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Effect of grazing and abandoned cultivation on a *Stipa-Bouteloua* Community

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Abstract

A *Stipa-Bouteloua* community, cultivated in the autumn of 1928 and abandoned in the spring of 1932, reverted to a community dominated by needle-and-thread (*Stipa comata* Trin. and Rupr.). An exclosure to prevent grazing was constructed in 1978 to include equal portions of previously cultivated and adjacent native range, while the remainder of the area continued to be subjected to moderate to heavy grazing pressure. This permitted a study to determine the effects of the brief period of cultivation on forage production, species recovery, and soil physical and chemical characteristics compared to those of native prairie. After 14 years of protection from grazing, needle-and-thread accounted for 79% of foliar cover of the abandoned cultivation and 18% of the untreated range while blue grama [*Bouteloua gracilis* (HBK.) Lag. ex Steud] occupied 1 and 51% on the same treatments, respectively. After 60 years, the soil on the abandoned cultivated area showed reduced carbon, total nitrogen, available phosphorus, and hydraulic conductivity but increased $N0_3$-N. Grazing reduced hydraulic conductivity, NH_4-N, available mineralizable nitrogen (chemical index), available phosphorus, and total carbohydrates but increased carbon, total nitrogen, and $N0_3$-N. Cultivation and grazing resulted in reduced root mass. To facilitate a rapid transition from blue grama to needle-and-thread stable communities, input of energy, such as cultivation, may well be required.

Key Words: botanical composition, soil quality, organic matter, rangeland, range management, aeration of soil

Overgrazing of a *Stipa-Bouteloua* community (Coupland 1961) favors an increase in the cover of blue grama [*Bouteloua gracilis* (HBK.) Lag. ex Steud] (Smoliak et al. 1972). It is often generalized that, given the right conditions, such as decreased stocking rate or even rest rotation, succession from a seral state will automatically follow. However, succession to the original cover will not necessarily occur when grazing pressure is relieved (Dormaar and Willms 1990) since blue grama appears to resist displacement by associated climax species. Therefore, the original *Stipa-Bouteloua* community is altered to one dominated by blue grama and more closely representative of the shortgrass prairie.

Blue grama appears to resist the succession to the original native community by resisting the establishment of other plant species. Several constraints by blue grama to succession can be suggested. Needle-and-thread (*Stipa comata* Trin. and Rupr.) communities have less root mass in the upper 13 cm of the soil profile than blue grama communities (5,500 vs 12,200 kg/ha, respectively), according to Lutwick and Dormaar (1976). Any available nitrogen is either immediately sequestered within the extra root mass of blue grama, and/or nitrification is at a standstill because of a lack of ammoniacal nitrogen (Brady 1984, Rice 1984). Furthermore, the high root mass and ability of blue grama to extract water to a considerably lower soil moisture potential than associated species [-8.0 MPa vs -3.0 for western wheatgrass (*Agropyron smithii* Rydb.) Majerus 1975)] limits available water for germination and establishment of competing species. Resistance to change may also result from allelopathic effects of blue grama but that hypothesis (Dormaar and Willms 1990) has not been tested.

These possible constraints to succession from a blue grama to a *Stipa-Bouteloua* community may decrease with cultivation, which improves aeration and reduces competition. Aeration oxidizes the organic matter and produces ammonium-nitrogen (NH_4-N) and subsequently nitrate-nitrogen (NO_3-N) that is available for plants. The effects of abandoned cultivation on the soil and vegetation of a *Stipa-Bouteloua* community, however, have not been studied in depth. The objectives of the study were to determine the effects of abandoned cultivation on species diversity and recovery, and soil physical and chemical characteristics of a *Stipa-Bouteloua* community, with and without the effects of grazing, and to learn more about recovery of overgrazed Mixed Prairie.

Materials and Methods

Site

The study area is located about 20 km northeast of Lethbridge, Alberta Lat. N: 49°46′; Long. W:112°46′) on a *Stipa-Bouteloua* site in the Mixed Prairie Association. Homestead inspectors' reports show that part of the site was broken in the autumn of 1928 and wheat was grown in each of the next 3 years. The site was seeded to rye (*Secale cereale* L.) and sweet clover (*Melilotus* spp. Mill.) in the autumn of 1931 and grazed until the present along with the contiguous uncultivated native prairie at moderate to heavy rates of stocking. Sweet clover is now absent and it is not known if it even became established after seeding. An exclosure (50 × 100 m) was erected in 1978 across the boundary of the abandoned cultivated land and the uncultivated native prairie to produce the following treatments: grazed, abandoned cultivation (Gc); ungrazed, abandoned cultivation (Uc); grazed, native prairie (Gn); and ungrazed, native prairie (Un).

