Long-term Plant Species Shift Caused by Nitrogen Fertilization of Native Rangeland

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Nitrogen fertilization research projects were conducted by rangeland scientists at the NDSU Dickinson Research Extension Center during the 48 year period between 1957 and 2004 in an attempt to find and develop fertilization management practices that could be used to recover the degraded ecological condition, to return the natural botanical composition, and to restore the herbage biomass production of deteriorated native rangeland ecosystems. The deterioration of the rangeland resources was causes by naive implementation of eastern farming and grazing practices to the semiarid grasslands west of the 20 inch rainfall line. During the homestead period between 1900 and 1936 excessively heavy grazing with stocking rates greater than 60% heavier than the biological carrying capacity (Whitman et al. 1943) resulted in rangeland resource deterioration that caused a decrease in herbage biomass production and a disproportional reduction of mid cool season grass species, such as western wheatgrass, and leaving a predominance of short warm season grass species, such as blue grama.

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

Nitrogen fertilization of degraded native rangeland resulted in a short-term plant species composition shift with an increase in mid cool season grasses and a decrease in short warm season grasses. Application of nitrogen fertilizer to native rangeland in spring or fall, at low rates, high rates, annually, biennially, or one time all caused the same short-term shift in species composition, albeit at proportionally different rates (Rogler and Lorenz 1957, Whitman 1963, Whitman 1969, Goetz 1969, Power and Alessi 1971, Lorenz and Rogler 1972, Taylor 1976, Whitman 1978, Goetz et al. 1978, Wight and Black 1979). Conclusions from comparatively long studies with 6 to 10 years of monitoring data, at first, considered this short-term shift in plant species composition to be beneficial and a feasible practice to restore the natural balance in the botanical species composition of the Northern Plains mixed grass prairie.

However, Taylor (1976) conducted a study for 15 years and found that residual effects from nitrogen fertilization of native rangeland were still occurring 12 years after the treatments had stopped. Goetz et al. (1978) found several undesirable aspects related to the short-term changes in plant species composition that had implications for long-term adverse consequences in mixed grass prairie communities. Detrimental complications could develop from nitrogen fertilizer induced changes in plant species because the increasing mid cool season grasses were primarily single stalked, low-cover, plants and the decreasing short warm season grasses were primarily multiple stemmed, high-cover, plants and the shift in plant species would cause a decrease in basal cover and a reduction in live plant material covering the soil and would open an otherwise closed community. The resulting reductions in ground cover would expose greater amounts of soil to erosion and to higher levels of solar radiation, and would create larger areas of open spaces available for potential invasion by undesirable perennial forbs, domesticated cool season grasses, and introduced annual and perennial grasses.

None of the relatively long nitrogen fertilization studies from the 1950's to the 1980's were conducted long enough to document the undesirable long-term changes in plant species composition caused by applications of nitrogen fertilizer to native rangeland proposed by Goetz et al. 1978. This current project compiled unfertilized and fertilized vegetation data collected from a nitrogen fertilization pasture study and from an adjacent nitrogen fertilization plot study, followed the short-term and long-term plant species composition

changes caused by nitrogen fertilization of a native rangeland upland range site community during 35 years from 1970 to 2004, and corroborated the long-term adverse implications of nitrogen fertilization in native rangeland that were hypothesized to occur by Goetz et al. 1978.

Procedure

The short-term and long-term changes in plant species composition evaluated during this investigation occurred on an upland range site community of the mixed grass prairie. The vegetation data was collected from two studies; a nitrogen fertilization of native rangeland plot study adjacent to a nitrogen fertilization of native rangeland pasture study. The research plots and research pastures were located on the SW¼, sec. 23, T. 140 N., R. 97 W., at the Dickinson Research Extension Center. The native rangeland plant community was strongly rolling upland mixed grass prairie. The soils were Vebar, Parshall, and Flasher fine sandy loams.

The nitrogen fertilization of native rangeland plot study IV was conducted by Dr. Harold Goetz and Dr. Warren C. Whitman from 1970 to 1978. The 30 X 100 foot plots were arranged in a randomized block design with three replications. The ammonium nitrate fertilizer (33-0-0) was broadcast applied in the spring. The unfertilized vegetation data was taken from the check 0 lbs N/ac treatment and the fertilized vegetation data was taken from the annual 67 lbs N/ac applied every year (EY) treatment. 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: warm season short grass, cool season mid grass, perennial forbs, and annual forbs. The plant material was oven dried and weighed (Whitman 1972). Quantitative plant 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 replication for a total of 1500 points per treatment (Goetz et al. 1978).

