Vegetation response to time-controlled grazing on Mixed and Fescue Prairie

WALTER D. WILLMS, SYLVER SMOLIAK, AND JOHAN F. DORMAAR

Abstract

Improved carrying capacity of grasslands has been attributed to the effect of time-controlled grazing with high animal density, which can be achieved by increased stocking rates as well as by fencing. Therefore, a study was conducted to test the hypothesis that time-controlled grazing with high animal densities and high stocking rates will improve grassland condition. The study was made over a 6-year period on 3 sites with time-controlled grazing imposed. One site was on native grassland in the Fescue Prairie and 2 sites, 1 on seeded and the other on native grassland, were in the Mixed Prairie. On each site, stocking densities averaged 3, 6, and 15 cow-calf pairs/ha, respectively, and stocking rates averaged 1.65, 4.45, and 2.72 animal unit months/ha, respectively. Species composition and root mass and distribution were compared on grazed and protected areas within each site. Utilization averaged about 80% of available forage over the study period. Range condition was less on grazed areas than on protected areas in the Fescue Prairie (38 vs 53% of climax) and in the Mixed Prairie (49 vs 53%). Average ash-free root mass, throughout the sampling profile, tended to be greater on the ungrazed vs the grazed area of the native Mixed Prairie site but not on the seeded Mixed Prairie or Fescue Prairie sites. The grazed areas of the Mixed Prairie sites tended to have more available phosphorus, possibly due to the application of manure, but less nitrogen and organic matter. The results led to a rejection of the hypothesis and a conclusion that high animal density and high stocking rates with time-controlled grazing would result in range deterioration.

Key Words: botanical composition, regrowth, yield, root biomass, root distribution

Authors are range ecologist, retired range ecologist, and soil scientist, respectively, Agriculture Canada Research Station, Lethbridge, Alberta T1J 4B1. Contribution No. 3878886.

The authors wish to thank Mr. and Mrs. Blake Holtman for their cooperation in permitting access to their ranch and providing relevant data. The project could not have have succeeded without their help. Mr. R.G. Gschaid and Mr. B.W. Kesler assisted with the species and root sampling while various summer assistants harvested forage plots and performed other related duties. The study was funded in part by a grant from the Farming for the Future Council of Alberta Agriculture.

Manuscript accepted 8 March 1990.

Short-duration grazing received considerable attention over the last decade within the context of Holistic Resource Management (HRM) (Savory 1983). Although HRM is a model for decision-making, several important ecological principles are inherent that affect grazing management, and these are often applied through short-duration or time-controlled grazing that enables greater control of livestock. These principles relate to the effects of high animal densities with timed grazing and rest periods (Savory and Parsons 1980). Consequently, while the effects of high animal densities, including grazing, trampling, and distribution of feces, are beneficial, long-term protection from grazing is detrimental; and while the practice of HRM will result in a higher successional level with subsequent benefits accruing through improvements in the water, energy, and nutrient cycles, long-term protection will result in community degradation and possibly desertification. Therefore, to achieve the desired animal densities, applicants of HRM have been advised to increase stocking rates to at least double the conventional rates (Savory 1983).

However, conventional wisdom holds that the effects of high stocking rates are generally undesirable species composition changes, reduced productivity, and increased erosion. These effects are attributed to the loss of high-yielding forage species, loss of ground cover, and increased soil bulk density resulting in reduced infiltration (Pluhar et al. 1987). Excessive defoliation reduces plant vigor and retards root development (Johnston 1961). Consequently, severely grazed plants lose their competitiveness and are replaced by those that are avoided by livestock.

The detrimental effects expected from high stocking rates in conventional grazing systems conflict with those claimed when HRM is applied. Consequently, a study was conducted to test the hypothesis that high animal densities and high stocking rates, with timed grazing and rest periods, would result in a more desirable plant community than one which was protected from grazing. A desirable community was defined as one having a greater proportion of productive forage species present. Specific objectives were to measure the effect of 6 years of grazing treatment on species composition, root mass and distribution, and forage production within 3 plant communities.

