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ABSTRACT -- We evaluated the effects of long-term (1988 to 2000) grazing on northern mixed-grass prairie at the Central Grasslands Research Extension Center in south-central North Dakota. We did not detect a difference in herbaceous basal cover between grazing intensities following 12 consecutive years of season-long moderate (50% removal of annual above-ground standing crop) and heavy (80% removal of annual above-ground standing crop) grazing. However, both moderate and heavy grazing intensities reduced above-ground herbaceous standing crop, total root biomass, and soil organic carbon. Moderate grazing intensity maintained a greater amount of deep (10 to 20 cm) and total root biomass relative to heavy grazing intensity. Several of our findings were in contrast to earlier studies on the same grazing intensity trials, highlighting the importance of considering both short- and long-term effects of grazing intensity on mixed-grass prairie.

Key words: grasslands, grazing, root biomass, soil organic matter.

Historically, the prairies of the Northern Great Plains were shaped by the grazing of massive herds of bison (*Bos bison*) and numerous other herbivores as related in journals of Lewis and Clark (DeVoto 1953) and passing trappers, traders, explorers, and military expeditions (Burpee 1910, Bray and Bray 1976, Gough 1988, Abel 1997). The historical impact of these native, free-ranging herbivores on plants and plant communities of the western United States is debated (Belsky 1986, McNaughton 1993, Paintner and Belsky 1993, Biondini et al. 1998). A common,

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present day use of prairie grasslands is grazing of domestic livestock in ranching operations. Despite numerous quantitative reports concerning the effects of domesticated livestock grazing on plants and plant communities of the Northern Great Plains, most studies have been short-term or lacking in the grazing management details needed to make meaningful comparisons among studies (Black and Clark 1942, Hubbard 1951, Smoliak 1960, Currie 1978, Galt and Kramer 1978, Olson et al. 1985, Kirby et al. 1986, Hart et al. 1988, Biondini and Manske 1996).

In 1988, a long-term grazing intensity trial was initiated at the Central Grasslands Research Extension Center (CGREC) in south-central North Dakota. The trial was initiated to evaluate the effects of grazing intensity on mixed-grass prairie in the Northern Great Plains. In a preliminary assessment of grazing intensity impacts from 1989 to 1990, Shariff et al. (1994a, b) reported that plant communities subjected to moderate intensity grazing had greater net above-ground primary productivity and growing season root productivity than similar plant communities rested or subjected to heavy grazing intensity. They also reported that below-ground root biomass was inconsistent among grazing treatments and years, and recommended that this grazing intensity trial be continued and their study be revisited in 10 years. In a summary of the first seven years of the trial (1988 to 1995), Biondini et al. (1998) concluded that climatic variations control major trends in plant species composition with grazing intensity playing a secondary role. They also found that a heavy grazing intensity resulted in reduced peak root biomass and stated that moderate grazing intensity appeared to sustain range condition of northern mixed-grass prairie. In our study, we examined the responses of basal cover and peak standing crop of herbaceous plant species, root biomass, and soil organic carbon to long-term (12 year) exposure to moderate and heavy grazing intensities.

STUDY AREA

We conducted our study during the 2000 growing season at the CGREC located approximately 12 km northwest of Streeter in south-central North Dakota. The CGREC lies within the physiographic boundaries of the Missouri Coteau. The Missouri Coteau, extending approximately 1300 km northwestward from east-central South Dakota, through North Dakota, and into Saskatchewan (Clayton and Freers 1967), is of glacial origin. It is characterized by irregular, rolling, rocky plains. The topography of the area is largely the result of the collapse of supra-glacial sediment. Local relief ranges from 30 to 100 m (Bluemle 1977). Soils of the CGREC are predominately mollisols of the Williams series (fine-loamy, mixed Typic Argiboroll).

The majority of precipitation at the CGREC falls as rain during the growing season (April through September). The 48-year (1951 to 1998) precipitation average for the CGREC was 45.8 cm. Precipitation received October 1998 to September 1999 and from October 1999 to September 2000 at the CGREC was 69.4 cm and 39.8 cm, respectively. January is the coldest month, with an average temperature of -13°C, and July the warmest month, with an average temperature of 21°C (Jensen 1972).

