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Article *in* Journal of Soil and Water Conservation · January 1990

Walter David Willms
Agriculture and Agri-Food Canada

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Johan F. Dormaar and Walter D. Willms

ABSTRACT: Native prairie communities have evolved to produce relatively low but sustained production. Demand for greater production has resulted in overgrazing and, consequently, lower and more unstable annual yields and increased risk of soil erosion. Because the Rough Fescue Prairie is best suited for grazing, studies were made to determine its carrying capacity and assess the effects of overgrazing. Overgrazing resulted in an increase in plant species that were shallow-rooted and less productive, but more resistant to grazing. This was associated with higher soil temperatures and reduced infiltration. Consequently, the soil was transformed to one characteristic of a drier microclimate. Soil color changed from black to dark brown as stocking rate increased from light to very heavy. Grazing caused a redistribution of nitrogen in the soil by concentrating a greater proportion in a shallower Ah horizon. Productivity deteriorated rapidly with overgrazing, but more than 20 years of drastically reduced stocking rates are required to enable recovery.

RANGELANDS are unsuited to cultivation because of such physical limitations as low and erratic precipitation, rough topography, poor drainage, and cold temperatures (*18*). Instead, rangelands are a source of forage for free-ranging native and domestic animals. In many areas, rangelands are also a source of wood products, water, and recreation. Native prairie represents a major forage-producing component of rangelands.

In Canada, there are 13.6 million ha (33.6 million acres) of native prairie. Of these, 6.5 million ha (16.1 million acres) are in Alberta. About 13% of Alberta's native prairie is classified as the Rough Fescue Prairie association, with the majority being in the Foothills.

The Rough Fescue Prairie historically has been the home of many animal species, the most conspicuous of which was the plains bison (*Bison bison bison* Linnaeus). It is believed that bison used this prairie for their wintering grounds (*16*) by taking advantage of the relatively good quality grass and the presence of warm chinook winds that ensured access to it by eliminating snow cover. Although information is scarce, it appears that mankind's first attempt to manage the prairie resource involved burning the range to eliminate excess litter as a means of attracting bison into an area for hunting. This was likely done in the fall or spring, while plants were dormant and the herbage flammable.

The native people lived off the land and existed by not exceeding the land's production capabilities. Although production was low, their subsistence was assured until the arrival of European settlers in the 1800s. With the introduction of livestock and the plow, production took on a new meaning; management could best be defined as exploitation when settlers removed buffers that had previously allowed stable production. The result was a fluctuating boom-and-bust cycle that depended on current moisture conditions.

Johan F. Dormaar is a soil scientist and Walter D. Willms is a range ecologist at the Agriculture Canada Research Station, Lethbridge, Alberta T1J 4B1. This article is LRS contribution no. 3878947.

The prolonged drought in the 1920s and 1930s and the inability to farm on a viable scale due to the short growing season and the unevenness of the terrain caused many settlers to abandon the land. These circumstances ensured that the primary agricultural value of the Rough Fescue Prairie would be for livestock grazing. However, without proper knowledge of its carrying capacities, much of the grassland was overgrazed and deteriorated. Science has allowed the return to sustained production, but at a higher level of efficiency than was achieved by either the native people or European settlers.

The Rough Fescue Prairie in western Canada is found on highly productive soils, but cultural practices are limited by steep terrain. Consequently, management of grassland vegetation is through management of grazing by cattle (*23*). This is normally accomplished using a continuous grazing system where the cattle are turned onto the range in spring and removed in autumn. The most critical management decision is to determine a stocking rate so that livestock production per unit area of rangeland is maximized while the forage resource is maintained over time.

Jenny (*9*) suggested that soil is a function of an initial state represented by parent material and topography, by the age of the system, and by influx variables represented by climate and the biotic factor. Because soils are, therefore, dynamic natural bodies, the physical presence of domestic animals, together with the concomitant changes in the range vegetation, will act upon and affect the soil resource. Herein, we describe the historical nature of productivity on the Rough Fescue Prairie and examine some buffering processes that allow stable and sustainable biomass production.

