RANGE PROGRAM RESEARCH PROJECT REPORT

Restoration of Native Mixed Grass Prairie on Degraded Untilled Land through Implementation of Biologically Effective Grazing Management

North Dakota State University
Dickinson Research Extension Center

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Progress Report of Project Year Twelve

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The Schnell Recreation Area, located approximately 2 miles (3.22 kilometers) east of Richardton, North Dakota, in eastern Stark County, has been managed by the Bureau of Land Management (BLM) since 1993. The area comprises 1,988 acres (804.5 hectares) of degraded land dominated with undesirable introduced cool-season domesticated grasses, primarily smooth bromegrass, crested wheatgrass, and Kentucky bluegrass. The area shows degradation of two types, each of which has a distinct cause: 1. land with native plant ecosystems that were first degenerated by management practices antagonistic to plant biological requirements and ecosystem biogeochemical processes and subsequently invaded with undesirable introduced species and 2. land that was seeded with cool-season domesticated grasses after native plant ecosystems were destroyed by tillage. The Bureau of Land Management's identified goals for the Schnell Recreation Area are to restore the native grassland condition and vegetation diversity of the degraded untilled areas that have been invaded by undesirable species and to convert the seeded cool-season domesticated grasses on the previously tilled haylands to a mixture of native species. The desired purpose of the restored prairie and converted grassland is to provide high-quality habitat for maintenance and production of grassland migratory birds, neo-tropical birds, and other resident wildlife.

This project was developed to test and evaluate the use of biologically effective grazing management practices in the restoration of native mixed grass prairie plant species composition and grassland ecosystem biogeochemical processes on degraded untilled land and to monitor the progress of the improvements in the ecosystem. The biologically effective management practice implemented was the twice-over rotation grazing system which coordinates two grazing periods with grass growth stages and meets the biological requirements of the plants.

This research project was conducted during the 2006 to 2011 growing seasons. The plant community characteristics data were not collected in 2012 and a progress report was not written. The pastures were grazed by 117 steers with mean weight of 650 pounds during the 2012 growing season, however, the designed grazing management rotation protocol was not followed. This research project resumed in the spring of 2013 with plant community data collection and grazing according to the designed rotation management protocol and was continued during 2014. No cattle grazing or data collection occurred during 2015 and 2016. Cattle grazed and plant data was collected during 2017.

Procedures

A three-pasture twice-over rotation grazing management system was used on the grasslands of the Schnell Recreation Area from early June until mid October, with each pasture grazed for two periods. A fourth pasture at the Schnell Recreation Area was not grazed and was used as a control. Each of the three pastures in the rotation was grazed for 14 to 16 days during the first period, the 45-day interval from 1 June to 15 July. The length of the first period on each pasture is the same percentage of 45 days as the percentage of the total season's grazeable forage each pasture contributes (Manske 2000a). During the second period, after mid July and before mid October, each pasture was grazed for double the number of days it was grazed during the first period. Livestock were removed in mid October.

The coordinated defoliation improves plant health and stimulates biological and ecological processes within grass plants and the ecosystem so that beneficial changes to plant growth, soil organisms, and biogeochemical cycles in the ecosystem result (Manske 2000a). During the first grazing period, grasses are between the third-leaf and flowering stages, the stages of plant development at which grazing produces beneficial effects by stimulating the defoliation resistance mechanisms that increase tillering from axillary buds and enhance activity of rhizosphere organisms. Increased vegetative reproduction by tillering contributes to the development of greater plant basal cover and to the production of greater grass herbage weight; increased activity of the soil organisms in the rhizosphere supplies the plant with greater quantities of nutrients

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to support additional growth (Manske 2000a). Removing livestock from native rangeland pastures in mid October, during the early fall, allows native grasses to store nutrients that will maintain plant processes over the winter and to retain the fall vegetative growth that will become next season's lead tillers (Manske 2003a). This practice ensures healthy plants in the spring and greater herbage production during the next growing season (Manske 2000a).

Plant growth data were collected on permanent plots organized in a paired-plot design. A 16' X 32' stock panel exclosure that prevented livestock access and an adjacent area of equal size accessible by livestock were established for nondestructive sampling on silty range sites in each of the four pastures. An additional area of similar size accessible by livestock was established for destructive sampling at each sample site location. During the grazing season, aboveground herbage biomass was collected on each pasture rotation date by the standard clipping method (Cook and Stubbendieck 1986). The herbage material from five 0.25m^2 quadrats (frames) at each sample site was sorted in the field by biotype categories: domesticated grasses, cool-season grasses, warm-season grasses, sedges, forbs, standing dead, and litter. The herbage of each biotype category from each frame was placed in labeled paper bags of known weight, oven dried at 140° F (60° C), and weighed. Plant species composition was determined during peak growth between mid July and mid August by the ten-pin point frame method (Cook and Stubbendieck 1986), with 2000 points collected along permanent transect segments both inside (ungrazed) and outside (grazed) each exclosure. Basal cover, relative basal cover, percent frequency, relative percent frequency, and importance value were determined for the ten-pin point frame data. Densities of forbs and shrubs were determined by counting individual stems of each plant species rooted inside twenty-five 0.1m^2 quadrats placed along permanent transect segments both inside (ungrazed) and outside (grazed) each exclosure. Density per 0.1m^2 quadrat, relative density, percent frequency, relative percent frequency, and importance value were determined for the density data. A standard paired plot t-test was used to analyze differences between means (Mosteller and Rourke 1973).