The plant communities of sites sampled in our study were dominated by Kentucky bluegrass (*Poa pratensis* L.), needle-and-thread (*Hesperostipa comata* Trin. & Rupr.), blue grama (*Bouteloua gracilis* [H.B.K.], Lag. Ex Griffiths), western wheatgrass (*Agropyron smithii* Rydb.), and sun sedge (*Carex heliophila* Mack.). Common forbs included goldenrods (*Solidago* spp.), white sage (*Artemisia ludoviciana* Nutt.), fringed sage (*A. frigida* Willd.), and yarrow (*Achillea millefolium* L.). Western snowberry (*Symphoricarpos occidentalis* Hook.) and prairie wild rose (*Rosa arkansana* Porter) were the common woody plants.

The long-term grazing intensity trial, which provided the experimental treatments used in our study, began in 1988 on mixed-grass prairie (Section 14, T138N, R70W) that had received little to no livestock grazing since 1979. Two season-long grazing intensity treatments (moderate and heavy) and a control that received no grazing were replicated three times (13.2 ha each) in a completely randomized design. Moderate and heavy intensity grazing treatments were defined by the annual above-ground biomass remaining at termination of grazing periods, which averaged 50% and 20%, respectively. Stocking rate for the moderate and heavy intensity grazing treatments averaged 0.4 and 1.1 animal unit months/ha, respectively. Between 1988 and 2000, the moderate and heavy intensity grazing treatments were grazed between 86 and 181 days each year from mid-May through October.

METHODS

We estimated above-ground biomass at peak standing crop (mid-July to August) by clipping ten randomly located 0.25-m^2 quadrats per replication. Quadrats were protected from grazing by five 2 x 5-m portable exclosures per replication installed before cattle (*Bos taurus*) were allowed to graze an area. At peak standing crop, we clipped all above-ground standing biomass in quadrats and separated it by grasses, forbs, and shrubs. We oven-dried all clipped vegetation samples at 60°C for 48 to 72 hr to obtain a constant weight.

We estimated plant basal cover by using a 10-pin point frame along two parallel 10-m transects in each replicate (Mueller-Dombois and Ellenberg 1974). We randomly located 50 frames along alternate sides of each transect. We recorded percentage basal cover of grasses, forbs, litter, and bare ground. Non-grazed controls were not sampled for plant basal cover because of the small amount of undisturbed area following 12 years of continuous herbaceous biomass sampling.

Within each grazing unit, we used a 10.5-cm diameter hand-augur to collect cores for estimating root biomass and soil organic carbon. In the first half of August 2000, we collected twenty randomly located cores per replicate to a depth of 20 cm. We separated each core into 0 to 10-cm and 10 to 20-cm segments. We soaked 10 core samples per replicate in containers of water for 15 to 30 min and then washed each sample by hand. We then poured all sample-containing water through a 2-mm screen to segregate root material (Bartos and Sims 1974). We oven dried root material for 12 hours at 65°C and then weighed it. We then ashed the root material for 8 hours at 460°C and reweighed it. We expressed root biomass on an ash-free basis converted to grams per m^2 for both the 0 to 10-cm and 10 to 20-cm depths. We used the remaining 10 soil cores per grazing replicate to estimate soil organic carbon among treatments. We dried the soil samples at 60°C to a constant weight and ground them to pass through a 2-mm screen. We estimated soil organic carbon by using loss on ignition.

Within each grazing unit, we randomly collected two additional 10.5-cm diameter soil cores at the 0 to 10-cm and 10 to 20-cm depth for estimating soil bulk density. We weighed each core wet in the field and then oven dried them at 105°C and reweighed them. We calculated mean soil bulk density by depth increment as outlined by the USDA, NRCS (1996). Using the mean bulk density of 0.81 g/m^3 for the 0 to 10-cm depth and 1.03 g/m^3 for the 10 to 20-cm depth, we converted soil organic carbon concentration for each site and each depth increment to a mass basis (kg/m^2).

