greatly. Cool season grass herbage weight had increased 166.3%, composition had increased 39.2%, and basal cover had increased 40.3%. Warm season grass herbage weight had decreased 71.5%, composition had decreased 85.1%, and basal cover had decreased 67.8%. Upland sedge herbage weight had decreased 16.0%, composition had decreased 56.1%, and basal cover had decreased 14.2%. Forb herbage weight had increased 70.0%, composition had decreased 11.2%, and basal cover had decreased 75.4%. The quantity of forb plants and the number of forb species had greatly decreased on the fertilized pasture. A few of the remaining plants were fringed sage that had greatly increased in size and weight. Fringed sage composed around 50% of the forb basal cover and almost all of the forb herbage weight. A small amount of domesticated and introduced mid cool season grasses had encroached into the fertilized pasture by 1982. This plant species intrusion was not recognized as a serious problem at that time because the domesticated and introduced grasses had produced only 517.05 lbs per acre of herbage weight and occupied only 1.96% basal cover.

The residual effects from nitrogen fertilization of native rangeland continued to change the plant species composition for an additional twenty two years after the fertilization treatments had stopped. During 1997 to 2004, the total herbage weight was 69.7% greater on the fertilized pasture than on the unfertilized pasture. However, the composition of the herbage weight had greatly changed; domesticated and introduced grasses composed 78.0%, native grasses composed 17.3%, and forbs composed 4.6% of the total herbage weight. Cool season grass herbage weight had decreased 72.3%, composition had decreased 82.4%, and basal cover had decreased 75.3%. Warm season grass herbage weight had decreased 69.9%, composition had decreased 82.1%, and basal cover had decreased 67.7%. Upland sedge herbage weight had decreased 37.5%, composition had decreased 58.9%, and basal cover had decreased 38.0%. Forb herbage weight had decreased 54.0%, composition had decreased 69.5%, and basal cover had decreased 64.1%. Domesticated and introduced grass herbage weight had increased 1539.0%, composition had increased 936.9%, and basal cover had increased 405.7%. The small encroachment of nonnative grasses had transformed into an overwhelming occupation.

After eleven years of fertilization treatments, native mid cool season grasses had greatly increased in herbage weight and basal cover. Herbage weight the other native grasses had decreased less than the mid cool season grasses had increased. Total native grass herbage weight had increased 63.6%, however, total native grass basal cover had decreased 27.9% in eleven years. Twenty two years after treatments had stopped, native grass herbage weight had decreased 82.7% and basal cover had decreased 60.3%. Fertilization of native rangeland caused native warm season grasses, cool season grasses, and upland sedges to decrease greatly, and after 33 years of plant species composition change, the native grasses only composed 17.3% of the total herbage weight and 38.0% of the total basal cover.

Domesticated and introduced grasses started from zero and increased slowly, and after eleven years of fertilization treatments, domesticated and introduced grasses composed 14.1% of the total herbage weight and composed 11.2% of the total basal cover. Twenty two years after treatments had stopped, domesticated and introduced grass herbage weight had increased 342.5% and basal cover had increased 532.1%. Fertilization of native rangeland caused domesticated and introduced grasses to increase greatly, and after 33 years of plant species composition change, the domesticated and introduced grasses composed 78.0% of the total herbage weight and 56.4% of the total basal cover.

Nitrogen fertilization of native rangeland changed the plant species composition from a mixed grass prairie community of warm season grasses, cool season grasses, upland sedges, and prairie forbs to a community dominated by introduced and domesticated mid cool season grasses in 33 years. The residual effects from nitrogen fertilization continue to change the plant species composition of the fertilized rangeland pasture.

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Table 1. Precipitation in inches for growing season months and the annual total precipitation for 1972-1982, Dickinson, North Dakota.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Growing Season	Annual Total
Long-term mean 1892-2007	1.43	2.34	3.55	2.22	1.73	1.33	0.95	13.55	16.00
1972	1.27	5.09	4.29	2.72	2.90	0.74	1.56	18.57	20.76
% of LTM	88.81	217.52	120.85	122.52	167.63	55.64	164.21	137.05	129.75
1973	3.21	1.30	3.04	0.91	0.47	2.23	0.67	11.83	13.53
% of LTM	224.48	55.56	85.63	40.99	27.17	167.67	70.53	87.31	84.56
1974	2.82	4.15	2.00	1.50	0.90	0.56	0.52	12.45	14.15
% of LTM	197.20	177.35	56.34	67.57	52.02	42.11	54.74	91.88	88.44
1975	4.25	3.34	4.27	0.64	0.54	0.80	1.42	15.26	17.71
% of LTM	297.20	142.74	120.28	28.83	31.21	60.15	149.47	112.62	110.69
1976	2.11	1.42	3.74	0.75	0.40	1.77	0.65	10.84	12.68
% of LTM	147.55	60.68	105.35	33.78	23.12	133.08	68.42	80.00	79.25
1977	0.13	2.60	5.38	1.08	1.52	5.78	2.16	18.65	23.13
% of LTM	9.09	111.11	151.55	48.65	87.86	434.59	227.37	137.64	144.56
1978	1.81	3.99	2.10	2.41	2.01	2.56	0.29	15.17	17.63
% of LTM	126.57	170.51	59.15	108.56	116.18	192.48	30.53	111.96	110.19
1979	1.28	0.91	3.06	2.22	2.21	1.27	0.17	11.12	12.81
% of LTM	89.51	38.89	86.20	100.00	127.75	95.49	17.89	82.07	80.06
1980	0.03	0.12	2.67	1.43	3.31	0.76	2.41	10.73	12.58
% of LTM	2.10	5.13	75.21	64.41	191.33	57.14	253.68	79.19	78.63
1981	0.66	1.30	3.71	1.57	4.05	2.75	0.23	14.27	15.76
% of LTM	46.15	55.56	104.51	70.72	234.10	206.77	24.21	105.31	98.50
1982	1.85	4.32	3.43	2.02	2.63	1.77	6.51	22.53	26.58
% of LTM	129.37	184.62	96.62	90.99	152.02	133.08	685.26	166.27	166.13
1972-1982	1.77	2.59	3.43	1.57	1.90	1.91	1.51	14.67	17.30
% of LTM	123.78	110.68	96.62	70.72	109.83	143.61	158.95	108.27	108.13

Table 2. Precipitation in inches for growing-season months and the annual total precipitation for 1997-2004, Dickinson, North Dakota.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Growing Season	Annual Total
Long-term mean 1892-2007	1.43	2.34	3.55	2.22	1.73	1.33	0.95	13.55	16.00
1997	3.29	0.92	2.19	6.36	0.91	0.09	0.98	14.74	23.13
% of LTM	230.07	39.32	61.69	286.49	52.60	6.77	103.16	108.78	144.56
1998	0.85	1.86	6.55	1.82	2.90	2.03	4.50	20.51	17.63
% of LTM	59.44	79.49	184.51	81.98	167.63	152.63	473.68	151.37	110.19
1999	1.48	3.94	1.99	0.99	3.23	2.25	0.32	14.20	12.81
% of LTM	103.50	168.38	56.06	44.59	186.71	169.17	33.68	104.80	80.06
2000	1.38	1.80	3.09	3.45	0.35	1.11	0.73	11.91	12.58
% of LTM	96.50	76.92	87.04	155.41	20.23	83.46	76.84	87.90	78.63
2001	2.08	1.75	7.15	3.99	0.00	2.53	0.24	17.74	15.76
% of LTM	145.45	74.79	201.41	179.73	0.00	190.23	25.26	130.92	98.50
2002	1.39	2.06	4.75	2.98	2.81	0.17	1.31	15.47	26.58
% of LTM	97.20	88.03	133.80	134.23	162.43	12.78	137.89	114.17	166.13
2003	0.69	2.67	2.81	0.93	1.46	2.17	0.72	11.45	12.59
% of LTM	48.25	114.10	79.15	41.89	84.39	163.16	75.79	84.50	78.69
2004	0.96	1.40	0.54	2.42	0.63	1.53	2.78	10.26	15.54
% of LTM	67.13	59.83	15.21	109.01	36.42	115.04	292.63	75.72	97.13
1997-2004	1.52	2.05	3.63	2.87	1.54	1.49	1.45	14.54	17.08
% of LTM	106.29	87.61	102.25	129.28	89.02	112.03	152.63	107.31	106.75

Table 3. Evaluation of mean herbage yield on native rangeland pasture fertilization trial, 1972-1988.

Years	Unfertilized Mean Herbage Yield lbs/ac	Fertilized Mean Herbage Yield lbs/ac	Weight Difference from Unfertilized lbs/ac	Percent Difference from Unfertilized %
1972	3160.00	4421.00	1261.00	39.91
1973	2367.00	3448.00	1081.00	45.67
1974	3079.00	5270.00	2191.00	71.16
1975	2462.00	4069.00	1607.00	65.27
1976	2315.00	2842.00	527.00	22.76
1977	1640.00	2021.00	381.00	23.23
1978	1998.95	3201.20	1202.25	60.14
1979	1308.90	1976.55	667.65	51.01
1980	1296.45	1386.85	90.40	6.97
1981	1809.15	2263.05	453.90	25.09
1982	1911.60	3657.95	1746.35	91.36
1983				
1984	1115.00			
1985	1279.30			
1986	1702.01			
1987	1622.56			
1988	451.23			

Table 4. Monthly dry matter weight in pounds per acre for treatments on the evaluation of native rangeland pasture fertilization trial, 1982.

Plant Categories Treatments	15 May	15 Jun	15 Jul	15 Aug	15 Sep
Unfertilized					
cool season	429.6	834.9	1506.1	1232.0	1147.7
warm season	9.3	178.1	520.2	965.9	404.4
total native grass	438.9	1013.0	2026.3	2197.9	1552.1
introduced grass	0.0	0.0	0.0	0.0	0.0
forbs	31.4	199.5	231.6	222.6	203.4
total yield	470.3	1212.5	2257.9	2420.5	1755.5
Fertilized					
cool season	1085.4	2690.6	3260.0	2332.8	2233.6
warm season	54.2	71.0	229.8	162.7	126.1
total native grass	1139.6	2761.6	3489.8	2495.5	2359.7
introduced grass	0.0	201.2	895.9	707.1	264.0
forbs	10.7	205.5	480.3	638.0	133.2
total yield	1150.3	3168.3	4866.0	3840.6	2756.9

Table 5. Percent composition of weight yield for treatments on the evaluation of native rangeland pasture fertilization trial, 1982.

Plant Categories Treatments	15 May	15 Jun	15 Jul	15 Aug	15 Sep
Unfertilized					
cool season	91.35	68.86	66.70	50.90	65.38
warm season	1.98	14.69	23.04	39.90	23.04
total native grass	93.32	83.55	89.74	90.80	88.41
introduced grass	0.0	0.0	0.0	0.0	0.0
forbs	6.68	16.45	10.26	9.20	11.59
total yield	470.3	1212.5	2257.9	2420.5	1755.5
Fertilized					
cool season	94.36	84.92	67.00	60.74	81.02
warm season	4.71	2.24	4.72	4.24	4.57
total native grass	99.07	87.16	71.72	64.98	85.59
introduced grass	0.0	6.35	18.41	18.41	9.58
forbs	0.93	6.49	9.87	16.61	4.83
total yield	1150.3	3168.3	4866.0	3840.6	2756.9

Table 6. Dry matter weight in pounds per acre for treatments on the evaluation of native rangeland pasture fertilization trial, 1982-1988.

Years Treatments	Warm Season Grass	Cool Season Grass	Sedge	Total Native Grass	Domesticated Grass	Forbs	Total Yield
1982							
unfertilized	517.15	898.28	281.90	1697.33	0.0	214.27	1911.60
fertilized	147.40	2392.55	236.70	2776.65	517.05	364.25	3657.95
1983							
unfertilized							
fertilized							
1984							
unfertilized	222.39	324.14	448.77	995.30	0.0	119.70	1115.00
fertilized							
1985							
unfertilized	231.72	364.06	615.47	1211.25	0.0	68.05	1279.30
fertilized							
1986							
unfertilized	379.73	519.63	587.30	1486.66	0.0	215.35	1702.01
fertilized							
1987							
unfertilized	339.96	457.55	676.40	1473.91	0.0	148.65	1622.56
fertilized							
1988							
unfertilized	92.03	89.54	208.58	390.15	0.0	61.08	451.23
fertilized							

Table 7. Percent composition of weight yield for treatments on the evaluation of native rangeland pasture fertilization trial, 1982-1988.

Years Treatments	Warm Season Grass	Cool Season Grass	Sedge	Total Native Grass	Domesticated Grass	Forbs	Total Yield
1982							
unfertilized	27.05	46.99	14.75	88.79	0.0	11.21	1911.60
fertilized	4.03	65.41	6.47	75.91	14.13	9.96	3657.95
1983							
unfertilized							
fertilized							
1984							
unfertilized	19.95	29.07	40.25	89.26	0.0	10.74	1115.00
fertilized							
1985							
unfertilized	18.11	28.46	48.11	94.68	0.0	5.32	1279.30
fertilized							
1986							
unfertilized	22.31	30.53	34.51	87.35	0.0	12.65	1702.01
fertilized							
1987							
unfertilized	20.95	28.20	41.69	90.84	0.0	9.16	1622.56
fertilized							
1988							
unfertilized	20.40	19.84	46.22	86.46	0.0	13.54	451.23
fertilized							

Table 8. Basal cover of plant categories for treatments on the evaluation of native rangeland pasture fertilization trial, 1982-1988.

Years Treatments	Warm Season Grass	Cool Season Grass	Sedge	Total Native Grass	Domesticated Grass	Forbs	Total Basal Cover
1982							
unfertilized	9.94	4.47	6.64	21.05	0.36	1.40	22.81
fertilized	3.20	6.27	5.70	15.17	1.96	0.34	17.47
1983							
unfertilized							
fertilized							
1984							
unfertilized							
fertilized							
1985							
unfertilized	14.78	4.48	8.93	28.19	0.08	2.48	30.75
fertilized							
1986							
unfertilized	10.11	8.69	12.18	30.98	0.0	4.66	35.64
fertilized							
1987							
unfertilized	4.96	5.42	10.30	20.68	0.0	4.69	25.37
fertilized							
1988							
unfertilized	8.51	5.21	7.88	21.60	0.0	5.23	26.83
fertilized							

Table 9. Evaluation of mean herbage yield on native rangeland pasture fertilization trial, 1997-2004.

Years	Unfertilized Mean Herbage Yield lbs/ac	Fertilized Mean Herbage Yield lbs/ac	Weight Difference from Unfertilized lbs/ac	Percent Difference from Unfertilized %
1997	1442.66a	2238.32b	795.66	55.15
1998	1385.57a	1997.12a	611.55	44.14
1999	1157.94a	2293.04b	1135.10	98.03
2000	696.71a	1132.48b	435.77	62.55
2001	1495.00a	3034.71b	1539.71	102.99
2002	1261.17a	1877.24b	616.07	48.85
2003				
2004	705.75a	1090.86b	385.11	54.57

Means for each year in the same row and followed by the same letter are not significantly different (P<0.05).

Table 10. Dry matter weight in pounds per acre for treatments on the evaluation of native rangeland pasture fertilization trial, 1997-2004.

Years Treatments	Warm Season Grass	Cool Season Grass	Sedge	Total Native Grass	Domesticated Grass	Forbs	Total Yield
1997							
unfertilized	226.21a	279.02a	456.70a	961.94a	159.13a	321.59a	1442.66a
fertilized	238.10a	285.44a	428.87a	952.42a	1063.03b	222.88a	2238.32b
1998							
unfertilized	322.07a	527.35a	305.42a	1154.84a	0.0a	230.73a	1385.57a
fertilized	33.06b	157.47a	204.09a	394.62b	1524.01b	78.50a	1997.12a
1999							
unfertilized	190.30a	501.66a	159.37a	851.33a	168.65a	137.96a	1157.94a
fertilized	27.12b	58.76b	91.82a	177.69b	2031.62b	83.73a	2293.04b
2000							
unfertilized	148.67a	186.49a	165.08a	500.23a	105.37a	91.10a	696.71a
fertilized	40.91a	39.01b	77.78a	157.71b	949.32b	25.45b	1132.48b
2001							
unfertilized	227.64a	465.27a	341.58a	1034.49a	185.06a	275.45a	1495.00a
fertilized	28.31b	44.72b	137.73a	210.75b	2757.11b	66.84b	3034.71b
2002							
unfertilized	217.65a	493.10a	335.87a	1046.61a	31.87a	182.68a	1261.17a
fertilized	29.97b	82.30b	136.54b	248.81b	1551.84b	76.59a	1877.24b
2003							
unfertilized							
fertilized							
2004							
unfertilized	73.50a	286.39a	182.45a	542.34a	51.85a	111.56a	705.75a
fertilized	16.17a	63.99b	135.35a	215.51b	818.50b	56.85a	1090.86b

Means for each year in the same column and followed by the same letter are not significantly different (P<0.05).

Table 11. Percent composition of weight yield for treatments on the evaluation of native rangeland pasture fertilization trial, 1997-2004.

Years Treatments	Warm Season Grass	Cool Season Grass	Sedge	Total Native Grass	Domesticated Grass	Forbs	Total Yield
1997							
unfertilized	16.01a	19.20a	30.68a	65.90a	12.08a	22.03a	1442.66
fertilized	11.18a	13.23a	20.36a	44.77a	44.73a	10.49b	2238.32
1998							
unfertilized	26.84a	37.44a	21.65a	85.92a	0.0a	14.08a	1385.57
fertilized	1.63b	8.20b	10.25b	20.08b	75.97b	3.95b	1997.12
1999							
unfertilized	18.13a	44.46a	12.83a	75.41a	12.32a	12.26a	1157.94
fertilized	1.44b	2.94b	4.02a	8.40b	88.02b	3.58b	2293.04
2000							
unfertilized	22.35a	26.72a	23.09a	72.17a	13.73a	14.10a	696.71
fertilized	4.01b	3.80b	6.65b	14.46b	83.27b	2.27b	1132.48
2001							
unfertilized	16.25a	32.83a	21.88a	70.97a	10.99a	18.04a	1495.00
fertilized	1.12b	1.83b	4.77b	7.72b	89.17b	2.40b	3034.71
2002							
unfertilized	17.57a	39.79a	26.47a	83.83a	2.26a	13.91a	1261.17
fertilized	1.56b	4.40b	7.23b	13.18b	82.73b	4.09b	1877.24
2003							
unfertilized							
fertilized							
2004							
unfertilized	10.42a	40.59a	26.01a	77.02a	7.31a	15.66a	705.75
fertilized	1.61b	5.88b	12.81a	20.29b	74.47b	5.23b	1090.86

Means for each year in the same column and followed by the same letter are not significantly different (P<0.05).

Table 12. Basal cover of plant categories for treatments on the evaluation of native rangeland pasture fertilization trial, 1997-2004.

Years Treatments	Warm Season Grass	Cool Season Grass	Sedge	Total Native Grass	Domesticated Grass	Forbs	Total Basal Cover
1997							
unfertilized							
fertilized							
1998							
unfertilized	9.93a	3.63a	4.33a	17.93a	1.17a	1.97a	21.07a
fertilized	2.70b	0.85b	3.37a	6.92b	4.67b	0.73a	12.32b
1999							
unfertilized	7.90a	7.16a	5.33a	20.39a	4.09a	2.57a	27.05a
fertilized	2.43b	1.72b	2.02b	6.17b	17.40b	0.71b	24.28a
2000							
unfertilized	7.25a	3.79a	6.17a	17.21a	1.49a	2.61a	21.31a
fertilized	3.25a	0.92b	5.47a	9.64b	10.40b	0.63b	20.67a
2001							
unfertilized	6.87a	6.20a	8.17a	21.24a	2.86a	4.37a	28.47a
fertilized	2.35b	1.73b	5.63a	9.71b	17.90b	0.82a	28.43a
2002							
unfertilized	7.00a	5.81a	9.77a	22.58a	2.87a	5.10a	30.55a
fertilized	2.48b	1.20b	4.52b	8.20b	13.09b	1.65b	22.94b
2003							
unfertilized	7.92a	4.28a	8.28a	20.48a	1.27a	2.98a	24.73a
fertilized	2.85b	1.20b	6.72a	10.77b	8.88b	2.17a	21.82a
2004							
unfertilized	4.48a	4.34a	6.10a	14.92a	6.25a	5.25a	26.42a
fertilized	1.37a	1.45b	6.20a	9.02b	16.64b	1.87b	27.53a

Means for each year in the same column and followed by the same letter are not significantly different ($P<0.05$).

Table 13. Basal cover of plant subcategories for treatments on the evaluation of native rangeland pasture fertilization trial, 1982, 1985-1988, 1998-2004.

Years Treatments	Warm Season Grass		Cool Season Grass		Domesticated Grass		
	mid warm	short warm	mid cool	short cool	crested wheatgrass	smooth bromegrass	bluegrass
1982							
unfertilized	0.64	9.30	2.47	2.00	0.00	0.03	0.33
fertilized	0.03	3.17	4.80	1.47	0.67	0.63	0.66
1985-1988							
unfertilized	1.56	8.39	2.83	3.36	0.00	0.03	0.00
fertilized							
1998-2004							
unfertilized	0.95	6.98	3.04	2.37	0.21	1.65	0.59
fertilized	0.19	2.55	1.03	0.31	4.54	4.21	3.64

Table 14. Fate of applied fertilizer nitrogen on native rangeland pasture, 1972-1982, following first approximation percentages of fertilizer nitrogen fate in grazed semiarid rangeland developed by Power (1977).

Biotic and Abiotic Nitrogen Sinks	Fate of N as Percent of Applied Data from Power 1977 %			Fate of N from 50 lbs N/ac per year lbs N/yr			Fate of N from 550 lbs N/ac per 11 years lbs N/11 yrs		
Retained in Ecosystem			92%			46.0			506.0
Plants		22%			11.0			121.0	
aboveground herbage	2%			1.0			11.0		
crown	1%			0.5			5.5		
roots	19%			9.5			104.5		
Litter		16%			8.0			88.0	
Soil Mineral Nitrogen		41%			20.5			225.5	
ammonium NH_4	2%			1.0			11.0		
nitrate NO_3	39%			19.5			214.5		
Soil Organic Nitrogen unmeasured estimate		13%			6.5			71.5	
Lost to Ecosystem			8%			4.0			44.0
Beef Tissue		3%			1.5			16.5	
Gaseous Losses unmeasured estimate		5%			2.5			27.5	
Leaching		0%			0.0			0.0	

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Influence of Soil Mineral Nitrogen on Native Rangeland Plant Water Use Efficiency and Herbage Production

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Native rangelands managed by traditional grazing practices are deficient in available soil mineral nitrogen and produce less than potential quantities of herbage biomass (Wight and Black 1972). The biogeochemical processes of these rangeland ecosystems typically function at levels that cycle nitrogen at rates of about 59 pounds or less of mineral nitrogen per acre per year and produce only one half to one third of the potential quantities of herbage biomass (Wight and Black 1972). The remedy for the problem of low herbage production on native rangeland is not repetitive applications of nitrogen fertilizer because the additional herbage produced from nitrogen fertilization has unprofitably high costs (Manske 2009b) and the long-term effects from nitrogen fertilization cause shifts in plant species composition with reductions of the native grass species and increases of the domesticated and introduced grass species (Manske 2009a). However, the results from more than three decades of nitrogen fertilization research on native rangelands provides insight into the underlying causes of the problem of herbage production at below potential quantities on native rangelands managed by traditional grazing practices.

