Grazing and Burning Treatment Effects on Soil Mineral Nitrogen and Rhizosphere Volume

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

Report DREC 11-1066c

Insufficient nitrogen availability limits productivity more often than water in temperate grasslands (Tilman 1990). Enhancement of the nitrogen cycle in grassland ecosystems that causes an increase in available inorganic (mineral) nitrogen results in greater productivity of herbage, livestock, and wildlife.

Soil organic matter of mixed grass prairie ecosystems generally contains about three to eight tons of organic nitrogen per acre. Organic nitrogen is a form of nitrogen not directly usable by grass plants. Organic nitrogen must be converted into mineral nitrogen in order to be usable by plants. The biogeochemical processes of the nitrogen cycle in grassland ecosystems that convert nitrogen into the various forms are a function of the interactions among rhizosphere organisms, grass plants, and large grazing herbivores (Manske 1999).

This project uses soil mineral nitrogen and rhizosphere volume data to evaluate the effects that grazing treatments and burning treatments have on rhizosphere organism activity and on enhancement of biogeochemical processes of the nitrogen cycle in grassland ecosystems and the resulting increase in quantity of available mineral nitrogen converted from soil organic nitrogen.

Study Areas

This project was conducted at two locations. The NDSU Dickinson Research Extension Center ranch is located in Dunn county in western North Dakota, at 47° 14' north latitude, 102° 50' west longitude. Mean annual temperature is 42.5° F (5.8° C). January is the coldest month, with a mean temperature of 14.5° F (-9.7° C). July and August are the warmest months, with mean temperatures of 69.4° F (20.8° C) and 68.8° F (20.4° C), respectively. Long-term (1982-2006) mean annual precipitation is 16.87 inches (428.59 mm). The growing-season precipitation (April through October) is 14.09 inches (357.86 mm) and is 83.50% of the annual precipitation. June has the greatest monthly precipitation, at 3.27 inches (83.09 mm). The precipitation received during the 3-month period of May, June, and July (8.11 inches, 205.99 mm) accounts for 48.07% of the annual precipitation (Manske 2007a). Soils are primarily Typic Haploborolls developed on sedimentary deposits. The fine loamy soils have 5 to 6 tons of organic nitrogen per acre. Native vegetation is the Wheatgrass-Needlegrass Type (Barker and Whitman 1988) of the mixed grass prairie.

The USDI Lostwood National Wildlife Refuge is located in Burke and Mountrail counties in northwestern North Dakota between 48° 50' and 48° 30' north latitude and 102° 40' and 102° 20' west longitude. The region has cold winters and hot summers typical of continental climates. January is the coldest month, and July and August are the warmest months. Long-term (1936-1989) mean annual precipitation is 16.50 inches (419.10 mm). The growing-season precipitation (April through October) is 13.80 inches (350.52 mm) and is 83.64% of the annual precipitation. June has the greatest monthly precipitation, at 3.32 inches (84.33 mm). The precipitation received during the 3-month period of May, June, and July (7.70 inches, 195.58 mm) accounts for 46.67% of the annual precipitation (Manske 2007b). Soils are primarily Typic Haploborolls and Typic Argiborolls developed on glacial terminal moraine. The fine loamy soils have 4 to 6 tons of organic nitrogen per acre. Native vegetation is the Wheatgrass-Needlegrass Type (Barker and Whitman 1988) of the mixed grass prairie.

Procedures

The effects from defoliation treatments on enhancement of the nitrogen cycle and rhizosphere organism biomass and activity were evaluated from differences in soil mineral nitrogen content and in rhizosphere volume. The quantitative soil mineral nitrogen study was conducted on grazing treatments and on repeated prescribed burning treatments. The quantitative rhizosphere volume study was conducted on grazing treatments.

The grazing treatments were conducted at the Dickinson Research Extension Center ranch between 1983 and 2002 on mixed grass prairie that had a history of management with moderate to heavy seasonlong grazing. The treatments were (1) long-term nongrazed control (NG), (2) 6.0-month seasonlong (6.0-m SL), (3) 4.5-month seasonlong (4.5-m SL), and (4) twice-over rotation (TOR). Each of the grazing treatments had two replications. The long-term nongrazed management treatment had not been grazed, mowed, or burned for more than 30 years before the initiation of these research treatments in 1983. Livestock on the 6.0-month seasonlong management treatment grazed one native range pasture for 6.0 months (183 days) from mid May until mid November. Livestock on the 4.5-month seasonlong management treatment grazed one native range pasture for 4.5 months (135 days) from early June until mid October. Livestock on the twice-over rotation management treatment followed a double rotation sequence through three native range pastures for 4.5 months (135 days) from early June until mid October. Each of the three pastures in the rotation were grazed for about 15 days during the first period, the 45-day interval from 1 June to 15 July. 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.

The repeated every-other-year prescribed burning treatments were conducted by refuge manager Karen Smith at the Lostwood National Wildlife Refuge during a thirteen year period between 1978 and 1990 on degraded mix grass prairie that had greater than 50% of the upland occupied with western snowberry colonies (Smith 1988). The number of repeated every-other-year prescribed burns was (1) no burns control, (2) one burn, (3) two burns, (4) three burns, and (5) four burns. The prescribed burns were conducted during four seasons: (6) early spring, (7) spring, (8) early summer, and (9) mid summer. Annual burns were not possible because of insufficient production of plant biomass for fuel (Smith 1985). The refuge land had not been burned for more than 100 years before the initiation of these prescribed burn treatments in 1978. However, between 1940 and 1975, about 26% of the refuge was annually grazed with a deferred-type seasonlong management for 4.5 to 5.0 months at low to moderate stocking rates, primarily during July through November (Smith 1988). Some areas were grazed only one time and other areas were grazed as many as 22 times over the 35-year period (Smith 1988). About 15% of the refuge was never burned, grazed, or mowed (Smith 1997). The no burns control treatment had 6 replications with an average size of 436.8 acres (176.90 ha) and had no grazing, mowing, or burning during the thirteen year study period. The every-other-year prescribed burning treatments had an average size of 530.5 acres (214.85 ha) and had no grazing or mowing during the thirteen year study period. The one burn, two burns, and three burns treatments had 4 replications each, and the four burns treatment had 3 replications. The early spring burns had 1 replication, the spring burns had 3 replications, the early summer burns had 7 replications, and the mid summer burns had 4 replications.