Results

In the Richardton, North Dakota, area, the long-term mean (LTM) (1971-2000) annual temperature is 43.0° F (6.1° C) (table 1). January is the coldest month, with a mean temperature of 13.5°

F (-10.3° C). July and August are the warmest months, with mean temperatures of 70.0° F (21.1° C) and 68.9° F (20.5° C), respectively. Plants experience temperature stress during months with mean monthly temperatures below 32.0° F (0.0° C). From November through March each year, plants in western North Dakota cannot conduct active growth because mean temperatures are below 32.0° F (0.0° C) (table 1).

The long-term annual precipitation in the Richardton, North Dakota, area is 17.78 inches (451.61 mm) (table 1). The growing season precipitation (April through October) is 14.79 inches (375.67 mm), 83.18% of the annual precipitation. The seasonal period during which the greatest precipitation occurs is spring--April, May, and June-- with 7.63 inches (193.80 mm), 42.91% of the annual precipitation. June has the greatest monthly precipitation, 3.39 inches (86.11 mm). The precipitation received during the 3-month period of May, June, and July accounts for 45.84% of the annual precipitation (8.15 inches, or 207.01 mm). The precipitation received during the 5-month period of November through March averages 2.99 inches, (75.95 mm), 16.82% of annual precipitation. The seasonal period during which the least precipitation occurs is winter--January, February, and March--with 1.79 inches (45.47 mm), 10.07% of the annual precipitation.

A technique reported by Emberger et al. (1963) was used to identify water deficiency months from temperature and precipitation data. This method graphs the mean monthly temperature (°C) and monthly precipitation (mm) on the same axis, with the scale of the precipitation data at twice that of the temperature data. The temperature and precipitation data are plotted against an axis of time. The resulting ombrothermic diagram shows general monthly trends and indicates the months with water deficiency conditions, unfavorable periods during which perennial plants experience water stress. Water deficiency exists during months when the precipitation data bar drops below the temperature data curve. Plants are under temperature stress when the temperature curve drops below the freezing mark (0° C). The long-term ombrothermic graph for the Richardton, North Dakota, area (figure 1) shows that August and September typically have near water deficiency conditions and that November, December, January, February, and March have temperature stress conditions for perennial plants.

Precipitation during the growing season months in 2006 to 2011 was 12.31 inches (312.67

mm), 83.23% of LTM. Mean precipitation during April to July was 82.66% of LTM and during August to October was 84.05% of LTM (table 2). Weather data for the 2012, 2013, 2014, 2015, 2016, and 2017 growing seasons is not available.

The aboveground herbage produced by domesticated grasses was greater than the herbage produced by native grasses on pastures 1, 2, and the control pasture 4, which was not grazed (tables 3, 4-6). The percent native grass herbage produced was 5.7% on pasture 1; and 24.3% on pasture 2; respectively, during and 2017. The percent native grass herbage produced was 13.0% on the nongrazed control pasture 4, respectively.

Grazing behavior differences between mature cows, young heifers, and young steers is expected to cause some differences in the vegetation data.

The standing dead and litter weight was greater than the live herbage weight produced on pastures 1 and 2 on the control ungrazed pasture 4 (tables 4, 5, and 6) during 2017. The average live herbage weight and the average standing dead and litter weight, respectively, were 1612.34 lbs/ac and 4463.96 lbs/ac on pasture 1 (table 4), 1925.93 lbs/ac and 2283.52 lbs/ac on pasture 2 (table 5), and 1713.03 lbs/ac and 4165.05 lbs/ac on control pasture 4 (table 7). Standing dead and litter composed 73.5%, 54.3%, and 70.9% of the aboveground biomass on pastures 1, 2, and 4, respectively. Live herbage composed only 36% of the aboveground biomass on the two grazed pastures.