Study methods

The study, located at the Agriculture Canada substation in the Porcupine Hills near Stavely, Alberta, began in 1949 to determine the carrying capacity of the Rough Fescue Prairie. Four fields, with a permanent exclosure [0.5 ha (1.2 acres)] in each to provide a control, were fenced to enclose areas of 65, 49, 32, and 16 ha (160, 120, 80, and 40 acres) (*23*). Each field was stocked with 13 cow-calf pairs from mid-May to mid-November in each year of the study to the present (1989). This resulted in fields stocked at four different rates: light, 1.2 animal unit months (AUM)/ha (0.49 AUM/acre); moderate, 1.6 AUM/ha (0.65 AUM/acre); heavy, 2.4 AUM/ha (0.98 AUM/acre); and very heavy, 4.8 AUM/ha (1.95 AUM/acre).

The very heavily stocked field supported 4.8 AUM/ha until 1959. While stocking with 13 cow-calf pairs continued in the following years, declining forage productivity necessitated removing the cattle at various times since then. Grazing in that field was terminated when the cows began losing weight, which occurred when use of available forage was about 80%. Consequently, after 1960 the stocking rate on the very heavily stocked field varied from 2.5 to 4.8 AUM/ha and averaged 3.2 AUM/ha; the planned stocking rate was achieved only twice, in 1972 and again in 1989.

The topography of the site is undulating, varying in elevation from 1,280 to 1,420 m (4,200 to 4,658 feet) above sea level. The climate is dry subhumid with a mean annual precipitation of 550 mm (21.6 inches). The pedon has been classified as Orthic Black Chernozemic or Argic Cryoboroll fine, montmorillonite developed on till overlying sandstone (*2*). Table 1 describes this soil. The vegetation is typical of the Rough Fescue Prairie association (*13*), with rough fescue (*Festuca campestris* Rydb.) representing about 44% basal area of vegetation and Parry oat grass (*Danthonia parryi* Scribn.) about 23%; the balance is comprised of an assortment of grasses, forbs, and shrubs (Table 2).

Results and discussions

Effects of grazing. The greater stocking rate resulted in increased forage use (Table 2), which resulted in increased grazing pressure. This corresponded to a reduction in range condition and an increase in grazing-resistant species that were shorter, less-productive, and shallow-rooted. Rough fescue was replaced by Parry oat grass, bluebunch fescue *Festuca idahoensis* Elmer), wheat grass (*Agropyron* spp.), and June grass (*Koeleria cristata* (L.) Pers.). Prolonged heavy grazing pressure resulted in a cover of weedy species, including pasture sage (*Artemisia frigida* Willd.), locoweed [*Oxtropis campestris* (L.) DC.], pussy-toes (*Antennaria* spp.), and dandelion (*Taraxacum officinale* Weber) (*23*). Bare ground increased from zero to 15% on the very heavily grazed range (*14*). The effect on annual production was a shift from stability at a reasonably high level of about 2,000 kg/ha (1,780 pounds/acre) to one that was closely linked with current precipitation and, therefore, highly variable and, on average, only about 50% of maximum (Table 2).

Vegetation changes led to a reduction of organic matter and a loss of soil structure, which contributed to surface sealing, reduced infiltration rates (Table 3), and, presumably, increased evaporation. The net effect was reduced soil water (*10, 11, 17*). Not only did evaporation increase but there was also less snow catch. Over time, this caused the character of the soil to change to that of a drier microclimate associated with warmer temperatures in the summer (Table 3) and a change in soil color in the Ah horizon. Soil color (dry) changed from black (10YR 2/1) under light grazing, to very dark gray (10YR 3/1) under moderate grazing, to dark grayish brown (10YR 3/2) under heavy grazing, and to dark brown (10YR 3/3) under very heavy grazing (*12*). The change in soil color was correlated with a change in soil organic matter from 11.7% under light grazing to 9.7% under very heavy grazing over 20 years (Table 3). Evidence of this transformation also was observed on a nearby range that was managed with a short-duration grazing system (*5*). Over a 5-year period, grazing that removed about 80% of available forage resulted in a change in color from 5YR 2/1 to 5YR 2/2-3/2 (dry), suggesting either a loss of organic matter or differential rates of accumulation.