Materials and Methods

Site Description

The study was made at 3 sites in Alberta, which were all parts of the Shipwheel Cattle Feeders, Ltd.: 2 near Taber and 1 in the foothills near Fort Macleod. The Taber sites were situated in the Mixed Prairie (MP) Association; 1 site (MPs) had been seeded to Russian wildrye (*Elymus junceus* Fisch.) and crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) in 1979 and the other consisted of native grassland (MPn) representative of the *Stipa-Bouteloua* type (Coupland 1950). The MPs site had been in a cereal-summerfallow rotation before 1979. The recommended stocking rates were 1.0 and 2.0 animal unit months (AUM)/ha for the MPn and MPs sites, respectively (Wroe et al. 1988). The soils are of the Orthic Brown Subgroup of the Chernozemic order (Aridic Ustochrept), developed on sandy alluvial parent material (Bowser et al. 1963). The climate is dry and subhumid with precipitation over a 30-year period averaging 382 mm, although actual precipitation from 1982 to 1986 was 364, 343, 317, 380, and 440 mm, respectively.

The Fort Macleod site was situated on the edge of the Porcupine Hills in SW Alberta at the interface of the Mixed Prairie and Fescue Prairie Associations found at low and high elevations, respectively. These grasslands have been described by Moss and Campbell (1947) and their response to grazing was reported by Looman (1969). The study areas selected at Fort Macleod appeared more representative of the Fescue Prairie than of Mixed Prairie Association and were defined as such (FP). About 70% of the grassland on the ranch was in fair to poor condition (Wroe 1984) in 1981 when the grazing system was applied. The recommended stocking rate was about 0.8 AUM/ha (Wroe et al. 1988).

The soil of the Fort Macleod site is a member of the Orthic Black Subgroup of the Chernozemic order (Udic Haploboroll) and developed on Laurentide till overlying sandstone. The Ah (=A1) horizon consisted of 46% sand and 27% clay. The climate is dry, subhumid, and while annual precipitation averages about 435 mm, it was 355, 381, 405, 474, and 456 mm from 1982 to 1986, respectively.

Treatments

At each site, paddocks were fenced to form a cell with a radial design that merged at a centrally located corral containing the single water source. At Taber, the MPn site (58 ha) was fenced into 16 paddocks and the MPs site (111 ha) was fenced into 12 paddocks. At Fort Macleod, the FP site (971 ha) was fenced into 17 paddocks. In 1982, 1 study area was selected in each of 2 paddocks (replicates) at both Taber sites and in each of 5 paddocks at the Fort Macleod site. Each study area was partitioned into 2 parts with 1 part randomly allocated for cattle exclusion (control), with a single permanent exclosure measuring 10×30 m, and the remaining part subject to the grazing treatment. The study areas were located sufficiently far removed from the cell center to avoid impeding animal movement. The MP sites, but not the exclosures, had received manure applications of about 9,070 kg/ha, from a nearby feedlot, biannually since 1981.

Each site was managed according to principles of HRM (Savory 1983) with particular emphasis on the timing of grazing and rest periods. Although the duration of grazing within each paddock varied according to its size, herd density, and growing conditions, annual stocking rates over the duration of the study period averaged 1.65, 4.45, and 2.72 AUM/ha on the FP, MPs, and MPn sites, respectively, while densities averaged 3, 6, and 15 cow-calf pairs/ha, respectively.

Cattle were put onto the range in early May and removed in late October. The calves were weaned in September. Cattle movement among paddocks was timed to prevent heavy use during periods of rapid growth and to allow recovery following grazing. As forages senesced, the grazing and rest periods became longer and the degree of utilization increased. Grazing periods at each site varied from 1 to 3 days in rotation 1 during the growing season and 4 to 7 days in rotations 2 and 3 during the senescent period.