The soil of the site is a member of the Orthic Dark Brown Subgroup of the Chernozemic Order (Typic Haploboroll) and developed on sandy clay loam (51% sand, 26% clay) fluvial parent material. The climate is moderately cool and semiarid with an average annual precipitation of 425 mm.

Vegetation

The species composition of each treatment was estimated by foliar cover (Daubenmire 1959, Robertson and Adams 1990) in 1992 from 15, 0.1-m²plots spaced 10 m apart along a randomly oriented transect. The composition estimates were made near the

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time of maximum vegetative expression in late summer before grazing. Species cover was expressed as percent of total cover and composition estimated on a weight basis that was used to derive a range condition index (Wroe et al. 1988, Robertson and Adams 1990). Herbage yield was estimated by harvesting ten, 0.25-m^2 plots each September from 1980 to 1992. The plots were located randomly in each treatment. Litter was removed prior to harvesting the vegetation at ground level.

Soil

The Ah (=A1) horizon in each treatment was sampled to a depth of 20 cm on 24 April 1991 in 4 subplots, each paired with 1 of 4 subplots in another treatment. The layout of the site produced contiguous treatments of Gc-Gn, Uc-Un, Gc-Uc, and Gn-Un. Therefore, each treatment was sampled with 2 plots of 4 subsamples each. The samples from outside the exclosure were obtained 8 m from the fence, well outside the zone of abnormal livestock impact. Samples were hand-sieved through a 2-mm screen, and stored in sealed, double polyethylene bags at 4° C. At the time of sieving, roots and other debris were removed from the soil and discarded. Moisture content of the soil was determined gravimetrically.

Enzymes accumulated in soil have biological significance (Dormaar et al. 1984) as they participate in the cycling of elements and thus play an important role in the initial phases of the decomposition of organic residues. Specifically, dehydrogenase activity in soils correlates with biological activity and microbial populations. Dehydrogenase activity was determined at pH 7.6 on moist soil within 24 hours after collection by measuring the triphenylformazan (formazan) produced by reduction of 2,3,5-triphenyltetrazolium chloride when soil was incubated with 2-amino-2-(hydroxymethyl)propane-1:3-diol buffer (0.5M) at 30° C for 5 hours (Ross 1971).

Following the enzyme analyses, the remainder of each soil sample was dried. The size distribution of the individual particles in the soil samples was established on a portion of the dried samples by the hydrometer method as outlined by Gee and Bauder (1986). Subsamples were also ground to pass a 0.5-mm sieve. Soil pH was measured in 0.01M $CaCl_2$ (solution:soil ratio of 2:1).

At the time of sampling, undisturbed core samples, 55 mm diam. and 30 mm deep, were taken with a drop-hammer type sampler at 0- to 3-cm and 3- to 6-cm depths at each subplot. The core samples were refrigerated at 4° C until needed. Saturated hydraulic conductivity was determined using the Tempe Cell method (Sommerfeldt et al. 1984). The cores were then oven-dried, weighed, and bulk densities calculated.

Grazing affects a number of soil chemical parameters (Johnston et al. 1971, Dormaar et al. 1984, Willms et al. 1988). Therefore, organic matter was determined as per Walkley and Black (1934); carbohydrates as per the phenol-sulfuric acid method of Dubois et al. (1956) as modified by Doutre et al. (1978); Kjeldahl nitrogen (total N) as outlined by the Association of Official Agricultural Chemists (1970); NO_3-N and NH_4-N by KCl and steam distillation as per Keeney and Nelson (1982); and $NaHCO_3$-soluble phosphorus, or available phosphorus (P), as per Olsen et al. (1954). Total P was determined as per Na_2CO_3 fusion outlined by Jackson (1958). Autoclaveable-nitrogen, as an index of chemical-nitrogen availability, was determined as described by Keeney (1982). The monosaccharide distribution in hydrolysates of the soil samples was assessed as outlined by Dormaar (1984, 1987).

Root mass was determined in the Ah (average 24 cm; range 22 to 26 cm) horizon by extracting 16 (4 from each main treatment) 6½ cm diameter cores on 13 June 1991. The roots were washed as described by Lauenroth and Whitman (1971). The washed roots were dried at 60° C for 24 hours. Ash content of the roots was determined after ignition at 550° C for 4 hours. Root mass is reported on an ash-free, oven-dry basis for the average depth of the Ah horizons.