The quantitative soil mineral nitrogen study was conducted on the nongrazed, 4.5-month seasonlong, and twice-over rotation grazing treatments; on the no burns, one burn, two burns, three burns, and four burns every-other-year prescribed burning treatments; and on the early spring, spring, early summer, and mid summer every-other-year prescribed burning treatments. Field samples of grazing and burning treatment soils were collected from nearly level loam soils. Aboveground vegetation was clipped from soil sample areas and discarded. Each soil field sample consisted of five soil cores that were air dried, ground, and thoroughly mixed. Twenty percent of each field sample was retained for quantitative laboratory analysis.

Field samples were collected during mid June 1989 at the start of the seventh year of the grazing treatment study. Each soil core from the grazing treatments was collected with a bucket auger and was 2 inches (5.08 cm) in diameter and 6 inches (15.24 cm) in depth. Two field samples were collected in each of the two replications of each nongrazed control and grazing treatment, resulting in four replicated field samples per grazing treatment.

Field samples were collected during July and August 1990 after thirteen years of every-other-year prescribed burning treatments. Each soil core from the burn treatments was collected with a soil probe and was 1 inch (2.54 cm) in diameter and 6 inches (15.24 cm) in depth. One field sample was collected during each time period for each replication of the no burns and the seasonal period and number of repeated every-other-year prescribed burning treatments. A mean of the July and August sample periods was determined for each treatment replication.

In the laboratory, subsamples of soil from the field samples were analyzed for total incubated mineralizable nitrogen (N) using procedures outlined by Keeney (1982). Inorganic forms of nitrogen were extracted from the soil subsamples by adding a reagent; alkaline phosphate-borate buffer to the grazing treatment soils, and 2 M KCl to the burning treatment soils. The mixtures of reagent and soil were shaken for one hour. The extract was quantified into parts per million (ppm) of mineral nitrogen, ammonia (NH_3), ammonium (NH_4), and nitrate NO_3), with steam distillation (Keeney and Nelson 1982). These quantified values of mineral nitrogen were converted from parts per million to pounds per acre-foot. Soil nitrite (NO_2) was not quantified because it is seldom present in detectable amounts.

The rhizosphere volume study was conducted on the nongrazed (NG), 6.0-month seasonlong (6.0-m SL), 4.5-month seasonlong (4.5-m SL), and twice-over rotation (TOR) grazing treatments in 2002 during the twentieth year of the grazing treatment study. Two replications of soil cores containing western wheatgrass roots and rhizospheres were collected monthly during June, July, August, and September from nearly level loam soils in each grazing treatment. Plastic PVC pipe 3 inches (7.62 cm) in diameter and 4 inches (10.16 cm) long was forced into sample site soil. Intact soil-plant-rhizosphere cores and pipe were excavated and transported to the laboratory.

In the laboratory, the soil matrix of collected soil cores was carefully removed from between the rhizospheres surrounding the roots of western wheatgrass plants. The roots and rhizospheres of other plant species were separated from the soil cores and discarded. The western wheatgrass rhizospheres were sprayed with a clear acrylic coating to prevent damage during further handling. The length and diameter of the rhizosphere around each root of every plant, including associated tillers, were measured with a vernier caliper. During the process of extraction from matrix soil, portions of some rhizospheres were damaged and small segments were detached from the root surface. The length measurements of damaged rhizospheres were the length of the root, including the regions of detached rhizosphere segments. The length and diameter measurements were used to determine the volume of the rhizosphere around each root. The sum of the individual roots' rhizosphere volume was the total rhizosphere volume per replicated soil core. The total rhizosphere volume reported as cubic centimeters per cubic meter of soil (Gorder, Manske, and Stroh 2004) was converted to cubic feet per acre-foot. Differences among treatments in the means of mineral nitrogen content and rhizosphere volume were analyzed by a standard paired-plot t-test (Mosteller and Rourke 1973).

Results

Precipitation during the 1989 growing season at the Dickinson Research Extension Center ranch was low at 10.60 inches (75.24% of LTM). During 1989, plants experienced water stress during July, August, and September. The previous growing season of 1988 had drought conditions receiving only 5.30 inches of precipitation (37.62% of LTM). During 1988, plants experienced water stress during April, June, July, August, September, and October. The drought of 1988 started in August 1987 and near-drought conditions lasted through the growing season of 1992 (Manske 2007a).

Precipitation during the 1990 growing season at the Lostwood Wildlife Refuge was near normal at 14.44 inches (104.64% of LTM). Below normal precipitation occurred during June, September, and October. The previous growing season of 1989 had low precipitation at 10.84 inches (78.55% of LTM). Below normal precipitation occurred during April, May, August, and October. The growing season of 1988 had drought conditions receiving 9.61 inches (69.64% of LTM). Below normal precipitation occurred during April, July, August, and October (Manske 2007b).

Precipitation during the 2002 growing season at the Dickinson Research Extension Center ranch was greater than normal at 18.85 inches (133.79% of LTM). June, July, and August were wet months with precipitation greater than 125% of LTM. September and October had water deficiencies receiving precipitation at less than 75% of LTM and plants experienced water stress during September (Manske 2007a).

Mineral nitrogen in pounds per acre-foot (lbs/ac-ft) is the quantity of mineral nitrogen available in the soil and usable by grassland plants for growth of aboveground herbage and belowground root biomass. Differences in the pounds of available mineral nitrogen on the grazing treatments and burning treatments indicates the differences in the effects the defoliation treatments have on the rhizosphere organism activity and on the enhancement of the nitrogen cycle and the quantity of mineral nitrogen converted from soil organic nitrogen.

The mineral nitrogen available on the one, two, three, and four repeated every-other-year burning treatments and on the early spring, spring, early summer, and mid summer seasonal every-other-year burning treatments was low and was not significantly different ($P<0.05$) from that on the no burns control treatment (table 1). The number of repeated every-other-year burning treatments and the seasonal period of prescribed burning treatments did not affect the quantity of available mineral nitrogen in the soil. The mineral nitrogen available on all of the every-other-year burning treatments and no burns control treatment was significantly less ($P<0.05$) than the mineral nitrogen available on all of the grazing treatments and nongrazed control treatment (table 1, figure 1). The mineral nitrogen available on the no burns treatment and every-other-year prescribed burning treatments was less than 30% of the mineral nitrogen available on the nongrazed treatment. The antagonistic effects on the rhizosphere organism activity from the previous management with deferred grazing practices caused the available mineral nitrogen to decrease 70.6% on the no burns treatment and to decrease 74.5% on the prescribed repeated burning treatments.

The mineral nitrogen available on the 4.5-m and 6.0-m seasonlong grazing treatments and on the nongrazed control treatment were significantly different ($P<0.05$) (table 1, figure 1). After six grazing seasons, the seasonlong grazing treatments did not beneficially affect the rhizosphere organisms and the biogeochemical nitrogen cycle processes and did not increase the quantity of available mineral nitrogen. The seasonlong grazing treatments were antagonistic to rhizosphere organism activity causing a reduction in the quantity of soil organic nitrogen converted into mineral nitrogen.