Percent basal cover of domesticated grasses were greater than the basal cover of native grasses and sedges on pasture 1 and control pasture 4 (table 8). Basal cover of native grasses and sedges were greater than basal cover of domesticated grasses on grazed pasture 2 (table 8). The basal cover of native grasses and sedges and the basal cover of domesticated grasses, respectively, were 1.5% and 26.8% on pasture 1 (table 10), 18.3% and 18.0% on pasture 2 (table 12), and 3.5% and 23.9% on control pasture 4 (table 14). Domesticated grasses composed 94.4%, 49.3%, and 86.9% of the basal cover on pastures 1, 3 and 4, respectively. Native grasses and sedges composed 5.3%, 50.1%, and 12.7% of the basal cover on pastures 1, 2, and 4, respectively. During 2017, basal cover of native grasses and sedges decreased 91.7%, 27.1%, and 29.6% on pastures 1, 2 and 4, respectively, from the basal cover during 2006. Basal cover of cool season and warm season grasses and sedges on pastures 1 and 2 averaged 110.6%

greater on the grazed treatments than on the ungrazed treatments.

Plant species composition included early, mid, and late succession forbs. Forb density was lower on the grazed pastures 1 and 2 than on the control pasture 4 (table 17). Early succession forbs composed 0.0%, of the forb density on pastures 1, 2, and 4, respectively. Mid succession forbs composed 19.2%, 8.7%, and 16.7% of the forb density on pastures 1, 2, and 4, respectively. Blue wild lettuce was the primary mid succession forb. Late succession forbs composed 73.1%, 91.3%, and 73.3% of the forb density on pastures 1, 2, and 4, respectively. Western yarrow, white prairie aster, silver leaf scurfpea, wavyleaf thistle, and american vetch were the primary late succession forbs (tables 17-25).

Herbage biomass of domesticated grasses increased 36.3% and 55.8% on pastures 1 and 2 and decreased 23.2% on pasture 4. Herbage biomass of native grasses decreased 77.3% and 32.2% on pastures 1 and 2 and increased 59.7% on pasture 4 during 2017 compared to herbage biomass during 2006.

Basal cover of domesticated grasses increased 410.5% and 313.8% on pastures 1 and 2, and increased 23.9% on pasture 4. Basal cover of native grasses decreased 85.1% on pasture 1 and increased 73.5% and 20.7% on pastures 2 and 4 during 2017 compared to basal cover during 2006.

Herbage biomass of forbs decreased 81.8%, 71.7%, and 53.7% on pastures 1, 2, and 4 and density of forbs decreased 61.2%, 64.1%, and 23.1% on pastures 1, 2, and 4 during 2017 compared to herbage biomass and density during 2006.

As a result of the management of the Schnell Recreation Area from 2012 to 2017, pastures 1 and 2 have greater amounts of domesticated grasses and lower amounts of native grasses during 2017 than they had during 2006.

In order to reduce the unwanted domesticated grasses and to increase the desirable native grasses, the livestock stocking rate must be between 80% and 100% of the standard assessed stocking rate.

Removal of cattle grazing from the Schnell Recreation Area for thirteen years from 1993 to 2005 caused degradation of the mixed grass prairie communities on control pasture NR 4 and on pastures NR 1 and NR 2. The transition from plant

communities dominated by native grasses to plant communities dominated by domesticated grasses was the visible change but was not the first degrading change. Before the native grass species decreased and the domesticated grass species increased, the rhizosphere biomass decreased. After thirteen years with no cattle grazing, the rhizosphere biomass on control pasture NR 4 decreased to 52.23 kg/m^3, and the rhizosphere biomass on pastures NR 1 and NR 2 decreased to 77.99 kg/m^3. These low quantities of rhizosphere biomass are less than 20% of potential rhizosphere biomass.

When defoliation by grazing is removed from a mixed grass prairie, the native grass live root biomass decreases. This decrease in active root surface causes a reduction in root length for interaction with symbiotic rhizosphere organisms and causes a decrease in absorption of water and nutrients from the soil. The loss of active root length is a contributing factor in the reduction of rhizosphere biomass. The primary cause for the reduction in rhizosphere biomass was, however, the great reduction in the quantity of carbohydrates exuded from the grass roots into the rhizosphere zone. Without defoliation by grazing, only a small quantity of plant material leaks from the grass roots into the rhizosphere; this low amount of carbon compounds is barely enough to sustain a small rhizosphere biomass.

Rhizosphere organism biomass and activity are limited by access to simple carbon chains because the microflora trophic levels lack chlorophyll and have low carbon (energy) content. Partial defoliation of grass plants at vegetative phenological growth stages by large grazing graminivores causes greater quantities of exudates containing simple carbon compounds to be released through the plant roots into the rhizosphere. With the increase in availability of carbon compounds in the rhizosphere, activity of the microorganisms increases. The increase in rhizosphere organism activity causes an increase in rhizosphere volume and biomass.