Nitrogen fertilization of native rangeland increases the quantity of available soil mineral nitrogen. Total herbage biomass production on native rangeland increases with the increases in quantity of soil mineral nitrogen (Rogler and Lorenz 1957, Whitman 1957, Whitman 1963, Smika et al. 1965, Goetz 1969, Power and Alessi 1971, Lorenz and Rogler 1972, Goetz 1975, Taylor 1976, Whitman 1976, Goetz et al. 1978, Wight and Black 1979). The greater quantities of available soil mineral nitrogen cause the soil water use efficiency to improve in grassland plants (Smika et al. 1965, Wight and Black 1972, Whitman 1976, 1978). Water use efficiency (pounds of herbage produced per inch of water use) is difficult to measure quantitatively because soil water can be lost through evaporation or transpiration. Precipitation use efficiency (pounds of herbage produced per inch of precipitation received) is less complicated to measure than water use efficiency. Wight and Black (1972) found that precipitation use efficiency of grasslands improved with increased quantities of soil mineral nitrogen and that the pounds of herbage produced per inch of precipitation were greater on the nitrogen fertilized treatments than on the unfertilized treatments. Wight and Black (1979) compared herbage production on traditionally managed rangeland with the typical ambient deficiency of available mineral nitrogen to herbage production on nitrogen fertilized rangeland without a deficiency of available mineral nitrogen. During ten years of study with normal growing season precipitation, the deficiency of mineral nitrogen on the traditionally managed rangeland caused the weight of herbage production per inch of precipitation received to be reduced an average of 49.6% below the herbage produced per inch of precipitation on the rangeland without a mineral nitrogen deficiency.

Nitrogen cycling in Northern Plains rangeland ecosystems managed by traditional grazing practices is inadequate to supply the quantity of mineral nitrogen necessary for minimum potential herbage production. A deficiency in available mineral nitrogen causes reductions in grassland plant water use efficiency and reductions in herbage biomass production to below potential levels during growing seasons with normal precipitation and no deficiency in available water. During growing seasons with below normal precipitation, both the deficiency in available water and the deficiency in available mineral nitrogen contribute to the resulting reductions in herbage production. During drought growing seasons, the percent reduction in herbage production is greater than the percent reduction in precipitation because of the additional reductions in water use efficiency and herbage production caused by the deficiency of mineral nitrogen. Semiarid rangelands would produce herbage biomass at the maximum level for whatever soil water was available if the ecosystems were not deficient in mineral nitrogen (Power and Alessi 1971). Herbage production on native rangeland ecosystems at minimum potential herbage yields would require nitrogen cycling at a rate of about 100 pounds of available mineral nitrogen per acre per year and that maximum potential herbage yields would be produced at rates of about 165 pounds of mineral nitrogen per acre per year (Wight and Black 1972).

Native rangeland plants need hydrogen, carbon, and nitrogen to produce herbage biomass. The hydrogen comes from soil water absorbed through the roots. The carbon comes from atmospheric carbon dioxide fixed through photosynthesis in the leaves. The nitrogen comes from the mineral nitrogen mineralized from soil organic nitrogen by rhizosphere microorganisms (Manske 2007). The total amount of energy fixed by chlorophyllous plants on rangeland ecosystems is not limited by the availability of radiant energy from the sun or by the availability of atmospheric carbon dioxide. The availability of water, which is an essential requirement for plant growth and has a dominant role in physiological processes, does not limit herbage production on rangeland ecosystems to the extent that mineral nitrogen availability does (Wight and Black 1972). Available soil mineral nitrogen is the major herbage growth limiting factor in Northern Plains rangelands (Wight and Black 1979). Grassland soils are not deficient of nitrogen and do not require application of additional fertilizer nitrogen. Most of the grassland nitrogen is immobilized in the soil as organic nitrogen in living tissue and nonliving detritus. Grassland soils in the Northern Plains contain about 3 to 8 tons of organic nitrogen per acre. Soil organic nitrogen must be converted into mineral nitrogen through mineralization by soil microorganisms in order to be available to grassland plants. The greater the biomass of soil microorganisms, the greater the quantity of available mineral nitrogen.

Rangelands managed by the twice-over rotation grazing strategy are not deficient in available mineral nitrogen. The biologically effective twice-over rotation grazing management strategy is designed to use partial defoliation of grass tillers at beneficial phenological growth stages to meet the biological requirements of grassland plants and to stimulate rhizosphere organism activity that enhances the biogeochemical processes in grassland ecosystems and increases the quantity of organic nitrogen mineralized into inorganic (mineral) nitrogen at amounts sufficient for herbage production at maximum potential yield levels (Manske 2007).

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Enhancement of the Nitrogen Cycle Improves Native Rangeland

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Available soil mineral nitrogen is the major limiting factor of herbage growth on native rangelands (Wight and Black 1979). Rangeland soils, however, are not deficient of nitrogen. Most of the nitrogen in rangeland ecosystems is in the organic form. A large amount of the organic nitrogen is immobilized in living tissue of microorganisms, plants, and animals as essential constituents of proteins and nucleic acids. An additional large amount of the soil organic nitrogen is contained in the soil organic matter detritus that is at various stages of physical breakdown and decomposition and is derived from dead organisms, excreta, and sloughed material. A small portion of the soil nitrogen is in the mineral form as ammonium, nitrate, and nitrite. The amount of available mineral nitrogen in the soil is affected by the rate of mineralization of the organic nitrogen by soil microorganisms. A minimum rate of mineralization of about 100 pounds of mineral nitrogen per acre per year is required to sustain herbage production at potential levels on native rangeland (Wight and Black 1972). Mineralization at these high rates can not be obtained from traditional grazing practices (Wight and Black 1972). Grazing management specifically designed to enhance soil microorganism activity can be implemented to obtain mineralization rates of 100 pounds of mineral nitrogen per acre per year or greater. Enhancement of the nitrogen cycle, with increases in the quantity of available soil mineral nitrogen, increases herbage growth and production and improves new wealth generation from native rangeland natural resources.

The nitrogen cycle in rangeland ecosystems is complex. Nitrogen is versatile and has several oxidation states and can exist as a gas, a dissolved cation or anion, a precipitated salt, an adsorbed or interlayer ion in clay, and as dissolved or solid organic molecules of varying complexity (Russelle 1992). Nitrogen moves through a variety of biological and chemical pathways and the movement within the cycle is difficult to predict and highly variable among different climatic zones because the nitrogen cycle pathways are directly or indirectly influenced by regional temperature and moisture regimes. Biological pathways are also influenced by metabolic rates of microorganisms, plants, and animals (Russelle 1992). The nitrogen cycle in rangelands is open and has inputs (gains) that transfer in from outside sources and has outputs (losses) that transfer out of the ecosystem.

Nitrogen inputs on rangelands arrive through atmospheric pathways as wet deposits in rain, snow, or hail and as dry deposits of gases or minute particles. Lightning discharges cause atmospheric nitrogen (N_2) and oxygen (O_2) to combine and produce nitrogen oxides, mainly nitric acid (NO) and dinitrogen oxide (N_2O), that are deposited on rangeland in precipitation. Inorganic nitrogen, as ammonium (NH_4) and nitrate (NO_3), and complex organic compounds removed by erosive forces from distant soil surfaces are deposited on rangelands in precipitation, wind, and sometimes overland water movement. The ambient amount of wet and dry nitrogen deposition in temperate regions from natural sources is around 5 to 6 pounds per acre per year (Brady 1974). Nitrogen deposits from other sources are primarily nitrogen oxides expelled in the exhaust emissions from cars, aircraft, and factories. The amount of nitrogen deposits from sources related to anthropogenic activity is highly variable, influenced by distance and direction from population centers, and can range from 0 to 15 pounds per acre per year or greater (Gibson 2009).

Symbiotic and nonsymbiotic fixation of atmospheric nitrogen is an input source of nitrogen for some mesic grasslands but generally not for semiarid rangelands. Strains of symbiotic Rhizobium bacteria form nodules on the roots of legumes and can fix atmospheric dinitrogen gas (N_2) in soil air and synthesize it into complex forms. Some of this fixed nitrogen is required by the bacteria, some of the nitrogen can be available to the host plant, and some of the nitrogen can be passed into the surrounding soil by excretion or by the sloughing off of the roots with nodules (Brady 1974). Legumes are not an abundant component in native rangelands and the legumes that are present in mature soils have low levels of nodulation and may not fix nitrogen (Gibson 2009). A few nonsymbiotic soil microorganisms are able to fix atmospheric dinitrogen (N_2) from soil air into their body tissue (Brady 1974). Nitrogen fixation by free living soil bacteria in semiarid rangelands is not known to be important and considered to be insignificantly low or nonexistent (Legg 1995, Gibson 2009).

Potential outputs for nitrogen from rangeland ecosystems can be lost to the atmosphere through denitrification of mineral nitrogen, ammonia volatilization, and volatilization by fire; lost through transfers by wind and water erosion of surface soil and by hydrologic leaching; and lost through animal production of both domesticated livestock and wildlife.

Denitrification is the reduction of inorganic nitrogen by removal of oxygen from the nitrite (NO_2) and nitrate (NO_3) mineral nitrogen to form gaseous nitrous oxides (NO and N_2O) or nonreactive dinitrogen gas (N_2) and can be mediated both chemically and biologically (Brady 1974). Losses from denitrification in rangelands is greatest in the nitrous oxide form (N_2O), followed by losses in the dinitrogen form (N_2). Losses in the nitric oxide form (NO) occur on rangelands only under acid conditions (Brady 1974). Chemical denitrification is of little importance in native rangelands unless nitrate is present in high concentrations (Russelle 1992). Biological denitrification occurs when soil microorganisms are deficient of oxygen as a result of poor drainage or poor soil structure causing soil saturation or lack of aeration. Denitrification probably accounts for only a small part of the total nitrogen losses from pastures and rangelands (Legg 1975, Gibson 2009).

Ammonia volatilization can occur near the soil surface during mineralization of soil organic nitrogen by soil microorganisms (Foth 1978). Gaseous ammonia (NH_3) forms as an intermediate stage and is usually readily hydrolyzed to form ammonium (NH_4) which is a stable form of mineral nitrogen. However, under conditions of increasing aridity and decreasing availability of hydrogen ions, the hydrolyzation process decreases and the amount of ammonia that escapes into the atmosphere by volatilization increases (Gibson 2009).

Nitrogen contained in aboveground herbage and litter is volatilized when rangelands are burned by prescribed fire and wild fire. Combustion causes nitrogen losses approaching 90%, primarily as ammonia (NH_3), dinitrogen oxide (N_2O), and other nitrogen oxides (Russelle 1992). Little belowground nitrogen is volatilized when the soil is moist during a burn, however, when the soil is dry, belowground temperatures can increase enough to denature protein, killing portions of the grass crowns and root material and volatilizing some belowground nitrogen.

Nitrogen in soil, litter, and organic detritus can be transferred from one area to another through movement by wind and water. The transferred nitrogen is a loss from one area and a gain at the deposition area. Nitrogen losses through erosion removal are variable and influenced by live plant density, litter cover, extent of branching fiberous root systems, and soil infiltration rates. The quantity of nitrogen lost through erosional movement can be decreased with enhancement of the nitrogen cycle and improvement in productivity of the rangeland ecosystem (Russelle 1992).

Soluble nitrate (NO_3) moves downward in the soil profile with soil water. In mesic grasslands, nitrogen can be lost as a result of water movement below the rooting depth (Russelle 1992). None of the mineral nitrogen in western rangelands is lost by hydrologic leaching through the soil profile (Power 1970) because very little water moves below the three foot soil depth and water loss by leaching is low or nonexistent in arid and semiarid rangelands under cover of perennial vegetation (Brady 1974, Wight and Black 1979).

Livestock grazing semiarid rangelands in the Northern Plains consume about 25% of the aboveground herbage, leaving a significant part of the nitrogen absorbed by the growing vegetation in the remaining live aboveground herbage, the standing dead vegetation, and the litter. Most of the nitrogen consumed by grazing livestock and wildlife is returned to the soil surface in urine and feces waste. Almost all of the nitrogen in urine is immediately available to plants. A portion of the urea in urine can be volatilized in warm dry conditions (Gibson 2009). Grazing animals retain only a small amount of the nitrogen consumed, about 15% to 17% in a nonlactating animal and about 30% in a lactating animal (Russelle 1992). The quantity of nitrogen lost as animal product increases as enhancement of the nitrogen cycle improves productivity of the rangeland ecosystem.

Differences in nitrogen inputs and outputs on rangeland soils determine the quantity of net accumulation of nitrogen. The total nitrogen content in soils accumulates gradually over several thousand years. Organic matter accumulation is benefitted in northern soils because little or no chemical oxidation activity of organic matter takes place during the cold periods. The dark surface layer of most soils in the Northern Plains has an accumulation of 2% to 5% organic matter (Larson et al. 1968, Wright et al. 1982). An acre of soil 6 inches deep contains about 1000 pounds of nitrogen for each percent of organic matter (Foth 1978). Nitrogen content and percent organic matter decrease with soil depth. A net accumulation of 2 pounds of nitrogen per acre per year results in a soil with 5 tons of nitrogen per acre in 5000 years.

The nitrogen cycle within rangeland soils functions around the two processes of immobilization and mineralization. These processes take place simultaneously with plant growth, dieback, and decomposition (Legg 1975). Immobilization is the process of tying up nitrogen in organic forms.

Mineralization is the process of converting organic nitrogen into mineral (inorganic) nitrogen.

Biological immobilization of nitrogen occurs when autotrophic plants and soil microorganisms absorb inorganic nitrogen and build essential organic nitrogen compounds of amino acids and nucleic acids. Amino acids are building blocks of proteins that form enzymes, hormones, and important structural components of cells. Nucleic acids, deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), are the genetic material that control all cellular functions and heredity. In rangeland soils, nitrogen is tied up in organic forms for three to four years (Power 1972). Biological immobilization of mineral nitrogen by plants and soil microorganisms is beneficial for rangeland ecosystems because about 95% of the total nitrogen is preserved within the soil as organic nitrogen and not subjected to great potential losses through denitrification and ammonia volatilization (Legg 1975, Gibson 2009).

Chemical immobilization of mineral nitrogen by adsorption of ammonium onto clay particles can be an advantage or a disadvantage for rangeland ecosystems depending on the type and amount of clay present. The ammonium ions are apparently the right size to fit into the cavities between crystal units normally occupied by potassium making the ammonium more or less a rigid part of the crystal (Brady 1974, Foth 1978). The type of clay mineral affects the retention of the ammonium. Clay materials with expanding lattices, such as vermiculite, illite, and montmorillonite, have greater surface area and adsorptive capacity for ammonium than clay minerals with nonexpanding lattices, such as kaolinite (Brady 1974, Legg 1975). Chemical immobilization of ammonium to clay material protects that portion of the soil mineral nitrogen from potential losses. The ammonium is slowly released from the clay and made available to plants and soil microorganisms. When the quantity of clay is too high or when the ammonium release rate is too slow, available mineral nitrogen may be too low to maintain ecosystem productivity at potential levels.

Mineralization occurs when organic nitrogen immobilized in living tissue or contained in soil organic matter detritus is processed by soil microorganisms to form mineral nitrogen. Mineralization consists of a series of reactions. Complex proteins and other organic nitrogen compounds are simplified by enzymatic digestion that hydrolyze the peptide bonds and liberate and degrade the amino acids by deamination to produce ammonia (NH_3) and carbon dioxide, or other low molecular weight carbon compounds (Power 1972, Brady 1974). Most of the released ammonia is readily hydrolyzed into ammonium (NH_4) which becomes part of the inorganic nitrogen pool in the soil.

Some of the ammonium produced during the mineralization process by soil microorganisms or the ammonium released from adsorption to clay material is nitrified in a complex two stage process coordinated by two distinct groups of soil bacteria. Ammonium is nitrified by enzyme oxidation that releases energy for the first group of bacteria and produces nitrite (NO_2) and water. In short order, the second group of bacteria oxidize the nitrite by enzyme activity that releases energy and produces nitrate (NO_3) which becomes part of the inorganic nitrogen pool in the soil. The speed of this coordinated two stage nitrification process prevents accumulation of nitrite in the soil. Concentrations of nitrite are toxic to higher plants (Brady 1974).

The quantity of available soil mineral nitrogen varies cyclically with changes in soil temperature, soil microorganism biomass, and plant phenological growth and development during the growing season (Whitman 1975) and is the net difference between the total quantity of organic nitrogen mineralized by soil microorganisms and the quantity of mineral nitrogen immobilized by plants (Brady 1974, Legg 1975). The relationships between soil microorganism activity and phenology of plant growth activity results in a dynamic cycle of available mineral nitrogen (Goetz 1975). When soil microorganism activity is greater than plant growth activity, the quantity of available mineral nitrogen increases. When plant growth activity is greater than soil microorganism activity, the quantity of available mineral nitrogen decreases. This cycle in available soil mineral nitrogen results in three peaks and three low periods during the growing season (Whitman 1975). The quantity of mineral nitrogen increases an average of 25% to 50% between the low periods and the peaks in the cycle with some variations occurring on different range sites and at different soil depths (Goetz 1975).

Mineralization and nitrification processes of soil microorganism activity start slowly in the spring when the soil temperature permits formation of liquid water around 30° F. Available mineral nitrogen increases with increases in soil temperature and microorganism biomass reaching the first peak in mineral nitrogen around mid May just prior to start of rapid plant growth. The quantity of mineral nitrogen decreases rapidly with increasing plant growth rates during spring reaching the first low period during June and the first two weeks of July. The second peak in mineral nitrogen is reached at the end of the active growing season usually around late July or early August. A second low period in mineral nitrogen occurs from around mid August to mid or late September when plants have slow growth rates and during growth and development of fall tillers and fall tiller buds that will produce the early plant growth during the subsequent growing season. The third peak in mineral nitrogen occurs around mid October just prior to the end of the perennial plant growing season during autumn. Mineral nitrogen declines during the third low period as winter freeze up approaches (Goetz 1975, Whitman 1975).

The greater the quantity of mineral nitrogen available during periods of active plant growth, the greater the quantity of herbage biomass production. Rangeland ecosystem biogeochemical processes that cycle nitrogen need to function at rates that provide 100 pounds of mineral nitrogen per acre to produce the minimum potential quantity of herbage biomass and need to provide 165 pounds of mineral nitrogen per acre to produce the maximum potential quantity of herbage biomass (Wight and Black 1972) (table 1).

Traditional management practices, like 6.0 month seasonlong, repeated seasonal, and deferred grazing, were designed to use rangelands as a source of grazable forage for livestock and, even when operated with strong land stewardship ethics, traditional practices do not provide mineral nitrogen at quantities great enough to produce the potential quantity of herbage. Rangelands managed for about 35 years with a moderately stocked 6.0 month seasonlong grazing practice provided 62 pounds of mineral nitrogen per acre (Manske 2009), rangelands managed with an unspecified traditional grazing practice provided 59 pounds of mineral nitrogen per acre (Wight and Black 1972), and rangelands managed for 35 years with a low to moderately stocked 4.5 to 5.0 month deferred grazing practice provided 31 pounds of mineral nitrogen per acre (Manske 2008) (table 1). Rangelands managed with traditional grazing practices provide mineral nitrogen at deficiency rates of less than 100 pounds per acre causing decreases in plant water use efficiency and reducing herbage biomass production an average of 49.6% per inch of precipitation (Wight and Black 1979) (table 1). As a consequence of traditional grazing practices providing low quantities of mineral nitrogen and producing less than potential quantities of herbage biomass, native rangelands are incorrectly considered to be low producing, low income generating, resources.

Grazing management that is designed to meet the biological requirements of the plants and soil microorganisms and to stimulate ecosystem biogeochemical processes provide greater quantities of mineral nitrogen than do traditional practices. During the seventh grazing season, rangelands managed with a three pasture twice-over rotation grazing system provided 178 pounds of mineral nitrogen per acre (Manske 2008) (table 1). The greater quantity of mineral nitrogen resulted from greater soil microorganism activity. The twice-over rotation grazing system stimulated soil microorganism activity in the rhizosphere by increasing the quantity of plant fixed carbon exudated through grass roots into the rhizosphere. Removal of 25% to 33% of the leaf material by grazing livestock after the three and a half new leaf stage and before the flowering (anthesis) stage increased plant carbon exudates (Manske 2007). Soil microorganism growth and activity is limited by available carbon. Rhizosphere organisms increase in biomass and activity with increases in carbon. The rhizosphere volume on traditional grazing practices after twenty years of 6.0 month seasonlong and 4.5 month seasonlong was 50 and 68 cubic feet per acre, respectively (table 1). The rhizosphere volume was 227 cubic feet per acre on a twice-over rotation grazing system after twenty years (Manske 2008) (table 1). The greater rhizosphere organism biomass on rangelands managed with a twice-over rotation system had increased activity that mineralized and nitrified a greater quantity of organic nitrogen into mineral nitrogen. The greater quantity of available soil mineral nitrogen permitted the production of maximum potential herbage biomass, the growth of greater pounds of calf weight per acre, the generation of greater wealth per acre, and the improvement of native rangeland natural resources (Manske et al. 2008).

Table 1. Grazing management effects on mineral nitrogen and rhizosphere volume in native rangelands.

Standards for Mineral Nitrogen		Mineral Nitrogen	Source
Minimum potential herbage biomass		100 lbs/ac	Wight and Black 1972
Maximum potential herbage biomass		165 lbs/ac	Wight and Black 1972
Mineral nitrogen deficiency of less than 100 lbs/ac results in 49.6% reduction in herbage production per inch of precipitation.			Wight and Black 1979
Grazing Management		**Mineral Nitrogen**	
4.5-5.0 month Deferred	35 yrs	31 lbs/ac	Manske 2008
Traditional, not specified	long-term	59 lbs/ac	Wight and Black 1972
6.0 month Seasonlong	35 yrs	62 lbs/ac	Manske 2009
4.5 month Seasonlong	6 yrs	112 lbs/ac	Manske 2008
Twice-over Rotation	6 yrs	178 lbs/ac	Manske 2008
Grazing Management		**Rhizosphere Volume**	
6.0 month Seasonlong	20 yrs	50 ft^3/ac	Manske 2008
4.5 month Seasonlong	20 yrs	68 ft^3/ac	Manske 2008
Twice-over Rotation	20 yrs	227 ft^3/ac	Manske 2008

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Halogeton,
A Poisonous Plant Recently Introduced into North Dakota Rangelands

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Several small and medium sized patches of halogeton, a plant toxic to sheep, cattle, and herbivorous wildlife, have been located in the Badlands Area of western North Dakota, on both sides of the Little Missouri River and north of Interstate Highway 94, by Carmen Waldo, Natural Resources Specialist (Minerals) with the US Forest Service in the Medora Ranger District.

Halogeton, previously unknown to occur in North Dakota, was initially introduced during the 1930's into North America from the cold desert region of Eurasia. The plant spread rapidly and quickly became a serious problem weed in the Intermountain Great Basin Region of western United States. The plant thrives on the arid alkaline and saline soils in Nevada, Utah, Wyoming, Idaho, Oregon, and Colorado. Halogeton is listed as a noxious weed in the states of Arizona, California, Colorado, Hawaii, New Mexico, and Oregon.