The mineral nitrogen available on the twice-over rotation treatment was more than 100 lbs/ac and was significantly greater ($P<0.05$) than that on the 4.5-m and 6.0-m seasonlong grazing treatments and on the nongrazed control treatment (table 1, figure 1). The twice-over rotation treatment beneficially affected the rhizosphere organisms and the available mineral nitrogen was increased 67.7% greater than on the nongrazed treatment and 131.9% and 188.7% greater than on the seasonlong grazing treatments.

The twice-over rotation treatment consisted of three native range pastures grazed for about 15 days each during the first period from 1 June to 15 July when grass tillers are between the three and a half new leaf stage and the flowering stage. The available mineral nitrogen was high on each of the three rotation pastures and was not significantly different ($P<0.05$) among the first, second, and third pasture grazed in the rotation sequence (table 2). Effects from first period grazing treatments on the first, second, and third pastures of the twice-over rotation sequence stimulated the rhizosphere organism activity that increased the mineral nitrogen 87.7%, 54.6%, and 60.8% greater than that on the nongrazed treatment, respectively.

Rhizosphere volume in cubic feet per acre-foot ($ft^3/ac\text{-}ft$) is the quantity of space occupied by active rhizosphere organisms on the grazing treatments. Differences in rhizosphere volume indicates the differences in the effects the grazing treatments have on the rhizosphere organism biomass and activity and subsequently on the proportional differences in the quantity of mineral nitrogen converted from soil organic nitrogen.

Rhizosphere volume on the 6.0-m seasonlong grazing treatment was significantly lower ($P<0.05$) than that on the nongrazed control treatment (table 1, figure 2) and was lower than, but not significantly different ($P<0.05$) from, that on the 4.5-m seasonlong grazing treatment (table 1, figure 2). The rhizosphere volume was greatly reduced in size as a result of the antagonistic effects from the 6.0-m seasonlong treatment on rhizosphere organism activity. The rhizosphere volume on the 6.0-m seasonlong treatment was 51.2% smaller than on the nongrazed treatment and 26.4% smaller than on the 4.5-m seasonlong treatment. Rhizosphere volume on the 4.5-m seasonlong grazing treatment was lower than, but not significantly different ($P<0.05$) from, that on the nongrazed control treatment (table 1, figure 2). After 20 grazing seasons, the 4.5-m seasonlong treatment was slightly antagonistic to the activity of the rhizosphere organisms. The rhizosphere volume was 33.7% smaller on the 4.5-m seasonlong treatment than on the nongrazed treatment. Rhizosphere volume on the twice-over rotation treatment was significantly greater ($P<0.05$) than the rhizosphere volume on the 6.0-m seasonlong and the 4.5-m seasonlong grazing treatments and on the nongrazed control treatment (table 1, figure 2). The twice-over rotation treatment greatly stimulated the activity of the rhizosphere organisms. The rhizosphere volume on the twice-over rotation treatment was 356.4%, 235.8%, and 122.7% greater than on the 6.0-m seasonlong, 4.5-m seasonlong, and nongrazed treatments, respectively.

Rhizosphere volume changes as a result of increases or decreases in rhizosphere organism activity. The effects on rhizosphere volume during the growing season from the grazing treatments are shown in figures 3 and 4. Rhizosphere volume on the nongrazed control treatment increased slightly during the early summer in July and remained at about the same volume for the duration of the season. The volume at the end of the season on the nongrazed treatment was about 40% greater than the volume at the beginning. Rhizosphere volume on the 6.0-m seasonlong grazing treatment declined gradually during the growing season and the volume at the end of the season was less than half the volume of the beginning. The 6.0-m seasonlong treatment was antagonistic to the activity of the rhizosphere organisms during the entire grazing period. The rhizosphere volume on the 6.0-m seasonlong treatment was significantly reduced ($P<0.05$) and was 73% less than that on the nongrazed treatment. Rhizosphere volume on the 4.5-m seasonlong treatment remained about the same during the growing season except for a substantial decrease during July. The volume at the end of the season was the same as the volume at the beginning. The antagonistic effects on rhizosphere organism activity from the 4.5-m seasonlong treatment caused a 35.2% decrease in rhizosphere volume, but not significant ($P<0.05$) from that on the nongrazed treatment. Rhizosphere volume on the twice-over rotation treatment increased slowly during the early growing season and then, following the first grazing period that occurred when grass tillers were between the three and a half new leaf stage and the flower stage from early June to mid July, the volume increased rapidly and more than doubled in size. At the end of the growing season, the volume on the twice-over rotation treatment was 105% greater than the volume at the beginning. The twice-over rotation treatment greatly stimulated the activity of the rhizosphere organisms. The rhizosphere volume on the twice-over rotation treatment significantly increased ($P<0.05$) and was 900.6%, 265.3%, and 170.1% greater than the rhizosphere volumes on the 6.0-m seasonlong, 4.5-m seasonlong, and nongrazed treatments, respectively.

The first grazing period on the third pasture in the twice-over rotation sequence was for 15 days during early July. The rhizosphere volume increased 20.3% during the two weeks following the first grazing period and increased 85.7% during the next five weeks (figure 5). The rhizosphere volume increased 123.4% in size because of the enhanced rhizosphere organism activity that resulted from the beneficial effects of partial defoliation during the first grazing period on the twice-over rotation treatment.

Discussion

In grassland ecosystems, the conversion of plant usable mineral nitrogen from soil organic nitrogen requires active rhizosphere organisms. Rhizosphere organisms require short chain carbon exudates from roots of grass plants. Rhizosphere organisms trade nitrogen to grass plants for carbon, and grass plants trade carbon to soil microorganisms for nitrogen. This interdependent symbiotic relationship between grass plants and rhizosphere organisms is controlled by partial defoliation of aboveground plant parts. The effects of defoliation can be beneficial or antagonistic depending on the degree of foliage removal and phenological growth stage of the grass tillers. Knowledge of grass developmental morphology and physiological processes that help grass tillers withstand and recover from defoliation is necessary to comprehend the biological requirements of grasses and the effects from defoliation management practices.

Grazing Defoliation

Grass plants have developed defoliation resistance mechanisms in response to grazing during the period of coevolution with herbivores (McNaughton 1979, 1983; Coleman et al. 1983; Briske and Richards 1995; Manske 1999) that help grass tillers withstand and recover from partial defoliation by grazing.