Measurements

At the MP sites, production and utilization were measured within each paddock by clipping paired plots (1-m^2) inside and outside of 10 temporarily placed cages (1.5×1.5 m). Forage within plots was clipped at ground level and oven-dried. Plots were clipped at the end of each grazing period, after which the cages were moved to a new location. At the FP site, paired plots (0.5-m^2) were harvested before and after each grazing period at 7 sampling areas randomly distributed in the vicinity of each study area. Since the duration of the grazing period during plant growth was less than 4 days, growth during that period was assumed to be negligible.

Basal areas of species were determined in 1987 using the point sampling method with the aid of a point frame having 35 pins spaced 2.5 cm in a row. At each study area, 2,800 points were sampled on both the grazed and protected areas for a total of 14,000 points on each treatment. These values were also used to determine range condition (Wroe et al. 1988) after applying a weighting factor by species (Lodge and Campbell 1965) to convert basal area to a dry weight basis. Range condition is the present species composition as a percent of the composition at climax.

Vegetation densities were determined as the proportion of points contacting vegetation. Since the seeded plants were not randomly distributed on the MPs site, species composition was also estimated by counting individual stems within 7 plots (0.5×1.0 m) randomly located in both grazed and ungrazed treatments. The plots were placed perpendicular to the rows and all grass tillers and forb plants were counted within the entire plot.

Root mass and vertical distribution, together with analysis of soil organic matter and nitrogen and phosphorus constituents, were determined at the MP sites at the end of the experiment in 1987, by extracting ten 7.5-cm cores to a depth of 90 cm both inside and outside each exclosure. The cores were partitioned into 15-cm segments to 60 cm. One core was randomly selected for soil analysis and the remaining 9 for root analysis. At the FP site, stony soils prevented use of a coring tool. Consequently, pits (30×30 cm) were excavated, at 5-cm increments, to a depth of 30 cm. Single samples were taken both inside and outside each exclosure. The root mass of each sample was washed, oven-dried, weighed, and ashed to determine ash-free weight.

Percent organic matter was determined as per Walkley and Black (1934). Total nitrogen (N) was established using a macro-kjeldahl procedure (Association of Official Agricultural Chemists 1970); nitrate-N (NO_3-N) and ammonium-N (NH_4-N) were determined by KCl extraction and steam distillation (Bremner 1965). The analysis for available phosphorus (P) was carried out according to Olsen et al. (1954); total P was determined as per $HC10_4$ digestion outlined by Bray and Kurtz (1945).

The regrowth potential of forage was measured at the FP site only. Immediately following the first grazing in spring, 3 paired plots were located both inside and outside each exclosure and clipped to near ground level. Regrowth was measured by clipping the plots again prior to the next grazing period. This procedure was repeated at each exclosure in each of 4 years with care taken to avoid overlapping the plots.

Statistical Analyses

All data were analyzed as a randomized, complete block design using analyses of variance with 2, 2, and 5 replications at the MPn, MPs, and FP sites, respectively. This resulted in a very conservative test, with 1 df for both treatment and error, for tests made on MP sites. Species composition and root mass were transformed by logarithmic transformation (Steel and Torrie 1980) before analysis because their errors were correlated with the mean. Since root mass within a sample was correlated with depth, treatment effects at each depth were tested separately.

Results

Forage utilization was high on each site over the 5-year study period (Table 1), averaging 80% or more over the first 4 years when complete seasonal data were available. Partial utilization, calculated from forage available in grazing periods 1, 2, and 3, averaged, respectively, 32, 42, and 51% on the MPn site, 42, 53, and 26% on the MPs site, and 22, 42, and 58% on the FP site.

Table 1. Forage yield and utilization from 1983 to 1987 on 3 sites within different plant communities managed in a short-duration grazing system.

	1983	1984	1985	1986	1987[1]
Mixed Prairie					
Native (MPn)					
Forage yield (kg/ha)	398	165	815	1184	832
Utilization (kg/ha)	308	144	762	1016	402
(%)	77	87	93	86	48
Seeded[2] (MPs)					
Forage yield (kg/ha)	1448	414	2427	1771	2943
Utilization (kg/ha)	1185	326	2168	1276	2572
(%)	82	79	89	72	87
Fescue Prairie[3] (FP)					
Forage yield (kg/ha)	570	337	347	784	768
Utilization (kg/ha)	481	240	288	690	431
(%)	84	71	83	88	56

[1]Estimates made in July at conclusion of root sampling.
[2]Seeded to Russian wildrye and crested wheatgrass.
[3]Values to 1986 reported by Dormaar et al. (1989).