Halogeton (Halogeton glomeratus (M. Bieb.) C.A. Mey.) is a member of the Goosefoot family and is an introduced, warm season, summer annual herb with horizontal spreading branches that curve upward to around 2 feet in height. The taproot can grow to about 20 inches in depth. Immature plants appear similar to young Russian thistle and kochia plants. Mature plants have red stems with small, round, fleshy, blue-green leaves about a half inch long with a single hair protruding out of the end. The leaf resembles a miniature sausage or wiener on a stick. Plants have small, inconspicuous yellow flowers during July through September and produce enormous quantities of seed, averaging around 75 seeds per inch of stem. Two types of seeds are produced each year. The black winged seeds, developed after mid August, can remain viable for about 1 year, and have a short after-ripening period that permits quick germination. The black seeds can imbibe water and germinate in less than 1 hour. The brown wingless seeds, developed before mid August, are dormant at maturity permitting the seeds to survive in soil for 10 years or more. The seeds are dispersed by wind, water, human activities, through the digestive tract of sick animals, and when dry plants break off at ground level and tumble with the wind. Germination of most seeds occurs during late fall or early spring.

Halogeton plants contain unusually heavy concentrations of soluble oxalates which are bound primarily as sodium salts. Concentrations of the soluble oxalates are highest in the leaves (14 to 25%) and lowest in the stems (1 to 4%) and seeds (2%). Most of the sodium oxalates in the stems are insoluble and thus nonpoisonous. The content of the soluble sodium oxalates tends to be relatively high during midsummer and may exceed 30% in leaf samples from late August to frost. Dead plants remain almost as poisonous as the living plants. After ingestion, soluble sodium oxalates are readily absorbed into the circulatory system. The sodium ions are replaced by calcium withdrawn from blood serum. This calcium reduction disrupts blood coagulation, and nerve and muscle function resulting in staggering and muscular spasms similar to milk fever. These calcium oxalates formed in the blood are precipitated in the liver and kidneys, which then interferes with normal function of these organs. A lethal dose of foliage at 0.3 to 0.5% of the animal's body weight can cause death within 24 hours. About 1.5 lbs of foliage can kill a sheep and about 3 to 5 lbs can kill a cow. As little as 12 oz of foliage can be fatal to animals in poor condition. Cattle generally develop subacute symptoms from halogeton poisoning when abundant good forage is available because the bitter taste of halogeton discourages consumption of large enough quantities of foliage to cause acute symptoms and death.

Halogeton competes poorly with healthy, established perennial vegetation, however, open areas with bare saline-alkali soils facilitate its invasion and establishment. Control can be troublesome because of the large quantity of seeds produced annually and the long survival period of the brown seeds. Three herbicides have been shown to effectively manage halogeton in the Great Basin Region. Control of young plants during June, prior to the start of flowering, is possible with 2, 4-D applied at 1.0 to 2.0 lbs acid equivalent (ae) (1.1 to 2.1 qt product) per acre and, when plants are mature, application of 2.0 to 6.0 lbs ae (2.1 to 6.3 qt product) per acre is effective. One application of tebuthiuron (Spike 20P) at 0.5 lb active ingredient (ai) (2.5 lb product) per acre should provide control for 3 to 5 years. Metsulfuron (Ally XP, Cimarron, Cimarron X-tra, and Cimarron Max) is effective at 0.2 oz ai (0.33 lb product) per acre. There are no currently registered biocontrol agents for halogeton, however, there are a few experimental agents ready for field testing.

Halogeton has the biological ability to develop into a very troublesome noxious poisonous plant in our western rangelands, however, during these early stages of invasion, eradication from North Dakota soils still is possible if decisive action is implemented before the plant population reaches crisis level.

CDFA/BCSP Distribution of *Halogeton glomeratus* (M. Bieb.) C. A. Mey.

Map from http://www.cdfa.ca.gov/PHPPS/ipc/weedinfo/usedimages/halogetonmap.html

Sheri Hagwood@USDA-NRCS PLANTS Database

Grass Plant Responses to Defoliation

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Management of grassland ecosystems has customarily been applied from the perspective of the "use" of the grassland creating conflict among competing user groups and imposing antagonistic effects on grassland plants and soil organisms that cause degradation of biogeochemical processes, reduction of available mineral nitrogen, reduction of grass tiller density, and reduction of grassland productivity (Manske 2007a). Management strategies that place priority with the living components of the ecosystem meet the biological requirements of grassland plants and soil organisms, and are beneficial for biogeochemical processes, thereby increasing soil mineral nitrogen and enhancing health and productivity of grassland ecosystems (Manske 2007b).

Implementation of biologically effective management strategies that are beneficial for grassland ecosystems requires knowledge of grass plant responses to defoliation resulting from activation of the defoliation resistance mechanisms developed in grass plants during coevolution with herbivores (McNaughton 1979, 1983; Coleman et al. 1983; Briske 1991; Briske and Richards 1995; Manske 1999). The defoliation resistance mechanisms help grass tillers withstand and recover from partial defoliation by grazing and are: herbivore-induced compensatory physiological processes (McNaughton 1979, 1983; Briske 1991); stimulation of vegetative reproduction of secondary tillers from axillary buds (Mueller and Richards 1986, Richards et al. 1988, Murphy and Briske 1992, Briske and Richards 1994, Briske and Richards 1995); and stimulation of rhizosphere organism activity and the increased conversion of inorganic nitrogen from soil organic nitrogen (Coleman et al. 1983, Ingham et al. 1985).

Compensatory physiological processes within grass plants enable rapid recovery of defoliated tillers through: increased growth rates of replacement leaves and shoots that produces larger leaves with greater mass (Langer 1972, Briske and Richards 1995); increased photosynthetic capacity of remaining mature leaves and rejuvenated portions of older leaves not completely senescent (Atkinson 1986, Briske and Richards 1995); and increased allocation of carbon and nitrogen from remaining leaf and shoot tissue, not from material stored in the roots (Richards and Caldwell 1985, Briske and Richards 1995, Coyne et al. 1995). Compensatory physiological processes are activated by seasonable partial defoliation by grazing of grass tillers during phenological growth between the three and a half new leaf stage and the flowering (anthesis) stage (Manske 2007b).

Vegetative reproduction by tillering is the asexual process of growth and development of tillers from axillary buds (Dalh 1995). The meristematic activity in axillary buds and the subsequent development of vegetative secondary tillers is regulated by auxin, a growth-inhibiting hormone produced in the apical meristem and young developing leaves of lead tillers (Briske and Richards 1995). Auxin interferes with the metabolic function of cytokinin, a growth hormone (Briske and Richards 1995). Partial defoliation temporarily reduces the production of the blockage hormone, auxin (Briske and Richards 1994). This abrupt reduction of plant auxin in the lead tiller allows for cytokinin synthesis or utilization in multiple axillary buds, stimulating the development of vegetative tillers (Murphy and Briske 1992, Briske and Richards 1994). Vegetative growth of secondary tillers from axillary buds can be stimulated by partial defoliation of young leaf material from grass tillers at phenological growth between the three and a half new leaf stage and the flowering (anthesis) stage (Manske 2007b).

The rhizosphere is the narrow zone of soil around active roots of perennial grassland plants and is comprised of bacteria, protozoa, nematodes, springtails, mites, endomycorrhizal fungi (Anderson et al. 1981, Curl and Truelove 1986) and ectomycorrhizal fungi (Caesar-TonThat et al. 2001, Manske and Caesar-TonThat 2003). Active rhizosphere organisms are required in grassland ecosystems for the conversion of plant usable inorganic nitrogen from soil organic nitrogen. Rhizosphere organism biomass and activity are limited by access to simple carbon chains (Curl and Truelove 1986) because the microflora trophic levels lack chlorophyll and have low carbon (energy) content. Partial defoliation of grass plants at vegetative phenological growth stages by large grazing herbivores causes greater quantities of exudates containing simple carbon compounds to be released through the plant roots into the rhizosphere (Hamilton and Frank 2001). With the increase in availability of carbon compounds in the rhizosphere, activity of the microorganisms increases (Anderson et al. 1981, Curl and Truelove 1986, Whipps 1990). The increase in rhizosphere organism activity causes an increase in microorganism biomass and an increase in rhizosphere volume (Gorder, Manske, and Stroh 2004). The elevated rhizosphere organism activity caused by the increase in available carbon compounds results in a greater quantity of organic nitrogen converted into inorganic nitrogen (Coleman et al. 1983, Klein et al. 1988, Burrows and Pfleger 2002, Rillig et al. 2002, Bird et al. 2002, Driver et al. 2005). The increase in inorganic nitrogen available to defoliated grass plants allows the plant to recover more quickly from defoliation, to accelerate the growth rate, to increase vegetative tiller development from axillary buds, and to increase the total herbage biomass production (Manske 1999, 2003).

The defoliation resistance mechanisms not only permit grass plants to tolerate defoliation but to benefit from partial defoliation by grazing at some vegetative phenological growth stages. The activation of the defoliation resistance mechanisms in grass plants on various grazing management strategies from the differences of timing and frequency of defoliation by grazing are not completely understood. The goal of this project was to increase the knowledge of activation of the defoliation resistance mechanisms with grazing management strategies so that partial defoliation by grazing can be intentionally used beneficially to stimulate vegetative tillering from axillary buds in grass plants.

Vegetative tiller development of grass plants as a response to timing and frequency of partial defoliation by grazing has been studied at the North Dakota State University Dickinson Research Extension Center since 1983. This vegetative tiller development as a response to defoliation research project was funded by North Dakota State Board of Agricultural Research and Education (SBARE) and conducted at the Dickinson Research Extension Center in southwestern North Dakota during 2000 and 2001. Detailed data was collected from western wheatgrass tillers to evaluate grass plant response to changes in time of defoliation and differences in severity of defoliation. These data will assist in the refinement of grazing management practices so that the biological requirements of grass plants and soil organisms can be met and increase vegetative tillering from axillary buds.

Study Area

The native rangeland study sites were on the Dickinson Research Extension Center ranch, operated by North Dakota State University and located 20 miles north of Dickinson, in southwestern North Dakota, U.S.A. (47° 14' N. lat., 102° 50' W. long.).

Soils were primarily Typic Haploborolls. Long-term mean annual temperature was 42.4° F (5.8° C). January was the coldest month, with a mean temperature of 14.6° F (-9.7° C). July and August were the warmest months, with mean temperatures of 69.8° F (21.0° C) and 68.8° F (20.4° C), respectively. Long-term annual precipitation was 16.69 inches (423.96 mm). The amount of precipitation received during the growing season (April to October) was 13.90 inches (353.08 mm), 83.28% of annual precipitation (Manske 2009a).

The native rangeland vegetation was the Wheatgrass-Needlegrass Type (Barker and Whitman 1988, Shiflet 1994) of the mixed grass prairie. The dominant native range grasses were western wheatgrass (*Agropyron smithii*) (*Pascopyrum smithii*), needle and thread (*Stipa comata*) (*Hesperostipa comata*), blue grama (*Bouteloua gracilis*), and threadleaf sedge (*Carex filifolia*).

The study sites were managed with three different grazing strategies. The 6.0-month seasonlong management strategy started in mid May. Livestock grazed a single native range pasture for 183 days, until mid November. The 4.5-month seasonlong management strategy started in early June. Livestock grazed a single native range pasture for 137 days, until mid October. The 4.5-month twice-over rotation management strategy started in early June, when livestock were moved to one of three native range pastures. Livestock remained on native range for 137 days, grazing each pasture for two periods, one 15-day period between 1 June and 15 July (when lead tillers of grasses were between the third-leaf stage and flowering stage) and one 30-day period after 15 July (after secondary tillers of grasses reached the third-leaf stage) and prior to mid October. The first pasture grazed in the sequence was the last pasture grazed the previous year.

Procedures

Three study site exclosures were established on native rangeland silty range sites with livestock grazing controlled by three different management strategies: 6.0-month seasonlong (6.0 m SL), 4.5-month seasonlong (4.5 m SL), and 4.5-month twice-over rotation (4.5 m TOR). The silty range sites were located on gently sloping upland terrace landscape positions with deep fine sandy loam soils. Sites with near 10 inch (25 cm) surface horizon depth were reconnoitered prior to the start of the study, however, the exclosure construction crew relocated the 4.5 m SL site to a more level grade but with a shallower surface horizon depth. The depths of the surface horizon on the study sites of the 6.0 m SL, 4.5 m SL, and 4.5 m TOR management strategies were 9.6 inches (24.4 cm), 8.1 inches (20.6 cm), and 9.8 inches (24.5 cm), respectively. The surface horizon of the soil on the 4.5 m SL management strategy was significantly shallower than that on the 6.0 m SL and 4.5 m TOR management strategies.

Within each exclosure, 35 microplots were located and seven randomly selected microplots were assigned to each of the five defoliation treatments. Grass tillers within each microplot were separated from the surrounding plant community by inserting into the sample site soil a PVC conduit barrier with a 3 inch (7.62 cm) diameter and 6 inch (15.24 cm) depth that was open at both ends. The PVC barriers prevented lateral movement of soil water, consequently, the only source of soil water in the microplots was precipitation.

Every western wheatgrass tiller within each microplot was individually identified with a distinguishing loop of colored wire that encircled the tiller at its base. New tillers were identified with different colored wire loops as they developed and carry over tillers were remarked at the start of the second year.

The western wheatgrass tillers were categorized as lead tillers, rhizome tillers, crown tillers, or fall tillers during data collection according to biological characteristics observed and relative position in the microplot. However, not all of the tillers classified as lead tillers were actually dominant tillers; some were subordinate secondary tillers. The tillers classified as rhizome tillers, crown tillers, or fall tillers were the type of tiller as classified, however, not all of these tillers were subordinate secondary tillers; some were actually lead tillers. Differentiation of tillers into distinguishable categories of dominant lead tillers and subordinate secondary tillers is not clear-cut. There appears to be a continuum of hierarchical levels within the tiller population from greatest dominance to lowest subordinate.

With the power of hindsight, the study tillers were divided into two synthetic groups based on relative rates of growth and development. Tillers with seemingly rapid or unimpeded growth were reclassified as lead tillers, and tillers with obviously inhibited growth and development were reclassified as secondary tillers. The lead tillers were subdivided into tillers that developed into sexually reproductive flowering stages (reproductive lead tillers) and tillers that remained vegetative at the end of the growing season (vegetative lead tillers). The secondary tillers with inhibited growth rates were subdivided into tillers that remained vegetative at the end of the growing season (slow growth secondary tillers) and tillers that terminated growth during the growing season (early senescent secondary tillers). Tillers that were initiated between mid August and mid October were classified as fall tillers. Vegetative tillers with intact apical meristem tissue that survived the winter period and continued growth and development during the next growing season were classified as carry over tillers.

Four defoliation treatments, based on actual livestock grazing patterns, and a control of no defoliation were applied to the western wheatgrass tillers in the microplots during the first year in each of the three exclosures. Two treatments to evaluate the effect of time of defoliation were conducted at critical phenological stages of development: 1) before apical meristem elevation (mid May), and 2) during apical meristem elevation (mid June). No apical meristem tissue was removed from treated tillers. Two treatments to evaluate the effects of severity of defoliation were conducted: 1) 25%, and 2) 50% removal of current aboveground biomass. The five defoliation treatments were: A) no defoliation, control, B) defoliation, mid May-25%, C) defoliation, mid May-50%, D) defoliation, mid June-25%, and E) defoliation, mid June-50%.

All western wheatgrass tillers within a microplot received the same timing and severity of defoliation treatment. Defoliation treatment clip heights were based on percent height-weight data determined during the week before the date of each defoliation treatment from 40 typical tillers collected at ground level from near the study areas. The typical tillers were cut into segments of 1.0 inch (2.5 cm) height increments from the base upwards. The height increments were oven dried and weighed separately. Percent of mean total tiller weight was determined for each height increment. The height of the tillers in each microplot was measured and the appropriate proportion of height equal to 25% or 50% of the typical tillers weight was removed from each microplot tiller. Defoliation treatments were conducted 11 May and 22 June 2000. The height of the tillers in each microplot was remeasured and a post defoliation tiller height was determined for each microplot (table 1).

Data collection began in early May and continued into October for two years (2000 and 2001). Sample periods occurred weekly during the first year and biweekly during the second year. The data collected for each tiller included number of leaves produced, phenological growth stage, and height of tallest leaf. New tillers were added to the data set as they developed during the growing season or early fall. A standard paired-plot t-test was used to analyze differences among means (Mosteller and Rourke 1973).

Table 1. Defoliation treatment tiller height before and after removal of 25% or 50% of tiller weight.

Date Treatment	Management Strategy	Pretreatment Height cm	Post treatment Height cm	Removed Height cm	Percent Height Removed %
11 May 2000					
May 25%	6.0 m SL	10.9	8.6	2.2	20.5
	4.5 m SL	8.7	6.9	1.8	20.6
	4.5 m TOR	9.2	7.4	1.8	19.4
	mean	9.6	7.7	1.9	20.2
May 50%	6.0 m SL	12.0	7.1	4.9	40.6
	4.5 m SL	9.1	5.5	3.6	39.8
	4.5 m TOR	10.9	6.5	4.4	40.5
	mean	10.8	6.4	4.3	40.3
22 June 2000					
June 25%	6.0 m SL	15.8	12.6	3.2	20.2
	4.5 m SL	13.6	10.9	2.7	19.9
	4.5 m TOR	14.1	11.3	2.8	19.9
	mean	14.5	11.6	2.9	20.0
June 50%	6.0 m SL	15.4	9.2	6.2	40.2
	4.5 m SL	14.9	9.0	5.9	39.4
	4.5 m TOR	17.4	10.4	7.0	40.1
	mean	15.9	9.6	6.4	39.9

Results

The basic design of this study was intended to test a simple straight forward treatment-response relationship between a defoliation event and the grass tiller reaction. However, the western wheatgrass tillers on the three grazing management strategies did not respond similarly to each of the defoliation treatments, disclosing that stimulation of the defoliation resistance mechanisms that help grass tillers withstand and recover from partial defoliation was not simple and was influenced by additional conditions or other factors. Activation of the physiological processes within the grass plants and the biogeochemical processes within the grassland ecosystem that provide resistance to defoliation depend on complex interactions among grazing animals, grass plants, and rhizosphere soil organisms (Manske 2007b).

The quantity of vegetative tiller development in grassland ecosystems and the rate of tiller growth and recovery following partial defoliation are affected by hierarchical dominant tiller regulation, by growing season environmental variables, and by availability of essential elements (Briske and Richards 1995, Manske 1998). Stimulation of vegetative tiller development from axillary buds requires the reduction of the inhibiting hormone, auxin, and growth and development of stimulated vegetative tillers requires procurement of sufficient quantities of essential elements from the surrounding environment. The major elements needed by grass plants are hydrogen, carbon, and nitrogen. The hydrogen comes from soil water (H_20) absorbed through the roots and distributed throughout the plant within the xylem vascular tissue. The source of carbon is atmospheric carbon dioxide ($C0_2$). Plants capture and fix carbon with the hydrogen from soil water during the process of photosynthesis which converts radiant energy from sunlight into chemical energy. The assimilated carbon is combined in several ways to form various types of sugars and starches that collectively are carbohydrates (CH_20). The source of nitrogen is inorganic nitrogen ($N0_3$) mineralized from soil organic nitrogen by rhizosphere organisms. This available mineral nitrogen is transferred from the rhizosphere through the endomycorrhizal fungi to the roots of the host grass plant and is than preferentially moved up to the active axillary bud meristmatic tissue shortly after stimulation by the growth hormone, cytokinin. Phosphorus and minor mineral nutrients are absorbed by grass plant roots from soil with assistance from rhizosphere endomycorrhizal fungi (Manske 2007b).

The amount of vegetative tiller growth and development on grassland ecosystems is not limited by the availability of radiant energy from the sun or by the availability of atmospheric carbon dioxide and these two essential elements were not quantified. The environmental variables of temperature and precipitation were determined for the study area, and the resource availability of mineral nitrogen and the volume of the rhizosphere were determined for the silty range sites on the three grazing management strategies, 6.0 m SL, 4.5 m SL, and 4.5 m TOR.

The average monthly temperature and monthly precipitation data for 1999 to 2001 collected from the Dickinson Research Extension Center ranch were used to characterize growing-season conditions and to identify water-deficiency months. The ombrothermic diagram (figure 1) developed through use of the ombrothermic graph technique reported by Emberger et al. (1963) identified monthly periods with water-deficiency conditions. Water-deficiency periods are indicated when the monthly precipitation data bar drops below the mean monthly temperature data curve. During water-deficiency periods perennial plants experience water stress, a condition that results when plants are unable to absorb adequate water to match the transpiration rate. Water-deficiency periods lasting for a month place plants under water stress severe enough to reduce herbage biomass production. During fall, average monthly temperatures are near or below freezing (32°F, 0°C), and most grass leaves are senescent and contain only a small amount of green tissue; however, plant growth continues at low levels.

The precipitation during the growing seasons of 2000 and 2001 was normal (table 2). During 2000 and 2001, 14.99 inches (107.84% of LTM) and 16.40 inches (117.98% of LTM) of precipitation were received, respectively. August of 2000 was a wet month and received 158.38% of LTM precipitation. April, May, June, July, and October received normal precipitation at 90.00%, 79.17%, 116.36%, 113.99%, and 109.77% of LTM. September was a dry month and received 79.56% of LTM precipitation. Perennial plants were under water stress conditions during September, 2000 (figure 1) (Manske 2009a). April, June, July, and September of 2001 were wet months and each received 192.86%, 196.30%, 200.41%, and 141.61% of LTM precipitation, respectively. May was a very dry month and received 22.08% of LTM precipitation. August and October were extremely dry months and received no precipitation. Perennial plants were under water stress conditions during May, August, and October, 2001 (figure 1) (Manske 2009a).

The availability of water, which is essential in physiological processes, does not limit herbage production on grassland ecosystems to the extent that mineral nitrogen availability does (Wight and Black

1972). Available soil mineral nitrogen is the major herbage growth limiting factor in Northern Plains rangelands (Wight and Black 1979). Available mineral nitrogen was determined from four replicated field soil core samples collected to a depth of 6 inches during mid June from silty range sites in each of the three grazing management strategies at the start of the seventh year of the grazing treatment study. Subsamples of field soil cores were analyzed for total incubated mineralizable nitrogen (N) using procedures outlined by Keeney (1982) and Keeney and Nelsen (1982). The available mineral nitrogen was 178, 112, and 62 lbs/acre-foot on the 4.5 m TOR, 4.5 m SL, and 6.0 m SL management strategies, respectively (table 3) (Manske 2008, 2009b). The quantity of soil mineral nitrogen at the relocated exclosure site of the 4.5 m SL management strategy appears to have been well below 100 lbs/ac. All mineral nitrogen values for the three management strategies were significantly different from each other (table 3).

The rhizosphere volume, which reflects the activity and biomass levels of soil microorganisms, was determined from length and diameter measurements of the rhizosphere soil cylinder around each root of every western wheatgrass tiller located in two replicated soil cores of 3 inches in diameter and 4 inches deep collected during June, July, August, and September from silty range sites in each of the three grazing management strategies during 2002 (Gorder, Manske, and Stroh 2004). The seasonal mean rhizosphere volume was 227, 68, and 50 ft^3/acre-foot on the 4.5 m TOR, 4.5 m SL, and 6.0 m SL management strategies, respectively (table 3) (Manske 2008). The rhizosphere volume on the 4.5 m SL and 6.0 m SL management strategies were not significantly different and the rhizosphere volume on both the seasonlong management strategies were significantly less than the rhizosphere volume on the 4.5 m TOR management strategy (table 3).