Areas that are predominantly in grassland generally are designated as having limited potential for severe erosion (*1*). This leaves the perception that native prairie cannot erode, no matter how badly overgrazed it is. However, livestock activity can affect the water-intake characteristics of the soil (*11*) by removing cover and by compacting the soil. Provided the soil was covered by vegetation, type of cover had little influence on water-intake rate. However, as grazing intensity increased, water intake decreased. Water-holding capacity, representing field water capacity plus the water held in organic matter, of undisturbed cores was lower in heavy grazing treatments than in light grazing treatments (*14*). The consequence of reduced infiltration and water-holding capacity was increased runoff. Soil erosion by water began when about 15% of the soil surface became bare (*11, 14*). This condition was present only in the very heavily stocked field and appeared to reduce the depth of the Ah horizon by 4 cm (1.6 inches) (*4*).

Water infiltration is influenced by bulk density, which is affected by large animals that exert physical pressure on the soil by their weight (*8*). The effect of animals on bulk densities is also a function of stocking rate, which describes the frequency and duration of impact. On the Rough Fescue Prairie, bulk densities in the surface 0 to 10 cm (0 to 4 inches) increased from about 0.75 Mg/m^3 in the exclosures within each field to 0.83 Mg/m^3 in the lightly grazed field and 0.90 Mg/m^3 under heavy grazing (Table 4) (*14*). However, frost action over winter had an ameliorating effect (*5, 19*).

Increasing the grazing pressure caused an increase in the excreta load which, together with increased bulk densities and decreased water-intake characteristics, has serious ramifications for water quality. Total nitrogen (N) content (in percent) increased with very high grazing pressure even though total N in the Ah horizon remained the same (Table 3). Total N was less mineralizable and potentially not as available but more acid-hydrolyzable at the very high stocking rates. This means that a redistribution of the N within the system occurred (*4*). The increased excreta loads affect soil and water quality in processes that are complex and still not well understood.

Denitrification losses have been more pronounced in undergrazed than in overgrazed grassland soils (*7*), possibly due to cooler temperatures (*5, 12*) and more water present (*11, 12*) in the former soils. Plant species that increase or invade as a consequence of overgrazing tend to produce root extracts that inhibit nitrification (*15*). Nitrification may be a mechanism whereby these plants conserve the low amounts of N available in grassland soils.

Persistent trampling affects the physical and chemical characteristics of soil over an entire field (*5*) but also on microsites within a field (*21*). To maintain plant vigor and to allow carryover in the following year, range is stocked season-long at a moderate rate. This leads, however, to the formation of patches where intensive trampling on microsites also increases bulk densities (*21*). Higher bulk densities were found on paths (0.92 Mg/m^3) than in grazed (0.89 Mg/m^3, $P>0.05$) areas (*14*). Further, soil organic matter, carbohydrates, and depth of the Ah horizon were greater ($P>0.05$) in undergrazed patches, while urease activity, nitrate N, ammonium N, and available phosphorus were greater ($P>0.05$) on overgrazed patches (Table 4). This confirmed earlier field-based conclusions.

Although the effects of livestock on rangeland are dramatic and highly visible, native animals also have contributed to the erosion

Table 1. Pedon description of the Orthic Black Chernozemic soil at the Agriculture Canada Substation, Stavely, Alberta (*4*).

Horizon	*Thickness (cm)*	*Description*
Ah_1	14 to 20	Black (10YR 2/1, moist) clay loam; moderate fine granular; soft, very friable; mildly acidic.
Bm_1	8 to 21	Dark yellowish brown (10YR 3/4, moist) clay loam; weak, fine subangular blocky; neutral.
Bm_2	12 to 20	Dark yellowish brown (10YR 4/4, moist) loam to clay loam; moderate coarse, prismatic to subangular blocky; firm; neutral.
Ck	8	Yellowish brown (10YR 5/4, moist) with very pale brown (10YR 8/3, moist) clay loam; angular blocky; friable; strongly effervescent; mildly alkaline.