Above-ground herbaceous standing crop, total herbaceous basal cover, root biomass, and soil organic carbon were tested by using a one-way ANOVA. We used Tukey's HSD test for pairwise comparisons among groups (Sokal and Rohlf 1981). Means were considered different at $P<0.05$.

RESULTS

Graminoid ($F_{2,6} = 5.74$, $P = 0.01$) and total ($F_{2,6} = 54.70$, $P = 0.001$) herbaceous above-ground biomass varied by grazing treatment. Graminoid and total above-ground herbaceous biomass were greater ($P \leq 0.05$) under both no and moderate grazing intensities compared to the heavy intensity, and the non-grazed treatment had greater ($P \leq 0.05$) graminoid and total above-ground herbaceous biomass than the moderately grazed treatment (Fig. 1). Graminoids accounted for 70% of the total above-ground biomass across all grazing intensity treatments.

We did not detect a difference in herbaceous basal cover among grazing intensity treatments ($F_{1,4} = 0.17$, $P = 0.83$) (Table 1). Kentucky bluegrass was the dominant species contributing 30 to 50% of the total basal cover. While we failed to detect a difference in total basal cover, short statured herbaceous plants (i.e.,

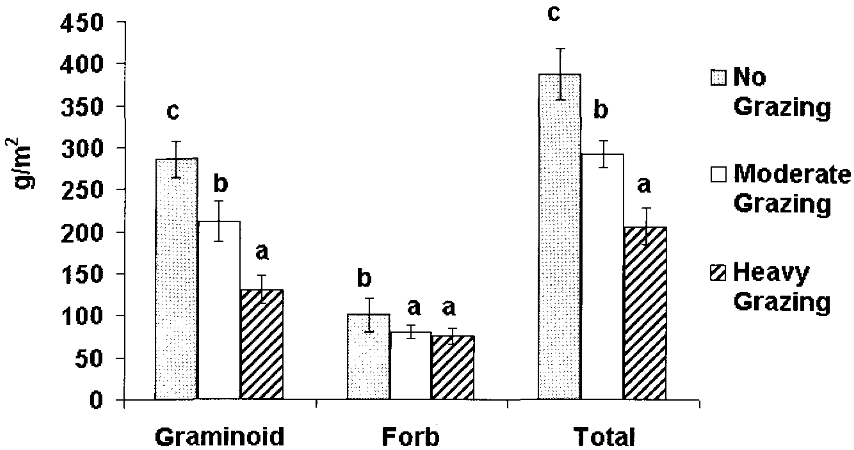

Figure 1. Peak herbaceous standing crop and one SE on three grazing intensity treatments in 2000. Different letters within a group denote differences at $P \leq 0.05$.

blue grama, Wilcox's dichanthelium [*Dichanthelium wilcoxianum* (Vasey) Freckmann] and sedges) contributed over 35% of the total basal cover in the heavy intensity treatments compared to less than 20% in the moderate treatment.

Root biomass varied by treatment in both the top 10-cm ($F_{2,6} = 5.17$, P = .0.01) and 10 to 20-cm ($F_{2,6} = 13.40$, P = .0.001) depth of the soil profile. In the top 10 cm, root biomass was greater ($P \leq 0.05$) in the no grazing treatment compared to the moderately and heavily grazed treatments (Fig. 2). At the 10 to 20-cm soil depth, root biomass was similar under no grazing and moderate grazing intensity treatments with both having greater root biomass ($P \geq 0.05$) than the heavy grazing intensity (Fig. 2).

Soil organic matter in the top 10 cm of the soil profile also varied by treatment ($F_{2,6} = 20.60$, $P = 0.001$). Soil organic matter was greater ($P \leq 0.05$) in the top 10 cm of the non-grazed treatment compared to the moderate and heavy grazing intensities (Fig. 3). There was no difference in organic matter in the top 10 cm of the soil profile between the moderate and heavy season-long grazing intensities. Additionally, we did not detect a difference in soil organic matter among grazing intensities at the 10 to 20-cm depth ($F_{2,6} = 0.24$, $P = 0.79$).

Table 1. Percent plant basal cover and one SE on two season-long grazing intensity trials in 2000.