Statistical Analysis

The error term in this unreplicated experiment was assumed to be represented by the sampling error. Undoubtedly, the constraints imposed by the lack of replication weaken the conclusions from a statistical test. Nevertheless, results from a statistical test, when taken in combination with the standard error, assist in the interpretation of the treatment effect.

The data were analyzed for each paired comparison separately, with the F-ratio having 1 and 3 df, and in a single analysis for the entire data set assuming a completely random design. In the single analysis, the experimental unit was the sample plot consisting of 4 subsamples each and the experimental error consisted of the sample $\times$ treatment interaction. Since each treatment had 2 sets of 4 samples, the treatment and error degrees of freedom for the model were 3 and 4, respectively (Steel and Torrie 1980). The results of the 4 paired comparisons that were common to both analyses were virtually identical, therefore the paired plot analysis was dropped in favor of the completely random model.

Replication is undeniably desirable and useful; nevertheless, valid information and data can be gained from long-established, unreplicated field experiments, including long-term grazing trials, by virtue of their antiquity (Johnston et al. 1971, Smoliak et al. 1972, Willms et al. 1988). In the present experiment, the area sampled was about 1 ha, while the variability within the soil was assumed to be random.

Results and Discussion

Vegetation

Cultivation and abandonment resulted in a shift in species dominance from blue grama to needle-and-thread (Table 1) and, subsequently, greater forage production potential. Over a 13-year period, forage production in the exclosure averaged 630 and 1,170 kg ha^{-1} from the native range and abandoned cultivation, respectively.

Cultivation over a 3-year period eliminated the original vegetation and, after abandonment, succession began from residual seeds in the soil. Inherent dormancy in needle-and-thread seed is high (M.E. Majerus, personal communication), which likely contributed to its persistence and eventual dominance in the stand. Germination and establishment of blue grama has greater risks associated with it than needle-and-thread because it is more susceptible to burial, due to its small size, and because it requires higher soil temperatures (Wilson 1981) that are normally not achieved until late spring when the probability for moisture deficits is high. Consequently, cool-season species are favored in the establishment from seed. Seeding rye and sweet clover may also have contributed to the suppression of blue grama in 1931 by shading and reducing soil temperature.

The grazed needle-and-thread community (abandoned cultivation) is characterized by a large amount of exposed soil, which indicates decreased stability and the potential for other species to increase in abundance. Normally, native species such as blue grama and the various forbs would increase in response to grazing pressure and maintain vegetation cover. Instead, grazing resulted in an increase of nonindigenous annual species (Table 1) which, as opportunists, took advantage of good moisture conditions in late spring.

Persistent heavy grazing pressure from either sheep or cattle results in a seral community characterized by an increase of blue grama and a decrease of needle-and-thread (Clarke et al. 1947, Smoliak 1974). In the present study, protection from grazing on a

Table 1. Species composition and site characteristics of a *Stipa-Bouteloua* prairie in 1992 as affected by abandoned cultivation and grazing.

Species and site characteristics[1]	Native range		Abandoned cultivation	
	Grazed (Gn)	Ungrazed (Un)	Grazed (Gc)	Ungrazed (Uc)
Decreaser grasses & forbs	(%)			
Agropyron smithii	3.5	0	0	0
Stipa comata	1.0	17.9	41.7	79.0
Eurotia lanata	12.0	20.9	3.4	4.3
Vicia americana	0	0.1	0	0
Total	16.5	38.9	45.1	83.3
Increaser grasses & forbs				
Bouteloua gracilis	63.0	50.7	3.4	1.4
Carex spp	5.7	1.4	3.5	0.3
Koeleria macrantha	0	0	0	1.1
Sphaeralcea coccinea	2.9	0.5	7.5	1.1
Erigeron caespitosus	0	5.9	0	0
Artemisia frigida	0	0	0	6.0
Lithospermum incisum	3.6	0	0	0
Other forbs	1.2	0.7	0.3	1.1
Total	76.4	59.2	14.7	11.0
Invaders				
Agropyron cristatum	0	0	0.3	2.9
Lepidium densiflorum	2.2	0.1	12.2	0.2
Lappula squarrosa	2.9	0.2	11.2	0
Descurainia pinnata	1.9	1.5	10.4	0.1
Chenopodium spp.	0.6	0	3.5	0
Other invaders	0	0	2.6	0.6
Total	7.6	1.8	38.2	3.8
Site characteristics				
Litter (%)	8	42	6	48
Exposed soil (%)	34	2	89	19
Range condition[2] (%)	25	49	35	90

[1]Values derived as outlined by Daubenmire (1959).
[2]Values derived as outlined by Wroe et al. (1988).

low seral, never-cultivated plant community followed a predictable successional response of the dominant species (Wroe et al. 1988) with an increase of needle-and-thread and a decrease of blue grama on the native range (Table 1). Corresponding to these changes was an increase in litter.