Table 2. Long-term effects of grazing at fixed stocking rates on species composition (percent of basal area) in the Rough Fescue Prairie and on forage production and use (22, 23).

	Stocking rate (AUM/ha)				
	0	*1.2*	*1.6*	*2.4*	*4.8**
	% of basal area				
Species composition					
Graminoids	80.1	72.3	66.8	76.6	62.7
Parry oat grass	23.4	24.5	32.7	48.0	35.3
Idaho fescue	5.0	5.2	5.6	12.5	11.9
Rough fescue	43.8	37.7	20.7	7.9	2.5
Other graminoids	5.1	2.2	4.0	2.1	3.3
Forbs	11.6	18.5	20.4	18.0	31.8
Shrubs	8.3	9.2	12.8	5.4	5.5
Available forage (kg/ha)	—	2199	2171	1865	1170

*This rate was achieved until 1959, but was variable thereafter.

potential. Prior to the settlement of the prairies, terrifying flashfloods often led to abrupt rises of streams and quick inundation of lowlands. This was blamed, at the time, on the vast herds of bison that trampled the ground until it was impervious to water (*3*). Presently, the greatest impact may be from pocket gophers (*Thomomys talpoides talpoides* Richardson) that have markedly influenced the development of rangeland soils during the thousands of years they have inhabited North America (*20*). However, unlike the bison, which have long since disappeared from the prairies, even the pocket gopher is influenced by livestock activity. Together, they compound the erosion problem.

Soil movement as a result of gopher activity within the study area was examined by Shantz (*17*). On areas that were suitable for pocket gophers in each of the four fields, soil displacement increased with the degree of grazing. Soil displacement was three times as great in the very heavily grazed field as in the heavily grazed field and seven times as great as in the lightly grazed field. That is, soil displacement on areas of poor range, as defined by Johnston and associates (*12*), was double that of good range and six times that of excellent range.

Soil temperatures also correlated with the activity of pocket gophers. More than four times more soil was displaced on sites having high soil temperatures (16 °C in June) than on sites having moderate temperatures (13 °C) or less (*17*). Although gophers may not be attracted to warmer soil temperatures per se, their presence indicates sites that are drier and that have less dead vegetation and more palatable regrowth. Soil disturbance by the pocket gopher exacerbated soil creep on slopes caused by tramping by livestock (*19*).

Grazing effects are imposed either on a short or long term, and their duration, after corrective action is taken, may be described similarly. Retrogression in the composition of plant species, caused by overgrazing occurs rapidly, but succession, following rest from grazing, is slow (*23*). The rate of retrogression and succession depends upon the plant species and grazing pressure. Rough fescue began to decline immediately after imposing very heavy grazing pressure and was nearly eliminated after 5 years, while range condition reached a minimum after 13 years (*23*). Succession of the plant community to a near climax state required more than 20 years of rest (*23*).

While vegetation responds rapidly to grazing, the soil response is delayed because at least some effect is through the plant. However, soil effects were noted 18 years after very heavy grazing pressure was imposed (*12*). A stable minimum level of soil quality or an estimate of recovery has not been made, although new evidence obtained from a study of abandoned cropland indicates that more than 75 years are required for recovery of some chemical constituents (*6*).

The cost of overgrazing must be evaluated over the long term, for which evidence is only speculative. Strictly in terms of beef production per unit area, greatest yields were obtained with maximum use, although individual animal gains and forage productivity declined (*22*). However, overgrazing reduced management stability as forage production became more closely linked with current precipitation. Consequently, forage production became unpredictable and reliance on preserved forages increased. With continued heavy grazing pressure, reduced productivity and increased instability are likely to increase over the long term as soils continue to degrade.