Traditional grazing management practices are not beneficial for grassland ecosystems. The deferred grazing, 6.0-m seasonlong, and 4.5-m seasonlong management strategies are antagonistic to rhizosphere organism activity and biogeochemical processes of the nitrogen cycle and these traditional grazing practices do not stimulate beneficial grass growth processes. The rhizosphere organism biomass and activity and the quantity of available mineral nitrogen decrease by small amounts annually along with proportional decreases in grass density and herbage biomass production. After two, three, or more decades of management of grassland ecosystems with traditional grazing practices, the losses in productivity are substantial. The deferred grazing strategy caused a 70.6% decrease in available mineral nitrogen after 35 years of treatment. The 6.0-m seasonlong grazing strategy caused a 41.9% decrease in mineral nitrogen and a 51.2% decrease in rhizosphere volume after 20 years of seasonlong treatment. The 4.5-m seasonlong grazing strategy caused a 27.7% decrease in mineral nitrogen after 6 years of treatment and caused a 33.7% decrease in rhizosphere volume after 20 years of treatment.

The twice-over rotation grazing management strategy is beneficial for grassland ecosystems. The advantageous effects from partial defoliation managed with a twice-over rotation grazing strategy caused a 67.7% increase in available mineral nitrogen after six years of treatment and caused a 122.7% increase in rhizosphere volume after 20 years of treatment.

Burning Defoliation

Prescribed burning of grasslands severely removes all or nearly all of the aboveground plant material. Complete defoliation by fire of grass tillers does not activate the defoliation resistance mechanisms that help grass tillers withstand and recover from partial defoliation. Replacement of fire removed plant material must develop from crown buds and stored root carbohydrate reserves. Growth of roots and shoots that depends on stored carbohydrates occurs at greatly reduced rates (Coyne et al. 1995) compared to replacement growth after partial defoliation by grazing that triggers the compensatory physiological processes, stimulates vegetative reproduction by tillering, and stimulates rhizosphere organism activity with the resulting increase in available mineral nitrogen (Manske 1999).

The quantity of mineral nitrogen on the prescribed burning treatments and no burns treatment was not different, and was less than 30% of the quantity of mineral nitrogen on the nongrazed treatment, indicating that the previous management practices on the burning and no burns treatments were antagonistic to the rhizosphere organisms and the nitrogen cycle biogeochemical processes, and that none of the prescribed burning treatments stimulated activity of the rhizosphere organisms. The nongrazed treatment had more than 37 years with no defoliation events and had 106 pounds per acre-foot of available mineral nitrogen. The burning and no burns treatments had no grazing defoliation events during the period from 1975 to 1990, however, the entire area, except for about 15% of the land, was managed with periodic deferred-type seasonlong grazing from July through November in combination with full growing season rest for 35 years, between 1940 and 1975. As a result, the burning and no burns treatments had only around 31 pounds per acre-foot of available mineral nitrogen.

The intended purpose for deferment of grazing on a wildlife refuge was the avoidance of disturbance from grazing livestock of ground nesting birds from nest initiation through egg hatch. The intended biological purpose of deferred grazing was to increase grass density by promoting seedling development from increased seed stalk quantities and to use trampling by livestock to scatter and plant the resulting seeds. However, grassland ecosystem processes do not function in accordance with these proposed deferred grazing hypotheses.

The combination of periodic deferred-type seasonlong grazing and full growing season rest used to manage the Lostwood Wildlife Refuge between 1940 and 1975 caused the mixed grass prairie ecosystem to degrade and permitted the increase of western snowberry. This deterioration did not occur at a uniform rate. In the mid to late 1930's, only about 5% of the land area was occupied with western snowberry. The shrub composition in the plant community did not change much during the next 20 years. A substantial increase in shrub cover occurred between 1953 and 1969, and the western snowberry colonies expanded rapidly and infested extensive areas of degraded grassland between 1969 and 1975; as a result, over 50% of the upland was transformed into a shrubland of western snowberry and associated Kentucky bluegrass by 1979 (Smith 1988).

A prescribed repeated every-other-year burning regime designed with the intent to reduce the invading western snowberry and exotic grasses and to renovate the mixed grass prairie plant community (Smith 1985) was conducted for 13 years between 1978 and 1990. Nevertheless, the nitrogen cycle biogeochemical processes of the degraded grassland were not restored and the available mineral nitrogen was not increased by any of the prescibed burning treatments and, consequently, the quantity of aboveground biomass production on the burning treatments remained low and was not different from that produced on the no burns treatment (Manske 2007b). However, the percent composition of the aboveground biomass did change as a result of the prescribed burn treatments. The composition of introduced grasses, early succession and weedy forbs, and shrubs decreased with the increasing number of repeated prescribed burning treatments. Native grasses, sedges, and perennial forbs benefitted from the reduction in competition for sunlight from the decreased canopy cover of the taller shrubs (Manske 2007b).

Repeated prescribed burning does reduce undesirable opportunistic grasses, forbs, and shrubs. However, prescribed burning does not stimulate vegetative reproduction by tillering, prescribed burning does not stimulate endomycorrhizal fungal colonization of grass roots, prescribed burning does not stimulate rhizosphere organism biomass and activity, and prescribed burning does not stimulate conversion of soil organic nitrogen into mineral nitrogen (Manske 2007b).

Degraded grassland ecosystems are not restored by prescribed burning practices because restoration of native plant composition and biomass production takes place after the improvement of rhizosphere organism activity and the increase of available mineral nitrogen. Prescribed burning does not enhance the nitrogen cycle biogeochemical processes in grassland ecosystems.

Conclusion

Productivity on grassland ecosystems depends on the level of rhizosphere organism activity, on the quantity of available mineral nitrogen converted from soil organic nitrogen, and on the effectiveness of beneficial physiological processes within grass tillers.

Traditional grazing practices of deferred grazing, 6.0-m seasonlong, and 4.5-m seasonlong management are antagonistic to grass tiller biological requirements, and to rhizosphere organism biomass and activity. Over numerous growing seasons, the antagonistic effects from traditional grazing management result in greatly reduced biogeochemical processes of the nitrogen cycle and substantially decreased quantities of available mineral nitrogen that cause degradation of ecosystem plant communities and reduction of herbage biomass production. Nondefoliation management is antagonistic to grass tiller biological requirements and to rhizosphere organism biomass and activity causing slow degradation of the grassland ecosystem. The degree of ecosystem deterioration caused by the antagonistic effects from long-term nondefoliation treatments is greater than that from long-term traditional grazing management.