Range condition on native prairie was less on grazed areas compared with the exclosure (Table 2) but the difference was significant ($P = 0.008$) only in the FP site. Although statistically significant differences in basal area were difficult to detect because of minimal replication, significant effects were noted with a greater proportion of annual weeds including cheatgrass (*Bromus tectorum* L.) ($P = 0.001$) and flixweed (*Descurainia sophia* (L.) Webb) ($P = 0.090$) and a reduced proportion of rough fescue (*Festuca scabrella* Torr.) ($P = 0.002$) with grazing on the MPs and FP sites, respectively (Table 2). Vegetation densities were greater in protected than in grazed native sites but similar between treatments in the MPs site.

Tiller numbers of Russian wildrye and crested wheatgrass plants were similar on protected and grazed areas of the MPs site (Table 3). However, tiller numbers of cheatgrass and flixweed were significantly greater on the grazed portion.

Root mass was greater ($P = 0.080$) on the ungrazed vs grazed areas (0.69 vs 0.63 mg/cm^3) only on the MPn site although differences at individual depths were not detected. However, due to the conservative nature of the test, and the relatively low SEM values, a trend is suggested for greater mass below 30 cm depth on the MP sites (Fig. 1), particularly at between 45 to 60 cm depth on the MPs site ($P = 0.160$). Root mass of the FP site was virtually the same at each depth (Fig. 2).

At the FP site, regrowth averaged 169.2 and 151.1 g/m^2 ($P = 0.077$) on protected and grazed sites, respectively, over a 4-year period (Table 4). The interaction between year and treatment was not significant ($P = 0.806$).

Table 2. Range condition (% of climax) of native grasslands, vegetation density (no. hits on plants/no. points sampled) and basal area (%) of plant species[1] or types on grazed or protected grasslands in the Mixed Prairie and Fescue Prairie Associations in 1987, after 6 years of time-controlled grazing (means back-transformed from the logarithmic means).

	Protected	Grazed	Probability[2]
		Mixed Prairie-Native	
Range condition	53.1	48.6	0.144
Density	0.274	0.223	0.158
Graminoids	85.3	84.6	0.868
Carex spp.	15.0	9.1	0.082
Koeleria gracilis	6.5	12.4	0.145
Stipa spartea/comata	23.7	20.0	0.451
Bouteloua gracilis	5.2	2.0	0.482
Agropyron spp.	1.4	2.1	0.675
Poa sandbergii	14.2	23.7	0.558
Forbs	13.5	15.4	0.737
Artemisia frigida	1.6	4.9	0.130
Phlox hoodii	2.6	0.9	0.500
		Mixed Prairie - Seeded	
Density	0.268	0.283	0.847
Graminoids	99.9	98.3	0.122
Elymus junceus	37.9	33.3	0.274
Agropyron cristatum	57.6	42.4	0.568
Bromus tectorum	1.1	8.7	0.001
		Fescue Prairie	
Range condition	53.1	38.1	0.008
Density	0.201	0.180	0.099
Graminoids	64.1	61.4	0.638
Carex spp.	17.7	17.9	0.942
Stipa comata	4.3	4.2	0.890
Festuca scabrella	5.9	0.6	0.002
Agropyron spp.	13.3	8.7	0.356
Forbs	31.4	33.3	0.685
Artemisia frigida	3.2	5.2	0.202

[1]Nomenclature follows Moss (1983).
[2]Probability that means from protected and grazed areas are similar.

Table 3. Tiller numbers (no./0.5 m²) by plant species or types on grazed or protected seeded site in the Mixed Prairie area in 1987, after 6 years of time-controlled grazing (means back-transformed from the logarithmic means).