		Grazing treatment	
Scientific name	Common name	Moderate (N = 3)	Heavy (N = 3)
Agropyron smithii	Western wheatgrass	1.5	1.3
Bromus inermis	Smooth brome	0.1	1.1
Bouteloua gracilis	Blue grama	1.3	1.2
Carex spp.	Sedges	0.4	2.8
Dichanthelium wilcoxianum	Wilcox's dichanthelium	0.6	1.5
Koeleria pyramidata	Prairie junegrass	0.1	0.6
Poa pratensis	Kentucky bluegrass	5.9	4.5
Hesperostipa comata	Needle-and-thread	0.1	0.3
Nassella viridula	Green needlegrass	0.4	0.2
Forbs		1.6	1.7
Total[1]		12.0 ± 1.7	15.0 ± 1.3
Litter		86.6	80.6
Bare		1.5	4.5

[1]No difference ($P \geq 0.05$) in total basal cover was found between grazing intensity treatments.

DISCUSSION

In the early 1990's, Biondini et al. (1998) reported no difference in herbaceous basal cover on the same grazing intensity treatments. They also observed Kentucky bluegrass to be the dominant species. Both observations were consistent with those of our study. Biondini et al. (1998) concluded that herbaceous basal cover on semi-arid, mixed grass prairie was correleted more strongly to precipitation than grazing intensity. After 12 years of continuous grazing in our trial, it continued to appear that herbaceous basal cover was relatively independent of grazing intensity in the Kentucky bluegrass-dominated mixed-grass prairie we sampled.

We found graminoid and total above-ground herbaceous biomass to be greatest in the non-grazed treatment. These results did not agree with the

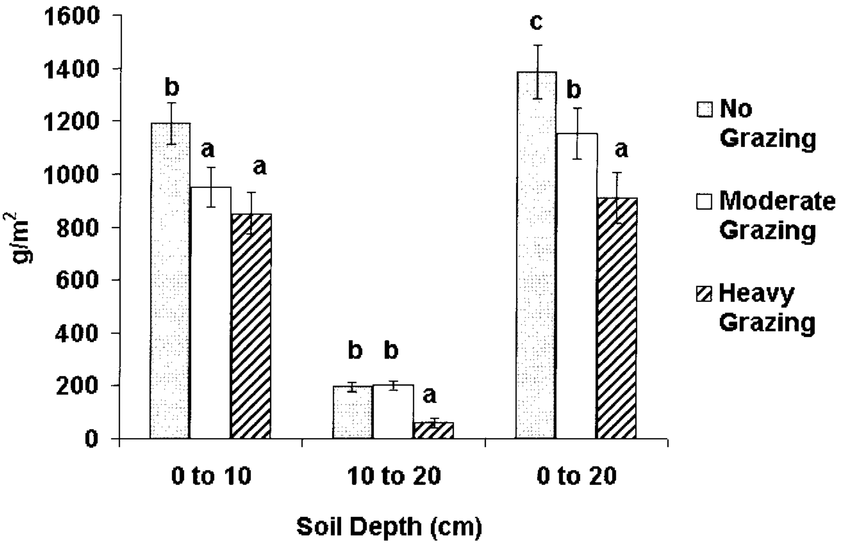

Figure 2. Ash-free root biomass and one SE on three grazing intensity treatments in 2000. Different letters within a depth denote differences at $P \leq 0.05$.