Tiller Dynamics

Control Treatment

The first year on the control treatment of the 6.0 month seasonlong management strategy (table 4a) started in early May with 469.9 /m^2 vegetative tillers including 344.6 /m^2 lead tillers and 125.3 /m^2 secondary tillers. An unknown quantity of these tillers were carry over tillers from the previous growing season. Vegetative reproduction produced 0.0 /m^2 tillers during the first growing season with 0.0 /m^2 initiated during May and 0.0 /m^2 initiated during mid season. A total of 469.9 /m^2 different tillers were present during the first growing season. During mid season, 219.3 /m^2 lead tillers developed into reproductive flowering stages (46.7% of the tiller population). Before reaching maturity, 31.3 /m^2 vegetative tillers terminated. Between mid August and mid October, 219.3 /m^2 fall tillers developed. During mid October, 438.6 /m^2 live vegetative tillers remained, of which, 125.3 /m^2 were lead tillers, 94.0 /m^2 were secondary tillers, and 219.3 /m^2 were fall tillers. During the winter period, 0.0 /m^2 tillers terminated. The second year on the control treatment (table 4b) started in early May with 783.2 /m^2 vegetative tillers including 501.2 /m^2 lead tillers and 281.9 /m^2 secondary tillers, of which, 438.6 /m^2 were carry over tillers and 344.6 /m^2 were early spring initiated tillers; there were 313.3 /m^2 more tillers than during May of the first growing season. Vegetative reproduction produced 31.3 /m^2 tillers during the second growing season with 0.0 /m^2 initiated during May and 31.3 /m^2 initiated during mid season. A total of 814.5 /m^2 different tillers were present during the second growing season; there were 344.6 /m^2 more total tillers than during the first growing season. During mid season, 156.6 /m^2 lead tillers developed into reproductive flowering stages (19.2% of the tiller population). Before reaching maturity, 250.6 /m^2 vegetative tillers terminated. Between mid August and mid October, 313.3 /m^2 fall tillers developed. During mid October, 720.5 /m^2 live vegetative tillers remained, of which, 219.3 /m^2 were lead tillers, 188.0 /m^2 were secondary tillers, and 313.3 /m^2 were fall tillers; there were 281.9 /m^2 more live vegetative tillers than during mid October of the first growing season.

The first year on the control treatment of the 4.5 month seasonlong management strategy (table 4a) started in early May with 281.9 /m^2 vegetative tillers including 188.0 /m^2 lead tillers and 94.0 /m^2 secondary tillers. An unknown quantity of these tillers were carry over tillers from the previous growing season. Vegetative reproduction produced 0.0 /m^2 tillers during the first growing season with 0.0 /m^2 initiated during May and 0.0 /m^2 initiated during mid season. A total of 281.9 /m^2 different tillers were present during the first growing season. During mid season, 94.0 /m^2 lead tillers developed into reproductive flowering stages (33.3% of the tiller population). Before reaching maturity, 62.7 /m^2 vegetative tillers terminated. Between mid August and mid October, 94.0 /m^2 fall tillers developed. During mid October, 219.3 /m^2 live vegetative tillers remained, of which, 94.0 /m^2 were lead tillers, 31.3 /m^2 were secondary tillers, and 94.0 /m^2 were fall tillers. During the winter period, 0.0 /m^2 tillers terminated. The second year on the control treatment (table 4b) started in early May with 407.2 /m^2 vegetative tillers including 219.3 /m^2 lead tillers and 188.0 /m^2 secondary tillers, of which, 219.3 /m^2 were carry over tillers and 188.0 /m^2 were early spring initiated tillers; there were 125.3 /m^2 more tillers than during May of the first growing season. Vegetative reproduction produced 125.3 /m^2 tillers during the second growing season with 31.3 /m^2 initiated during May and 94.0 /m^2 initiated during mid season. A total of 532.5 /m^2 different tillers were present during the second growing season; there were 250.6 /m^2 more total tillers than during the first growing season. During mid season, 31.3 /m^2 lead tillers developed into reproductive flowering stages (5.9% of the tiller population). Before reaching maturity, 188.0 /m^2 vegetative tillers terminated. Between mid August and mid October, 156.6 /m^2 fall tillers developed. During mid October, 469.9 /m^2 live vegetative tillers remained, of which, 219.3 /m^2 were lead tillers, 94.0 /m^2 were secondary tillers, and 156.6 /m^2 were fall tillers; there were 250.6 /m^2 more live vegetative tillers than during mid October of the first growing season.

The first year on the control treatment of the 4.5 month twice-over rotation management strategy (table 4a) started in early May with 877.1 /m^2 vegetative tillers including 626.5 /m^2 lead tillers and 250.6 /m^2 secondary tillers. An unknown quantity of these tillers were carry over tillers from the previous growing season. Vegetative reproduction produced 62.7 /m^2 tillers during the first growing season with 31.3 /m^2 initiated during May and 31.3 /m^2 initiated during mid season. A total of 939.8 /m^2 different tillers were present during the first growing season. During mid season, 344.6 /m^2 lead tillers developed into reproductive flowering stages (36.7% of the tiller population). Before reaching maturity, 250.6 /m^2 vegetative tillers terminated. Between mid August and mid October, 250.6 /m^2 fall tillers developed. During mid October, 595.2 /m^2 live vegetative tillers remained, of which, 219.3 /m^2 were lead tillers, 125.3 /m^2 were secondary tillers, and 250.6 /m^2 were fall tillers. During the winter period, 31.3 /m^2 tillers terminated. The second year on the control treatment (table 4b) started in early May with 1033.8 /m^2 vegetative tillers including 626.5 /m^2 lead tillers and 407.2 /m^2 secondary tillers, of which, 563.9 /m^2 were carry over tillers and 469.9 /m^2 were early spring initiated tillers; there were 156.6 /m^2 more tillers than during May of the first growing season. Vegetative reproduction produced 250.6 /m^2 tillers during the second growing season with 125.3 /m^2 initiated during May and 125.3 /m^2 initiated during mid season. A total of 1284.4 /m^2 different tillers were present during the second growing season; there were 344.6 /m^2 more total tillers than during the first growing season. During mid season, 375.9 /m^2 lead tillers developed into reproductive flowering stages (29.3% of the tiller population). Before reaching maturity, 438.6 /m^2 vegetative tillers terminated. Between mid August and mid October, 188.0 /m^2 fall tillers developed. During mid October, 657.8 /m^2 live vegetative tillers remained, of which, 250.6 /m^2 were lead tillers, 219.3 /m^2 were secondary tillers, and 188.0 /m^2 were fall tillers; there were 62.7 /m^2 more live vegetative tillers than during mid October of the first growing season.

Mid May 25% Treatment

The first year on the mid May 25% defoliation treatment of the 6.0 month seasonlong management strategy (table 4a) started in early May with 845.8 /m^2 vegetative tillers including 595.2 /m^2 lead tillers and 250.6 /m^2 secondary tillers. An unknown quantity of these tillers were carry over tillers from the previous growing season. Vegetative reproduction produced 62.7 /m^2 tillers during the first growing season with 0.0 /m^2 initiated during May and 62.7 /m^2 initiated during mid season. A total of 908.5 /m^2 different tillers were present during the first growing season. During mid season, 156.6 /m^2 lead tillers developed into reproductive flowering stages (17.2% of the tiller population). Before reaching maturity, 94.0 /m^2 vegetative tillers terminated. Between mid August and mid October, 94.0 /m^2 fall tillers developed. During mid October, 751.8 /m^2 live vegetative tillers remained, of which, 313.3 /m^2 were lead tillers, 344.6 /m^2 were secondary tillers, and 94.0 /m^2 were fall tillers. During the winter period, 281.9 /m^2 tillers terminated. The second year on the mid May 25% defoliation treatment (table 4b) started in early May with 626.5 /m^2 vegetative tillers including 375.9 /m^2 lead tillers and 250.6 /m^2 secondary tillers, of which, 469.9 /m^2 were carry over tillers and 156.6 /m^2 were early spring initiated tillers; there were 219.3 /m^2 fewer tillers than during May of the first growing season. Vegetative reproduction produced 219.3 /m^2 tillers during the second growing season with 156.6 /m^2 initiated during May and 62.7 /m^2 initiated during mid season. A total of 845.8 /m^2 different tillers were present during the second growing season; there were 62.7 /m^2 fewer total tillers than during the first growing season. During mid season, 188.0 /m^2 lead tillers developed into reproductive flowering stages (22.2% of the tiller population). Before reaching maturity, 219.3 /m^2 vegetative tillers terminated. Between mid August and mid October, 563.9 /m^2 fall tillers developed. During mid October, 1002.4 /m^2 live vegetative tillers remained, of which, 250.6 /m^2 were lead tillers, 188.0 /m^2 were secondary tillers, and 563.9 /m^2 were fall tillers; there were 250.6 /m^2 more live vegetative tillers than during mid October of the first growing season.

The first year on the mid May 25% defoliation treatment of the 4.5 month seasonlong management strategy (table 4a) started in early May with 626.5 /m^2 vegetative tillers including 532.5 /m^2 lead tillers and 94.0 /m^2 secondary tillers. An unknown quantity of these tillers were carry over tillers from the previous growing season. Vegetative reproduction produced 62.7 /m^2 tillers during the first growing season with 62.7 /m^2 initiated during May and 0.0 /m^2 initiated during mid season. A total of 689.2 /m^2 different tillers were present during the first growing season. During mid season, 31.3 /m^2 lead tillers developed into reproductive flowering stages (4.5% of the tiller population). Before reaching maturity, 125.3 /m^2 vegetative tillers terminated. Between mid August and mid October, 281.9 /m^2 fall tillers developed. During mid October, 814.5 /m^2 live vegetative tillers remained, of which, 469.9 /m^2 were lead tillers, 62.7 /m^2 were secondary tillers, and 281.9 /m^2 were fall tillers. During the winter period, 313.3 /m^2 tillers terminated. The second year on the mid May 25% defoliation treatment (table 4b) started in early May with 501.2 /m^2 vegetative tillers including 250.6 /m^2 lead tillers and 250.6 /m^2 secondary tillers, of which, 501.2 /m^2 were carry over tillers and 0.0 /m^2 were early spring initiated tillers; there were 125.3 /m^2 fewer tillers than during May of the first growing season. Vegetative reproduction produced 156.6 /m^2 tillers during the second growing season with 94.0 /m^2 initiated during May and 62.7 /m^2 initiated during mid season. A total of 657.8 /m^2 different tillers were present during the second growing season; there were 31.3 /m^2 fewer total tillers than during the first growing season. During mid season, 62.7 /m^2 lead tillers developed into reproductive flowering stages (9.5% of the tiller population). Before reaching maturity, 188.0 /m^2 vegetative tillers terminated. Between mid August and mid October, 501.2 /m^2 fall tillers developed. During mid October, 908.5 /m^2 live vegetative tillers remained, of which, 313.3 /m^2 were lead tillers, 94.0 /m^2 were secondary tillers, and 501.2 /m^2 were fall tillers; there were 94.0 /m^2 more live vegetative tillers than during mid October of the first growing season.

The first year on the mid May 25% defoliation treatment of the 4.5 month twice-over rotation management strategy (table 4a) started in early May with 657.8 /m^2 vegetative tillers including 407.2 /m^2 lead tillers and 250.6 /m^2 secondary tillers. An unknown quantity of these tillers were carry over tillers from the previous growing season. Vegetative reproduction produced 31.3 /m^2 tillers during the first growing season with 31.3 /m^2 initiated during May and 0.0 /m^2 initiated during mid season. A total of 689.2 /m^2 different tillers were present during the first growing season. During mid season, 188.0 /m^2 lead tillers developed into reproductive flowering stages (27.3% of the tiller population). Before reaching maturity, 281.9 /m^2 vegetative tillers terminated. Between mid August and mid October, 313.3 /m^2 fall tillers developed. During mid October, 532.5 /m^2 live vegetative tillers remained, of which, 156.6 /m^2 were lead tillers, 62.7 /m^2 were secondary tillers, and 313.3 /m^2 were fall tillers. During the winter period, 0.0 /m^2 tillers terminated. The second year on the mid May 25% defoliation treatment (table 4b) started in early May with 1033.8 /m^2 vegetative tillers including 751.8 /m^2 lead tillers and 281.9 /m^2 secondary tillers, of which, 532.5 /m^2 were carry over tillers and 501.2 /m^2 were early spring initiated tillers; there were 375.9 /m^2 more tillers than during May of the first growing season. Vegetative reproduction produced 250.6 /m^2 tillers during the second growing season with 31.3 /m^2 initiated during May and 219.3 /m^2 initiated during mid season. A total of 1284.4 /m^2 different tillers were present during the second growing season; there were 595.2 /m^2 more total tillers than during the first growing season. During mid season, 313.3 /m^2 lead tillers developed into reproductive flowering stages (24.4% of the tiller population). Before reaching maturity, 438.6 /m^2 vegetative tillers terminated. Between mid August and mid October, 156.6 /m^2 fall tillers developed. During mid October, 689.2 /m^2 live vegetative tillers remained, of which, 313.3 /m^2 were lead tillers, 219.3 /m^2 were secondary tillers, and 156.6 /m^2 were fall tillers; there were 156.6 /m^2 more live vegetative tillers than during mid October of the first growing season.

Mid May 50% Treatment

The first year on the mid May 50% defoliation treatment of the 6.0 month seasonlong management strategy (table 4a) started in early May with 908.5 /m^2 vegetative tillers including 751.8 /m^2 lead tillers and 156.6 /m^2 secondary tillers. An unknown quantity of these tillers were carry over tillers from the previous growing season. Vegetative reproduction produced 0.0 /m^2 tillers during the first growing season with 0.0 /m^2 initiated during May and 0.0 /m^2 initiated during mid season. A total of 908.5 /m^2 different tillers were present during the first growing season. During mid season, 62.7 /m^2 lead tillers developed into reproductive flowering stages (6.9% of the tiller population). Before reaching maturity, 219.3 /m^2 vegetative tillers terminated. Between mid August and mid October, 469.9 /m^2 fall tillers developed. During mid October, 1096.4 /m^2 live vegetative tillers remained, of which, 375.9 /m^2 were lead tillers, 250.6 /m^2 were secondary tillers, and 469.9 /m^2 were fall tillers. During the winter period, 250.6 /m^2 tillers terminated. The second year on the mid May 50% defoliation treatment (table 4b) started in early May with 908.5 /m^2 vegetative tillers including 657.8 /m^2 lead tillers and 250.6 /m^2 secondary tillers, of which, 845.8 /m^2 were carry over tillers and 62.7 /m^2 were early spring initiated tillers; there were no more tillers than during May of the first growing season. Vegetative reproduction produced 125.3 /m^2 tillers during the second growing season with 125.3 /m^2 initiated during May and 0.0 /m^2 initiated during mid season. A total of 1033.8 /m^2 different tillers were present during the second growing season; there were 125.3 /m^2 more total tillers than during the first growing season. During mid season, 250.6 /m^2 lead tillers developed into reproductive flowering stages (24.2% of the tiller population). Before reaching maturity, 219.3 /m^2 vegetative tillers terminated. Between mid August and mid October, 501.2 /m^2 fall tillers developed. During mid October, 1065.1 /m^2 live vegetative tillers remained, of which, 438.6 /m^2 were lead tillers, 125.3 /m^2 were secondary tillers, and 501.2 /m^2 were fall tillers; there were 31.3 /m^2 fewer live vegetative tillers than during mid October of the first growing season.

The first year on the mid May 50% defoliation treatment of the 4.5 month seasonlong management strategy (table 4a) started in early May with 344.6 /m^2 vegetative tillers including 313.3 /m^2 lead tillers and 31.3 /m^2 secondary tillers. An unknown quantity of these tillers were carry over tillers from the previous growing season. Vegetative reproduction produced 31.3 /m^2 tillers during the first growing season with 31.3 /m^2 initiated during May and 0.0 /m^2 initiated during mid season. A total of 375.9 /m^2 different tillers were present during the first growing season. During mid season, 62.7 /m^2 lead tillers developed into reproductive flowering stages (16.7% of the tiller population). Before reaching maturity, 94.0 /m^2 vegetative tillers terminated. Between mid August and mid October, 188.0 /m^2 fall tillers developed. During mid October, 407.2 /m^2 live vegetative tillers remained, of which, 219.3 /m^2 were lead tillers, 0.0 /m^2 were secondary tillers, and 188.0 /m^2 were fall tillers. During the winter period, 94.0 /m^2 tillers terminated. The second year on the mid May 50% defoliation treatment (table 4b) started in early May with 313.3 /m^2 vegetative tillers including 156.6 /m^2 lead tillers and 156.6 /m^2 secondary tillers, of which, 313.3 /m^2 were carry over tillers and 0.0 /m^2 were early spring initiated tillers; there were 31.3 /m^2 fewer tillers than during May of the first growing season. Vegetative reproduction produced 125.3 /m^2 tillers during the second growing season with 94.0 /m^2 initiated during May and 31.3 /m^2 initiated during mid season. A total of 438.6 /m^2 different tillers were present during the second growing season; there were 62.7 /m^2 more total tillers than during the first growing season. During mid season, 156.6 /m^2 lead tillers developed into reproductive flowering stages (35.7% of the tiller population). Before reaching maturity, 125.3 /m^2 vegetative tillers terminated. Between mid August and mid October, 94.0 /m^2 fall tillers developed. During mid October, 250.6 /m^2 live vegetative tillers remained, of which, 156.6 /m^2 were lead tillers, 0.0 /m^2 were secondary tillers, and 94.0 /m^2 were fall tillers; there were 156.6 /m^2 fewer live vegetative tillers than during mid October of the first growing season.

The first year on the mid May 50% defoliation treatment of the 4.5 month twice-over rotation management strategy (table 4a) started in early May with 939.8 /m^2 vegetative tillers including 689.2 /m^2 lead tillers and 250.6 /m^2 secondary tillers. An unknown quantity of these tillers were carry over tillers from the previous growing season. Vegetative reproduction produced 125.3 /m^2 tillers during the first growing season with 62.7 /m^2 initiated during May and 62.7 /m^2 initiated during mid season. A total of 1065.1 /m^2 different tillers were present during the first growing season. During mid season, 125.3 /m^2 lead tillers developed into reproductive flowering stages (11.8% of the tiller population). Before reaching maturity, 188.0 /m^2 vegetative tillers terminated. Between mid August and mid October, 689.2 /m^2 fall tillers developed. During mid October, 1441.0 /m^2 live vegetative tillers remained, of which, 407.2 /m^2 were lead tillers, 344.6 /m^2 were secondary tillers, and 689.2 /m^2 were fall tillers. During the winter period, 407.2 /m^2 tillers terminated. The second year on the mid May 50% defoliation treatment (table 4b) started in early May with 1378.3 /m^2 vegetative tillers including 532.5 /m^2 lead tillers and 845.8 /m^2 secondary tillers, of which, 1033.8 /m^2 were carry over tillers and 344.6 /m^2 were early spring initiated tillers; there were 438.6 /m^2 more tillers than during May of the first growing season. Vegetative reproduction produced 156.6 /m^2 tillers during the second growing season with 94.0 /m^2 initiated during May and 62.7 /m^2 initiated during mid season. A total of 1535.0 /m^2 different tillers were present during the second growing season; there were 469.9 /m^2 more total tillers than during the first growing season. During mid season, 250.6 /m^2 lead tillers developed into reproductive flowering stages (16.3% of the tiller population). Before reaching maturity, 750.5 /m^2 vegetative tillers terminated. Between mid August and mid October, 281.9 /m^2 fall tillers developed. During mid October, 845.8 /m^2 live vegetative tillers remained, of which, 281.9 /m^2 were lead tillers, 281.9 /m^2 were secondary tillers, and 281.9 /m^2 were fall tillers; there were 595.2 /m^2 fewer live vegetative tillers than during mid October of the first growing season.

Mid June 25% Treatment

The first year on the mid June 25% defoliation treatment of the 6.0 month seasonlong management strategy (table 4a) started in early May with 469.9 /m^2 vegetative tillers including 375.9 /m^2 lead tillers and 94.0 /m^2 secondary tillers. An unknown quantity of these tillers were carry over tillers from the previous growing season. Vegetative reproduction produced 62.7 /m^2 tillers during the first growing season with 62.7 /m^2 initiated during May and 0.0 /m^2 initiated during mid season. A total of 532.5 /m^2 different tillers were present during the first growing season. During mid season, 94.0 /m^2 lead tillers developed into reproductive flowering stages (17.7% of the tiller population). Before reaching maturity, 31.3 /m^2 vegetative tillers terminated. Between mid August and mid October, 125.3 /m^2 fall tillers developed. During mid October, 532.5 /m^2 live vegetative tillers remained, of which, 188.0 /m^2 were lead tillers, 219.3 /m^2 were secondary tillers, and 125.3 /m^2 were fall tillers. During the winter period, 62.7 /m^2 tillers terminated. The second year on the mid June 25% defoliation treatment (table 4b) started in early May with 501.2 /m^2 vegetative tillers including 438.6 /m^2 lead tillers and 62.7 /m^2 secondary tillers, of which, 469.9 /m^2 were carry over tillers and 31.3 /m^2 were early spring initiated tillers; there were 31.3 /m^2 more tillers than during May of the first growing season. Vegetative reproduction produced 94.0 /m^2 tillers during the second growing season with 0.0 /m^2 initiated during May and 94.0 /m^2 initiated during mid season. A total of 595.2 /m^2 different tillers were present during the second growing season; there were 62.7 /m^2 more total tillers than during the first growing season. During mid season, 188.0 /m^2 lead tillers developed into reproductive flowering stages (31.6% of the tiller population). Before reaching maturity, 94.0 /m^2 vegetative tillers terminated. Between mid August and mid October, 469.9 /m^2 fall tillers developed. During mid October, 783.2 /m^2 live vegetative tillers remained, of which, 219.3 /m^2 were lead tillers, 94.0 /m^2 were secondary tillers, and 469.9 /m^2 were fall tillers; there were 250.6 /m^2 more live vegetative tillers than during mid October of the first growing season.

The first year on the mid June 25% defoliation treatment of the 4.5 month seasonlong management strategy (table 4a) started in early May with 438.6 /m^2 vegetative tillers including 250.6 /m^2 lead tillers and 188.0 /m^2 secondary tillers. An unknown quantity of these tillers were carry over tillers from the previous growing season. Vegetative reproduction produced 31.3 /m^2 tillers during the first growing season with 0.0 /m^2 initiated during May and 31.3 /m^2 initiated during mid season. A total of 469.9 /m^2 different tillers were present during the first growing season. During mid season, 94.0 /m^2 lead tillers developed into reproductive flowering stages (20.0% of the tiller population). Before reaching maturity, 156.6 /m^2 vegetative tillers terminated. Between mid August and mid October, 125.3 /m^2 fall tillers developed. During mid October, 344.6 /m^2 live vegetative tillers remained, of which, 62.7 /m^2 were lead tillers, 156.6 /m^2 were secondary tillers, and 125.3 /m^2 were fall tillers. During the winter period, 0.0 /m^2 tillers terminated. The second year on the mid June 25% defoliation treatment (table 4b) started in early May with 344.6 /m^2 vegetative tillers including 219.3 /m^2 lead tillers and 125.3 /m^2 secondary tillers, of which, 344.6 /m^2 were carry over tillers and 0.0 /m^2 were early spring initiated tillers; there were 94.0 /m^2 fewer tillers than during May of the first growing season. Vegetative reproduction produced 188.0 /m^2 tillers during the second growing season with 62.7 /m^2 initiated during May and 125.3 /m^2 initiated during mid season. A total of 532.5 /m^2 different tillers were present during the second growing season; there were 62.7 /m^2 more total tillers than during the first growing season. During mid season, 125.3 /m^2 lead tillers developed into reproductive flowering stages (23.5% of the tiller population). Before reaching maturity, 156.6 /m^2 vegetative tillers terminated. Between mid August and mid October, 125.3 /m^2 fall tillers developed. During mid October, 375.9 /m^2 live vegetative tillers remained, of which, 188.0 /m^2 were lead tillers, 62.7 /m^2 were secondary tillers, and 125.3 /m^2 were fall tillers; there were 31.3 /m^2 more live vegetative tillers than during mid October of the first growing season.