The nitrogen fertilization of native rangeland pasture study had two grazing trials and was conducted from 1972 to 1982. Grazing trial I used yearling steers and was conducted from 1972 to 1976 by Dr. Warren C. Whitman and Dr. Harold Goetz. Grazing trial II used cow-calf pairs and was conducted from 1978 to 1981 by Paul E. Nyren and Dr. Harold Goetz and continued during 1981 to 1982 by Dr. Llewellyn L. Manske and Dr. Harold Goetz. A long-term plant species composition shift study was conducted by Dr. Llewellyn L. Manske from data collected during 1972 to 1988 and 1997 to 2004 (Manske 2009a). The unfertilized pasture was 18 acres of untreated native rangeland. The fertilized pasture was 12 acres of native rangeland fertilized annually with ammonium nitrate fertilizer (33-0-0) broadcast applied in granular form at a rate of 50 lbs N/ac in early spring, usually around early to mid April, for eleven years from 1972 to 1982. The growing season of 1982 was the last year of fertilizer application. Grazing studies were terminated at this location in 1988 and the pastures were heavily grazed from 1989 to 2004 by cattle that were not in research projects.

Aboveground herbage biomass production was sampled on the unfertilized and fertilized native rangeland pastures by the clipping method from inside and outside exclosure cages from 1972 to 1982, on the unfertilized pasture from inside and outside exclosure cages from 1984 to 1988, and on the unfertilized and fertilized pastures from 1997 to 2004. All of the herbage samples were oven dried and weighed. During 1972 to 1976, aboveground herbage biomass was sampled by hand clipping to ground level with one clip per year at the end of the grazing period during mid August to mid September. The plant material was not separated into categories. During 1977 to 1981, aboveground herbage biomass was sampled by hand clipping to ground level with two clips per year, at the beginning (mid June to mid July) and at the end (late July to mid August) of the grazing period. The plant material was not separated into categories. During 1982 to 1988, aboveground herbage biomass was sampled by hand clipping to ground level with four clips per year, early to mid June, mid June to mid July, mid July to mid August, and mid August to mid September. The plant material was separated into five categories: warm season grass, cool season grass, sedge, domesticated grass, and forbs. Herbage weight data was not collected in 1983, between 1989 and 1996, and in 2003. During 1997 and 2004, aboveground herbage biomass was sampled by hand clipping to ground level with one clip per year during late June to mid August. The plant material was separate into five categories: warm season grass, cool season grass, sedge, domesticated grass, and forbs.

Quantitative plant species composition was determined by percent basal cover sampled with the ten-pin point frame method on the unfertilized and fertilized pastures in 1982, on the unfertilized pasture

from 1985 to 1988, and on the unfertilized and fertilized pastures from 1998 to 2004 during the period of mid July to mid August.

Results

The mean precipitation during the growing seasons of 1970-1978, 1972-1982, and 1997-2004 were normal and were not significantly different (table 1).

Mean aboveground total ungrazed herbage weight on the nitrogen fertilization plot study (1970-1978) was 2252.56 lbs/ac on the unfertilized plots and 2975.89 lbs/ac on the fertilized plots. The total herbage weight on the fertilized plots was 32.1% greater than, but not significantly different from, the total herbage weight on the unfertilized plots (table 2). Mean aboveground total ungrazed herbage weight on the nitrogen fertilization pasture study (1972-1982) was 2122.55 lbs/ac on the unfertilized pasture and 3141.51 lbs/ac on the fertilized pasture. The total herbage weight on the fertilized pasture was 48.0% greater than, but not significantly different from, the total herbage weight on the unfertilized pasture (table 2). Mean aboveground total ungrazed herbage weight on the fertilized pasture study after termination of fertilizer application (1997-2004) was 1348.47 lbs/ac on the unfertilized pasture and 2288.09 lbs/ac on the fertilized pasture. The total herbage weight on the fertilized pasture was 69.7% greater than and significantly different from the total herbage weight on the unfertilized pasture (table 2). The mean total herbage weight on the unfertilized and fertilized plots during 1970 to1978 and on the unfertilized and fertilized pastures during 1972 to 1982 were not significantly different (table 2). The mean total herbage weight on the fertilized pasture after treatments had been terminated during 1997 to 2004 was not significantly different from the total herbage weight on the unfertilized and fertilized treatments of the fertilized plot study and of the fertilized pasture study (table 2). The mean total herbage weight on the unfertilized pasture after the treatments had been terminated during 1997 to 2004 was significantly lower than the herbage weight on the unfertilized and fertilized treatments of the fertilized plot study (1970-1978) and of the fertilized pasture study (1972-1982) (table 2).