Grazing on pastures NR 1 and NR 2 was managed with the twice-over rotation strategy for six years from 2006 through 2011, and the rhizosphere weights increased greatly during these six grazing seasons. Control pasture NR 4 was not grazed during the six year study period.

The rhizosphere weights on grazed pastures NR 1 and NR 2 were not significantly different from the other during each of the six grazing seasons. During the first two years, the rhizosphere weights on the grazed pastures and on the ungrazed control pasture were not significantly different. The 2006 rhizosphere weights and the 2007 rhizosphere weights were not significantly different. The rhizosphere weights on the grazed pastures were numerically greater than the rhizosphere weights on the ungrazed control pasture, but were not significantly different during the first two years, 2006 and 2007.

The annual changes of the rhizosphere weights on the ungrazed control pasture responded differently than the annual increases of the rhizosphere weights on the grazed pastures. The rhizosphere weights on the ungrazed control pasture changed little each year from the second year to the fourth year, during which the growing season precipitation was slightly more than 75% of the long-term mean. Mean rhizosphere weight change from the second to the fourth year was 2.5 kg/m^3 per year. The rhizosphere weights on the ungrazed control pasture increased markedly during the fifth and sixth years, 2010 and 2011, during which the growing season precipitation was greater than 100% of the long-term mean. Mean rhizosphere weight change was 23.8 kg/m^3 per year during the fifth and the sixth years. During the period from the second year to the sixth year, during which the growing season precipitation was slightly less than 90% of the long-term mean, the rhizosphere weight increased at a mean rate of 13.2 kg/m^3 per year on the ungrazed control pasture.

After the second year, rhizosphere weights on the grazed pastures were significantly greater during each year than those on the ungrazed control pasture. The rhizosphere weights on the grazed pastures increased at a mean rate of 27.1 kg/m^3 per year during the second year to the fourth year, during which the growing season precipitation was slightly more than 75% of the long-term mean. The rhizosphere rate of weight increase was 850.1% greater on the grazed pastures than on the ungrazed control pasture during 2007 to 2009. During the fifth and sixth years, 2010 and 2011, during which the growing season precipitation was greater than 100% of the long-term mean, the rhizosphere weight increase on the grazed pastures was 37.0 kg/m^3 per year, which was 55.2% greater than the rhizosphere weight increase on the ungrazed control pasture. The rhizosphere weights on the grazed pastures increased greatly during each grazing season from the second year to the sixth year, 2007 to 2011. When growing season precipitation was slightly less than 90% of the long-term mean from the second year to the sixth year, the rhizosphere weight increased at a mean rate of 30.5 kg/m^3 per year on the grazed pastures which

was 131.5% greater than the change in rhizosphere weight on the ungrazed control pasture during the same period. The rhizosphere weights each year during 2008 to 2011 were numerically the greatest on the grazed pastures and were significantly greater than the rhizosphere weights on the ungrazed control pasture during each respective year. The rhizosphere biomass increases from the second to the sixth years on the grazed pastures NR 1 and NR 2 appeared to be related to increases in carbon exudates that resulted from partial defoliation of grass lead tillers by grazing during vegetative growth stages.

The total available soil mineral nitrogen of nitrate and ammonium on grazed pastures NR 1 and NR 2 was 83.87 lbs/ac on the exclosures and 87.32 lbs/ac on the grazed areas, with an increase of 4.1% on the grazed areas. The quantity of mineral nitrogen was greater on the grazed areas than on the ungrazed exclosures. The quantities of mineral nitrogen were not significantly different on the exclosures and the grazed areas. The quantity of nitrate was 31.00 lbs/ac on the exclosures and 28.75 lbs/ac on the grazed areas, with a decrease of 7.3% on the grazed areas. The quantity of ammonium was 52.87 lbs/ac on the exclosures and 58.57 lbs/ac on the grazed areas, with an increase of 10.8% on the grazed areas. The exclosures had greater nitrate and lower ammonium and the grazed areas had lower nitrate and greater ammonium. The greater quantities of nitrate appear to be related to the greater quantities of easily decomposed labile roots of domesticated grasses. The greater quantities of ammonium appear to be related to the greater quantities of native grass roots and greater rhizosphere biomass.

Pasture 1 had greater percent domesticated grasses and lower percent native grasses in the plant communities than control pasture 4 (table 28). Pasture 2 had greater percent native grasses and lower percent domesticated grasses in the plant communities than control pasture 4 (table 28). The primary domesticated grass on control pasture 4 was Kentucky bluegrass, and the primary domesticated grass on pasture 3 was smooth bromegrass in 2006 and 2007. Kentucky bluegrass had greater basal cover than smooth bromegrass in 2008, 2009, 2010, 2011, 2013, and 2014 on pasture 3. During the nine years of this study, relative basal cover has increased for Kentucky bluegrass and decreased for smooth bromegrass on pasture 3. The restoration of native prairie plant communities from degraded untilled land dominated with smooth bromegrass appears to require an intermediary step with increased Kentucky bluegrass in order to build up the rhizosphere organism biomass.