	Protected	Grazed	Probability[1]
Graminoides	940.4	888.8	0.320
Elymus junceus	426.8	501.6	0.469
Agropyron cristatum	236.9	111.9	0.265
Bromus tectorum	1.2	10.6	0.006
Forbs *Descurainia sophia)*	0.0	7.3	<0.001
Total	94.0	91.6	0.643

[1]Probability that means from protected and grazed areas are similar.

On MP sites, available phosphorus was generally more abundant in soils on grazed areas. Average percent organic matter, total nitrogen, ammonium, and nitrates were greater in the upper layers (0–30 cm) of soils in protected areas (Table 5).

Discussion

Species composition and root mass were not improved with grazing compared with protection. Consequently, the hypothesis

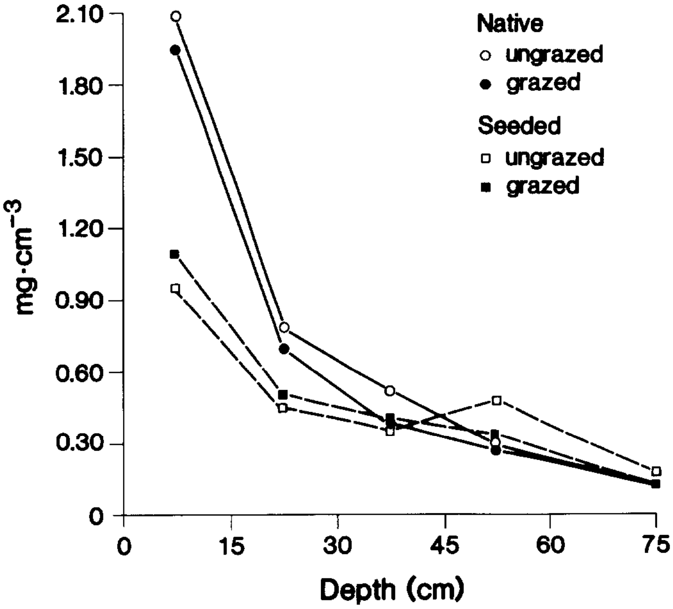

Fig. 1. Root mass and distribution on grazed and protected areas from native and a seeded site, in the Mixed Prairie Association, managed with short-duration grazing and high animal impact over a 6-year period. (Standard errors of the mean, at increasing depth increments, are for the grazed native site, 0.177, 0.048, 0.038, 0.025, 0.013; for the protected native site, 0.190, 0.055, and 0.051, 0.027, 0.013; for the grazed seeded site, 0.074, 0.055, 0.043, 0.031, 0.014; and for the protected seeded site, 0.064, 0.054, 0.038, 0.031, 0.014).

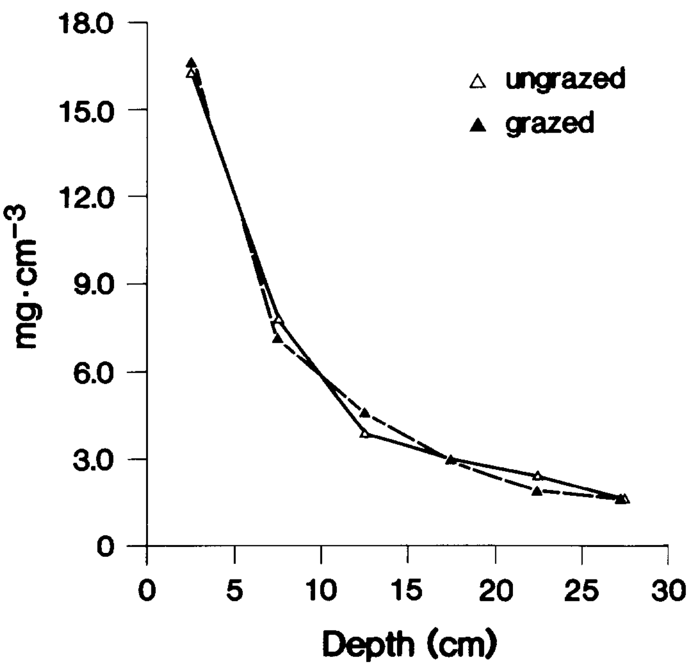

Fig. 2. Root mass and distribution on grazed and protected areas from a native site, in the Fescue Prairie Association, managed with short-duration grazing and high animal impact over a 6-year period. (Standard errors of the mean, at increasing depth increments, are for the grazed site, 2.47, 0.72, 0.33, 0.16, 0.24, 0.20; and for the protected site, 2.41, 0.78, 0.28, 0.16, 0.28, 0.21).