Fire has been an environmental factor on grassland ecosystems historically. Repeated prescribed burning reduces the undesirable opportunistic plants of introduced grasses, early succession and weedy forbs, and shrubs that increase in composition on degraded grassland ecosystems. However, prescribed burning that completely defoliates the plant material on grassland ecosystems does not stimulate beneficial physiological processes, does not stimulate rhizosphere organism biomass and activity, and does not stimulate conversion of mineral nitrogen from soil organic nitrogen. Consequently, the poor native plant species composition and the low herbage biomass production on degraded grassland ecosystems is not improved by burning. Repeated prescribed burning treatments do not restore degraded grassland ecosystems.

Partial defoliation controlled with the twice-over rotation grazing management strategy that removes 25% to 33% of the leaf material from grass tillers at phenological growth between the three and a half new leaf stage and the flower (anthesis) stage (early June to mid July); stimulates compensatory physiological processes resulting in greater replacement leaf, shoot, and root growth; stimulates vegetative reproduction by tillering resulting in greater grass tiller density and herbage biomass production; and stimulates rhizosphere organism biomass and activity resulting in quantities of available mineral nitrogen greater than 100 pounds per acre. Restoration of degraded grassland ecosystems and maintenance of healthy functioning grassland ecosystems requires annual partial defoliation by grazing that meets the biological requirements of grass tillers, that enhances rhizosphere organism activity, and that increases the quantity of available mineral nitrogen.

Grassland ecosystems have been customarily managed from the perspective of the “use”, e.g. for wildlife habitat or for livestock forage. The designated use receives priority consideration when management decisions are made. These management practices that focus on the use of a grassland ecosystem are antagonistic to the plants and to the rhizosphere organisms and cause reductions in grassland ecosystem productivity.

Management of partial defoliation by grazing that focuses on meeting the biological requirements of the plants and of the rhizosphere organisms is beneficial, and enhances the health and productivity of grassland ecosystems. Placing the decision priorities with the living components of the ecosystem is biologically effective, and results in greater forage for livestock, better habitat for wildlife, and more aesthetic open spaces for recreation and sightseeing as sustainable products from biologically managed grassland ecosystems.

Acknowledgment

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

Table 1. Mineral nitrogen (lbs/acre-foot) for grazing treatments and repeated every-other-year burning treatments and rhizosphere volume (ft^3/acre-foot) for grazing treatments.

	Mineral (inorganic) Nitrogen lbs/acre-foot	Rhizosphere Volume ft^3/acre-foot
Grazing Treatments		
Nongrazed (NG)	106.05 b	101.93 y
6.0-m Seasonlong (6.0-m SL)	61.61 c	49.75 z
4.5-m Seasonlong (4.5-m SL)	76.70 c	67.61 yz
Twice-over Rotation (TOR)	177.84 a	227.06 x
Burning Treatments		
No Burns	31.20 d	
One Burn	31.49 d	
Two Burns	30.71 d	
Three Burns	18.08 d	
Four Burns	27.28 d	
Early Spring Burns	11.88	
Spring Burns	27.64 d	
Early Summer Burns	30.74 d	
Mid Summer Burns	23.14 d	

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

Table 2. Mineral nitrogen (lbs/acre-foot) for the three pastures of the twice-over rotation treatment.

	Mineral (inorganic) Nitrogen lbs/acre-foot
Twice-over Rotation (TOR)	
First pasture grazed	199.05 a
Second pasture grazed	163.97 a
Third pasture grazed	170.50 a
Three pasture mean	177.84 a

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

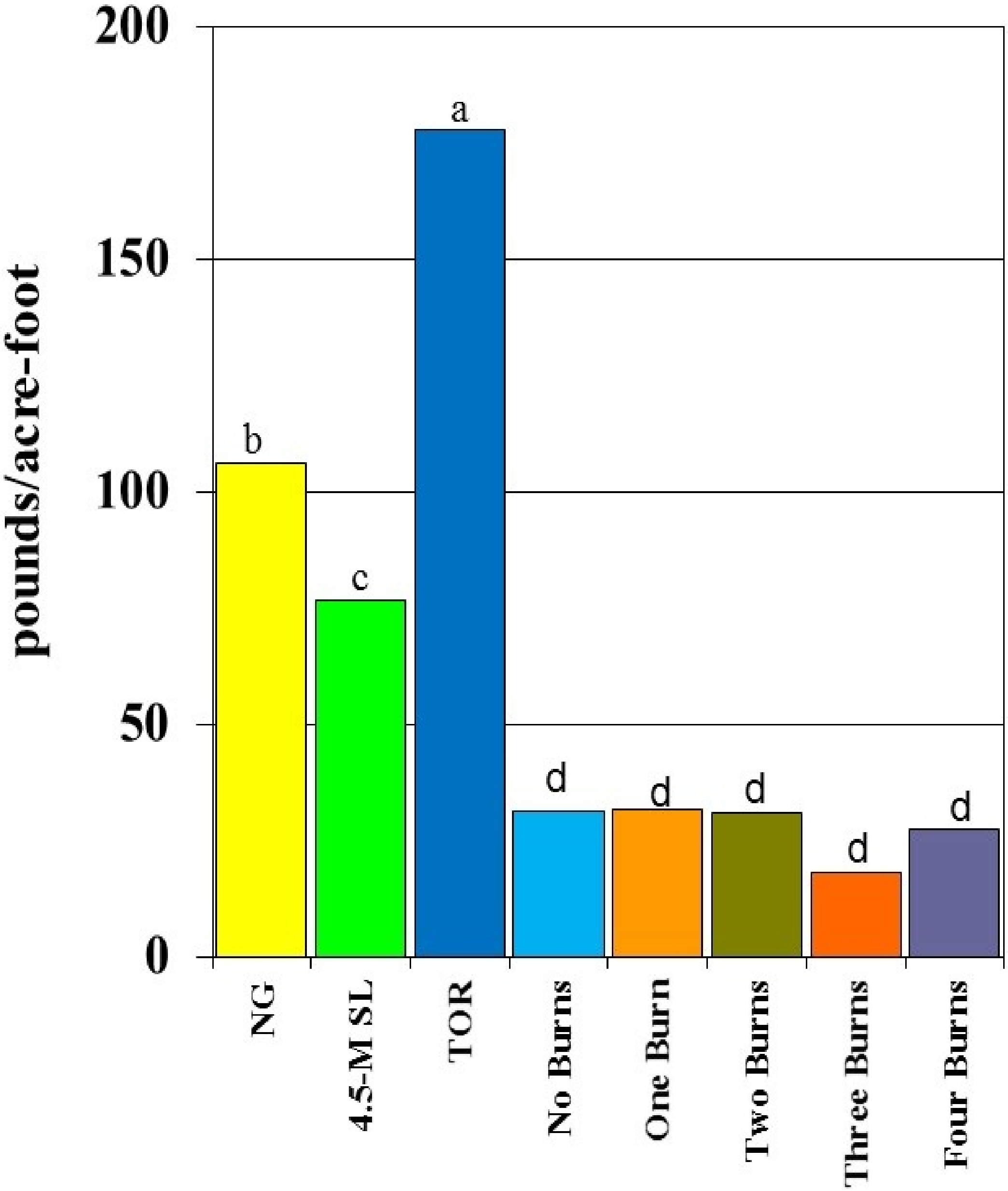

Figure 1. Mineral nitrogen in pounds per acre-foot for grazing treatments and every-other-year burn treatments.