Smooth bromegrass roots do not appear to readily develop symbiotic relationships with rhizosphere organisms. During a study that evaluated the effects on the percent mycorrhizal fungi infection in grass roots from prescribed every-other-year burning treatments conducted during the period from 1978 to 1990, Manske et al. (2006) found that the percent fungal infection in smooth bromegrass roots (41.8%) was significantly less than the percent infection in western wheatgrass (67.0%) and blue grama (78.8%) roots. Very few smooth bromegrass samples had fungal colonization within the root tissue. Almost all of the fungal infection observed in smooth bromegrass was resticted to the root hairs. The study also found that the number of repeated burns and the seasonal period of burns did not significantly change the level of fungal infection in domesticated and native grass roots.

Biologically effective grazing management can stimulate rhizosphere organism activity when a small amount of leaf material from grass plants between the third-leaf stage and the flowering stage is removed by grazing animals (Manske 1999). The rhizosphere volume per grass plant and the total rhizosphere volume per cubic meter of soil on pastures managed with the twice-over rotation system were significantly greater following the stimulation grazing period than the rhizosphere volume per grass plant and the total rhizosphere volume per cubic meter of soil on the 4.5-month seasonlong and 6.0-month seasonlong grazing treatments and the long-term nongrazed treatment (Gorder, Manske, and Stroh 2004).

The grassland ecosystems on degraded untilled land at the Schnell Recreation Area were dominated by cool-season domesticated grasses and had low native grass herbage biomass production, low native grass basal cover, low late succession native forb density, and low rhizosphere weight. However, a few native grasses and forbs in association with rhizosphere organisms did remain. Through the use of biologically effective management practices to stimulate the defoliation resistance mechanisms of these plants it will be possible to restore the biogeochemical processes in these grassland ecosystems.

The restoration of the prairie communities on the untilled land at the Schnell Recreation Area will require several years, and because of the extensive deterioration of the grassland ecosystem, it is estimated that full recovery will require greater than ten years and perhaps longer.

Discussion

Restoration of prairie ecosystems requires an understanding of the defoliation resistance mechanisms within grass plants, the symbiotic rhizosphere organisms' relationship with ecosystem biogeochemical processes and grass plants, and the stimulation of these processes with defoliation by grazing animals.

Grass plants evolved 20 million years ago with early herbivores that are now extinct. During this time, grasses developed biological processes that help the plants withstand and recover from defoliation (Manske 2000a). This complex of processes (McNaughton 1979, 1983, Briske 1991, Briske and Richards 1995), called defoliation resistance mechanisms, accelerates both the growth rate of the grazed plant and its development of foliage and roots. Two biological processes of primary concern to grassland managers are the increased beneficial activity of soil organisms (Coleman et al. 1983) and the stimulation of vegetative reproduction by secondary tiller development from axillary buds (Briske and Richards 1995). Grazing that removes a small amount of leaf area from the grass plant between the third-leaf stage and flowering stage can trigger these beneficial responses (Manske 1999).

There is a mutually beneficial relationship between the grass plant's root system and soil organisms. The narrow zone of soil around the roots of perennial grassland plants, the rhizosphere, contains bacteria, protozoa, nematodes, mites, springtails, and endomycorrhizal fungi (Elliot 1978, Anderson et al. 1981, Harley and Smith 1983, Curl and Truelove 1986, Whipps 1990, Campbell and Greaves 1990). The grass plant's roots release carbon compounds (Campbell and Greaves 1990), including sugars, to these rhizosphere organisms, and the organisms release mineral nitrogen that the plant's roots absorb (Ingham et al. 1985, Clarholm 1985, Biondini et al. 1988, Frederick and Klein 1994, Frank and Groffman 1998). The endomycorrhizal fungi also provide phosphorus, other mineral nutrients, and water that the plant needs for growth (Moorman and Reeves 1979, Harley and Smith 1983, Allen and Allen 1990, Koide 1993, Marschner and Dell 1994, Smith and Read 1997). Activity of the soil microorganisms increases with the availability of carbon compounds in the rhizosphere (Curl and Truelove 1986, Whipps 1990), and the elevated microorganism activity results in an increase in nitrogen available to the grass plant (Coleman et al. 1983, Klein et al. 1988, Burrows and Pfleger 2002,

Rillig et al. 2002, Bird et al. 2002, Driver et al. 2005).

Grazing lead tillers between the third-leaf stage and the flowering stage can increase the quantity of carbon compounds the defoliated plant releases into the rhizosphere (Hamilton III and Frank 2001). The increase in nitrogen produced by elevated rates of microorganism activity allows the plant to accelerate growth and recover more quickly from defoliation. This beneficial activity does not seem to occur when grazing is conducted during the middle and late growth stages of the grass plant.