The first year on the mid June 25% defoliation treatment of the 4.5 month twice-over rotation management strategy (table 4a) started in early May with 971.1 /m^2 vegetative tillers including 595.2 /m^2 lead tillers and 375.9 /m^2 secondary tillers. An unknown quantity of these tillers were carry over tillers from the previous growing season. Vegetative reproduction produced 62.7 /m^2 tillers during the first growing season with 31.3 /m^2 initiated during May and 31.3 /m^2 initiated during mid season. A total of 1033.8 /m^2 different tillers were present during the first growing season. During mid season, 156.6 /m^2 lead tillers developed into reproductive flowering stages (15.1% of the tiller population). Before reaching maturity, 407.2 /m^2 vegetative tillers terminated. Between mid August and mid October, 344.6 /m^2 fall tillers developed. During mid October, 814.5 /m^2 live vegetative tillers remained, of which, 313.3 /m^2 were lead tillers, 156.6 /m^2 were secondary tillers, and 344.6 /m^2 were fall tillers. During the winter period, 188.0 /m^2 tillers terminated. The second year on the mid June 25% defoliation treatment (table 4b) started in early May with 1096.4 /m^2 vegetative tillers including 845.8 /m^2 lead tillers and 250.6 /m^2 secondary tillers, of which, 626.5 /m^2 were carry over tillers and 469.9 /m^2 were early spring initiated tillers; there were 125.3 /m^2 more tillers than during May of the first growing season. Vegetative reproduction produced 188.0 /m^2 tillers during the second growing season with 156.6 /m^2 initiated during May and 31.3 /m^2 initiated during mid season. A total of 1284.4 /m^2 different tillers were present during the second growing season; there were 250.6 /m^2 more total tillers than during the first growing season. During mid season, 188.0 /m^2 lead tillers developed into reproductive flowering stages (14.6% of the tiller population). Before reaching maturity, 281.9 /m^2 vegetative tillers terminated.

Between mid August and mid October, 219.3 /m^2 fall tillers developed. During mid October, 1033.8 /m^2 live vegetative tillers remained, of which, 657.8 /m^2 were lead tillers, 156.6 /m^2 were secondary tillers, and 219.3 /m^2 were fall tillers; there were 219.3 /m^2 more live vegetative tillers than during mid October of the first growing season.

Mid June 50% Treatment

The first year on the mid June 50% defoliation treatment of the 6.0 month seasonlong management strategy (table 4a) started in early May with 563.9 /m^2 vegetative tillers including 438.6 /m^2 lead tillers and 125.3 /m^2 secondary tillers. An unknown quantity of these tillers were carry over tillers from the previous growing season. Vegetative reproduction produced 62.7 /m^2 tillers during the first growing season with 31.3 /m^2 initiated during May and 31.3 /m^2 initiated during mid season. A total of 626.5 /m^2 different tillers were present during the first growing season. During mid season, 156.6 /m^2 lead tillers developed into reproductive flowering stages (25.0% of the tiller population). Before reaching maturity, 62.7 /m^2 vegetative tillers terminated. Between mid August and mid October, 188.0 /m^2 fall tillers developed. During mid October, 595.2 /m^2 live vegetative tillers remained, of which, 219.3 /m^2 were lead tillers, 188.0 /m^2 were secondary tillers, and 188.0 /m^2 were fall tillers. During the winter period, 156.6 /m^2 tillers terminated. The second year on the mid June 50% defoliation treatment (table 4b) started in early May with 469.9 /m^2 vegetative tillers including 407.2 /m^2 lead tillers and 62.7 /m^2 secondary tillers, of which, 438.6 /m^2 were carry over tillers and 31.3 /m^2 were early spring initiated tillers; there were 94.0 /m^2 fewer tillers than during May of the first growing season. Vegetative reproduction produced 156.6 /m^2 tillers during the second growing season with 125.3 /m^2 initiated during May and 31.3 /m^2 initiated during mid season. A total of 626.5 /m^2 different tillers were present during the second growing season; there were the same number of total tillers as during the first growing season. During mid season, 125.3 /m^2 lead tillers developed into reproductive flowering stages (20.0% of the tiller population). Before reaching maturity, 94.0 /m^2 vegetative tillers terminated. Between mid August and mid October, 313.3 /m^2 fall tillers developed. During mid October, 720.5 /m^2 live vegetative tillers remained, of which, 375.9 /m^2 were lead tillers, 31.3 /m^2 were secondary tillers, and 313.3 /m^2 were fall tillers; there were 125.3 /m^2 more live vegetative tillers than during mid October of the first growing season.

The first year on the mid June 50% defoliation treatment of the 4.5 month seasonlong management strategy (table 4a) started in early May with 375.9 /m^2 vegetative tillers including 281.9 /m^2 lead tillers and 94.0 /m^2 secondary tillers. An unknown quantity of these tillers were carry over tillers from the previous growing season. Vegetative reproduction produced 0.0 /m^2 tillers during the first growing season with 0.0 /m^2 initiated during May and 0.0 /m^2 initiated during mid season. A total of 375.9 /m^2 different tillers were present during the first growing season. During mid season, 62.7 /m^2 lead tillers developed into reproductive flowering stages (16.7% of the tiller population). Before reaching maturity, 125.3 /m^2 vegetative tillers terminated. Between mid August and mid October, 156.6 /m^2 fall tillers developed. During mid October, 344.6 /m^2 live vegetative tillers remained, of which, 125.3 /m^2 were lead tillers, 62.7 /m^2 were secondary tillers, and 156.6 /m^2 were fall tillers. During the winter period, 125.3 /m^2 tillers terminated. The second year on the mid June 50% defoliation treatment (table 4b) started in early May with 250.6 /m^2 vegetative tillers including 156.6 /m^2 lead tillers and 94.0 /m^2 secondary tillers, of which, 219.3 /m^2 were carry over tillers and 31.3 /m^2 were early spring initiated tillers; there were 125.3 /m^2 fewer tillers than during May of the first growing season. Vegetative reproduction produced 94.0 /m^2 tillers during the second growing season with 62.7 /m^2 initiated during May and 31.3 /m^2 initiated during mid season. A total of 344.6 /m^2 different tillers were present during the second growing season; there were 31.3 /m^2 fewer total tillers than during the first growing season. During mid season, 94.0 /m^2 lead tillers developed into reproductive flowering stages (27.3% of the tiller population). Before reaching maturity, 94.0 /m^2 vegetative tillers terminated. Between mid August and mid October, 219.3 /m^2 fall tillers developed. During mid October, 375.9 /m^2 live vegetative tillers remained, of which, 156.6 /m^2 were lead tillers, 0.0 /m^2 were secondary tillers, and 219.3 /m^2 were fall tillers; there were 31.3 /m^2 more live vegetative tillers than during mid October of the first growing season.

The first year on the mid June 50% defoliation treatment of the 4.5 month twice-over rotation management strategy (table 4a) started in early May with 720.5 /m^2 vegetative tillers including 595.2 /m^2 lead tillers and 125.3 /m^2 secondary tillers. An unknown quantity of these tillers were carry over tillers from the previous growing season. Vegetative reproduction produced 62.7 /m^2 tillers during the first growing season with 62.7 /m^2 initiated during May and 0.0 /m^2 initiated during mid season. A total of 783.2 /m^2 different tillers were present during the first growing season. During mid season, 219.3 /m^2 lead tillers developed into reproductive flowering stages (28.0% of the tiller population). Before reaching maturity, 250.6 /m^2 vegetative tillers terminated. Between mid August and mid October, 344.6 /m^2 fall tillers developed. During mid October, 657.8 /m^2 live vegetative tillers remained, of which, 219.3 /m^2 were lead tillers, 94.0 /m^2 were secondary tillers, and 344.6 /m^2 were fall tillers. During the winter period, 219.3 /m^2 tillers terminated. The second year on the mid June 50% defoliation treatment (table 4b) started in early May with 689.2 /m^2 vegetative tillers including 563.9 /m^2 lead tillers and 125.3 /m^2 secondary tillers, of which, 438.6 /m^2 were carry over tillers and 250.6 /m^2 were early spring initiated tillers; there were 31.3 /m^2 fewer tillers than during May of the first growing season. Vegetative reproduction produced 250.6 /m^2 tillers during the second growing season with 156.6 /m^2 initiated during May and 94.0 /m^2 initiated during mid season. A total of 939.8 /m^2 different tillers were present during the second growing season; there were 156.6 /m^2 more total tillers than during the first growing season. During mid season, 281.9 /m^2 lead tillers developed into reproductive flowering stages (30.0% of the tiller population). Before reaching maturity, 156.6 /m^2 vegetative tillers terminated. Between mid August and mid October, 344.6 /m^2 fall tillers developed. During mid October, 845.8 /m^2 live vegetative tillers remained, of which, 438.6 /m^2 were lead tillers, 62.7 /m^2 were secondary tillers, and 344.6 /m^2 were fall tillers; there were 188.0 /m^2 more live vegetative tillers than during mid October of the first growing season.

Tiller Density

The number of total different tillers present were significantly greater during the first year on the control, May 50%, and June 25% treatments and during the second year on the control, May 25%, May 50%, and June 25% treatments and numerically greater during both years on the June 50% treatment of the 4.5 m TOR management strategy (tables 4a and 4b). The number of total different tillers were significantly lower during the first year on the control, May 50%, and June 50% treatments and during the second year on the May 50% and June 50% treatments and numerically lower during the first year on the June 25% treatment and during the second year on the control, May 25%, and June 25% treatments of the 4.5 m SL management strategy (tables 4a and 4b). On the 6.0 m SL management strategy, the number of total different tillers were intermediate during the first year on the control, May 50%, June 25%, and June 50% treatments and during the second year on all five treatments (tables 4a and 4b).

Monthly tiller densities, consisting of lead tillers, secondary tillers, and, from mid August to mid October, fall tillers, were greater during both years on all five treatments (except the first year on the May 25% treatment) of the 4.5 m TOR management strategy; were lower on all five treatments (except the first year on the May 25% treatment) of the 4.5 m SL management strategy; and were intermediate on all five treatments (except the first year on the May 25% treatment) of the 6.0 m SL management strategy (figures 2, 3, 4, 5, and 6). During the first year on the May 25% treatment, the monthly tiller densities were greater on the 6.0 m SL management strategy and were similar on the 4.5 m SL and 4.5 m TOR management strategies; except the vegetative lead tiller density was lower on the 4.5 m TOR management strategy during mid August to mid October (figure 3).

Mean monthly tiller densities, excluding the fall tillers, were significantly greater during the first year on the May 25% treatment of the 6.0 m SL management strategy and were significantly greater during the first year on the control, June 25%, and June 50% treatments and during the second year on the control, May 25%, June 25%, and June 50% treatments of the 4.5 m TOR management strategy (table 5). During both years on the May 50% treatment, there were no significant differences between the mean monthly densities of the 6.0 m SL and 4.5 m TOR management strategies (table 5). Mean monthly densities were significantly lower during the first year on the control, May 50%, June 25%, and June 50% treatments and during the second year on all five treatments of the 4.5 m SL management strategy (table 5). During the first year on the May 25% treatment, there were no significant differences between the mean monthly densities of the 4.5 m SL and 4.5 m TOR management strategies (table 5).

The change in mean monthly tiller densities from the first year to the second year were not significantly different on the control, May 50%, and June 50% treatments of the 6.0 m SL, 4.5 m SL, and 4.5 m TOR management strategies and on the June 25% treatments of the 6.0 m SL and 4.5 m SL management strategies (table 5). Mean monthly tiller densities increased significantly during the second year on the May 25% and June 25% treatments of the 4.5 m TOR management strategy and decreased significantly on the May 25% treatments of the 6.0 m SL and 4.5 m SL management strategies (table 5).

The total tiller density for the combined first and second years, excluding the carry over tillers during the second year, were significantly greater on the May 50% and June 25% treatments and numerically greater on the control and June 50% treatments of the 4.5 m TOR management strategy; and were significantly lower on the control, May 50%, June 25%, and June 50% treatments of the 4.5 m SL management strategy (table 6). The total two year tiller densities were intermediate on the control, May 50%, June 25%, and June 50% treatments of the 6.0 m SL management strategy (table 6). There were no significant differences in the total two year tiller densities on the May 25% treatments of the 6.0 m SL, 4.5 m SL, and 4.5 m TOR management strategies (table 6).

The 6.0 m SL, 4.5 m SL, and 4.5 m TOR grazing management strategies had been operational prior to the start of this defoliation study for 12 years, 14 years, and 17 years, respectively. The effects from these grazing management strategies would have been established within the respective ecosystems at some proportion related the length of operational time. The quantities of tillers were significantly or numerically greater on the five treatments of the 4.5 m TOR management strategy during both years, except the first year on the May 25% treatment. The quantities of tillers were significantly or numerically lower on the five treatments of the 4.5 m SL management strategy. The quantity of tillers on the five treatments of the 6.0 m SL management strategy were usually intermediate, except the first year on the May 25% treatment. The greater quantity of tillers on the 4.5 m TOR management strategy developed because of the significantly greater quantities of available soil mineral nitrogen that resulted from the greater soil organism activity in the significantly larger rhizosphere volume (table 3). The low quantity of tillers produced on the 4.5 m SL management strategy resulted because of the low quantities of soil mineral nitrogen, the low rhizosphere volume, and the effects from the soil characteristics related to the significantly shallower surface horizon depth. The quantity of tillers on the 6.0 m SL management strategy were lower than the tiller densities on the 4.5 m TOR management strategy because of the lower quantities of soil mineral nitrogen and lower rhizosphere volume, and would be expected to be lower than those on the 4.5 m SL management strategy had both seasonlong management strategies had similar duration of operation and surface horizon depth.

Tiller Initiation

The total number of tillers initiated through vegetative reproduction from axillary buds were significantly greater on the May 50% treatment and numerically greater on the control, May 25%, June 25%, and June 50% treatments of the 4.5 m TOR management strategy; and were significantly lower on the control, May 50%, June 25%, and June 50% treatments and numerically lower on the May 25% treatment of the 4.5 m SL management strategy (table 7). Vegetatively reproduced tillers were intermediate on the five treatments of the 6.0 m SL management strategy (table 7).

The number of vegetative tillers stimulated per lead tiller present at the time of defoliation treatment were significantly greater on the May 25% treatment and numerically greater on the May 50%, June 25%, and June 50% treatments of the 4.5 m TOR management strategy; were significantly lower on the May 50% treatment and numerically lower on the June 25% and June 50% treatments of the 4.5 m SL management strategy and on the May 25% treatment of the 6.0 m SL management strategy; and were intermediate on the May 50%, June 25%, and June 50% treatment of the 6.0 m SL management strategy and on the May 25% treatment of the 4.5 m SL management strategy (table 7).

Significantly greater numbers of vegetative tillers were stimulated on the May 25%, May 50%, and June 25% treatments than on the control treatment and numerically fewer tillers were stimulated on the June 50% treatment than on the control treatment of the 4.5 m TOR management strategy. Significantly fewer tillers were stimulated on the May 50% treatment and numerically fewer tillers were stimulated on the May 25%, June 25%, and June 50% treatments than on the control treatment of the 4.5 m SL management strategy; and numerically fewer tillers were stimulated on the May 25%, May 50%, June 25%, and June 50% treatments than on the control treatment of the 6.0 m SL management strategy (table 7). The defoliated tillers on the traditional 6.0 m SL and 4.5 m SL management strategies produced 141.0 /m^2 and 117.4 /m^2 fewer vegetative tillers than were produced by undefoliated tillers on the respective control treatments. The defoliated tillers produced 198.4 /m^2 more vegetative tillers than were produced by undefoliated tillers on the control treatment of the 4.5 m TOR management strategy.

The total number of initiated vegetative tillers was lower on the treatments of the 4.5 m SL and 6.0 m SL management strategies than the number of initiated tillers on the treatments of the 4.5 m TOR management strategy because of the significantly lower soil mineral nitrogen, and the significantly lower volume of rhizosphere on the two seasonlong management strategies. The number of stimulated vegetative tillers per lead tiller on all four defoliation treatments of the 4.5 m SL and 6.0 m SL management strategies was lower than the number of tillers that developed on the respective control treatments because the defoliated tillers were unable to recover fully from the single event defoliation treatment as a result of the insufficient quantities of soil mineral nitrogen inhibiting the compensatory physiological processes within the grass plants on the two seasonlong management strategies. The defoliated tillers on the June 50% treatment of the 4.5 m TOR management strategy recovered to slightly less than full pretreatment condition and produced slightly fewer tillers per lead tiller than were produced on the control treatment.

The defoliated tillers on the May 25%, May 50%, and June 25% treatments of the 4.5 m TOR management strategy fully recovered from the defoliation treatments and produced more vegetative tillers per lead tiller than were produced on the control treatment. The significantly larger rhizosphere volume and the significantly greater quantities of available soil mineral nitrogen on the 4.5 m TOR management strategy were the essential resources that permitted grass tillers to fully recover by the compensatory physiological processes within the grass plants, to support vegetative tiller growth from several axillary buds, and to increase herbage production following defoliation treatments.

Vegetative tillers initiated during early spring were significantly greater on the control, May 25%, and June 25% treatments and numerically greater on the May 50% and June 50% treatments of the 4.5 m TOR management strategy than on the defoliation treatments of the two seasonlong management strategies (table 8). Vegetative tillers initiated during May were significantly greater on the June 25% and June 50% treatments and numerically greater on the control and May 50% treatments of the 4.5 m TOR management strategy than on the defoliation treatments of the two seasonlong management strategies (table 8). Vegetative tillers initiated during mid season were significantly greater on the June 25% treatment of the 4.5 m SL management strategy and were significantly greater on the control and May 25% treatments and numerically greater on the May 50% and June 50% treatments of the 4.5 m TOR management strategy (table 8). Greater numbers of vegetative tillers were initiated during early spring and May on the treatments of the 4.5 m TOR management strategy than were initiated on the treatments of the 4.5 m SL and 6.0 m SL management strategies showing that grass plants on the 4.5 m TOR management strategy were in better condition and had access to carbohydrates and essential mineral nitrogen in much greater quantities than were available to grass plants on the 4.5 m SL and 6.0 m SL management strategies. The mid season vegetative tiller initiation period occurred simultaneously with the high resource demand period in which the dominant reproductive lead tillers progressed through the flowering stages and produced seeds. Greater numbers of lead tillers flowered and greater numbers of vegetative tillers were initiated during mid season on the treatments of the 4.5 m TOR management strategy than flowered and were initiated on the treatments of the 4.5 m SL and 6.0 m SL management strategies showing that the grass plants on the 4.5 m TOR management strategy were in better condition and had access to greater quantities of essential mineral nitrogen than the grass plants on the 4.5 m SL and 6.0 m SL management strategies.

Vegetative tillers initiated as fall tillers during mid August to mid October were numerically greater on the control and June 25% treatments of the 6.0 m SL management strategy; on the May 25% treatment of the 4.5 m SL management strategy; and on the June 50% treatment of the 4.5 m TOR management strategy (table 8). On the May 25% treatment, there were no significant differences between the fall initiated tiller densities of the 6.0 m SL and 4.5 m TOR management strategies. Vegetative tillers initiated during fall season were significantly lower on the control, May 50%, and June 25% treatments and numerically lower on the June 50% treatment of the 4.5 m SL management strategy (table 8). Greater numbers of vegetative tillers were initiated as fall tillers than were initiated during early spring and May on the five treatments of the 6.0 m SL and 4.5 m SL management strategies (table 8). A greater percentage of the total vegetative tillers were initiated during mid August to mid October as fall tillers on the five treatments of the 6.0 m SL and 4.5 m SL management strategies than the percent of total vegetative tillers initiated as fall tillers on the respective treatments of the 4.5 m TOR management strategy (table 8). The fall tiller initiation period, mid August to mid October, started after the lead tillers had completed most of their active growth and occurred simultaneously with the winter hardening process of perennial grasses. Young vegetative tillers on the 4.5 m SL and 6.0 m SL management strategies appeared to have lower competition for essential elements during this late season period than during the other vegetative tiller initiation periods.

The greatest number of total vegetative tillers initiated from axillary buds on the 4.5 m SL, 6.0 m SL, and 4.5 m TOR management strategies were 1002.4 /m^2 tillers on the May 25% treatment, 1159.1 /m^2 tillers on the May 50% treatment, and 1597.6 /m^2 tillers on the May 50% treatment, respectively. The lowest number of total vegetative tillers initiated on the 4.5 m SL, 6.0 m SL, and 4.5 m TOR management strategies were 438.6 /m^2 tillers on the May 50% treatment, 751.8 /m^2 tillers on the June 50% treatment, and 1221.7 /m^2 tillers on the control treatment, respectively (table 8). The lowest number of vegetative tillers initiated on the treatments of the 4.5 m TOR management strategy (1221.7 /m^2 tillers) was greater than the greatest number of vegetative tillers initiated on the treatments of the 4.5 m SL (1002.4 /m^2 tillers) and 6.0 m SL (1159.1 /m^2 tillers) management strategies (table 8). All of the treatments of the 4.5 m TOR management strategy initiated more vegetative tillers during the growing season than all the treatments of the 4.5 m SL and 6.0 m SL management strategies because of the greater quantities of available essential soil mineral nitrogen that resulted from the greater soil organism activity in the larger rhizosphere volume on the 4.5 m TOR management strategy.

Tiller Termination

The number of total tillers terminated during the growing season were significantly greater on the control and May 50% treatments and numerically greater on the May 25%, June 25%, and June 50% treatments of the 4.5 m TOR management strategy; were significantly lower on the control treatment and numerically lower on the May 25%, May 50%, June 25%, and June 50% treatments of the 4.5 m SL management strategy; and were intermediate on all five treatments of the 6.0 m SL management strategy (table 9). The mean percent of the tiller population terminated was 54.0%. Percent termination of the tiller population was greatest (61.1%) on the May 50% treatments and lowest (50.1%) on the June 25% treatments. There was no significant differences in the percent of total tillers that terminated among all the treatments of the 6.0 m SL, 4.5 m SL, and 4.5 m TOR management strategies.

The number of lead tillers terminated after flowering was significantly greater on the control, May 25%, and June 50% treatments and numerically greater on the May 50% and June 25% treatments of the 4.5 m TOR management strategy; was significantly lower on the control, May 25%, and June 50% treatments and numerically lower on the May 50% and June 25% treatments of the 4.5 m SL management strategy; and was intermediate on all five treatments of the 6.0 m SL management strategy (table 9). The percent of the tiller population that produced flower stages was around 33.0% on the control treatments and around 20.3% on the defoliation treatments, with a mean of 17.3% during the first year and a mean of 23.3% during the second year. The percent of the tiller population reaching flowering stages was depressed 48.6% the first year and 29.4% the second year by the defoliation treatments. There was no significant differences in the percent of total tillers that terminated after flowering among all the treatments of the 6.0 m SL, 4.5 m SL, and 4.5 m TOR management strategies.