This investigation evaluated the short-term and long-term plant species shift which occurred during the period from 1970 to 2004 as a result of application of nitrogen fertilizer to native rangeland. Percent differences in herbage weight, percent composition, and basal cover between the unfertilized and the fertilized vegetation data collected during six selected growing seasons that received above long-term mean precipitation were compared. Data from the nitrogen fertilization of native rangeland plot study IV was selected for 1970 (year 1), 1972 (year 3), and 1978 (year 9). Data from the nitrogen fertilization of native rangeland pasture study was selected for 1982 (year 11) during the years with annual fertilizer treatment application and for 1998 (year 27) and 2002 (year 31) during the years after termination of fertilizer treatment application.

The investigation encompassed the growing seasons of 1970 to 1982 and 1997 to 2004. The precipitation during the growing seasons of 1973, 1974, 1976, 1979, 1980, 2000, 2003, and 2004 was below the long-term mean of 13.55 inches. The precipitation during the growing seasons of 1971, 1975, 1977, 1981, 1997, 1999, and 2001 was above the long-term mean. The precipitation during the selected growing seasons was above the long-term mean. The growing seasons of 1970, 1972, 1978, 1982, 1998, and 2002 received 132.10%, 137.05%, 111.96%, 166.27%, 151.37%, and 114.17% of the long-term mean precipitation, respectively (table 3). Perennial plants were under water stress conditions during August and October, 1970; September, 1972; October, 1978; and September, 2002 (Manske 2008). Perennial plants did not experience water stress conditions during 1982 and 1998 (Manske 2008).

Total aboveground herbage weight produced was increased by annual nitrogen fertilization treatments on native rangeland. Total herbage weight on the fertilized treatments progressively increased and was 37.8%, 39.4%, 50.6%, and 91.4% greater than total herbage weight on the unfertilized treatments during years 1, 3, 9, and 11, respectively. This greater total herbage weight produced on the fertilized treatments during the eleven years of nitrogen application resulted from the increased cool season grass and forb herbage weight. The residual effects from nitrogen fertilization of native rangeland continued after the fertilizer treatments had been terminated. Total herbage weight on the fertilized treatments was 44.1% and 48.9% greater than total herbage weight on the unfertilized treatments during years 27 and 31, respectively. This greater total herbage weight produced on the fertilized treatments during the twenty years following termination of nitrogen application resulted from the increased domesticated cool season grass herbage weight (tables 4a and 4b).

Total basal cover of live plants was decreased by annual nitrogen fertilization treatments on native rangeland. Total basal cover on the fertilized treatments was 21.5%, 23.4%, 41.5%, and 24.9% lower than total basal cover on the unfertilized treatments during years 7, 11, 27, and 31, respectively (table 6).

Herbage weight of warm season grass on the fertilized treatments increased during the first year and then steadily decreased during the following 33 years. Warm season grass herbage weight on the fertilized treatments was 42.0% greater than warm season herbage weight on the unfertilized treatments during year 1. Warm season grass herbage weight on the fertilized treatments decreased greatly during the long-term shift and was 33.0%, 69.0%, 71.5%, 89.7%, and 86.2% lower than warm season grass herbage weight on the unfertilized treatments during years 3, 9, 11, 27, and 31, respectively (tables 4a and 4b).

Percent composition of warm season grass in the total herbage weight on the fertilized treatments increased during year 1 and was 3.1% greater than percent composition of warm season grass on the unfertilized treatments. Warm season grass percent composition on the fertilized treatments decreased greatly during the long-term shift and was 51.9%, 79.4%, 85.1%, 93.9%, and 91.1% lower than warm season grass percent composition on the unfertilized treatments during years 3, 9, 11, 27, and 31, respectively (tables 5a and 5b).

Basal cover of warm season grass on the fertilized treatments decreased greatly during the long-term shift and was 67.1%, 67.8%, 72.8%, and 64.4% lower than basal cover of warm season grass on the unfertilized treatments during years 7, 11, 27, and 31, respectively (table 6).

Herbage weight of cool season grass on the fertilized treatments increased greatly during the short-term shift as a result of nitrogen application and was 7.5%, 85.7%, 89.9%, and 166.4% greater than herbage weight of cool season grass on the unfertilized treatments during years 1, 3, 9, and 11, respectively. The residual effects from nitrogen fertilization of native rangeland became detrimental to native cool season grass after the nitrogen application treatments had been terminated. Cool season grass herbage weight on the fertilized treatments decreased greatly during the long-term shift and was 70.1% and 83.3% lower than cool season grass herbage weight on the unfertilized treatments during years 27 and 31, respectively (tables 4a and 4b).