The presence of litter is related to grazing and a modified soil environment (Facelli and Pickett 1991) that also influences the species composition. Smoliak (1965) found that adding litter in the form of straw mulch increased the proportion of needle-and-thread and decreased the proportion of blue grama.

Blue grama achieves a competitive advantage with heavy grazing pressure (Smoliak 1974) either by escaping heavy grazing pressure with a low stature, competing more effectively in the drier environment (Weaver and Albertson 1956, Kemp and Williams III 1980) created by grazing, or both. Once established, blue grama is an effective competitor and resists displacement (Laycock 1981) perhaps because of its superior ability to extract water at a very low soil water potential (Majerus 1975) or allelopathy (Dormaar and Willms 1990). Nevertheless, seral states dominated by blue grama that resist change may develop even when grazing pressure is removed. In the present study succession on the native range was observed, and evidence that the communities may eventually reach equality is denoted by the presence of species common to both and by a reduction of blue grama and an increase of needle-and-thread on the native range. However, the rapid transition to a needle-and-thread dominated community required the input of energy in the form of cultivation.

Soils

Soil moisture at the time of sampling was significantly reduced under grazing ($P<0.001$) but increased on abandoned cultivation ($P = 0.013$, Table 2). Moisture content was higher with protection from grazing, possibly due to increased snow catch by the standing litter and reduced evaporation due to the presence of more litter (Table 1). The higher moisture in the grazed or ungrazed, abandoned cultivation vs grazed or ungrazed, native prairie may well be due to greater snow catch by taller plant species, such as needle-and-thread, and/or increased moisture extraction by blue grama. The effect of grazing on soil bulk density depended on previous cultivation; grazing reduced bulk density on abandoned cultivation but raised density on native prairie. Hydraulic conductivity was highest in the ungrazed, native prairie treatment, and lowest in the ungrazed, abandoned cultivation.

The ungrazed, abandoned cultivation part of the exclosure may be viewed as a time frame in old field succession. First, cultivation allowed the oxidation of organic matter (Paul and Clark 1989), since the mineralizable N was still greater in the native range than in the cultivated fields, even though cultivation ceased in 1931. Indeed, organic matter was less in the cultivated than in the uncultivated fields.

Nitrate-N was higher in the grazed or ungrazed, abandoned cultivation fields, while NH_4-N was higher in the grazed or ungrazed, native prairie fields. Rice and Pancholy (1972) found that inhibition of nitrification increased with the progress of succession toward late seral vegetation. The amount of NH_4-N increased from the first successional stage to the late sere, whereas the NO_3-N decreased from the first successional stage to the last sere. Dormaar and Smoliak (1985) showed this to be the case as well for abandoned farmland reverting back to native prairie.

Neal (1969) established in the greenhouse that blue grama inhibited nitrification while needle-and-thread did not. The levels of NO_3-N and NH_4-N in relation to the presence or absence of these 2 grasses seem to show that this is the case in the field. Paul and Clark (1989) noted that nitrate usually does not accumulate in undisturbed grasslands, because competition for NH_4-N by plant roots and nitrogen-immobilizing microorganisms keep inorganic nitrogen rates low. Unfortunately, Neal (1969) only noted that substances that inhibit nitrifying bacteria are likely present in root extracts of certain plants. He did not attempt to identify this substance. However, his evidence seems to point to a compound, or compounds, that interfere with the process of nitrification. Preliminary examination of the chemical composition of root exudates of decreasers, increasers, and invaders, (J.F. Dormaar, unpublished data) show that root exudates of almost all increasers and invaders contain dioctyl adipate [bis(2-ethylhexyl)phthalate]. This compound may be tied to inhibition of nitrification.

Phosphorus is the 1 major element in soil organic matter which must be supplied almost entirely by the parent material. Therefore, no differences in total P were expected or found between fields. There were higher levels of available P in the native than in the cultivated fields.

All monosaccharides, i.e., deoxyhexoses, pentoses, and hexoses, were higher in the grazed or ungrazed native prairie than in the grazed or ungrazed abandoned cultivation soils. This was particularly evident for the pentoses. Pentoses generally are of plant origin. And, of course, the root mass in the native prairie fields was much higher than in the cultivated fields. With the increased root mass, and thus increased microbial populations, one could expect an increase in hexoses as well.