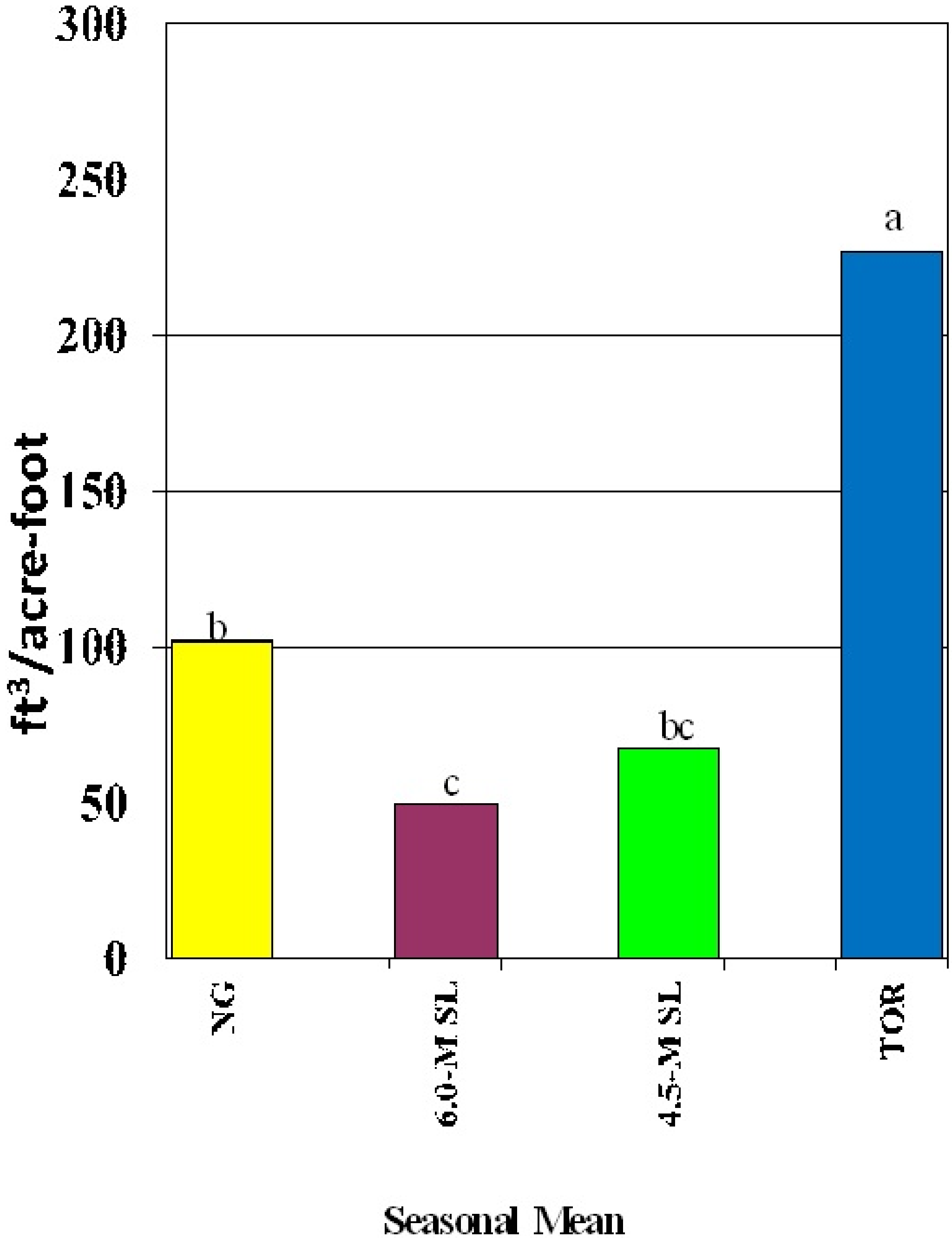

Figure 2. Seasonal mean rhizosphere volume in cubic feet per acre-foot for grazing treatments.