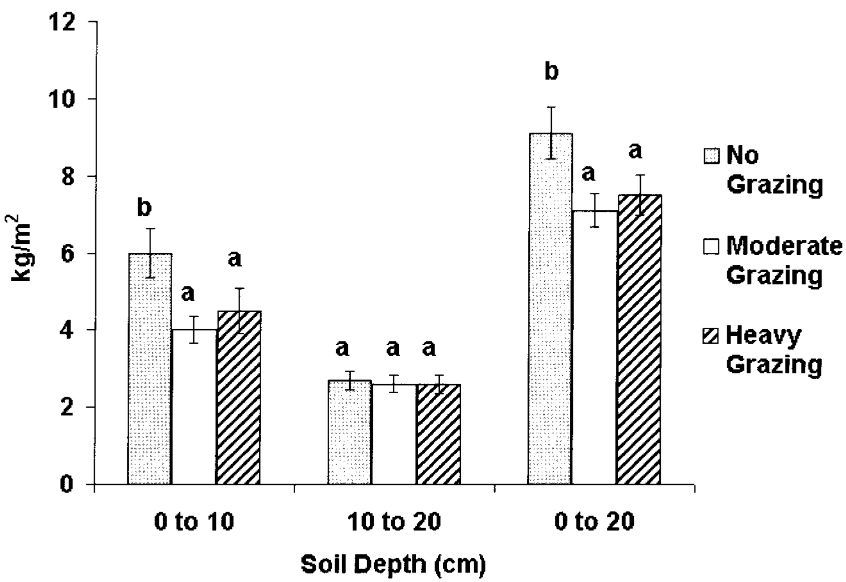

Figure 3. Soil organic carbon and one SE on three grazing intensity treatments in 2000. Different letters within a depth denote differences at $P \leq 0.05$.

preliminary study of these treatments (Shariff et al. 1994a) that concluded moderate grazing resulted in greater above-ground biomass, which supported the Grazing Optimization hypothesis (Dyer et al. 1993, McNaughton 1993, Noy-Meir 1993). On the same grazing intensity trial between 1989 and 1995, Biondini et al. (1998) reported differences between grazing intensities only in 1992 when the non-grazed treatment had the greatest above-ground herbaceous biomass, and 1994 when the moderate grazing intensity treatment had the greatest above-ground herbaceous biomass. Biondini et al. (1998) and ours did not support the hypothesis that above-ground productivity was maximized at a moderate grazing intensity. However, long-term yield data collected on these and additional grazing intensity trials generally supported the hypothesis although there appeared to be a year and treatment interaction (B. D. Patton, unpublished data).

Root biomass in the top 10 cm of the soil profile was greatest in the non-grazed treatment of our study. Our results were in contrast with those reported by both Shariff et al. (1994a) and Biondini et al. (1998). Shariff et al. (1994a) observed in their 1989-1990 assessment that the moderate grazing intensity produced a greater amount of root biomass in the top 10 cm of soil compared to the no grazing or heavy intensity treatments. Biondini et al. (1998) in 1995 reported that no grazing and moderate grazing produced similar amounts of root biomass in the upper 10 cm of soil. The results of our study suggested that both long-term moderate and heavy season-long grazing by livestock reduced root biomass in the upper soil profile.

Root biomass for the 10 to 20-cm soil depth was similar on the non-grazed and moderately grazed treatments with both being greater than the heavily grazed treatment. These findings agreed with Lorenz and Rogler (1967), who studied grazing effects on mixed grass prairie near Mandan, North Dakota. They reported a greater percentage of root biomass below 15 cm on a moderately grazed pasture compared to a heavily grazed pasture. Despite similar root biomass at the 10 to 20-cm depth for the no grazing and moderate grazing intensity treatments, root biomass for the total soil profile sampled was highest in the no grazing treatment. The results of our study suggested that defoliation of plants through long-term season-long grazing reduced energy allocation to the roots, hence reducing root growth and altering root depth distribution.

In 1995, Biondini et al. (1998) reported no difference in soil organic matter in the top 10 cm of soil on the same grazing intensity treatments. Our results were not in agreement with Biondini et al. (1998), but do agree with Willms et al. (2002). They reported that, after 70 continuous years of grazing or grazing exclusion of mixed-grass prairie, grazing exclusion produced more soil carbon in the top 15 cm of soil compared to moderate grazing.

CONCLUSIONS

Our study revealed no difference in total herbaceous basal cover between grazing intensity treatments following 12 consecutive years of season-long grazing at the CGREC. Herbaceous basal cover appeared to be independent of grazing intensity on the northern mixed-grass prairie we studied. Above-ground herbaceous standing crop was higher under no grazing than under either moderate (50% removal) or heavy (80% removal) season-long grazing intensities. These results did not support the hypothesis that above-ground productivity was maximized at a moderate grazing intensity. Long-term grazing reduced total root biomass and soil organic carbon. However, moderate grazing intensity maintained a greater amount of deep and total root biomass relative to a heavy grazing intensity.

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