Long-term non-defoliation (idle) management is a management choice that withholds defoliation from a grassland for a considerable length of time. Non-defoliation treatments increase the level of shading in a grassland ecosystem and thereby reduce the intensity of the light that reaches the leaves. Long-term nongrazed grass plants shift to erect growth forms with a small number of tillers with fewer leaves because the shading from other plants reduces the light intensity reaching the lower leaves of an individual plant (Briske and Richards 1995). Grass leaves grown under shaded conditions become longer but narrower, thinner, and lower in weight (Langer 1972) than leaves in sunlight. Shaded leaves have a reduced rate of photosynthesis, which decreases the carbohydrate supply and causes a reduction in growth rate of leaves and roots (Langer 1972). Root growth is reduced because roots are very sensitive to reductions in light intensity reaching the leaves. Shading also increases the rate of senescence in the lower older leaves.

Decomposition of leaf material through microbial activity can take place only after the leaves have made contact with the soil. Standing dead material not in contact with the soil does not decompose but breaks down slowly as a result of leaching and weathering. Accumulation of standing dead leaves reduces availability of carbon and nitrogen in soil. Under nongrazed treatments, dead leaves remain standing for several years. Increased mulch biomass resulting from long-term non-defoliation (Brand and Goetz 1986, Manske 1995) negatively affects the soil. Excessive mulch reduces water infiltration and early season soil temperatures, causing reduced soil bacterial activity in the top 12 inches of soil. Excess mulch accumulation also causes conditions that decrease mycorrhizal fungal and rhizosphere organism activity, slow nutrient cycles, and reduce available nutrients. Standing dead leaves shade early leaf growth in

spring, slowing the rate of growth, reducing the leaf area, and causing a reduction in the net primary productivity. Long-term effects of shading in nongrazed grasslands include reduced total plant densities and native grass species composition (Manske 1995) and increased composition of shade-tolerant or shade-adapted replacement species like smooth bromegrass and Kentucky bluegrass.

Management strategies that defer grazing until after the flowering stage were intended to enhance sexual reproduction and increase the quantity of seeds produced. However, deferred grazing does not improve grass plant density (Sarvis 1941, Manske et al. 1988). Most young grass plants in grassland ecosystems start not as seedlings but as vegetative tillers that grow from axillary buds on the crowns of an established plant. These vegetative tillers make up the majority of the plant population because they have a competitive advantage over seedlings. Tillers initially draw support from the root systems of parent tillers, while seedlings must rely only on their own less-developed structures.

Tiller development from axillary buds is regulated by lead tillers (Briske and Richards 1995) through a process called lead tiller dominance. The lead tillers produce an inhibitory hormone that prevents the growth hormone from activating growth within axillary buds (Briske and Richards 1995). Grazing that removes a small amount of young leaf tissue from the aboveground portion of lead tillers after the three-leaf stage and before the flowering stage reduces the amount of the inhibitory hormone in the plant (Briske and Richards 1994). With that inhibitory hormone reduced, the growth hormones stimulate vegetative reproduction (Murphy and Briske 1992, Briske and Richards 1994), and secondary tillers develop from the previous year's axillary buds (Langer 1972).

Positive grass plant responses to grazing depends on the timing of defoliation. Grazing grass plants prior to the third-leaf stage negatively affects grass growth (Manske 2000b). Early seasonal growth of grass plants depends on carbohydrates stored in the roots, rhizomes, and stem bases (Trlica 1977), and prematurely grazed plants are unable to replenish adequate amounts of carbohydrates to support active growth (Coyne et al. 1995, Manske 1999). Starting grazing after the third-leaf stage and before the flowering stage allows plants to establish sufficient leaf area to produce adequate photosynthetic assimilates to meet leaf growth requirements and

allows all leaf bud primordia in the apical meristem to develop into leaf buds (Manske 1999).

If no defoliation occurs before the flowering stage, as on a deferred grazing strategy, the lead tiller inhibits vegetative tiller development until the inhibitory hormone production naturally declines during the flowering stage. This hormone reduction permits one axillary bud to grow and develop into a secondary tiller, which in turn produces inhibitory hormones that prevent growth of the other six to eight axillary crown buds (Mueller and Richards 1986). These dormant axillary buds are never activated and become senescent with the lead tiller. No evidence has been found to suggest that grazing the lead tiller after it has reached the flowering stage has beneficial stimulatory effects on vegetative tiller development (Manske 2000a).

All grass species in the Northern Plains have strong lead tiller dominance except Kentucky bluegrass and meadow bromegrass, which have low levels of inhibitory hormones and relatively higher levels of tiller development. Plants with these growth characteristics have greater demands for water than grasses with strong lead tillers and cease growth processes during minor water deficiency periods.