The cost of overgrazing may be evaluated as the reduction in forage and, subsequently, animal production. But this does not take into account the cost of destroying the watershed or wildlife habitat. One approach in assessing the cost to agriculture only is to determine the reduction in stocking rate necessary to bring the range back to a condition that will support the various resources. With the assumption that optimum resource exploitation will occur near the climax state of the community, stocking rates can be set to achieve that goal (*24*). Consequently, the stocking rate on degraded range will be reduced, depending on the degree of degradation, and the cost of recovery, determined as the cost of providing alternate forage. For the Rough Fescue Prairie, a 50% reduction in stocking rate will be required to allow recovery from a degraded condition to an acceptable one (*24*). Although stocking may be increased gradually over time, more than 20 years will be required before the optimum rate is reached.

Table 3. Effects of long-term, fixed stocking rates on the physical and chemical properties of soil on the Rough Fescue Prairie (*4, 12, 14, 17*).

	Stocking rates (AUM/ha)				
Soil Property	*0*	*1.2*	*2.6*	*2.4*	*4.8**
Bulk density (Mg/m³ 0 to 10 cm depth)	0.75[a†]	0.83[b]	0.80[b]	0.83[b]	0.90[c]
Infiltration rate (cm/hr, 0 to 1 min.)	132[c]	103[bc]	96[b]	76[ab]	56[a]
Soil loss (kg/ha)†	—	54	16	16	1,219
Temperature (°C, 15 cm depth in June)	—	11[a]	12[a]	13[a]	16[b]
Water (% of dry soil in June)	—	53[c]	49[bc]	42[b]	32[a]
Organic matter (%)	—	11.7[a]	11.2[a]	10.7[a]	9.7[a]
Total N (% in Ah horizon	0.93[a]	0.94[a]	—	—	1.10[b]
Total N (t/ha in Ah horizon)	12.96	12.94	—	—	13.07
Mineralizable N (μg/g of soil)	73.9[c]	66.2[b]	—	—	49.8[a]
Hydrolyzable N (% of total N)	74.9[a]	82.5[b]	—	—	85.0[b]

*This rate was achieved until 1959, but was variable thereafter.
†Means within a row followed by the same letter do not differ significantly (P > 0.05); means without letters were not analyzed statistically.
‡Based on simulated rainfall at a rate of about 8.5 cm/hr.

Table 4. Soil characteristics on overgrazed and undergrazed patches on Rough Fescue Prairie (*21*).

Soil Characteristic	*Overgrazed*	*Undergrazed*
Organic matter (%)	11.48	13.13[b]
Carbohydrate (mg/g)	5.30[a*]	6.69[b]
Urease activity (g N/kg)	0.16[b]	0.14[a]
Nitrate N (mg/kg)	10.01[b]	5.14[a]
Ammonium N (mg/kg)	8.46[b]	5.14[a]
Available P (mg/kg)	6.04[b]	3.85[a]
Ah (depth, cm)	16.10[a]	22.40[b]

*Paired means with the same letter do not differ significantly (P > 0.05).

Conclusions

The physical presence of domestic animals, with the additional excreta load and effects on range vegetation, acts upon and affects the soil resource in a manner that is often detrimental. Because of increased bare ground and bulk densities and reduced water intake, anthropogenic erosion, which is exacerbated by pocket gopher activity, increases while the Black Chernozemic soil acquires characteristics associated with soils of a drier microclimate. Consequently, the quality of soil deteriorates, as does the quality of water in terms of storage and loading of sediments and nutrients. A stocking rate of 1.6 AUM/ha is certainly worth considering for the Rough Fescue Prairie because that rate maintains soil quality, productivity, and economic returns.

Despite a switch from native to domestic animals, properly managed range can sustain agricultural productivity and conserve related resources. Plants should not be grazed too early in spring when they are mobilizing resources for growth. Grazing should remove only about 50% of current production to avoid removing stored energy in the stem bases and to allow for carryover into the next year. The carryover not only provides emergency forage but, more importantly, sustains the nutrient status and hydrological properties at an optimum level, thereby stabilizing annual production.

