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Rangeland management impacts on soil biological indicators in southern Alberta

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Abstract

Quantitative techniques are needed to determine the effects of cultivation and livestock grazing on biological indicators of soils of the Northern Great Plains. Our objective was to determine how various management practices, which were representative of those used since European settlement in the 1880's, affected 3 biological indicators of soil quality. The study was conducted at 3 sites that are representative of the major grassland ecosystems in Canada: a Mixed Prairie site with *Stipa comata* Trin. & Rupr. dominant in the Brown (Aridic Haploboroll) Soil Zone, a Mixed Prairie site with *S. comata* Trin. & Rupr. and *S. viridula* Trin. dominant in the Dark Brown (Typic Haploboroll) Soil Zone, and a Fescue Prairie site with *Festuca campestris* Rydb. dominant in the Black (Udic Haploboroll) Soil Zone. At each site, 6 treatments representing common production practices were imposed and compared with the native community in a randomized complete block design with 4 replicates and a plot size of 3 x 10 m. The treatments included: 1) monoculture seeding of 2 grass species; 2) alfalfa (*Medicago sativa* L. 'Beaver'); 3) continuous spring wheat (*Triticum aestivum* L. 'Katepwa'); 4) spring wheat and fallow rotation; and 5) abandoned cultivated land. Our hypothesis that mineralizable-N, and phosphatase and dehydrogenase activities would be influenced by cultivation was confirmed by significant changes in these indicators that were detected after only 180 days after treatment establishment. The pool of readily decomposable organic matter was reduced with cultivation and not replenished over the period of the study. The 3 biological indicators were sensitive to not only time following external management changes, but also to seasonal fluctuations. We conclude that soil biological indicators can be used to quantify temporal and botanical changes in diverse ecotypes within the Northern Great Plains.

Key Words: steady state, soil transformations, introduced grasses, abandoned land, monoculture

Resumen

Técnicas cuantitativas son necesarias para determinar los efectos de la cultivación y el pastoreo del ganado en los indicadores biológicos de suelos de la Grandes Llanuras Norteñas (Northern Great Plains). Nuestro objetivo fue determinar como diferentes prácticas de manejo, que eran representativas de aquellas utilizadas desde el asentamiento de los europeos alrededor de 1880, afectaron tres indicadores biológicos de la calidad del suelo. El estudio fue conducido en tres lugares que son representativos del ecosistema pastoril más grande de Canadá: un sitio de Pradera Mixta con *Stipa comata* Trin. y Rupr. dominante en la zona de suelos Marrones (Aridic Haploboroll), otro sitio con Pradera Mixta con *S. comata* Trin. y Rupr. y *S. viridula* Trin. dominante en la zona de suelos Marrones Oscuros (Typic Haploboroll) y por ultimo un sitio con Pradera de Festuca con *Festuca campestris* Rydb. que es la dominante en la zona de suelos Negros (Udic Haploboroll). En cada sitio se utilizaron seis tratamientos representativos de las prácticas de producción más comunes y se comparó con la comunidad de especies nativas en un diseño de "bloque seleccionado completamente al azar" con cuatro réplicas y un tamaño de parcela de 3 X 10 metros. Los tratamientos incluyeron: 1) siembra de monocultivo de dos especies de pastos;2) alfalfa (*Medicago sativa* L. 'Beaver'); 3) siembra continua de trigo de primavera (*Triticum aestivum* L. 'Katepwa'); 4) trigo de primavera y rotación con barbecho;y 5) tierra de cultivo abandonado. Nuestra hipótesis de que el N mineralizable y que las actividades fosfatasas y dehidrogenasas serían influenciadas por la cultivación fueron confirmadas por cambios significativos en estos indicadores que fueron detectados después de solamente 180 días después del inicio del tratamiento. La materia orgánica de rápida descomposición fue reducida con la cultivación y no fue restablecida durante el período del estudio. Los tres indicadores biológicos fueron sensibles no solamente a los cambios que siguieron a los manejos externos, pero como asi también a las fluctuaciones estacionales. Concluímos que los indicadores biológicos de suelos pueden ser utilizados para cuantificar cambios temporarios y cambios botánicos en diversos ecotipos de la Grandes Llanuras Norteñas (Northern Great Plains).