Table 4. Regrowth (g/m²) in spring between the first and second grazing periods on grazed and protected areas of a Fescue Prairie site over a 4-year period.

Year[1]	Protected	Grazed
1983	203.1	147.5
1984	111.9	119.6
1985	130.5	99.8
1986	231.3	237.5
Average[2]	169.2	151.1

[1]Year effect was significant with $P = 0.012$.
[2]Location (protected vs grazed) effect was significant ($P = 0.077$); interaction of year × location was not significant ($P = 0.806$).

Table 5. Chemical constituents of soil on protected (P) and grazed (G) sites in the Mixed Prairie Association in relation to depth (n = 2).

	Native		Seeded	
	P	G	P	G
Organic matter (%)	1.88	1.62	2.48	1.86*
Total phosphorus (%)	0.054	0.058	0.074	0.082
Available phosphorus (mg/g)	2.35	26.40*	98.30	200.10*
Total nitrogen (%)	0.138	0.120	0.189	0.155
NH_4-N (mg/g)	6.50	4.25*	6.25	5.20
NO_3-N (mg/g)	0.70	0.60	0.85	0.80

*Means of paired values differed significantly ($P<0.10$).

that high animal densities and high stocking rates with time-controlled grazing would improve grassland condition was rejected. On the contrary, evidence from the study indicates that high stocking rates with high levels of utilization would result in grassland deterioration even though time-controlled grazing is applied. This is consistent with observations that removal of litter during dormancy would result in loss of productivity (Willms et al. 1986), that severity and not frequency of defoliation have the greatest effect on plant vigor (Schuster 1964), and the observation by Heitschmidt et al. (1987) and Pieper and Heitschmidt (1988) that stocking rate and not grazing system is responsible for changes in vegetative composition. Conversely, Pitts and Bryant (1987) in Texas and Hart et al. (1986) in Wyoming found that species composition was not affected by short-duration grazing vs continuous grazing at the same stocking rates.

The 3 sites were subjected to similar grazing pressures over the duration of the study with average stocking rates about twice those recommended (Wroe et al. 1988). This resulted in about 80% utilization of total available forage over 3 grazing periods within a season. Cattle numbers, or grazing times, were adjusted annually in response to forage yield thereby determining stocking rates and, together with the number of paddocks or field size, stock densities. The effect of animal impact on the plant community would depend on its botanical composition at the beginning of the study.

Range condition, which reflects botanical composition, at the beginning of the study on the FP site was about 50% (Dormaar et al. 1989) and, while condition was not measured on the MPn site at that time, it was likely similar judging from the present conditions of the grazed and protected areas. Since that time, range condition tended to improve in the exclosure and deteriorate on the grazed area. At 50% range condition, any improvement would be obtained by an increase of the climax dominant species which were needleandthread (*Stipa comata* Trin. and Rupr.) and wheatgrasses (*Agropyron smithii* Rydb./*dasystachyum* (Hook.) Scribn.) on the MPn site and rough fescue on the FP site, respectively. Changes in their composition were not dramatic although rough fescue did increase significantly when protected in the FP site (Dormaar et al. 1989).