Percent composition of cool season grass in the total herbage weight on the fertilized treatments decreased during year 1 and was 22.0% lower than percent composition of cool season grass on the unfertilized treatments. Percent composition of cool season grass on the fertilized treatments increased during the short-term shift as a result of nitrogen application and was 33.2%, 26.1%, and 39.2% greater than percent composition of cool season grass on the unfertilized treatments during years 3, 9, and 11, respectively. After the nitrogen application treatments had been terminated, cool season grass percent composition on the fertilized treatments decreased greatly during the long-term shift and was 78.1% and 88.9% lower than cool season grass percent composition on the unfertilized treatments during years 27 and 31, respectively (tables 5a and 5b).

Basal cover of cool season grass on the fertilized treatments increased greatly during the short-term shift as a result of nitrogen application and was 14.9% and 40.3% greater than basal cover of cool season grass on the unfertilized treatments during years 7 and 11, respectively. Cool season grass basal cover on the fertilized treatments decreased greatly during the long-term shift after the nitrogen application treatments had been terminated and was 76.6% and 79.4% lower than cool season grass basal cover on the unfertilized treatments during years 27 and 31, respectively (table 6).

The small quantity of upland sedge in the mixed grass prairie of the nitrogen fertilization plot study did not have a separate herbage weight sample category. Herbage weight of upland sedge on the fertilized treatments most likely changed little during the short-term shift and was probably less than 15% lower than herbage weight of upland sedge on the unfertilized treatments during years 1, 3, and 9. As the time from the start of the fertilization treatments increased, the residual effects from nitrogen application to native rangeland became increasingly detrimental to upland sedge. Herbage weight of upland sedge on the fertilized treatments decreased greatly during the long-term shift and was 16.0%, 33.2%, and 59.4% lower than herbage weight of upland sedge on the unfertilized treatments during years 11, 27, and 31, respectively (tables 4a and 4b).

Percent composition of upland sedge in the total herbage weight on the fertilized treatments

during the short-term shift most likely was slightly lower than percent composition of upland sedge on the unfertilized treatments during years 1, 3, and 9. Percent composition of upland sedge on the fertilized treatments decreased during the long-term shift and was 56.1%, 52.7%, and 72.7% lower than percent composition of upland sedge on the unfertilized treatments during years 11, 27, and 31, respectively (tables 5a and 5b).

Basal cover of upland sedge on the fertilized treatments changed little during the short-term shift as a result of nitrogen application and was 1.2% greater than basal cover of upland sedge on the unfertilized treatments during year 7. Upland sedge basal cover on the fertilized treatments decreased during the long-term shift and was 14.2%, 22.2%, and 53.7% lower than upland sedge basal cover on the unfertilized treatments during years 11, 27, and 31, respectively (table 6).

Forb herbage weight was comprised of perennial forbs and annual forbs. Annual forb herbage weight did not contribute significantly to the total forb herbage weight (Whitman 1978). Forb herbage weight on the fertilized treatments consisted primarily of fringed sage which increased greatly in size and weight during the short-term shift as a result of nitrogen application. Forb herbage weight on the fertilized treatments during the short-term shift was 150.3%, 65.6%, 8.4%, and 70.0% greater than forb herbage weight on the unfertilized treatments during years 1, 3, 9, and 11, respectively. Herbage weight of forbs on the fertilized treatments decreased during the long-term shift after the nitrogen application treatments had been terminated and was 66.0% and 58.1% lower than herbage weight of forbs on the unfertilized treatments during years 27 and 31, respectively (tables 4a and 4b).

Percent composition of forbs in the total herbage weight on the fertilized treatments during the short-term shift was 81.6% and 18.8% greater than percent composition of forbs on the unfertilized treatments during years 1 and 3, respectively. Percent composition of forbs on the fertilized treatments during the long-term shift was 28.0%, 11.2%, 72.0%, and 70.6% lower than percent composition of forbs on the unfertilized treatments during years 9, 11, 27, and 31, respectively (tables 5a and 5b).

Basal cover of forbs on the fertilized treatments increased during the short-term shift as a result of nitrogen application and was 66.4% greater than basal cover of forbs on the unfertilized treatments during year 7. Forb basal cover on the fertilized treatments decreased during the long-term shift as a result of a decrease in the quantity of forb plants and in the number of forb species and was 75.7%, 62.9%, and 67.7% lower than forb basal cover on the unfertilized treatments during years 11, 27, and 31, respectively (table 6).