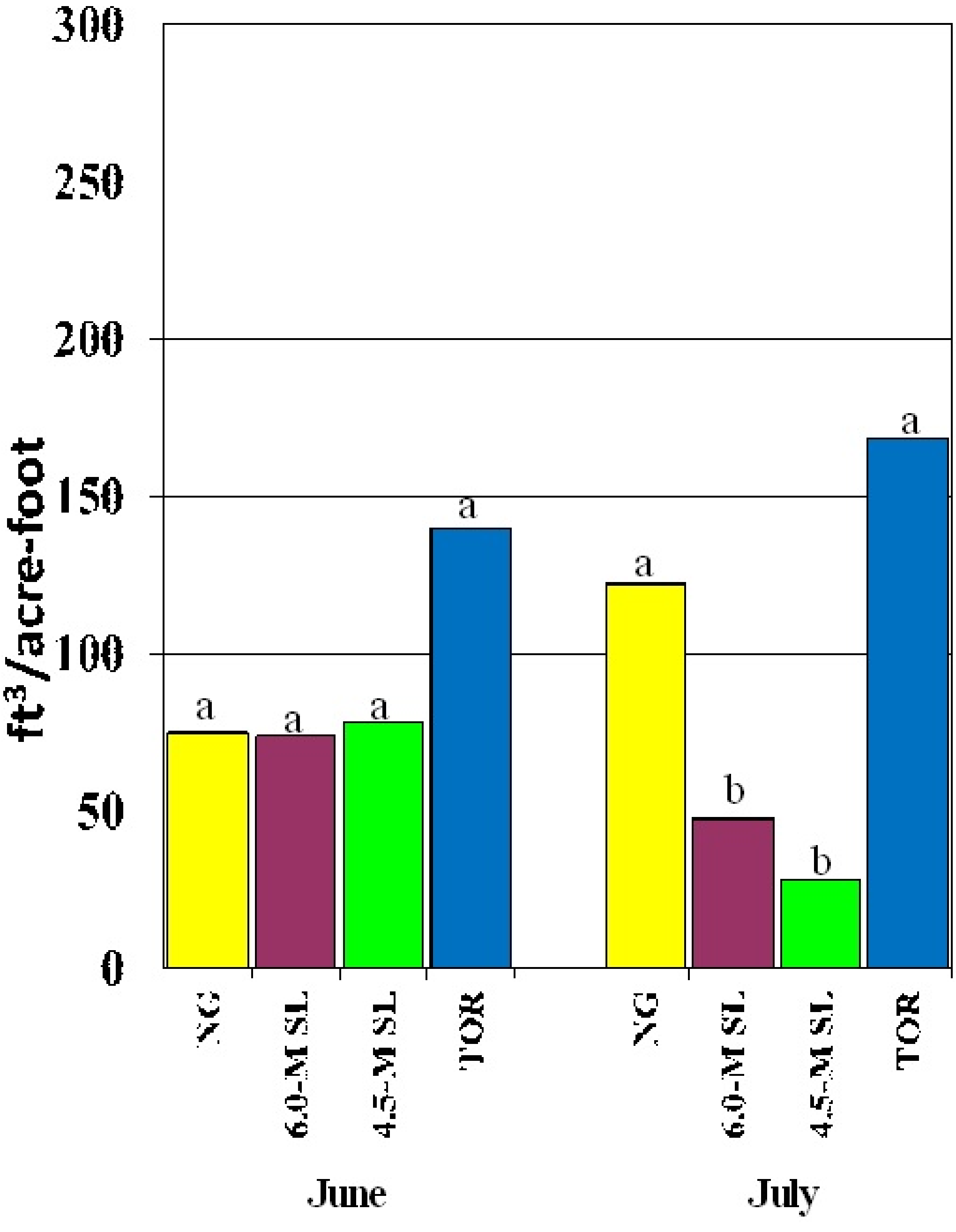

Figure 3. Monthly rhizosphere volume in cubic feet per acre-foot during June and July for grazing treatments.

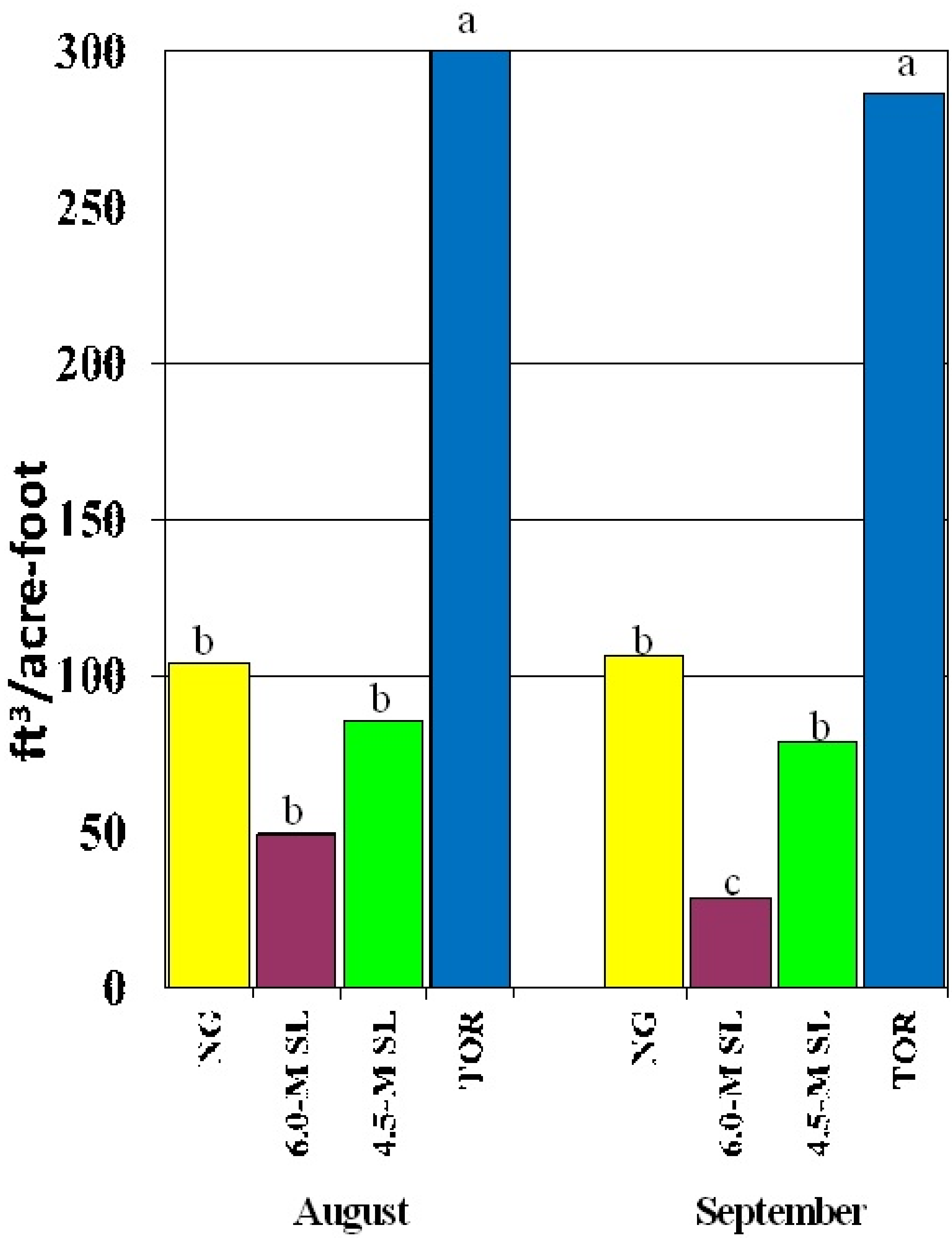

Figure 4. Monthly rhizosphere volume in cubic feet per acre-foot during August and September for grazing treatments.