The number of vegetative tillers terminated before reaching maturity was significantly greater on the May 50% and June 25% treatments and numerically greater on the control, May 25%, and June 50% treatments of the 4.5 m TOR management strategy; was significantly lower on the June 25% treatment and numerically lower on the May 25% and June 50% treatments of the 6.0 m SL management strategy and on the control and May 50% treatments of the 4.5 m SL management strategy; and was intermediate on the control and May 50% treatments of the 6.0 m SL management strategy and on the May 25%, June 25%, and June 50% treatments of the 4.5 m SL management strategy (table 9). The percent of the tiller population terminated during the early season, mid and fall season, and winter period was 2.5%, 22.4%, and 8.4%, respectively. There was no significant differences in the percent of total tillers that terminated before reaching maturity during any of the periods among all the treatments of the 6.0 m SL, 4.5 m SL, and 4.5 m TOR management strategies.

The relationships among the numbers of tillers terminated on the management strategies were similar to the relationships among the total tiller densities on the management strategies with greater numbers on the treatments of the 4.5 m TOR management strategy, intermediate numbers on the treatments of the 6.0 m SL management strategy, and lower numbers on the treatments of the 4.5 m SL management strategy. The percent of total tillers terminated, percent of lead tillers terminated after flowering, and percent of vegetative tillers terminated before reaching maturity were not different among the management strategies. Termination of lead tillers after reaching flowering stages occurred systematically because the apical meristem tissue was depleted during the process of inflorescence production. Termination of secondary tillers before reaching maturity most likely resulted from insufficient quantities of essential resources reaching those tillers. The allocation of essential elements and photosynthetic products to some tillers and not to other tillers required a controlling process and an hierarchical differentiation of tillers into categories.

Tiller Leaf Height

Mean tiller leaf height of the reproductive lead tillers was 17.5 cm during 2000 and 25.0 cm during 2001 with increases in leaf height on all treatments the second year. The mean monthly reproductive lead tiller leaf heights were not significantly different among the 6.0 m SL, 4.5 m SL, and 4.5 m TOR management strategies on the five treatments during the first and second years, respectively (tables 10a, 10b, and 10c). Mean tiller leaf height of the vegetative lead tillers was 13.6 cm during 2000 and 19.7 cm during 2001 with increases in leaf height on all treatments the second year. The mean monthly vegetative lead tiller leaf heights were not significantly different among the 6.0 m SL, 4.5 m SL, and 4.5 m TOR management strategies on the five treatments during the first and second years, respectively (tables 10a, 10b, and 10c).

Mean tiller leaf height of the slow growth secondary tillers was 7.9 cm during 2000 and 11.9 cm during 2001 with increases in leaf height on all treatments the second year, except on the June 25% and June 50% treatments of the 6.0 m SL management strategy and on the June 50% treatment of the 4.5 m SL management strategy. The mean monthly slow growth secondary tiller leaf heights were not significantly different among the 6.0 m SL, 4.5 m SL, and 4.5 m TOR management strategies on the five treatments during the first and second years, respectively, except on the May 50% treatment of the 4.5 m SL management strategy during 2000 and on the June 50% treatment of the 4.5 m SL management strategy during 2001 (tables 10a, 10b, and 10c). Mean tiller leaf height of the early senescent secondary tillers was 4.5 cm during 2000 and 7.6 cm during 2001 with increases in leaf height on all treatments the second year, except on the May 25% treatment of the 6.0 m SL management strategy and on the June 25% treatment of the 4.5 m TOR management strategy. The mean monthly early senescent secondary tiller leaf heights were not significantly different among the 6.0 m SL, 4.5 m SL, and 4.5 m TOR management strategies on the five treatments during the first and second years, respectively, except on the control and June 25% treatments of the 6.0 m SL management strategy and on the June 50% treatment of the 4.5 m SL management strategy during 2000 (tables 10a, 10b, and 10c).

Grazing management strategy and defoliation treatment did not appear to affect tiller leaf height. Mean tiller leaf height was affected by the relative hierarchical dominance of the tiller categories and by the greater precipitation during June and July of the second year. Both tiller density and tiller leaf height affect the quantity of herbage biomass production. When leaf heights are similar, the management strategy that supports the greatest tiller density will produce the greatest quantity of herbage biomass.

Tiller Growth and Development

Vegetative tillers did not all develop at the same rate. Rates of tiller growth and development were regulated by hormones and availability of essential elements. The dominant tillers with rapid or unimpeded growth were the reproductive lead tillers and vegetative lead tillers and the subordinate tillers with slow or inhibited growth were the slow growth secondary tillers and early senescent secondary tillers.

The reproductive lead tillers had the fastest rate of growth and development. They started with two or three leaves in early May and reached the early flower stages around mid June. Reproductive lead tiller development was significantly rapid on the June 50% treatment of the 6.0 m SL management strategy during 2000 and 2001, and was significantly slower on the May 50% and June 25% treatments of the 6.0 m SL management strategy during 2000 and on the control treatment of the 4.5 m SL management strategy during 2001 (tables 11a and 11b).

Mean percent of the tiller population to develop into reproductive flowering stages on the 6.0 m SL, 4.5 m SL, and 4.5 m TOR management strategies were 23.1%, 19.3%, and 23.4%, respectively, and were not significantly different. The percent of tillers at flower stages were significantly greater on the control treatments of the 6.0 m SL, 4.5 m SL, and 4.5 m TOR management strategies during the first year. The defoliation treatments reduced the number of tillers that developed into flower stages by around 38.5%. These reductions were significantly lower on the May 50% treatments of the 6.0 m SL and 4.5 m TOR management strategies and on the May 25% treatment of the 4.5 m SL management strategy. Greater numbers of tillers developed into flower stages during the second year than during the first year on the four defoliation treatments of the 6.0 m SL, 4.5 m SL, and 4.5 m TOR management strategies, except on the June 50% treatment of the 6.0 m SL management strategy.

The length of the annual flowering period was affected by the availability of essential elements. The flowering period started shortly after 15 June during the first year and was completed by late June on the control and June 50% treatments of the 6.0 m SL management strategy and on all five treatments of the 4.5 m SL management strategy; was completed by mid July on the May 25% treatment of the 6.0 m SL management strategy and on the May 50% and June 25% treatments of the 4.5 m TOR management strategy; and was completed by mid or late August on the May 50% and June 25% treatments of the 6.0 m SL management strategy and on the control, May 25%, and June 50% treatments of the 4.5 m TOR management strategy.

The flowering period started shortly after 21 June during the second year and was completed by mid July on the control, May 25%, June 25%, and June 50% treatments of the 6.0 m SL management strategy and on the control and May 25% treatments of the 4.5 m SL management strategy; and was completed by mid August on the May 50% treatment of the 6.0 m SL management strategy, on the May 50%, June 25%, and June 50% treatments of the 4.5 m SL management strategy, and on all five treatments of the 4.5 m TOR management strategy.

The flowering periods were extended beyond early August during the first year on two treatments of the 6.0 m SL management strategy and on three treatments of the 4.5 m TOR management strategy, and during the second year on one treatment of the 6.0 m SL management strategy, on three treatments of the 4.5 m SL management strategy, and on five treatments of the 4.5 m TOR management strategy.

The precipitation for June and July during the first year was 115.34% of the LTM (long-term mean) and during the second year was 198.06% of the LTM (table 2). The additional 5.56 inches of precipitation during the second year contributed to the extended length of the flowering periods and to the increased number of tillers that developed into flower stages on the treatments of the 6.0 m SL, 4.5 m SL, and 4.5 m TOR management strategies. The quantity of soil mineral nitrogen available on the 4.5 m TOR management strategy was significantly greater than that on the 6.0 m SL and 4.5 m SL management strategies (table 3). The increase in mineral nitrogen resulted from the increased soil microorganism activity in the significantly greater rhizosphere volume on the 4.5 m TOR management strategy (table 3). The greater quantity of mineral nitrogen and greater volume of the rhizosphere on the 4.5 m TOR management strategy contributed to the greater number of tillers developing flower stages and the longer flowering periods during both years.

The vegetative lead tillers had the second fastest rate of growth and development. They started with one, two, or three leaves in early May and reached the fifth leaf stage by early June and the sixth leaf stage by early July. Vegetative lead tiller development was significantly rapid on the control treatment of the 6.0 m SL management strategy and on the May 50% treatment of the 4.5 m TOR management strategy during 2000 and 2001, and was significantly slower on the May 25% treatment of the 4.5 m SL management strategy during 2000 and 2001 and on the May 50% and June 50% treatments of the 4.5 m SL management strategy during 2001 (tables 11a and 11b).

The slow growth secondary tillers and early senescent secondary tillers were the subordinate tillers and had very slow growth rates. The secondary tillers remained at the second and third leaf stages for more than half of the growing season. After the majority of the reproductive lead tillers had reached the anthesis (flowering) stage, a few of the secondary tillers advanced to the fourth and sometimes the fifth leaf stages. Slow growth secondary tiller development was relatively slow on all treatments. This slow rate of growth was significantly faster on the May 50% treatment of the 4.5 m TOR management strategy, and was significantly slower on the control treatment of the 4.5 m SL management strategy during 2000 and 2001 (tables 12a and 12b). Early senescent secondary tillers usually terminated before mid August. Growth and development of early senescent tillers was slow on all treatments, however, growth was significantly faster on the control treatment of the 4.5 m TOR management strategy during 2000 and on the June 25% treatment of the 6.0 m SL management strategy during 2001 (tables 12a and 12b).

Vegetatively reproduced tillers with three leaves or less were not independent and relied on allocation of essential elements and photosynthetic products from lead tillers. The four leaf stage appeared to be a transition phase between dependence on and independence from other tillers. After the development of the fifth or sixth leaf, vegetatively initiated tillers appeared to be able to procure essential elements independently and possibly could control distribution of essential elements and photosynthetic products to subordinate tillers; indicating that vegetatively produced tillers do not achieve independence from dominant tiller regulation of growth until after development of adequate mature leaf area and root system.

Discussion

Growth and development of grass tillers were affected by availability of essential elements and required energy from sunlight, carbon from atmospheric carbon dioxide, hydrogen from soil water, and nitrogen from soil inorganic nitrogen. Radiant energy from sunlight is usually available in sufficient amounts on rangelands (Wight and Black 1972), even after the reductions in energy due to ambient cloud cover. Availability of sunlight can be a limiting factor in areas where taller woody plants shade the grassland community (Kochy and Wilson 2000). Atmospheric carbon dioxide is readily available on rangelands and carbon is not a limiting factor for grass plants (Wight and Black 1972). Hydrogen from soil water is readily available on rangelands during some periods of the growing season with various degrees of deficiency during other periods, and soil water can be a limiting factor during periodic drought conditions (Manske 2009a). The availability of soil water, which is an essential requirement for plant growth and has a dominant role in physiological processes, does not limit herbage production on rangeland ecosystems to the extent that mineral nitrogen availability does (Wight and Black 1972). Available soil mineral nitrogen is the major limiting factor on native rangeland (Wight and Black 1979). The rate of mineralization of soil organic nitrogen by rhizosphere organisms determines the quantity of mineral nitrogen available on grasslands

(Manske 2008, 2009b). Soil mineral nitrogen available at amounts of less than 100 lbs/ac causes nitrogen deficiencies that limit plant physiological processes and production of herbage (Wight and Black 1972). Deficiencies of mineral nitrogen decrease grass plant soil water use efficiency and cause the weight of herbage produced per inch of precipitation received to be reduced an average of 49.6% below the quantity of herbage produced per inch of precipitation on grasslands with sufficient available mineral nitrogen at 100 lbs/ac or greater (Wight and Black 1979).

Growth and development of grass tillers were affected by grazing because defoliation removes vital leaf material from the plant, disrupts photosynthesis and physiological processes throughout the plant, alters the microclimate around the plant, and changes the soil environment affecting soil organism activity. Grass plants developed defoliation resistance mechanisms in response to grazing during the period of coevolution with herbivores. The defoliation resistance mechanisms help grass tillers withstand and recover from partial defoliation. The defoliation resistance mechanisms consist of three major components that are: compensatory physiological processes within grass plants, vegetative reproduction of secondary tillers from axillary buds, and symbiotic rhizosphere organism activity and the associated conversion of inorganic nitrogen from soil organic nitrogen (Manske 2007b).

Different grazing management strategies produce different effects on grassland ecosystems as a result of the variations with the timing and severity of defoliation events. Depending on the degree of foliage removal and phenological growth stage of the grass tillers, the effects from defoliation can be beneficial or antagonistic to the defoliation resistance mechanisms and to the rate of mineralization of soil organic nitrogen into mineral nitrogen by rhizosphere organisms. Low rates of mineralization occur on grasslands managed with traditional grazing management strategies (Wight and Black 1972). The quantity of available mineral nitrogen on traditionally managed grasslands ranges from a low of 31 lbs/ac on deferred management strategies up to 62 lbs/ac on moderately stocked seasonlong management strategies (Manske 2008, 2009b). High rates of mineralization with mineral nitrogen available at quantities from 164 lbs/ac to 199 lbs/ac can be obtained on grasslands managed with the twice-over rotation management strategy (Manske 2008, 2009b).

The quantity of total tillers present during the growing season was greatest on the 4.5 m TOR management strategy, except the first year on the May 25% treatment, because of the greater quantities of available mineral nitrogen resulting from the increased soil microorganism activity in the larger rhizosphere volume. The quantity of total tillers was intermediate on the 6.0 m SL management strategy, except the first year on the May 25% treatment, because the quantities of available mineral nitrogen and rhizosphere volume were lower than those on the 4.5 m TOR management strategy. The quantity of total tillers was lowest on the 4.5 m SL management strategy because of the low quantities of available mineral nitrogen, the low rhizosphere volume, and the shallower surface soil horizon depth.

Grass plants reproduce by two methods; sexually by seeds developing into seedlings and vegetatively by tillers developing from axillary buds. Seedlings are rare on rangeland ecosystems. Stimulation of vegetative tiller development from axillary buds requires the reduction of the inhibiting hormone, auxin, through partial defoliation of lead tiller leaf area while the tillers are in vegetative growth stages, and requires the availability of sufficient quantities of the essential elements for growth and development of the initiated tillers. All the treatments of the 4.5 m TOR management strategy initiated more vegetative tillers from axillary buds during the growing season than all the treatments of the 4.5 m SL and 6.0 m SL management strategies because of the greater quantities of available mineral nitrogen. The lowest number of vegetative tillers initiated on the 4.5 m TOR management strategy was on the control treatment and was greater than the number of tillers initiated on any of the treatments of the 4.5 m SL and 6.0 m SL management strategies.

Greater numbers of vegetative tillers were stimulated per lead tiller on the defoliation treatments of the 4.5 m TOR management strategy than vegetative tillers per lead tiller on the control treatment, except on the June 50% defoliation treatment. The increased soil organism activity in the large rhizosphere volume and the great quantities of available mineral nitrogen above 100 lbs/ac were the essential resources that permitted the partially defoliated tillers to fully recover, to develop more vegetative tillers per lead tiller, and to increase production following defoliation treatments. Fewer vegetative tillers were stimulated per lead tiller on the June 50% treatment of the 4.5 m TOR management strategy than on the control treatment because the defoliated tillers recovered to slightly less than full pretreatment condition and produced slightly fewer tillers per lead tiller than were produced on the control treatment.

Lower numbers of vegetative tillers were stimulated per lead tiller on the defoliation treatments of the 4.5 m SL and 6.0 m SL management strategies than vegetative tillers per lead tiller on the respective control treatments. The partially defoliated tillers were unable to recover fully from the single event defoliation treatments as a result of the significantly insufficient quantities of available mineral nitrogen on the two traditional seasonlong management strategies.

The numbers of vegetative tillers initiated during the early spring, during May, and during the mid season periods of the growing season were greater on the 4.5 m TOR management strategy than on the 4.5 m SL and 6.0 m SL management strategies. The greater numbers of vegetative tillers initiated during early spring and May showed that the grass plants on the 4.5 m TOR management strategy were in better condition and had access to carbohydrates and essential mineral nitrogen in much greater quantities than were available to grass plants on the 4.5 m SL and 6.0 m SL management strategies. The mid season period occurred simultaneously with the high resource demand period in which the dominant reproductive lead tillers progressed through the flowering stages and produced seeds. The greater numbers of vegetative tillers initiated during mid season showed that the grass plants on the 4.5 m TOR management strategy were in better condition and had access to essential mineral nitrogen in much greater quantities than were available to grass plants on the 4.5 m SL and 6.0 m SL management strategies.

Greater numbers of vegetative tillers were initiated during mid August to mid October as fall tillers than were initiated during early spring and May on the 4.5 m SL and 6.0 m SL management strategies. A greater percent of the total vegetative tillers stimulated were initiated during mid August to mid October as fall tillers on the 4.5 m SL and 6.0 m SL management strategies than the percent of total vegetative tillers initiated as fall tillers on the respective treatments of the 4.5 m TOR management strategy. The fall tiller initiation period, mid August to mid October, started after the lead tillers had completed most of their active growth and occurred simultaneously with the winter hardening process of perennial grasses. There appeared to be lower competition for essential elements during this late season period than during the other vegetative tiller initiation periods, giving the young initiated vegetative tillers access to a greater proportion of the significantly lower quantities of available mineral nitrogen on the 4.5 m SL and 6.0 m SL management strategies.

The total number of tillers terminated during the growing season was greatest on the 4.5 m TOR management strategy, intermediate on the 6.0 m SL management strategy, and lowest on the 4.5 m SL management strategy, which was the same relationship as with the total number of tillers present during the growing season. The mean percent of the tiller population that terminated was 54% and was not different among the management strategies.

The number of lead tillers terminated after flowering was greatest on the 4.5 m TOR management strategy, intermediate on the 6.0 m SL management strategy, and lowest on the 4.5 m SL management strategy. Tillers usually produced vegetative growth during the first growing season and developed into flower stages during the second growing season. Tillers rarely reached flowering stages during the initiation growing season. Termination of lead tillers after reaching the flowering stages occurred because the apical meristem tissue was depleted during the production of the inflorescence. The percent of the tiller population that produced flower stages was around 33% on the control treatments. The defoliation treatments did not remove the apical meristem from any tillers, however, the percent of the tiller population reaching flowering stages was reduced during two growing seasons. The depression in the numbers of tillers developing into flowering stages was 48.6% the first year and 29.4% the second year. The percentage of the tiller population terminated after reaching flower stages was not different among the management strategies.

The number of vegetative tillers terminated before reaching maturity was greatest on the 4.5 m TOR management strategy and was lower on the 4.5 m SL and 6.0 m SL management strategies. The percent of the vegetative tillers terminated during the early season, the mid and fall season, and the winter period was 2.5%, 22.4%, and 8.7%, respectively. The percentage of the tiller population terminated before reaching maturity was not different among the management strategies.

The quantity of available essential elements determined the quantity of tillers that could be sustained on each grazing management strategy with the greatest tiller densities, intermediate densities, and the lowest densities on the 4.5 m TOR, 6.0 m SL, and 4.5 m SL management strategies, respectively. More tillers were initiated than could be supported by the available quantity of essential elements. Some of the lower subordinate tillers terminated before reaching maturity as a result of not receiving sufficient resources. Allocation of essential elements to some tillers and not to other tillers would require a controlling process with a continuum of hierarchical differentiation of tillers into dominant and subordinate levels and would indicate that vegetatively reproduced tillers did not achieve independence at phenological growth stages of three leaves or less, that the fourth leaf stage was a transition phase, and that with the development of the fifth or sixth leaf the tillers could procure essential elements independently and possibly could control distribution of essential elements and photosynthetic products to subordinate secondary tillers.

Tiller leaf height and tiller growth and development did not appear to be affected by grazing management strategy or by defoliation treatment, however, they were strongly affected by the relative hierarchical dominance level of the tiller categories and by the greater precipitation received during June and July of the second year. The dominant lead tillers had greater leaf height and had rapid or unimpeded growth and development. The subordinate secondary tillers had shorter leaf height and had slow or inhibited growth and development. The tiller leaf height increased on all tiller categories during the second year which received 5.56 inches of precipitation during June and July greater than was received during the first year. The reproductive lead tillers started with two or three leaves in early May and reached the early flower stages around mid June. The vegetative lead tillers started with one to three leaves in early May and reached the fifth leaf stage by early June and the sixth leaf stage by early July. The secondary tillers developed relatively slow and remained at the second and third leaf stages for more than half of the growing season. After the majority of the lead tillers had completed most of the active growth, a few of the secondary tillers advanced to the fourth and fifth leaf stages. Some secondary tillers terminated before mid August as a result of not receiving sufficient quantities of essential elements or photosynthetic products. The surviving vegetative lead tillers, slow growth secondary tillers, and initiated fall tillers did not terminate at the end of the growing season; the tillers with intact apical meristems became carry over tillers and continued growth and development during the next growing season, and it appears likely that some vegetative tillers would continue active growth into the third growing season.

The grass plants on the 6.0 m SL, 4.5 m SL, and 4.5 m TOR management strategies did not respond similarly to identical timing and severity defoliation treatments because the defoliation by grazing during the previous growing seasons caused differential effects to the defoliation resistance mechanisms and to the rates of mineralization of soil organic nitrogen on the three management strategies.

Grass plant responses to defoliation were negative on the traditional 4.5 m SL and 6.0 m SL management strategies because the timing and severity of grass tiller defoliation was antagonistic to rhizosphere organism activity resulting in insufficient quantities of available mineral nitrogen that inhibited the defoliation resistance mechanisms from functioning at restorative levels causing incomplete recovery of partially defoliated grass tillers, decreased numbers of vegetatively initiated tillers, low grass tiller densities, and decreased quantities of herbage production.

Grass plant responses to defoliation were positive on the 4.5 m TOR management strategy because the timing and severity of grass tiller defoliation was beneficial to rhizosphere organism activity resulting in great quantities of available mineral nitrogen above 100 lbs/ac that permitted the defoliation resistance mechanisms to function at elevated levels causing full recovery of partially defoliated grass tillers, increased numbers of vegetatively initiated tillers, high grass tiller densities, and increased quantities of herbage production.

Grass plant responses to defoliation were positive or negative depending on the quantity of soil mineral nitrogen and whether the available mineral nitrogen was greater than or less than 100 lbs/ac, respectively.

The defoliation resistance mechanisms are activated following removal of a portion of the leaf material. The defoliation resistance mechanisms, however, do not function at full capacity following a single defoliation event. The functionality of the various processes increase in increments over several years with annually repeated partial defoliation occurring during vegetative phenological growth stages. Successful fulfillment of the defoliation resistance mechanisms requires availability of sufficient quantities of the essential elements and requires sufficient periods of time without further disruption to develop and perform all specific steps for each process. The compensatory physiological processes within the grass plants and the processes for vegetative reproduction of secondary tillers from axillary buds cannot function at elevated levels until the biogeochemical processes of nutrient cycling within the ecosystem that require rhizosphere organism activity are functioning at elevated levels with soil mineral nitrogen available at 100 lbs/ac or greater.