Domesticated grass herbage weight was comprised of crested wheatgrass, smooth bromegrass, Kentucky bluegrass, and Canada bluegrass. Domesticated grass herbage weight did not appear in the plant community data of the fertilized treatments during years 1, 3, and 9, and domesticated grass did not appear in the unfertilized treatment herbage weight data during years 1, 3, 9, 11, and 27. Domesticated grass herbage weight on the fertilized treatments during the long-term shift was 517 lbs/ac during year 11, 1524 lbs/ac during year 27, and 1552 lbs/ac during year 31. Domesticated grass herbage weight on the fertilized treatments was 4769.3% greater than domesticated grass herbage weight on the unfertilized treatments during year 31, which was 20 years after the nitrogen application treatments had been terminated (tables 4a and 4b).

Percent composition of domesticated grass on the fertilized treatments was 3560.6% greater than percent composition of domesticated grass on the unfertilized treatments during year 31. Percent composition of domesticated grass in the total herbage weight on the fertilized treatments increased during the long-term shift and was 14.1%, 76.0%, and 82.7% during years 11, 27, and 31, respectively. Coincidently, percent composition of total native grass on the fertilized treatments decreased during the long-term shift and was 75.9%, 20.1%, and 13.2% during years 11, 27, and 31, respectively (tables 5a and 5b).

Basal cover of domesticated grass on the fertilized treatments was 988.9%, 444.4%, 299.2%, and 356.1% greater than basal cover of domesticated grass on the unfertilized treatments during years 7, 11, 27, and 31, respectively. Basal cover of domesticated grass on the fertilized treatments increased greatly during the long-term shift and was 1.0%, 2.0%, 4.7%, and 13.1% during years 7, 11, 27, and 31, respectively. Coincidently, basal cover of total native grass on the fertilized treatments decreased greatly during the long-term shift and was 21.0%, 15.2%, 6.9%, and 8.2% during years 7, 11, 27, and 31, respectively (table 6).

Relative basal cover of domesticated grass on the fertilized treatments increased during the long-term shift and was 4.1%, 11.2%, 37.9%, and 57.1% during years 7, 11, 27, and 31, respectively. Coincidently, relative basal cover of total native grass on the fertilized treatments decreased greatly during the long-term shift and was 88.6%, 86.8%, 56.2%, and 35.7% during years 7, 11, 27, and 31, respectively.

During the short-term shift as a result of eleven years of nitrogen fertilization treatments on native rangeland, total herbage weight had increased 91.4%, total basal cover had decreased 23.4%, and plant species composition had changed greatly. Warm season grass herbage weight had decreased 71.5%, composition had decreased 85.1%, and basal cover had decreased 67.8%. Cool season grass herbage weight had increased 166.3%, composition had increased 39.2%, and basal cover had increased 40.3%. Upland sedge herbage weight had decreased 16.0%, composition had decreased 56.1%, and basal cover had decreased 14.2%. Forb herbage weight had increased 70.0%, composition had decreased 11.2%, and basal cover had decreased 75.7% (tables 7a and 7b). This short-term shift in plant species composition with a decrease in short warm season grass and an increase in mid cool season grass resulting from annual application of nitrogen fertilizer to native rangeland was considered by Whitman (1976) to be a beneficial cultural practice because the results from four nitrogen fertilization of native rangeland plot studies (1957-1978) with one, two, six, and nine years of monitoring data had not shown signs of ecosystem deterioration.

A small amount of domesticated grass had encroached onto the fertilized treatments during the short-term shift by year 11; herbage weight was 517.05 lbs/ac, percent composition was 14.1%, and basal cover was 2.0%. This domesticated grass intrusion was not recognized as a serious problem at these small quantities.

During the long-term shift, the residual effects from nitrogen applications to native rangeland continued to change the plant species composition for twenty years after the nitrogen fertilization treatments had been terminated. Warm season grass herbage weight had decreased 86.2%, composition had decreased 91.1%, and basal cover had decreased 64.4%. Cool season grass herbage weight had decreased 83.3%, composition had decreased 88.9%, and basal cover had decreased 79.4%. Upland sedge herbage weight had decreased 59.4%, composition had decreased 72.7%, and basal cover had decreased 53.7%. Forb herbage weight had decreased 58.1%, composition had decreased 70.6%, and basal cover had decreased 67.7%. Domesticated grass herbage weight had increased 4769.3%, composition had increased 3560.6%, and basal cover had increased 356.1% (tables 7a and 7b).