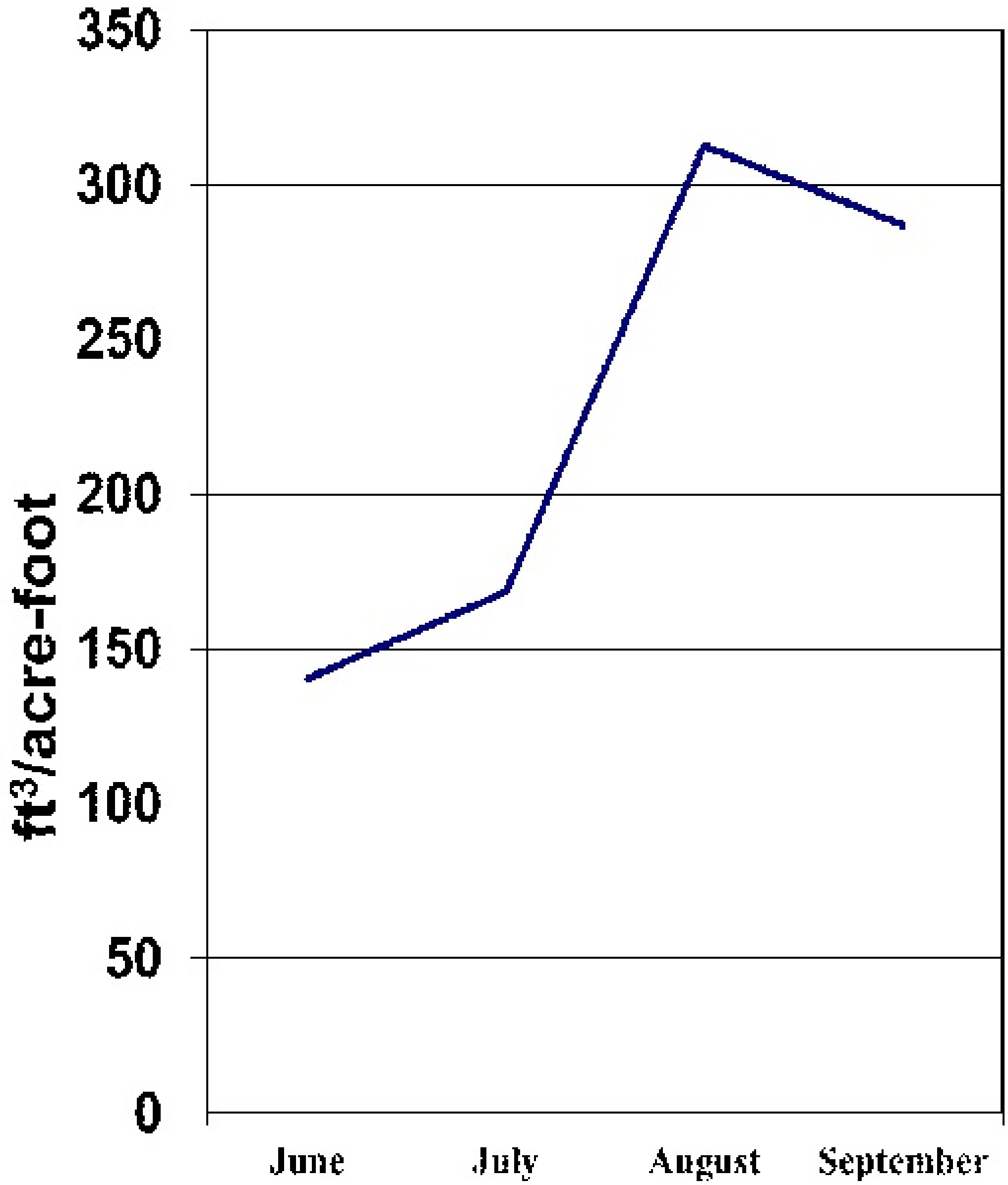

Figure 5. Rhizosphere volume change on the twice-over rotation treatment third pasture that was grazed for 15 days during early July.

Literature Cited

Barker, W.T., and W.C. Whitman. 1988. Vegetation of the Northern Great Plains. Rangelands 10:266-272.

Briske, D.D., and J.H. Richards. 1995. Plant response to defoliation: a physiological, morphological, and demographic evaluation. p. 635-710. *in* D.J. Bedunah and R.E. Sosebee (eds.). Wildland plants: physiological ecology and developmental morphology. Society for Range Management, Denver, CO.

Coleman, D.C., C.P.P. Reid, and C.V. Cole. 1983. Biological strategies of nutrient cycling in soil ecosystems. Advances in Ecological Research 13:1-55.

Coyne, P.I., M.J. Trlica, and C.E. Owensby. 1995. Carbon and nitrogen dynamics in range plants. p. 59-167. *in* D.J. Bedunah and R.E. Sosebee (eds.). Wildland plants: physiological ecology and developmental morphology. Society for Range Management, Denver, CO.

Gorder, M.M., L.L. Manske, and T.L. Stroh. 2004. Grazing treatment effects on vegetative tillering and soil rhizospheres of western wheatgrass. NDSU Dickinson Research Extension Center. Range Research Report DREC 04-1056. Dickinson, ND. 13p.

Keeney, D.R. 1982. Nitrogen - availability indices. p. 711-733. *in* R.H. Miller and D.R. Keeney (eds.). Methods of soil analysis. 2nd ed. American Society of Agronomy, Madison, WI.

Keeney, D.R., and D.W. Nelson. 1982. Nitrogen - inorganic forms. p. 643-698. *in* R.H. Miller and D.R. Keeney (eds.). Methods of soil analysis. 2nd ed. American Society of Agronomy, Madison, WI.

Manske, L.L. 1999. Can native prairie be sustained under livestock grazing? p. 99-108. *in* J. Thorpe, T.A. Steeves, and M. Gollop (eds.). Proceedings of the Fifth Prairie Conservation and Endangered Species Conference. Provincial Museum of Alberta. Natural History Occasional Paper No. 24. Edmonton, Alberta, Canada.

Manske, L.L. 2007a. Ombrothermic interpretation of range plant water deficiency from temperature and precipitation data collected at the Ranch Headquarters of the Dickinson Research Extension Center in western North Dakota, 1982-2006. NDSU Dickinson Research Extension Center. Range Research Report DREC 07-1019j. Dickinson, ND. 17p.

Manske, L.L. 2007b. Effects on vegetation, endomycorrhizal fungi, and soil mineral nitrogen from prescribed burning treatments repeated every-other-year in mixed grass prairie invaded by western snowberry. NDSU Dickinson Research Extension Center. Summary Range Research Report DREC 07-3044. Dickinson, ND. 19p.

McNaughton, S.J. 1979. Grazing as an optimization process: grass-ungulate relationships in the Serengeti. American Naturalist 113:691-703.

McNaughton, S.J. 1983. Compensatory plant growth as a response to herbivory. Oikos 40:329-336.

Mosteller, F., and R.E.K. Rourke. 1973. Sturdy Statistics. Addison-Wesley Publishing Co., MA. 395p.

Smith, K.A. 1985. Prescribed burning reduces height and canopy cover of western snowberry (North Dakota). Restoration and Management Notes 3:86-87.

Smith, K.A. 1988. Lostwood National Wildlife Refuge station plan. US Fish and Wildlife Service.

Smith, K.A. 1997. Lostwood National Wildlife Refuge comprehensive management plan. US Fish and Wildlife Service.

Tilman, D. 1990. Constraints and tradeoffs: toward a predictive theory of competition and succession. Oikos 58:3-15.