REFERENCES CITED

1. Agriculture Canada - Alberta Agriculture. 1986. *Potential for wind erosion map in southern Alberta 1986.* Edmonton, Alta.
2. Cannon, M. E. 1983. *Estimating range production from thickness of mollic epipedon and other soil or site characteristics.* M.Sc. thesis. Mont. State Univ., Bozeman.
3. Connell, E. S. 1984. *Son of the morning star.* North Point Press, San Francisco, Calif.
4. 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.
5. Dormaar, J. F., S. Smoliak, and W. D. Willms. 1990. *Distribution of nitrogen fractions in grazed and ungrazed fescue grassland Ah horizons.* J. Range Manage. 43: 6-9.
6. Dormaar, J. F., S. Smoliak, and W. D. Willms. 1990. *Soil chemical properties during succession from abandoned cropland to native range.* J. Range Manage. 43: 6-9.
7. Gould, W. D. 1982. *Denitrification in Alberta soils.* In L.J.L. Sears, K. K. Krogman, and T. G. Atkinson [eds.] *Research Highlights - 1981.* Agri. Can. Res. Sta., Lethbridge, Alta. pp. 67-68.
8. Heady, H. F. 1975. *Rangeland management.* McGraw-Hill Book Co., New York, N.Y.
9. Jenny, H. 1980. *The soil resource: Origin and behavior.* Springer-Verlag, New York, N.Y.
10. Johnston, A. 1961. *Comparison of lightly grazed and ungrazed range in the fescue grassland of southwestern Alberta.* Can. J. Plant Sci. 41: 615-622.
11. Johnston, A. 1962. *Effects of grazing intensity and cover on the water-intake rate of fescue grassland.* J. Range Manage. 15: 79-82.
12. Johnston, A., J. F. Dormaar, and S. Smoliak. 1971. *Long-term grazing effects on fescue grassland soils.* J. Range Manage. 24: 185-188.
13. Moss, E. H., and J. A. Campbell. 1947. *The fescue grassland of Alberta.* Can. J. Res. C 25: 209-227.
14. Naeth, M. A. 1988. *The impact of grazing on litter and hydrology in mixed prairie and fescue grassland ecosystems of Alberta.* Ph.D. thesis. Univ. Alta., Edmonton.
15. Neal, J. L. Jr. 1969. *Inhibition of nitrifying bacteria by grass and forb root extracts.* Can. J. Microbiol. 15: 633-635.
16. Reeves, B.O.K. 1978. *Bison killing in the southwestern Alberta Rockies.* Plains Anthropologist 23-82, pt. 2: 63-78.
17. Shantz, B. 1967. *Rodent-watershed relationships.* Project progr. Rpt. 85-5-5-132. Can. Wildlife Serv., Edmonton, Alta.
18. Stoddart, L. A., A. D. Smith, and T. W. Box. 1955. *Range management.* McGraw-Hill Book Co., New York, N.Y.
19. Thomas, A. S. 1960. *The tramping animal.* J. Brit. Grassland Soc. 15: 89-93.
20. Turner, G. T. 1973. *Effects of pocket gophers on the range.* In G. T. Turner, R. M. Hansen, V. H. Reid, H. P. Tietjen, and A. L. Ward [eds.] *Pocket gophers and Colorado mountain rangeland.* Bull. 554S. Colo. State Univ. Exp. Sta., Fort Collins. pp. 51-61.
21. Willms, W. D., J. F. Dormaar, and G. B. Schaalje. 1988. *Stability of grazed patches on rough fescue grasslands.* J. Range Manage. 41: 503-508.
22. Willms, W. D., S. Smoliak, and G. B. Schaalje. 1986. *Cattle weight gains in relation to stocking rate on rough fescue grassland.* J. Range Manage. 39: 182-187.
23. 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.
24. Wroe, R. A., M. G. Turnbull, S. Smoliak, and A. Johnston. 1981. *Guide to range condition and stocking rates for Alberta.* Alta. Energy and Natural Resources, Edmonton. □