The shifts in botanical composition at high stocking rates are similar to those reported in other studies on the Mixed Prairie (Clarke et al. 1947) and Fescue Prairie (Willms et al. 1985). The latter studies demonstrated continuous gradients of change from light to very heavy stocking rates under continous grazing. While the effects of continuous grazing appear similar to the effects of time-controlled grazing at high rates, there is no evidence that similarities will exist at lower stocking rates. Although the rate of succession within exclosures may have been impeded by below-average precipitation in most years of the study, it is likely that the rate of deterioration was also enhanced by the same conditions since regrowth was impaired and low precipitation would favor shallow-rooted species such as Sandberg's bluegrass (*Poa sandbergii* Vasey). Smoliak (1965a) found that light grazing, representing less than 25% removal on a Mixed Prairie site, resulted in increased blue grama (*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.) and Junegrass (*Koeleria cristata* (L.) Pers.) and reduced needleandthread and wheatgrasses.

The application of manure on 2 sites of the study may have confounded the results. However, the practice did not detract from the conclusion of the study, which was to reject the hypothesis of improved range condition with grazing, since added manure would have had the opposite effect (Smoliak 1965b). While adding manure did affect the alternate hypothesis, that range condition would deteriorate with the grazing practice tested, manure is obviously an effect of grazing and although the higher concentration through addition is abnormal over the entire field, it might be expected in localized areas.

Composition of seeded species on the MPs site was affected most with an increase in annual weeds on grazed areas. Weeds occupied a niche created by reduced plant cover and, perhaps, reduced root mass of perennial species. Their presence does not necessarily indicate reduced grassland condition since both are opportunists and neither is noxious in this plant community. Furthermore, the composition and tiller density of the seeded species were similar.

Root mass on the grazed areas of the MPn site tended to be less ($P = 0.080$) than on ungrazed areas. The results were similar to those reported by Schuster (1964) and Smoliak (1965a) for root mass in relation to grazing. The root mass near the surface on grazed areas of the MPs site was probably contributed largely by annual weeds. However, the tendency for reduced root mass below 30 cm indicates that loss of plant vigor had occurred. The generally greater mass at a depth of 45 cm ($P = 0.160$) was consistent between replicates but could not be explained. Differences in root mass found between the seeded and native sites were also reported by Smoliak and Dormaar (1985) who found 1,472 g/m^2 on native range and 1,150 g/m^2 on crested wheatgrass pasture.

The effects of grazing on root mass were expected to be similar on the FP and MP sites. However, Johnston (1961) reported almost twice the root mass on lightly grazed areas than on protected areas. His results contrast with those from most studies and indicate an interaction of root mass with plant community. He believed self-shading was responsible for inhibiting root development, a phenomenon which may have begun to assert itself at the FP site. However, since regrowth and the proportion of rough fescue increased within the exclosure, this indicates that plant vigor had also improved.

The application of manure increased available P on both MP sites but could not compensate for excessive N removal on the MPs site (Table 5). Manure would be beneficial to plant vigor and may have inhibited the rate of range deterioration on the MP sites.

Timed grazing with high stocking rates, as applied in this study, resulted in no improvement in the condition of the grassland. Range condition on the grazed native prairie was lower than in exclosures after 6 years of protection, while vegetation densities were greater in protected than in grazed native prairie areas.

Literature Cited

Association of Official Agricultural Chemists. 1970. Official methods of analysis. 11th ed., Washington, D.C.

Bowser, W.E., T.W. Peters, and A.A. Kjearsgaard. 1963. Soil survey of eastern portion of St. Mary and Milk Rivers Development Irrigation Project. Univ. of Alberta Bull. SS-5, Alberta Soil Surv. Rep. 22 pp.

Bray, R.H., and L.T. Kurtz. 1945. Determination of total, organic, and available forms of phosphorus in soils. Soil Sci. 59:39-45.

Bremner, J.M. 1965. Inorganic forms of nitrogen. *In:* Black, C.A. (ed.), Methods of soil analysis. Part 2. Chemical and microbiological properties. Agron. 9:1179-1237.

Clarke, S.E., E.W. Tisdale, N.A. Skoglund. 1947. The effects of climate and grazing practices on short-grass prairie vegetation in southern Alberta and southern Saskatchewan. Tech. Bull. 46. Canada Dept. Agr.

Coupland, R.T. 1950. Ecology of mixed prairie in Canada. Ecol. Monogr. 20:271-315.