The twice-over rotation grazing management system applies defoliation treatment to grass plants at the appropriate phenological growth stages to stimulate the defoliation resistance mechanisms and the activity of the symbiotic rhizosphere microorganisms. The phenological growth stages during which these two mechanisms can be manipulated are the same, between the third-leaf stage and flowering phenophase. This stimulation increases both vegetative tiller development of grasses and nutrient flow in the rhizosphere, resulting in increased aboveground herbage biomass, increased plant basal cover, and increased rhizosphere weight.

Table 1. Long-term (1971-2000) mean monthly temperature and monthly precipitation at Richardton, ND.

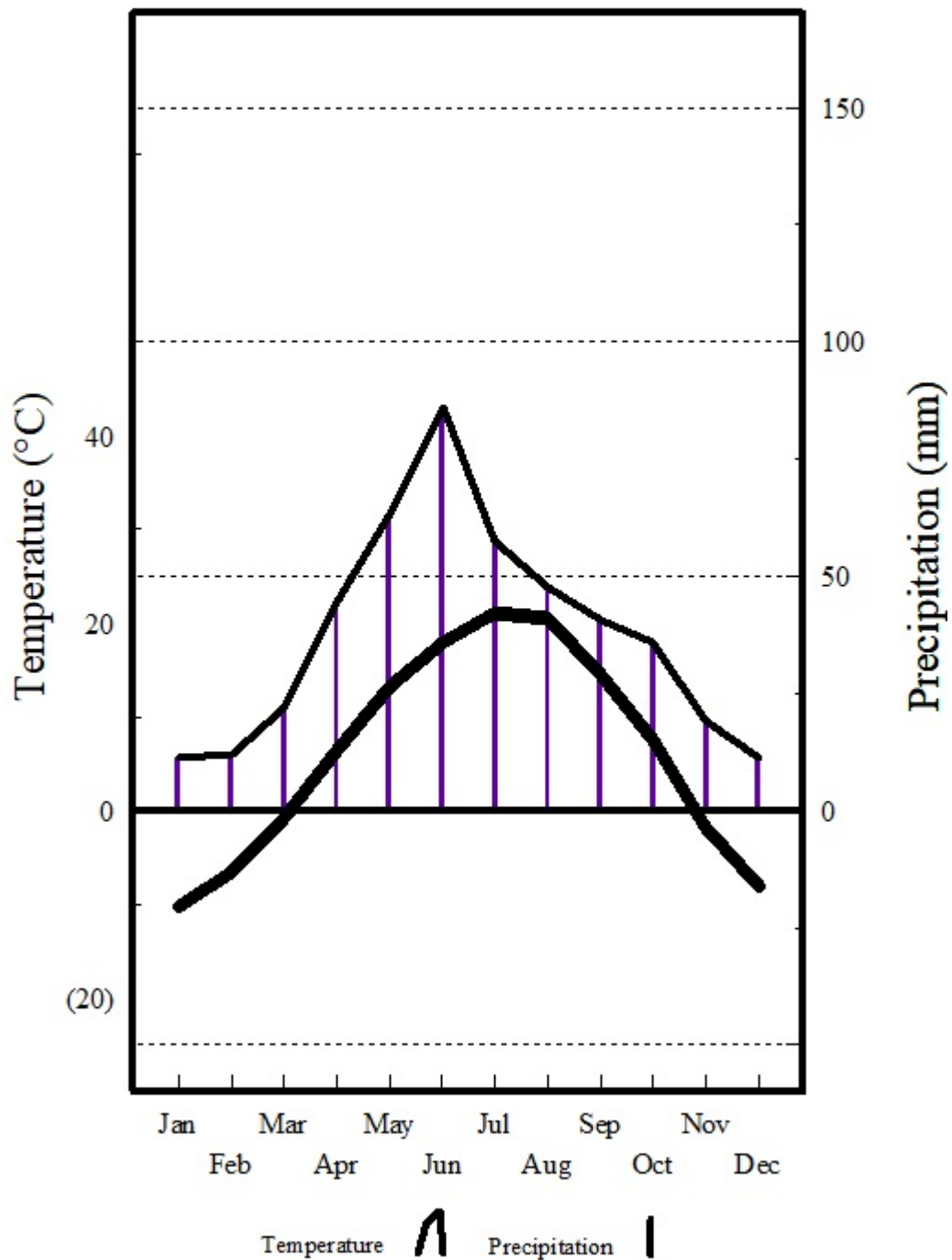|	º F	º C	in.	mm
Jan	13.50	-10.28	0.45	11.43
Feb	20.40	-6.44	0.48	12.19
Mar	30.30	-0.94	0.86	21.84
Apr	43.40	6.33	1.75	44.45
May	55.70	13.17	2.49	63.25
Jun	64.30	17.94	3.39	86.11
Jul	70.00	21.11	2.27	57.66
Aug	68.90	20.50	1.88	47.75
Sep	57.90	14.39	1.60	40.64
Oct	45.60	7.56	1.41	35.81
Nov	28.80	-1.78	0.75	19.05
Dec	17.40	-8.11	0.45	11.43
	MEAN		**TOTAL**	
	43.00	**6.11**	**17.78**	**451.61**

Fig. 1. Ombrothermic diagram of long-term (1971-2000) mean monthly temperature and monthly precipitation at Richardton, North Dakota.

