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

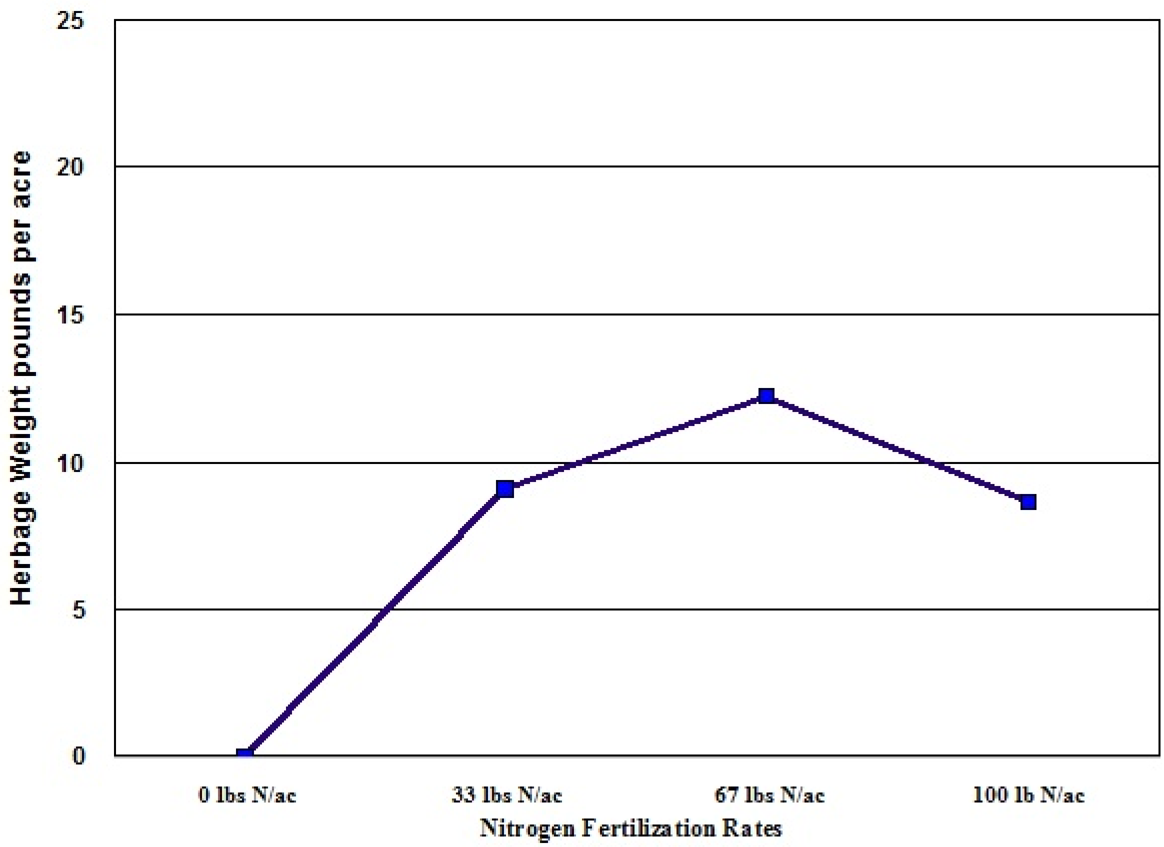

Figure 1. Herbage weight in pounds per acre per pound nitrogen fertilizer applied.

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