Dormaar, J.F., S. Smoliak, and W.D. Willms. 1989. Vegetation and soil responses to short-duration grazing on Fescue Grasslands. J. Range Manage. 42:252-256.

Hart, R.H., G.E. Schuman, M.J. Samuel, and M.D. Smith. 1986. Time-controlled grazing research in Wyoming, p. 73-82. *In:* Tiedeman, J.A. (ed.), Short duration grazing. Washington State Univ., Pullman, Wash.

Heitschmidt, R.K., S.L. Dowhower, and J.W. Walker. 1987. Some effects of rotational grazing treatment on quantity and quality of available forage and amount of ground litter. J. Range Manage. 40:318-321.

Johnston, A. 1961. Comparison of lightly grazed and ungrazed range in the Fescue Grassland of southwestern Alberta. Can. J. Plant Sci. 41:615-622.

Lodge, R.W., and J.B. Campbell. 1965. The point method and forage yield tables for determining carrying capacity. Mimeo. Publ., Agr. Can. Res. Sta., Swift Current, Sask.

Looman, J. 1969. The fescue grasslands of western Canada. Vegetatio 19:128-145.

Moss, E.H. 1983. Flora of Alberta. 2nd ed. Revised by J.G. Packer. Univ. of Toronto Press.

Moss, E.H., and J.A. Campbell. 1947. The fescue grassland of Alberta. Can. J. Res. C. 25:209-227.

Olsen, S.R., C.V. Cole, F.S. Watanabe, and L.A. Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA, Circ. 939. U.S. Govern. Print. Off., Washington, D.C.

Pieper, R.D., and R.K. Heitschmidt. 1988. Is short duration grazing the answer? J. Soil Water Conserv. 43:133-137.

Pitts, J.S., and F.C. Bryant. 1987. Steer and vegetation response to short duration and continuous grazing. J. Range Manage. 40:386-389.

Pluhar, J.J., R.W. Knight, and R.K. Heitschmidt. 1987. Infiltration rates and sediment production as influenced by grazing systems in the Texas Rolling Plains. J. Range Manage. 40:240-243.

Savory, A. 1983. The Savory Grazing Method or Holistic Resource Management. Rangelands 5:155-159.

Savory, A., and S.D. Parsons. 1980. The Savory Grazing Method. Rangelands 2:234-237.

Schuster, J.L. 1964. Root development of native plants under three grazing intensities. Ecology 45:63-70.

Smoliak, S. 1965a. A comparison of ungrazed and lightly grazed *Stipa-Bouteloua* prairie in southeastern Alberta. Can. J. Plant Sci. 45:270-275.

Smoliak, S. 1965b. Effects of manure, straw, and inorganic fertilizers on Northern Great Plains ranges. J. Range Manage. 18:11-14.

Smoliak, S., and J.F. Dormaar. 1985. Productivity of Russian wildrye and crested wheatgrass and their effect on prairie soils. J. Range Manage. 38:403-405.

Steel, R.G.D., and J.H. Torrie. 1980. Principles and procedures of statistics. A biometrical approach. 2nd ed. McGraw-Hill Book, Co., Toronto.

Walkley, A., and I.A. Black. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Sci. 37:29-38.

Willms, W.D., S. Smoliak, and J.F. Dormaar. 1985. Effects of stocking rate on a Rough Fescue Grassland vegetation. J. Range Manage. 38:220-225.

Willms, W.D., S. Smoliak, and A.W. Bailey. 1986. Herbage production following litter removal on Alberta native grasslands. J. Range Manage. 39:536-540.

Wroe, R.A. 1984. Savory Grazing Method, Taber and Ft. Macleod, p. 288-291. *In:* Proc. 21st Annu. Alberta Soil Sci. Workshop. Organizing Committee, Alberta Soil Science Workshop, Edmonton, Alberta.

Wroe, R.A., S. Smoliak, B.W. Adams, W.D. Willms, and M.L. Anderson. 1988. Guide to range condition and stocking rates for Alberta grasslands. Alberta Forestry, Lands, and Wildlife, Edmonton.