Table 2. Precipitation in inches for growing season months for 2006-2011, Richardton, North Dakota.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Growing Season
Long-term mean (1971-2000)	1.75	2.49	3.39	2.27	1.88	1.60	1.41	14.79
2006	2.53	0.60	0.37	0.79	1.40	2.33	1.40	9.42
% of LTM	144.57	24.10	10.91	34.80	74.47	145.63	99.29	63.69
2007	1.04	3.57	2.22	0.44	1.57	1.29	0.62	10.75
% of LTM	59.43	143.37	65.49	19.38	83.51	80.63	43.97	72.68
2008	0.45	1.32	3.93	2.04	0.56	1.70	1.45	11.45
% of LTM	25.71	53.01	115.93	89.87	29.79	106.25	102.84	77.42
2009	0.59	0.85	3.09	2.82	0.53	1.67	2.08	11.63
% of LTM	33.71	34.14	91.15	124.23	28.19	104.38	147.52	78.63
2010	0.71	3.29	4.35	1.42	0.90	2.30	0.46	13.43
% of LTM	40.57	132.13	128.32	62.56	47.87	143.75	32.62	90.80
2011	2.01	4.94	1.76	4.06	2.07	0.96	1.35	17.15
% of LTM	114.86	198.39	51.92	178.85	110.11	60.00	95.74	115.96
2006-2011	1.22	2.43	2.62	1.93	1.17	1.71	1.23	12.31
% of LTM	69.71	97.59	77.28	85.02	62.23	106.88	87.23	83.23

Table 3. Summary of aboveground herbage production in lbs/acre for native range on the silty sites at the Schnell Recreation Area, 2017.

	30th May	15th Jul	15th Oct
NR1 grazed			
Domesticated Grass	2080.14	888.43	1558.03
Native Grass	44.01	134.39	78.50
NR2 grazed			
Domesticated Grass	1481.91	739.77	2058.74
Native Grass	423.40	543.53	405.56
NR4 control	not grazed		
Domesticated Grass	1371.30	1109.65	1738.81
Native Grass	0.00	296.14	331.82

Table 8. Summary percent basal cover for native range on the silty sites at the Schnell Recreation Area, 2017.

	NR 1 Silty		NR 2 Silty		NR 4 Silty Control	
	ungrazed	grazed	ungrazed	grazed	ungrazed	not grazed
Domesticated Cool Season	17.80	26.80	14.20	18.00	17.40	23.90
Native Cool Season	0.60	0.50	0.40	3.20	0.10	0.50
Native Warm Season	0.00	0.00	0.90	4.00	0.10	2.40
Sedges	0.20	1.00	7.30	11.10	0.10	0.60
Forbs	0.00	0.10	0.00	0.20	0.20	0.10
Woody Species	0.00	0.00	0.00	0.00	0.50	0.00
Total Live	18.60	28.40	22.80	36.50	18.40	27.50
Litter	81.40	71.60	77.20	63.50	81.60	72.50

Table 17. Summary plant density for native range on the silty sites at the Schnell Recreation Area, 2017.

	NR 1 Silty		NR 2 Silty		NR 4 Silty Control	
	ungrazed	grazed	ungrazed	grazed	ungrazed	not grazed
Late Succession Forbs	0.36	0.76	0.48	0.84	1.72	0.88
Mid Succession Forbs	0.00	0.20	0.00	0.08	0.00	0.20
Early Succession Forbs	0.00	0.00	0.00	0.00	0.00	0.00
Woody Species	0.08	0.08	0.00	0.00	0.88	0.12
Total Live	0.44	1.04	0.48	0.92	2.60	1.20

Table 28. Summary of percent composition based on basal cover of native range plant community on the silty sites at the Schnell Recreation Area, 2017.

	NR 1 Silty grazed	NR 2 Silty grazed	NR 4 Silty Control not grazed
Domesticated Grass	94.37	49.32	86.91
Native Grass	1.76	19.73	10.55
Sedges	3.52	30.41	2.18
Forbs	0.35	0.55	0.36
Woody Species	0.00	0.00	0.00

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