Summary

Northern Plains ranchers who implemented the biologically effective twice-over rotation management strategy found that it required three to five years before grass tiller density increased significantly. An intensive timing and severity defoliation treatment study was conducted with western wheatgrass to determine treatments that activated vegetative reproduction of tillers from

axillary buds. Four defoliation treatments and a control with seven microplots each were established on silty range sites in 6.0 month seasonlong (6.0 m SL), 4.5 month seasonlong (4.5 m SL), and 4.5 month twice-over rotation (4.5 m TOR) management strategies. Mean tiller densities were 485.5 /m^2, 759.7 /m^2, 1148.7 /m^2 on the 4.5 m SL, 6.0 m SL, and 4.5 m TOR management strategies, respectively. The defoliated tillers on the traditional 4.5 m SL and 6.0 m SL management strategies produced 117.4 /m^2 and 141.0 /m^2 fewer vegetative tillers than were produced by undefoliated tillers on the respective control treatments. The defoliated tillers produced 198.4 /m^2 more vegetative tillers on the 4.5 m TOR management strategy than were produced by undefoliated tillers on the control treatment. The seasonal mean rhizosphere volume was 50, 68, and 227 ft^3/ac on the 6.0 m SL, 4.5 m SL, and 4.5 m TOR management strategies, respectively, and the available soil mineral nitrogen ranged between 31 and 62 lbs/ac on traditional management strategies and ranged between 164 and 199 lbs/ac on the 4.5 m TOR management strategy. The compensatory physiological processes that enable rapid recovery of defoliated tillers and the processes for vegetative reproduction of secondary tillers from axillary buds were not fully activated on the 6.0 m SL and 4.5 m SL management strategies because the timing and severity of grass tiller defoliation was antagonistic to rhizosphere organism activity causing insufficient quantities of available mineral nitrogen that resulted in incomplete recovery of defoliated tillers, decreased vegetative tillers from axillary buds, low tiller densities, and decreased herbage production. The defoliation resistance mechanisms functioned at elevated levels on the 4.5 m TOR management strategy because the timing and severity of grass tiller defoliation was beneficial to rhizosphere organism activity causing great quantities of available mineral nitrogen that resulted in full recovery of defoliated tillers, increased vegetative tillers from axillary buds, high tiller densities, and increased herbage production. Wight and Black (1979) found that activation of the processes for grass plant water use efficiency required 100 lbs/ac or greater soil mineral nitrogen. This study found that activation of the components of the defoliation resistance mechanisms that help grass tillers withstand and recover from defoliation and that produce vegetative tillers from axillary buds required 100 lbs/ac or greater soil mineral nitrogen. Stimulation of increased rhizosphere organism activity and increased mineralization of soil organic nitrogen into mineral nitrogen available at 100 lbs/ac or greater must occur before the other beneficial components of the defoliation resistance mechanisms can be fully activated.

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Table 2. Precipitation in inches for growing-season months and the annual total precipitation for 1999-2001, DREC Ranch, Manning, North Dakota.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Growing Season	Annual Total
Long-term mean									
1982-2008	1.40	2.40	3.24	2.43	1.73	1.37	1.33	13.90	16.69
1999	1.10	4.93	1.59	1.80	2.70	2.40	T	14.52	15.56
% of LTM	78.57	205.42	49.07	74.07	156.07	175.18	0.00	104.46	93.23
2000	1.26	1.90	3.77	2.77	2.74	1.09	1.46	14.99	20.23
% of LTM	90.00	79.17	116.36	113.99	158.38	79.56	109.77	107.84	121.21
2001	2.70	0.53	6.36	4.87	0.00	1.94	0.00	16.40	18.03
% of LTM	192.86	22.08	196.30	200.41	0.00	141.61	0.00	117.98	108.03
1999-2001	1.69	2.45	3.91	3.15	1.81	1.81	0.49	15.30	17.94
% of LTM	120.71	102.08	120.68	129.63	104.62	132.12	36.84	110.07	107.49

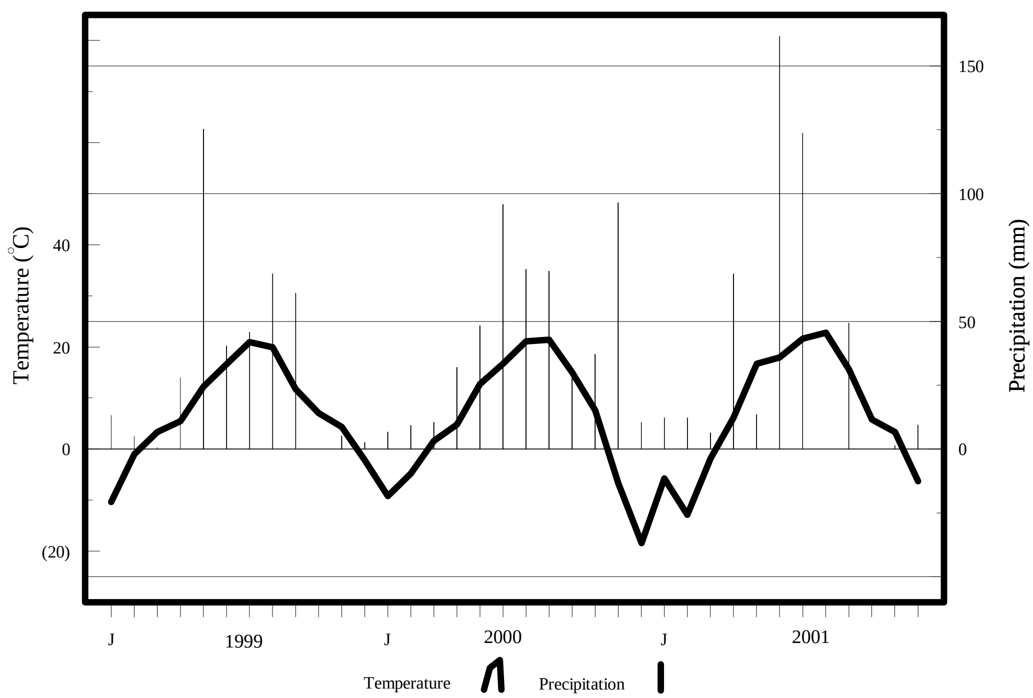

Fig. 1. Ombrothermic diagram of 1999-2001 mean monthly temperature and monthly precipitation at DREC Ranch, Manning, North Dakota.

Table 3. Mineral nitrogen and rhizosphere volume for grazing management strategies.

Grazing Management Strategy	Mineral Nitrogen lbs/acre-foot	Rhizosphere Volume ft^3/acre-foot
6.0-m Seasonlong	62c	50z
4.5-m Seasonlong	112b	68z
4.5-m Twice-over Rotation	178a	227x

Means in the same column and followed by the same letter are not significantly different (P<0.05).
Data from Manske 2008, 2009b.

Table 4a. Density per square meter of tiller types on the defoliation treatments of the management strategies during the first growing season, 2000.

Treatment Management Strategy	Live tillers early May #/m²	New tillers first season #/m²	Total first season tillers #/m²	Tillers at flower stages #/m²	Dead tillers first season #/m²	Live tillers fall #/m²	New fall tillers #/m²	Total live tillers mid October #/m²	Dead tillers winter period #/m²
Control									
6.0 m SL	469.9b	0.0c	469.9b	219.3b	31.3c	219.3b	219.3b	438.6b	0.0c
4.5 m SL	281.9c	0.0c	281.9c	94.0b	62.7b	125.3c	94.0c	219.3c	0.0c
4.5 m TOR	877.1a	62.7b	939.8a	344.6a	250.6b	344.6b	250.6b	595.2b	31.3b
May 25%									
6.0 m SL	845.8b	62.7b	908.5b	156.6b	94.0b	657.8a	94.0c	751.8b	281.9a
4.5 m SL	626.5b	62.7b	689.2b	31.3c	125.3b	532.5b	281.9b	814.5b	313.3a
4.5 m TOR	657.8b	31.3b	689.2b	188.0b	281.9a	219.3b	313.3b	532.5b	0.0c
May 50%									
6.0 m SL	908.5a	0.0c	908.5b	62.7b	219.3b	626.5a	469.9a	1096.4a	250.6b
4.5 m SL	344.6c	31.3b	375.9c	62.7b	94.0b	219.3b	188.0b	407.2b	94.0b
4.5 m TOR	939.8a	125.3a	1065.1a	125.3b	188.0b	751.8a	689.2a	1441.0a	407.2a
June 25%									
6.0 m SL	469.9b	62.7b	532.5b	94.0b	31.3c	407.2b	125.3b	532.5b	62.7b
4.5 m SL	438.6b	31.3b	469.9b	94.0b	156.6b	219.3b	125.3b	344.6b	0.0c
4.5 m TOR	971.1a	62.7b	1033.8a	156.6b	407.2a	469.9b	344.6b	814.5b	188.0b
June 50%									
6.0 m SL	563.9b	62.7b	626.5b	156.6b	62.7b	407.2b	188.0b	595.2b	156.6b
4.5 m SL	375.9c	0.0c	375.9c	62.7b	125.3b	188.0b	156.6b	344.6b	125.3b
4.5 m TOR	720.5a	62.7b	783.2b	219.3b	250.6b	313.3b	344.6b	657.8b	219.3b

Means in the same column and followed by the same letter are not significantly different ($P<0.05$).

Table 4b. Density per square meter of tiller types on the defoliation treatments of the management strategies during the second growing season, 2001.

Treatment Management Strategy	Carry over tillers #/m^2	New tillers early spring #/m^2	Live tillers early May #/m^2	New tillers second season #/m^2	Total second season tillers #/m^2	Tillers at flower stages #/m^2	Dead tillers second season #/m^2	Live tillers fall #/m^2	New fall tillers #/m^2	Total live tillers mid October #/m^2
Control										
6.0 m SL	438.6b	344.6b	783.2b	31.3c	814.5b	156.6b	250.6b	407.2b	313.3b	720.5b
4.5 m SL	219.3c	188.0b	407.2b	125.3b	532.5b	31.3c	188.0b	313.3b	156.6b	469.9b
4.5 m TOR	563.9b	469.9a	1033.8a	250.6a	1284.4a	375.9a	438.6a	469.9b	188.0b	657.8b
May 25%										
6.0 m SL	469.9b	156.6b	626.5b	219.3b	845.8b	188.0b	219.3b	438.6b	563.9a	1002.4a
4.5 m SL	501.2b	0.0c	501.2b	156.6b	657.8b	62.7c	188.0b	407.2b	501.2a	908.5b
4.5 m TOR	532.5b	501.2a	1033.8a	250.6a	1284.4a	313.3a	438.6a	532.5b	156.6b	689.2b
May 50%										
6.0 m SL	845.8a	62.7b	908.5b	125.3b	1033.8b	250.6b	219.3b	563.9b	501.2a	1065.1a
4.5 m SL	313.3b	0.0c	313.3c	125.3b	438.6c	156.6b	125.3b	156.6c	94.0c	250.6b
4.5 m TOR	1033.8a	344.6b	1378.3a	156.6b	1535.0a	250.6b	720.5a	563.9b	281.9b	845.8b
June 25%										
6.0 m SL	469.9b	31.3b	501.2b	94.0c	595.2b	188.0b	94.0b	313.3b	469.9a	783.2b
4.5 m SL	344.6b	0.0c	344.6c	188.0b	532.5b	125.3b	156.6b	250.6b	125.3c	375.9c
4.5 m TOR	626.5b	469.9a	1096.4a	188.0b	1284.4a	188.0b	281.9b	814.5a	219.3b	1033.8a
June 50%										
6.0 m SL	438.6b	31.3b	469.9b	156.6b	626.5b	125.3b	94.0b	407.2b	313.3b	720.5b
4.5 m SL	219.3c	31.3b	250.6c	94.0c	344.6c	94.0b	94.0b	156.6c	219.3b	375.9c
4.5 m TOR	438.6b	250.6b	689.2b	250.6a	939.8b	281.9a	156.6b	501.2b	344.6b	845.8b

Means in the same column and followed by the same letter are not significantly different ($P<0.05$).

Table 5. Mean monthly growing season tiller density (excluding the fall tillers) on the defoliation treatments of the management strategies, 2000, 2001.

Treatment Management Strategy	First Growing Season 2000 #/m²	Second Growing Season 2001 #/m²	Change during Second Growing Season #/m²
Control			
6.0 m SL	464.7b	704.9b	+240.2b
4.5 m SL	245.4c	391.6c	+146.2b
4.5 m TOR	814.5a	892.8a	+78.3b
May 25%			
6.0 m SL	840.6a	699.6b	-141.0c
4.5 m SL	610.9b	527.3c	-83.6c
4.5 m TOR	563.9b	1028.6a	+464.7a
May 50%			
6.0 m SL	856.3a	908.5a	+52.2b
4.5 m SL	302.8c	355.1c	+52.3b
4.5 m TOR	976.4a	1148.6a	+172.2b
June 25%			
6.0 m SL	516.9b	522.1b	+5.2b
4.5 m SL	402.0c	391.6c	-10.4b
4.5 m TOR	824.9a	1117.3a	+292.4a
June 50%			
6.0 m SL	584.8b	543.0b	-41.8b
4.5 m SL	349.8c	281.9c	-67.9b
4.5 m TOR	710.1a	788.4a	+78.3b

Means in the same column of each defoliation treatment and followed by the same letter are not significantly different ($P<0.05$).

Table 6. Density per square meter of total growing season tillers on the defoliation treatments of the management strategies, 2000, 2001.

Treatment Management Strategy	First Growing Season Tillers #/m^2	Fall Tillers First Year #/m^2	Total Tillers First Year #/m^2	Carry Over Tillers #/m^2	Second Growing Season Tillers #/m^2	Fall Tillers Second Year #/m^2	Total Tillers Second Year #/m^2	Two Year Total Tillers #/m^2
Control								
6.0 m SL	469.9b	219.3b	689.2b	438.6b	814.5b	313.3b	1127.7b	1378.3b
4.5 m SL	281.9c	94.0c	375.9c	219.3c	532.5b	156.6b	689.2c	845.8c
4.5 m TOR	939.8a	250.6b	1190.4b	563.9b	1284.4a	188.0b	1472.3b	2098.8b
May 25%								
6.0 m SL	908.5b	94.0c	1002.4b	469.9b	845.8b	563.9a	1409.7b	1942.2b
4.5 m SL	689.2b	281.9b	971.1b	501.2b	657.8b	501.2a	1159.1b	1629.0b
4.5 m TOR	689.2b	313.3b	1002.4b	532.5b	1284.4a	156.6b	1441.0b	1910.9b
May 50%								
6.0 m SL	908.5b	469.9a	1378.3a	845.8a	1033.8b	501.2a	1535.0b	2067.5b
4.5 m SL	375.9c	188.0b	563.9b	313.3b	438.6c	94.0c	532.5c	783.2c
4.5 m TOR	1065.1a	689.2a	1754.3a	1033.8a	1535.0a	281.9b	1816.9a	2537.4a
June 25%								
6.0 m SL	532.5b	125.3b	657.8b	469.9b	595.2b	469.9a	1065.1b	1253.0b
4.5 m SL	469.9b	125.3b	595.2b	344.6b	532.5b	125.3c	657.8c	908.5c
4.5 m TOR	1033.8a	344.6b	1378.3a	626.5b	1284.4a	219.3b	1503.6b	2255.5a
June 50%								
6.0 m SL	626.5b	188.0b	814.5b	438.6b	626.5b	313.3b	939.8b	1315.7b
4.5 m SL	375.9c	156.6b	532.5c	219.3c	344.6c	219.3b	563.9c	877.1c
4.5 m TOR	783.2b	344.6b	1127.7b	438.6b	939.8b	344.6b	1284.4b	1973.5b

Means in the same column and followed by the same letter are not significantly different ($P<0.05$).

Table 7. Vegetative tillers developed per lead tiller on the defoliation treatments of the management strategies.

Treatment Management Strategy	Density of Lead Tillers at Defoliation Treatment #/m^2	Density of Total Initiated Vegetative Tillers #/m^2	Number of Stimulated Vegetative Tillers per Lead Tiller #	Difference from Management Strategy Control
Control				
6.0 m SL	344.6b	908.5b	2.64a	
4.5 m SL	188.0c	563.9c	3.00a	
4.5 m TOR	595.2b	1221.7b	2.05b	
May 25%				
6.0 m SL	595.2b	1096.4b	1.84b	-0.80b
4.5 m SL	532.5b	1002.4b	1.88b	-1.12b
4.5 m TOR	407.2b	1253.0b	3.08a	+1.03a
May 50%				
6.0 m SL	751.8a	1159.1b	1.54c	-1.10b
4.5 m SL	313.3b	438.6c	1.40c	-1.60c
4.5 m TOR	689.2a	1597.6a	2.32b	+0.27a
June 25%				
6.0 m SL	344.6b	783.2b	2.27b	-0.37b
4.5 m SL	250.6c	469.9c	1.88b	-1.12b
4.5 m TOR	563.9b	1284.4b	2.28b	+0.23a
June 50%				
6.0 m SL	407.2b	751.8b	1.85b	-0.79b
4.5 m SL	281.9c	501.2c	1.78b	-1.22b
4.5 m TOR	626.5b	1253.0b	2.00b	-0.05b

Means in the same column and followed by the same letter are not significantly different (P<0.05).

Table 8. Density per square meter and percent of total for tillers initiated through vegetative reproduction during periods of the growing season.

	Seasonal Periods				Total Initiated Tillers	Seasonal Periods			
Treatment Management Strategy	Early Spring $\#/m^2$	May $\#/m^2$	Mid Season $\#/m^2$	Fall Season $\#/m^2$	$\#/m^2$	Early Spring %	May %	Mid Season %	Fall Season %
Control									
6.0 m SL	344.6b	0.0c	31.3c	532.5b	908.5b	37.9a	0.0c	3.5b	58.6b
4.5 m SL	188.0b	31.3c	94.0b	250.6c	563.9c	33.3b	5.6c	16.7b	44.4b
4.5 m TOR	469.9a	156.6b	156.6a	438.6b	1221.7b	38.5a	12.8b	12.8b	35.9c
May 25%									
6.0 m SL	156.6b	156.6b	125.3b	657.8b	1096.4b	14.3b	14.3b	11.4b	60.0b
4.5 m SL	0.0c	156.6b	62.7b	783.2b	1002.4b	0.0c	15.6b	6.3b	78.1a
4.5 m TOR	501.2a	62.7b	219.3a	469.9b	1253.0b	40.0a	5.0c	17.5b	37.5c
May 50%									
6.0 m SL	62.7b	125.3b	0.0c	971.1a	1159.1b	5.4b	10.8b	0.0c	83.8a
4.5 m SL	0.0c	125.3b	31.3c	281.9c	438.6c	0.0c	28.6a	7.1b	64.3b
4.5 m TOR	344.6b	156.6b	125.3b	971.1a	1597.6a	21.6b	9.8b	7.8b	60.8b
June 25%									
6.0 m SL	31.3b	62.7b	94.0b	595.2b	783.2b	4.0b	8.0b	12.0b	76.0a
4.5 m SL	0.0c	62.7b	156.6a	250.6c	469.9c	0.0c	13.3b	33.3a	53.3b
4.5 m TOR	469.9a	188.0a	62.7b	563.9b	1284.4b	36.6a	14.6b	4.9b	43.9c
June 50%									
6.0 m SL	31.3b	156.6b	62.7b	501.2b	751.8b	4.2b	20.8a	8.3b	66.7b
4.5 m SL	31.3b	62.7b	31.3c	375.9b	501.2c	6.3b	12.5b	6.3b	75.0a
4.5 m TOR	250.6b	219.3a	94.0b	689.2b	1253.0b	20.0b	17.5b	7.5b	55.0b

Means in the same column and followed by the same letter are not significantly different ($P<0.05$).

Table 9. Density per square meter and percent of total for vegetative tillers terminated during periods of the growing season before reaching maturity and for lead tillers terminated after flowering.

Treatment Management Strategy	Seasonal Periods: Early Season #/m²	Seasonal Periods: Mid and Fall Season #/m²	Seasonal Periods: Flowering Lead Tillers #/m²	Seasonal Periods: Winter Period #/m²	Total Terminated Tillers #/m²	Seasonal Periods: Early Season %	Seasonal Periods: Mid and Fall Season %	Seasonal Periods: Flowering Lead Tillers %	Seasonal Periods: Winter Period %
Control									
6.0 m SL	0.0b	281.9b	375.9b	0.0c	657.8b	0.0b	42.9b	57.1a	0.0c
4.5 m SL	0.0b	250.6b	125.3c	0.0c	375.9c	0.0b	66.7a	33.3b	0.0c
4.5 m TOR	281.9a	407.2b	720.5a	31.3b	1441.0a	19.5a	28.3b	50.0b	2.2c
May 25%									
6.0 m SL	31.3b	281.9b	344.6b	281.9a	939.8b	3.3b	30.0b	36.7b	30.0a
4.5 m SL	62.7b	250.6b	94.0c	313.3a	720.5b	8.7b	34.8b	13.0c	43.5a
4.5 m TOR	62.7b	657.8a	501.2a	0.0c	1221.7b	5.1b	53.9a	41.0b	0.0c
May 50%									
6.0 m SL	0.0b	438.6b	313.3b	250.6b	1002.4b	0.0b	43.7b	31.3b	25.0b
4.5 m SL	62.7b	156.6b	219.3b	94.0b	532.5b	11.8a	29.4b	41.2b	17.6b
4.5 m TOR	0.0b	908.5a	375.9b	407.2a	1691.6a	0.0b	53.7b	22.2c	24.1b
June 25%									
6.0 m SL	0.0b	125.3c	281.9b	62.7b	469.9b	0.0b	26.7c	60.0a	13.3b
4.5 m SL	0.0b	313.3b	219.3b	0.0c	532.5b	0.0b	58.8a	41.2b	0.0c
4.5 m TOR	125.3a	563.9b	344.6b	188.0b	1221.7b	10.3a	46.2b	28.2b	15.3b
June 50%									
6.0 m SL	0.0b	156.6b	281.9b	156.6b	595.2b	0.0b	26.3c	47.4b	26.3b
4.5 m SL	0.0b	219.3b	156.6c	125.3b	501.2b	0.0b	43.8b	31.2b	25.0b
4.5 m TOR	31.3b	375.9b	501.2a	219.3b	1127.7b	2.8b	33.3b	44.4b	19.5b

Means in the same column and followed by the same letter are not significantly different ($P<0.05$).

Table 10a. Mean monthly tiller leaf height (cm) on the defoliation treatments of the management strategies during the first growing season, 2000.

Treatment Management Strategy	Reproductive Lead Tillers cm	Vegetative Lead Tillers cm	Slow Growth Secondary Tillers cm	Early Senescent Secondary Tillers cm	Fall Tillers cm
Control					
6.0 m SL	19.4a	15.5a	8.9a	0.0c	3.9a
4.5 m SL	17.7a	16.7a	8.2a	6.5a	2.7a
4.5 m TOR	17.9a	13.9a	10.5a	6.6a	3.7a
May 25%					
6.0 m SL	18.7a	14.6a	8.2a	9.7a	1.4b
4.5 m SL	18.5a	11.4a	5.9a	5.5a	4.0a
4.5 m TOR	16.9a	14.0a	6.4a	5.5a	3.4a
May 50%					
6.0 m SL	19.4a	16.7a	8.6a	6.0a	2.4b
4.5 m SL	17.3a	12.6a	0.0c	4.0a	4.6a
4.5 m TOR	15.0a	14.0a	9.4a	4.5a	2.9b
June 25%					
6.0 m SL	18.1a	13.0a	10.1a	0.0c	2.5b
4.5 m SL	17.9a	14.9a	9.1a	4.1a	2.9ab
4.5 m TOR	15.9a	12.8a	7.9a	6.6a	4.2a
June 50%					
6.0 m SL	14.6a	10.9a	7.2a	4.7a	3.1ab
4.5 m SL	18.2a	13.8a	9.7a	0.0c	3.7b
4.5 m TOR	16.5a	9.8a	7.7a	3.5a	6.2a

Means in the same column of each defoliation treatment and followed by the same letter are not significantly different ($P<0.05$).