Laycock (1991) noted that not only is there a need to identify stable states in range vegetation, there is also a need to identify and understand the factors that can force a stable community across a threshold into a transitional phase moving toward another stable state. But this poses the question as to what processes, such as nutrient cycling and nitrogen transformations, increased aeration

Table 2. Effect of cultivation and grazing on physical and chemical constituents (24 April 1991) of Dark Brown Chernozemic soil, Picture Butte, Alberta (average of 8 samples).

	Native range				Abanonded cultivation				Comparison before main effects	
	Grazed (Gn)		Ungrazed (Un)		Grazed (Gc)		Ungrazed (Uc)		Grazed vs. ungrazed	Cultivated vs. uncultivated
	($\bar{X} \pm$ SE)								P	
Moisture (%)	6.6	0.1	12.7	0.1	7.3	0.2	13.7	0.2	<0.001	0.013
Bulk density: 0–3 cm (Mg/m^{-3})	1.04	0.02	0.91	0.01	1.17	0.02	1.26	0.02	0.364	<0.001
3–6 cm	1.26	0.01	1.19	0.02	1.30	0.02	1.36	0.02	0.921	0.001
Hydraulic conductivity: 0–3 cm ($cm\ hour^{-1}$)	10.52	0.20	18.48	0.31	6.02	0.11	1.74	0.07	<0.001	<0.001
3–6 cm	6.86	0.13	9.77	0.23	4.52	0.13	2.57	0.16	<0.001	<0.001
pH $CaCl_2$	7.8	0.04	7.7	0.04	7.9	0.05	7.7	0.04	0.007	0.084
Carbon (g/kg)	32.6	0.5	27.9	0.4	24.1	0.2	22.5	0.2	<0.001	<0.001
Nitrogen (g/kg)	2.51	0.08	2.12	0.05	1.93	0.02	1.76	0.01	<0.001	<0.001
NO_3-N (mg/kg)	5.5	0.1	4.6	0.1	9.3	0.5	7.9	0.1	0.029	0.001
NO_4-N (mg/kg)	4.2	0.07	5.5	0.1	2.5	0.01	3.4	0.1	0.001	<0.001
Chemical index[1]	75.6	0.03	75.7	0.06	54.2	0.04	59.3	0.07	0.004	<0.001
Dehydrogenase activity[2]	47	1	56	1	77	1	62	1	0.004	<0.001
Available P (mg/kg)	7.1	0.1	8.7	0.2	4.6	0.1	5.5	0.1	0.001	<0.001
Total P (mg/kg)	897	12	881	11	865	12	891	9	0.714	0.476
Carbohydrates (g/kg)	5.3	0.06	6.1	0.08	3.8	0.07	4.4	0.03	<0.001	<0.001
Deoxyhexoses (mg/kg)	176	7	194	5	127	3	133	3	0.068	<0.001
Pentoses (mg/kg)	537	13	526	7	273	12	297	9	0.675	<0.001
Hexoses (mg/kg)	505	5	505	12	347	6	344	10	0.967	<0.001
Monosaccharides (mg/kg)	1218	14	1225	8	747	13	774	13	0.334	<0.001
Root mass (g/m^2, 0.24 cm)	1350	7	1128	10	705	10	888	8	0.031	<0.001

[1] NH_4-N released on autoclaving (mg/kg of soil).
[2] Formazan released, mmol/g dry soil per hour.

and water infiltration, or allelopathy, occur while transition takes place.

This study allowed the examination of 3 management activities, i.e., grazing, cultivation, and protection from grazing. Each management action had significant consequences on both above and below ground measured constituents (Tables 1 and 2). Although, similar effects seemed to have been noted elsewhere (Dormaar and Smoliak 1985, Dormaar and Willms 1990), the large treatment effects for many of the variables measured in the present study emphasize that the detailed, step by step, soil chemical and plant successional processes of range recovery, both from cultivation and from grazing under semiarid climatic conditions, are poorly understood.

Dormaar and Willms (1990) noted that grassland significantly modified by grazing was still dominated by blue grama even though it was 19 years since grazing ceased. The blue grama soil had higher amounts of organic acids than the adjacent Mixed Prairie. It was hypothesized that allelopathy may be a factor in ecological process. The present study adds credence to to this hypothesis. Hence, it seems that our next step may be a study of the chemical constituents of root exudates of individual range grasses and forbs.

Many of the processes examined are dependent on the type of soil and vegetation involved in this site. The high amounts of blue grama on the native range, and presence of annual species, suggest that the area has been heavily grazed during the growing season since grazing started in 1931. Under reduced grazing pressure, species recovery could have been entirely different. The sandy nature of the soil would support needle-and-thread rather than blue grama, and management alone could provide for the improvement of the degraded native range. Some improvement is evident with protection from grazing since 1978.

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