In a 31 year period consisting of eleven years of annual nitrogen fertilization treatments of native rangeland and twenty years following termination of nitrogen applications, the native mixed grass prairie community dominated with western wheatgrass, needle and thread, blue grama, and threadleaf sedge shifted in plant species composition to a community dominated with crested wheatgrass, smooth bromegrass, Kentucky bluegrass, and Canada bluegrass.

These changes in plant species composition will not end at year 31. The negative residual effects from nitrogen fertilization of native rangeland will continue as long as fertilizer nitrogen remains in the ecosystem. Power (1977) determined the fate of applied nitrogen and calculated the nitrogen content in the various sinks of a grazed semiarid native mixed grass prairie ecosystem that had been annually fertilized with nitrogen for eleven years. Power (1977) found that 8% or 4.0 lbs/ac of the applied nitrogen was lost or removed from the ecosystem per year. At a constant rate of loss at 4.0 pounds of applied nitrogen per acre per year, the applied nitrogen would be used up in 126.5 years from the last year fertilizer was applied. The ecosystem should be devoid of fertilizer nitrogen sometime during the growing season in the year 2109 (Manske 2009b).

Discussion

Application of nitrogen fertilizer to native rangeland altered ecosystem biogeochemical processes that induced short-term plant species composition changes with a decrease in short warm season grass, an increase in mid cool season grass, and usually an abrupt expansion in undesirable perennial forbs. Following termination of nitrogen fertilizer applications, the residual effects from modified ecosystem processes continued to cause long-term plant species composition changes with near elimination of native warm season grass, cool season grass, upland sedge, and perennial forbs, and a great increase in domesticated and introduced mid cool season grass. The short-term shift in plant species had been documented by numerous research

projects. The long-term shift in plant species had been hypothesized to occur by Goetz et al. (1978) as a result of the decrease in basal cover and the increase in exposed soil areas that was expected to develop from the decrease in multiple stemmed short warm season grass and the increase in single stalked mid cool season grass. Application of nitrogen fertilizer to native rangeland caused a long-term plant species composition shift that nearly removed all of the native plant species and substituted domesticated mid cool season grass as a replacement community. Nitrogen fertilization of native rangeland is no longer considered to be beneficial for the rangeland ecosystem. Nitrogen fertilization of native rangeland is no longer considered to be a viable cultural practice to recover degraded ecosystem condition, to return the natural botanical composition, and to restore the native vegetation herbage biomass production to native rangeland ecosystems.

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Table 1. Mean precipitation in inches for growing season months during years of the plot fertilization treatment study (1970-1978), the pasture fertilization treatment study (1972-1982), and after termination of fertilizer application (1997-2004).

	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
Plot Data During treatments									
1970-1978	2.46	3.23	3.82	1.57	1.03	2.16	1.21	15.47a	17.89
% of LTM	172.03	138.03	107.61	70.72	59.54	162.41	127.37	114.17	111.81
Pasture Data During treatments									
1972-1982	1.77	2.59	3.43	1.57	1.90	1.91	1.51	14.40a	17.03
% of LTM	123.78	110.68	96.62	70.72	109.83	143.61	158.95	106.27	106.44
Pasture Data After treatments									
1997-2004	1.52	2.05	3.63	2.87	1.54	1.49	1.45	14.54a	17.08
% of LTM	106.29	87.61	102.25	129.28	89.02	112.03	152.63	107.31	106.75

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

Table 2. Evaluation of mean total herbage weight in pounds per acre on unfertilized and fertilized native rangeland on the plot fertilization treatment study (1970-1978), the pasture fertilization treatment study (1972-1982), and after termination of fertilizer application (1997-2004).

	Unfertilized Herbage Weight lbs/ac	Fertilized Herbage Weight lbs/ac	Weight Difference lbs/ac	Percent Difference %
Plot Data During treatments				
1970-1978	2252.56a	2975.89a	723.33	32.1
Pasture Data During treatments				
1972-1982	2122.55a	3141.51a	1018.96	48.0
Pasture Data After treatments				
1997-2004	1348.47b	2288.09a	939.62	69.7