Table 10b. Mean monthly tiller leaf height (cm) on the defoliation treatments of the management strategies during the second growing season, 2001.

Treatment Management Strategy	Reproductive Lead Tillers cm	Vegetative Lead Tillers cm	Slow Growth Secondary Tillers cm	Early Senescent Secondary Tillers cm	Fall Tillers cm
Control					
6.0 m SL	27.1a	18.1a	15.4a	8.1a	2.9b
4.5 m SL	23.0a	20.8a	16.4a	6.6a	9.3a
4.5 m TOR	26.7a	20.6a	15.1a	9.2a	6.1ab
May 25%					
6.0 m SL	22.2a	20.0a	14.5a	5.0a	6.6a
4.5 m SL	24.0a	19.9a	12.3a	6.5a	10.1a
4.5 m TOR	25.9a	20.7a	17.0a	7.7a	6.8a
May 50%					
6.0 m SL	28.0a	18.6a	13.0a	9.1a	8.0a
4.5 m SL	24.9a	19.6a	5.0a	4.8a	2.4a
4.5 m TOR	26.4a	21.3a	13.6a	7.3a	4.3a
June 25%					
6.0 m SL	23.2a	17.4a	8.5a	10.5a	9.0a
4.5 m SL	21.7a	21.1a	12.3a	8.5a	1.8b
4.5 m TOR	25.4a	20.5a	13.4a	5.3a	4.5ab
June 50%					
6.0 m SL	26.2a	18.0a	6.0a	10.1a	3.8a
4.5 m SL	25.2a	19.4a	0.0c	8.3a	3.1a
4.5 m TOR	25.6a	19.2a	15.3a	7.7a	5.8a

Means in the same column of each defoliation treatment and followed by the same letter are not significantly different (P<0.05).

Table 10c. Change in mean monthly tiller leaf height (cm) during the second growing season on the defoliation treatments of the management strategies, 2000, 2001.

Treatment Management Strategy	Reproductive Lead Tillers cm	Vegetative Lead Tillers cm	Slow Growth Secondary Tillers cm	Early Senescent Secondary Tillers cm	Fall Tillers cm
Control					
6.0 m SL	7.7b	2.6c	6.5b	8.1a	-1.0c
4.5 m SL	5.3b	4.1b	8.2b	0.1b	6.6a
4.5 m TOR	8.8b	6.7b	4.6b	2.6b	2.4b
May 25%					
6.0 m SL	3.5c	5.4b	6.3b	-4.7c	5.2b
4.5 m SL	5.5b	8.5a	6.4b	1.0b	6.1a
4.5 m TOR	9.0b	6.7b	10.6a	2.2b	3.4b
May 50%					
6.0 m SL	8.6b	1.9c	4.4b	3.1b	5.6a
4.5 m SL	7.6b	7.0b	5.0b	0.8b	-2.2c
4.5 m TOR	11.4a	7.3b	4.2b	2.8b	1.4b
June 25%					
6.0 m SL	5.1b	4.4b	-1.6c	10.5a	6.5a
4.5 m SL	3.8c	6.2b	3.2b	4.4b	-1.1c
4.5 m TOR	9.5b	7.7b	5.5b	-1.3c	0.3b
June 50%					
6.0 m SL	11.6a	7.1b	-1.2c	5.4b	0.7b
4.5 m SL	7.0b	5.6b	-9.7c	8.3a	-0.6b
4.5 m TOR	9.1b	9.4a	7.6b	4.2b	-0.4b

Means in the same column and followed by the same letter are not significantly different (P<0.05).

Table 11a. Mean monthly leaf stage as a percent of tiller population for lead tillers on the defoliation treatments of the management strategies during the first growing season, 2000.

Treatment Management Strategy	Reproductive Lead Tillers Leaf Stage							Vegetative Lead Tillers Leaf Stage					
	Tiller Density #/m^2	1-2 %	3 %	4 %	5 %	6-9 %	Flower Stages %	Tiller Density #/m^2	1-2 %	3 %	4 %	5 %	6-10 %
Control													
6.0 m SL	219.3	0.0	7.2	14.3	7.2	4.8	66.7	125.3	0.0	12.5	8.3	12.5	66.7
4.5 m SL	94.0	5.6	11.1	11.1	0.0	5.6	66.7	94.0	0.0	11.1	27.8	27.8	33.3
4.5 m TOR	344.6	1.5	6.1	10.6	12.1	13.6	56.1	229.7	0.0	11.1	15.1	35.7	38.1
May 25%													
6.0 m SL	156.6	0.0	0.0	20.0	13.3	0.0	66.7	349.8	0.0	11.9	15.1	41.3	31.7
4.5 m SL	31.3	16.7	0.0	16.7	0.0	0.0	66.7	490.8	4.2	24.0	21.4	24.4	26.1
4.5 m TOR	188.0	2.8	8.3	13.9	5.6	8.3	61.1	198.4	0.0	25.9	12.9	12.2	48.9
May 50%													
6.0 m SL	62.7	0.0	16.7	0.0	16.7	16.7	50.0	511.7	0.0	10.6	14.0	25.9	49.6
4.5 m SL	62.7	0.0	16.7	16.7	0.0	0.0	66.7	224.5	10.4	8.9	25.9	19.1	35.7
4.5 m TOR	125.3	0.0	12.5	16.7	4.2	0.0	66.7	454.2	0.0	12.0	10.6	16.3	61.1
June 25%													
6.0 m SL	94.0	0.0	0.0	16.7	11.1	22.2	50.0	235.0	0.0	13.0	20.4	4.2	62.5
4.5 m SL	94.0	0.0	11.1	16.7	5.6	0.0	66.7	114.9	0.0	6.7	23.3	20.0	50.0
4.5 m TOR	146.2	0.0	3.3	16.7	16.7	3.3	60.0	370.7	0.0	9.5	13.6	20.0	56.9
June 50%													
6.0 m SL	156.6	0.0	6.7	13.3	6.7	3.3	70.0	235.0	0.0	16.7	10.4	34.9	38.1
4.5 m SL	62.7	0.0	16.7	16.7	0.0	0.0	66.7	182.8	0.0	26.2	9.9	20.0	43.9
4.5 m TOR	219.3	0.0	0.0	16.7	14.3	7.2	61.9	339.4	0.0	12.5	10.5	34.6	42.4

Table 11b. Mean monthly leaf stage as a percent of tiller population for lead tillers on the defoliation treatments of the management strategies during the second growing season, 2001.

Treatment Management Strategy	Reproductive Lead Tillers Leaf Stage							Vegetative Lead Tillers Leaf Stage					
	Tiller Density $\#/m^2$	1-2 %	3 %	4 %	5 %	6-9 %	Flower Stages %	Tiller Density $\#/m^2$	1-2 %	3 %	4 %	5 %	6-10 %
Control													
6.0 m SL	156.6	0.0	13.3	6.7	13.3	3.3	63.3	292.4	0.0	13.6	12.1	7.6	66.7
4.5 m SL	31.3	0.0	16.7	16.7	16.7	0.0	50.0	208.9	8.3	19.4	7.5	12.3	52.4
4.5 m TOR	308.1	7.5	13.4	5.6	9.7	5.6	58.3	349.8	7.4	16.7	12.6	10.0	53.3
May 25%													
6.0 m SL	172.3	0.0	15.8	7.5	6.7	11.7	58.3	250.6	0.0	14.6	14.6	12.5	58.3
4.5 m SL	62.7	0.0	16.7	8.3	8.3	8.3	58.3	281.9	0.0	22.2	7.4	23.3	47.0
4.5 m TOR	308.1	1.9	10.9	12.2	11.7	5.0	58.3	349.8	0.0	14.5	12.8	7.6	65.2
May 50%													
6.0 m SL	245.4	2.4	9.5	4.8	14.6	10.4	58.3	438.6	0.0	14.3	10.7	10.7	64.3
4.5 m SL	151.4	0.0	20.0	10.0	6.7	6.7	56.7	125.3	0.0	27.8	12.2	13.3	46.7
4.5 m TOR	250.6	4.2	2.1	20.8	4.2	14.6	54.2	297.6	0.0	13.0	14.8	7.2	65.0
June 25%													
6.0 m SL	188.0	5.6	8.3	11.1	8.3	2.8	63.9	245.4	6.3	16.7	8.3	6.3	62.5
4.5 m SL	114.9	0.0	27.8	5.6	8.3	0.0	58.3	177.6	0.0	22.2	11.1	13.9	52.8
4.5 m TOR	188.0	0.0	13.9	8.3	11.1	5.6	61.1	657.8	0.0	11.9	15.9	9.5	62.7
June 50%													
6.0 m SL	114.9	8.3	12.5	8.3	0.0	0.0	70.8	370.7	1.5	16.2	12.9	12.5	57.0
4.5 m SL	94.0	5.6	11.1	11.1	5.6	5.6	61.1	135.7	16.7	16.7	6.7	13.3	46.7
4.5 m TOR	255.8	4.2	16.2	5.6	7.4	5.6	61.1	438.6	6.0	16.7	9.5	8.3	59.5

Table 12a. Mean monthly leaf stage as a percent of tiller population for secondary tillers on the defoliation treatments of the management strategies during the first growing season, 2000.

Treatment Management Strategy	Slow Growth Secondary Tillers Leaf Stage						Early Senescent Secondary Tillers Leaf Stage					
	Tiller Density #/m^2	1-2 %	3 %	4 %	5 %	6 %	Tiller Density #/m^2	1-2 %	3 %	4 %	5 %	6 %
Control												
6.0 m SL	120.1	52.8	25.0	22.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.5 m SL	31.3	16.7	83.3	0.0	0.0	0.0	46.7	25.0	25.0	25.0	0.0	0.0
4.5 m TOR	151.4	35.8	37.8	19.5	0.0	6.9	106.5	19.0	14.0	23.0	24.0	0.0
May 25%												
6.0 m SL	308.1	34.6	17.6	45.0	2.9	0.0	31.3	20.0	0.0	60.0	0.0	0.0
4.5 m SL	78.3	52.8	47.2	0.0	0.0	0.0	31.3	0.0	50.0	0.0	0.0	0.0
4.5 m TOR	146.2	47.6	52.4	0.0	0.0	0.0	47.0	8.3	45.8	20.8	0.0	0.0
May 50%												
6.0 m SL	271.5	25.7	30.6	43.7	0.0	0.0	20.9	66.7	0.0	0.0	0.0	0.0
4.5 m SL	0.0	0.0	0.0	0.0	0.0	0.0	23.5	0.0	75.0	0.0	0.0	0.0
4.5 m TOR	381.1	24.4	29.8	19.8	26.1	0.0	23.5	25.0	50.0	0.0	0.0	0.0
June 25%												
6.0 m SL	188.0	44.9	28.2	27.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.5 m SL	167.1	19.3	48.1	19.7	12.9	0.0	39.2	37.5	37.5	0.0	0.0	0.0
4.5 m TOR	245.4	31.7	34.6	19.6	14.2	0.0	75.2	13.3	33.3	23.3	0.0	10.0
June 50%												
6.0 m SL	182.8	53.7	31.3	12.3	2.8	0.0	20.9	66.7	0.0	0.0	0.0	0.0
4.5 m SL	104.4	36.1	20.8	26.4	16.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.5 m TOR	135.8	16.7	16.7	55.6	11.1	0.0	23.5	0.0	75.0	0.0	0.0	0.0

Table 12b. Mean monthly leaf stage as a percent of tiller population for secondary tillers on the defoliation treatments of the management strategies during the second growing season, 2001.

Treatment Management Strategy	Slow Growth Secondary Tillers Leaf Stage						Early Senescent Secondary Tillers Leaf Stage					
	Tiller Density $\#/m^2$	1-2 %	3 %	4 %	5 %	6 %	Tiller Density $\#/m^2$	1-2 %	3 %	4 %	5 %	6 %
Control												
6.0 m SL	156.6	16.7	11.1	17.8	23.1	31.3	119.1	40.0	30.0	10.0	0.0	0.0
4.5 m SL	78.3	16.7	56.9	26.4	0.0	0.0	109.6	38.8	36.3	0.0	0.0	0.0
4.5 m TOR	130.6	16.7	19.0	19.1	23.8	4.8	144.1	5.5	46.7	27.7	0.0	0.0
May 25%												
6.0 m SL	182.8	16.7	34.5	23.0	7.9	17.9	112.8	38.6	34.6	6.6	0.0	0.0
4.5 m SL	104.4	27.8	38.9	23.6	9.7	0.0	117.5	30.0	25.0	10.0	10.0	0.0
4.5 m TOR	235.0	16.7	29.1	10.7	16.4	27.1	162.9	20.9	33.8	15.3	10.0	0.0
May 50%												
6.0 m SL	161.9	21.4	33.9	2.4	13.1	29.2	75.2	0.0	45.0	35.0	0.0	0.0
4.5 m SL	20.9	66.7	0.0	0.0	0.0	0.0	81.4	50.0	30.0	0.0	0.0	0.0
4.5 m TOR	214.1	5.6	28.8	18.2	25.5	22.0	463.6	12.0	30.7	23.8	5.0	8.5
June 25%												
6.0 m SL	62.7	0.0	53.3	20.0	6.7	0.0	43.9	0.0	0.0	10.0	70.0	0.0
4.5 m SL	47.0	0.0	25.0	37.5	12.5	0.0	81.4	25.0	55.0	0.0	0.0	0.0
4.5 m TOR	167.1	29.4	30.6	13.8	17.2	9.1	156.6	22.7	41.7	10.7	0.0	0.0
June 50%												
6.0 m SL	26.1	66.7	0.0	16.7	0.0	0.0	47.0	0.0	12.5	62.5	0.0	0.0
4.5 m SL	0.0	0.0	0.0	0.0	0.0	0.0	62.7	26.7	26.7	0.0	26.7	0.0
4.5 m TOR	43.9	0.0	0.0	50.0	30.0	0.0	86.2	0.0	54.2	20.8	0.0	0.0

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Environmental Factors that Affect Range Plant Growth, 1892-2009

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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 2010).

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 (118-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 (19.4° 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 (118-year) annual precipitation for the area of Dickinson, North Dakota, is 16.00 inches (406.50 mm). The growing season precipitation (April to October) is 13.52 inches (343.21 mm), 84.43% of the annual precipitation. June has the greatest monthly precipitation, at 3.55 inches (90.07 mm). The seasonal distribution of precipitation (Table 2) shows the greatest amount of precipitation occurring in the spring (7.29 inches, 45.54%) and the smallest amount occurring in winter (1.55 inches, 9.71%). Total precipitation received in November through March averages less than 2.5 inches (15.63%). The precipitation received in May, June, and July accounts for 50.69% of the annual precipitation (8.11 inches).

Of the past 118 years (1892 to 2009), 14 (11.86%) were drought years, receiving 75% or less of the long-term mean precipitation level. Fifteen (12.71%) were wet years, receiving 125% or more of the long-term mean precipitation level. Eighty-nine years (75.42%) received normal annual precipitation amounts, between 75% and 125% of the long-term mean. Of the past 118 growing seasons, 18 (15.25% were drought growing seasons, 21 (17.80%) were wet growing seasons, and 79 (66.95%) 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 1892-2009 (Manske 2010). 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 11.9% of the past 118 years, and 15.3% of the growing seasons were drought growing seasons. The 118-year period (1892 to 2009) contained a total of 708 growing-season months. Water deficiency conditions occurred during 231.5 of these, a finding indicating that during 32.69% 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 13.6% and 10.2 % 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: 52.5% of the time in August, 50.0 % of the time in September, and 46.6% 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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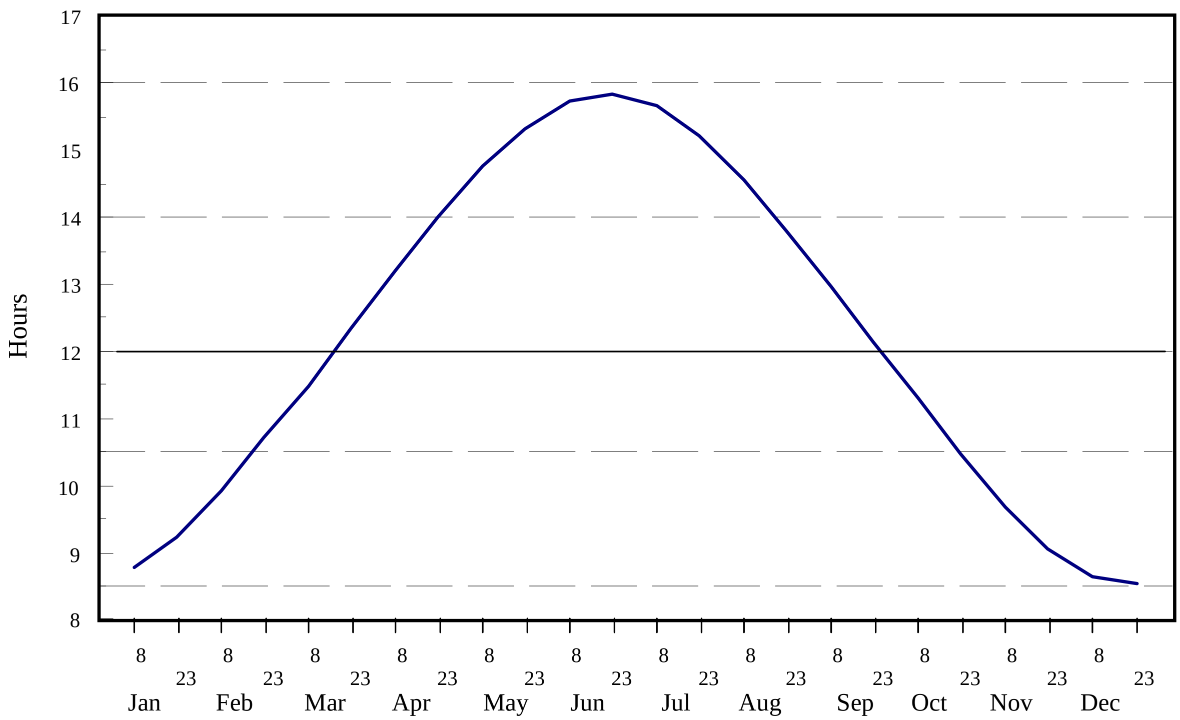

Fig. 1. Annual pattern of daylight duration at Dickinson, North Dakota.

Table 1. Long-term (1892-2009) mean monthly temperature and monthly precipitation at Dickinson, ND.

	º F	º C	in.	mm
Jan	11.47	-11.40	0.41	10.36
Feb	15.28	-9.29	0.41	10.35
Mar	26.18	-3.23	0.74	18.76
Apr	41.54	5.30	1.41	35.84
May	52.79	11.55	2.33	59.21
Jun	61.96	16.65	3.55	90.07
Jul	68.75	20.42	2.23	56.58
Aug	67.00	19.44	1.72	43.58
Sep	56.11	13.39	1.32	33.60
Oct	43.70	6.50	0.96	24.35
Nov	28.45	-1.97	0.53	13.51
Dec	16.94	-8.37	0.41	10.29
	MEAN		**TOTAL**	
	40.85	**4.92**	**16.00**	**406.50**

Table 2. Seasonal percentage of mean annual precipitation distribution (1892-2009).

Season	in.	%
Winter (Jan, Feb, Mar)	1.55	9.71
Spring (Apr, May, Jun)	7.29	45.54
Summer (Jul, Aug, Sep)	5.27	32.91
Fall (Oct, Nov, Dec)	1.90	11.84
TOTAL	16.00	

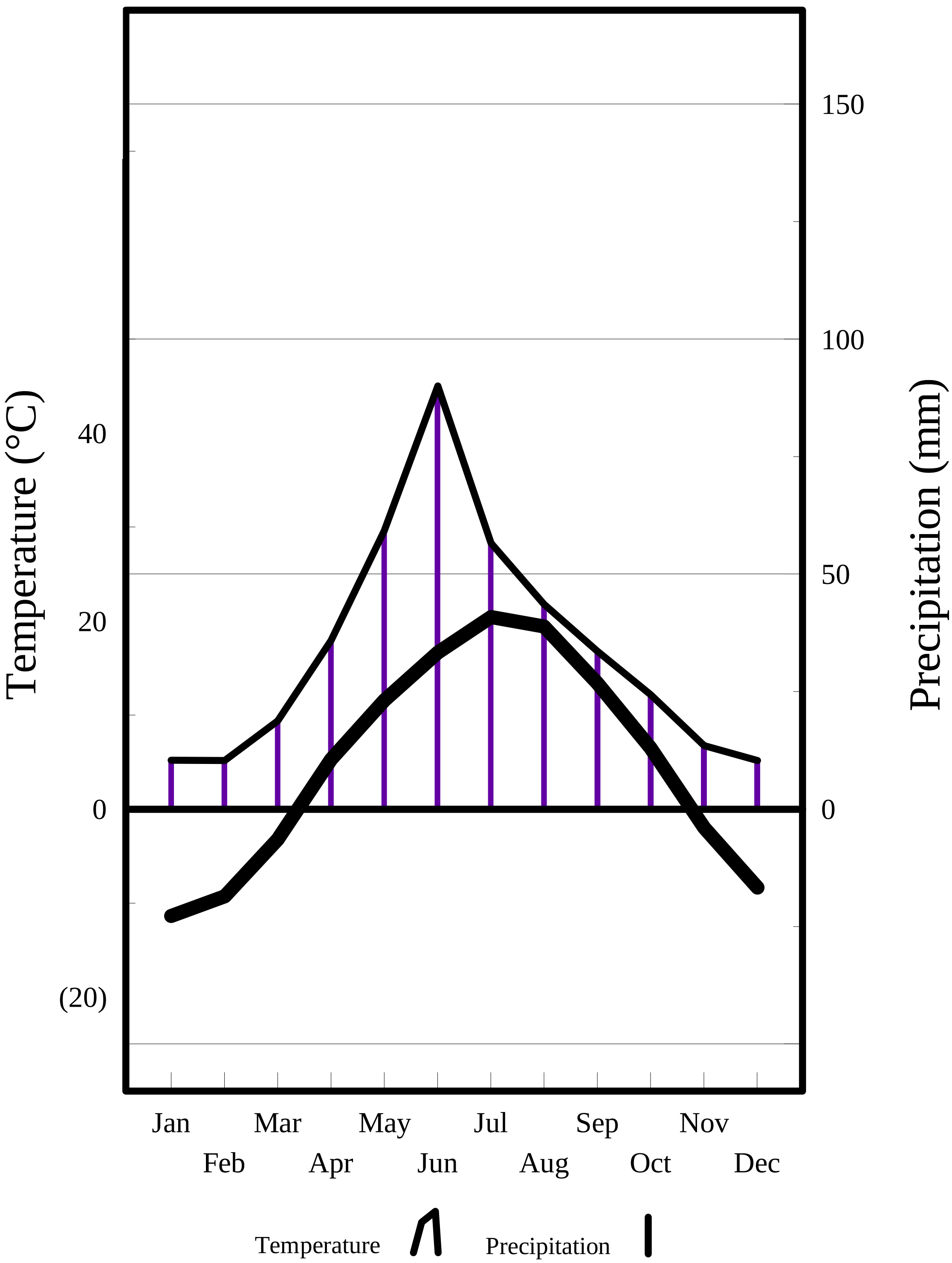

Fig. 2. Ombrothermic diagram of long-term (1892-2009) mean monthly temperature and monthly precipitation at Dickinson, North Dakota.

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