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

Table 3. Precipitation in inches for growing season months of samples years during 1970-2004, Dickinson, North Dakota.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Growing Season	Annual Total
Long-Term Mean 1892-2007	1.43	2.34	3.55	2.22	1.73	1.33	0.95	13.55	16.00
Plot Data									
1970 Year 1	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
1972 Year 3	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
1978 Year 9	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
Pasture Data									
1982 Year 11	1.85	4.32	3.43	2.02	2.63	1.77	6.51	22.53	26.58
% of LTM	129.37	184.62	96.62	90.99	152.02	133.08	685.26	166.27	166.13
1998 Year 27	0.85	1.86	6.55	1.82	2.90	2.03	4.50	20.51	24.04
% of LTM	59.44	79.49	184.51	81.98	167.63	152.63	473.68	151.37	150.25
2002 Year 31	1.39	2.06	4.75	2.98	2.81	0.17	1.31	15.47	26.58
% of LTM	97.20	88.03	133.80	134.23	162.43	12.78	137.89	114.17	166.13
2004 Year 33	0.96	1.40	0.54	2.42	0.63	1.53	2.78	10.26	15.54
% of LTM	67.13	59.83	15.21	109.01	36.42	115.04	292.63	75.72	97.13

Table 4a. Percent difference from fertilization treatment in herbage weight in pounds per acre on native rangeland plots on the upland range site, 1970-1978.

Year Treatment % Difference	Warm Season Short Grass	Cool Season Mid Grass	Sedge	Total Native Grass	Domesticated Grass	Forbs	Total Yield
Plot Data							
1970 Year 1							
Unfertilized lbs/ac	1078.00	905.00		1983.00		203.00	2186.00
Fertilized lbs/ac	1531.00	973.00		2504.00		508.00	3012.00
Difference %	42.02	7.51		26.27		150.25	37.79
1972 Year 3							
Unfertilized lbs/ac	1223.00	1653.00		2876.00		456.00	3332.00
Fertilized lbs/ac	819.00	3069.00		3888.00		755.00	4643.00
Difference %	-33.03	85.66		35.19		65.57	39.35
1978 Year 9							
Unfertilized lbs/ac	506.00	1874.00		2380.00		309.00	2689.00
Fertilized lbs/ac	157.00	3558.00		3715.00		335.00	4050.00
Difference %	-68.97	89.86		56.09		8.41	50.61

Table 4b. Percent difference from fertilization treatment in herbage weight in pounds per acre on native rangeland pasture on the upland range site, 1972-2004.

Year Treatment % Difference	Warm Season Grass	Cool Season Grass	Sedge	Total Native Grass	Domesticated Grass	Forbs	Total Yield
Pasture Data							
1982 Year 11							
Unfertilized lbs/ac	517.15	898.28	281.90	1697.33	0.00	214.27	1911.60
Fertilized lbs/ac	147.40	2392.55	236.70	2776.65	517.05	364.25	3657.95
Difference %	-71.50	166.35	-16.03	63.59	100.00	70.00	91.36
1998 Year 27							
Unfertilized lbs/ac	322.07	527.35	305.42	1154.84	0.00	230.73	1385.57
Fertilized lbs/ac	33.06	157.47	204.09	394.62	1524.01	78.50	1997.13
Difference %	-89.74	-70.14	-33.18	-65.83	100.00	-65.98	44.14
2002 Year 31							
Unfertilized lbs/ac	217.65	493.10	335.87	1046.62	31.87	182.68	1261.17
Fertilized lbs/ac	29.97	82.30	136.54	248.81	1551.84	76.59	1877.24
Difference %	-86.23	-83.31	-59.35	-76.23	4769.28	-58.07	48.85

Table 5a. Percent difference from fertilization treatment in percent composition of herbage weight for native rangeland plots on the upland range site, 1970-1978.

Year Treatment % Difference	Warm Season Short Grass	Cool Season Mid Grass	Sedge	Total Native Grass	Domesticated Grass	Forbs	Total Yield
Plot Data							
1970 Year 1							
Unfertilized %	49.31	41.40		90.71		9.29	2186.00
Fertilized %	50.83	32.30		83.13		16.87	3012.00
Difference %	3.08	-21.98		-8.36		81.59	
1972 Year 3							
Unfertilized %	36.70	49.61		86.31		13.69	3332.00
Fertilized %	17.64	66.10		83.74		16.26	4643.00
Difference %	-51.93	33.24		-2.98		18.77	
1978 Year 9							
Unfertilized %	18.82	69.69		88.51		11.49	2689.00
Fertilized %	3.88	87.85		91.73		8.27	4050.00
Difference %	-79.38	26.06		3.64		-28.02	

Table 5b. Percent difference from fertilization treatment in percent composition of herbage weight for native rangeland pasture on the upland range site, 1972-2004.

Year Treatment % Difference	Warm Season Grass	Cool Season Grass	Sedge	Total Native Grass	Domesticated Grass	Forbs	Total Yield
Pasture Data							
1982 Year 11							
Unfertilized %	27.05	46.99	14.75	88.79	0.00	11.21	1911.60
Fertilized %	4.03	65.41	6.47	75.91	14.13	9.96	3657.95
Difference %	-85.10	39.20	-56.14	-14.51	100.00	-11.15	
1998 Year 27							
Unfertilized %	26.84	37.44	21.65	85.93	0.00	14.08	1385.57
Fertilized %	1.63	8.20	10.25	20.08	75.97	3.95	1997.12
Difference %	-93.93	-78.10	-52.66	-76.63	100.00	-71.95	
2002 Year 31							
Unfertilized %	17.57	39.79	26.47	83.83	2.26	13.91	1261.17
Fertilized %	1.56	4.40	7.23	13.18	82.73	4.09	1877.24
Difference %	-91.12	-88.94	-72.69	-84.28	3560.62	-70.60	

Table 6. Percent difference from fertilization treatment in plant species basal cover for native rangeland plots (1970-1976) and for native rangeland pasture (1972-2004) on the upland range site.

Year Treatment % Difference	Warm Season Grass	Cool Season Grass	Sedge	Total Native Grass	Domesticated Grass	Forbs	Total Basal Cover
Plot Data							
1976 Year 7							
Unfertilized %	14.18	9.22	5.71	29.11	0.09	1.04	30.25
Fertilized %	4.66	10.59	5.78	21.03	0.98	1.73	23.74
Difference %	-67.14	14.86	1.23	-27.76	988.89	66.35	-21.52
Pasture Data							
1982 Year 11							
Unfertilized %	9.94	4.47	6.64	21.05	0.36	1.40	22.81
Fertilized %	3.20	6.27	5.70	15.17	1.96	0.34	17.47
Difference %	-67.81	40.27	-14.16	-27.93	444.44	-75.71	-23.41
1998 Year 27							
Unfertilized %	9.93	3.63	4.33	17.93	1.17	1.97	21.07
Fertilized %	2.70	0.85	3.37	6.92	4.67	0.73	12.32
Difference %	-72.81	-76.58	-22.17	-61.41	299.15	-62.94	-41.53
2002 Year 31							
Unfertilized %	7.00	5.81	9.77	22.58	2.87	5.10	30.55
Fertilized %	2.48	1.20	4.52	8.20	13.09	1.65	22.94
Difference %	-64.43	-79.35	-53.74	-63.68	356.10	-67.65	-24.91

Table 7a. Summary of percent difference from fertilization treatment in herbage weight and percent composition of herbage weight for native rangeland on the upland range site, 1970-2004.

	Warm Season Grass	Cool Season Grass	Sedge	Total Native Grass	Domesticated Grass	Forbs	Total
Herbage Weight							
1970 Year 1	42.02	7.51		26.27		150.25	37.79
1972 Year 3	-33.03	85.66		35.19		65.57	39.35
1978 Year 9	-68.97	89.86		56.09		8.41	50.61
1982 Year 11	-71.50	166.35	-16.03	63.59	100.00	70.00	91.36
1998 Year 27	-89.74	-70.14	-33.18	-65.83	100.00	-65.98	44.14
2002 Year 31	-86.23	-83.31	-59.35	-76.23	4769.28	-58.07	48.85
Percent Composition							
1970 Year 1	3.08	-21.98		-8.36		81.59	
1972 Year 3	-51.93	33.24		-2.98		18.77	
1978 Year 9	-79.38	26.06		3.64		-28.02	
1982 Year 11	-85.10	39.20	-56.14	-14.51	100.00	-11.15	
1998 Year 27	-93.93	-78.10	-52.66	-76.63	100.00	-71.95	
2002 Year 31	-91.12	-88.94	-72.69	-84.28	3560.62	-70.60	

Table 7b. Summary of percent difference from fertilization treatment in plant species basal cover for native rangeland on the upland range site, 1970-2004.

	Warm Season Grass	Cool Season Grass	Sedge	Total Native Grass	Domesticated Grass	Forbs	Total Basal Cover
Basal Cover							
1976 Year 7	-67.14	14.86	1.23	-27.76	988.89	66.35	-21.52
1982 Year 11	-67.81	40.27	-14.16	-27.93	444.44	-75.71	-23.41
1998 Year 27	-72.81	-76.58	-22.17	-61.41	299.15	-62.94	-41.53
2002 Year 31	-64.43	-79.35	-53.74	-63.68	356.10	-67.65	-24.91

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