European settlement of the Northern Great Plains had a great effect on the stability of the soil through the imposition of cultivation and grazing by livestock. Southern Alberta is represented by 3 major grassland ecosystems: a Mixed Prairie site with *Stipa comata* Trin. & Rupr. dominant in the Brown Soil Zone (around 2% organic C), a Mixed Prairie site with *S. comata* Trin. & Rupr. and *S. viridula* Trin. dominant in the Dark Brown Soil Zone (around 4% organic C), and a Fescue Prairie site with *Festuca campestris* Rydb. dominant in the Black Soil Zone (around 11% organic C).

When settlers arrived on the southern Alberta plains, the soils were at a steady state (Jenny 1980) that included fire and free-

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roaming bison. Cultivation, introduction of new grass species, elimination of fire and replacement of bison with confined grazing of cattle, often at intense grazing pressures, interrupted the original steady state.

Biologically and biochemically mediated processes in soils are fundamental to terrestrial ecosystem function and may be early indicators of soil changes. Hence, to identify early warning indicators of ecosystem stress, an understanding of the underlying biological processes is needed (Dick 1994). For example, soil enzyme activity has been shown to have temporal responsiveness (Dormaar et al. 1984) which must be accounted for if used as an indicator of soil quality.

Assuming native grassland communities evolved for optimum utilization of the local environment, an experiment was designed to examine short-term effects of human interruption of the existing rangeland steady state in 3 ecotypes in the Northern Great Plains. We hypothesized that biological activities including mineralizable-N and enzyme activities would be good indicators of steady state interruption, and thus also be good indicators of changes in rangeland soil quality.

Materials and Methods

Site Description

The study was conducted at 3 sites, widely separated geographically, and representative of major ecotypes of the Northern Great Plains (Table 1). One site was at the Agriculture and Agri-Food Canada substation at Onefour (49° 07'N, 110° 29'W) and represented the *Stipa-Bouteloua* faciation of the Mixed Prairie. The second site was at the Animal Diseases Research Institute (ADRI) near Lethbridge (49° 43'N, 112° 57'W) and represented the *Stipa-Bouteloua-Agropyron* faciation of the Mixed Prairie. A third site was at the Agriculture and Agri-Food Canada substation in the Porcupine Hills west of Stavely (50°12'N, 113° 57'W) and represented Fescue Prairie dominated by rough fescue (*Festuca campestris*). The vegetation at these sites has been described by Moss and Campbell (1947) and Coupland (1961).

Methods

At each site, 6 treatments representing common production practices were imposed and compared with the native community in a randomized complete block design with 4 replicates and plot sizes 3 x 10 m. The treatments included 1) monoculture seeding of 2 grass species; 2) alfalfa (*Medicago sativa* L. 'Beaver'); 3) continuous spring wheat (*Triticum aestivum* L. 'Katepwa'); 4) spring wheat and fallow in rotation; and 5) abandoned cultivated land. On the 2 mixed prairie sites (Onefour and Lethbridge), the introduced grass treatments were crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) and Russian wildrye (*Elymus junceus* Fisch.). On the fescue prairie, smooth bromegrass (*Bromus inermis* Leyss.) and orchard grass (*Dactylis glomerata* L.) were sown. All plots were established in spring (Table 1) by cultivating and seeding, or abandoning a previously uncultivated native plant community. The native treatment was left intact and undisturbed during plot preparation. The abandoned plot was cultivated several times during the first summer and plants that emerged from live tillers were removed until the second year. All seedings were using 15-cm row spacing. The *Stipa-Agropyron-Bouteloua* and *Festuca campestris* sites were prepared and established in spring 1993 and the *Stipa-Bouteloua* site was established in spring 1994. Each site was enclosed with a 4-strand barbed-wire fence that excluded livestock.

Soil samples were taken through the centre of the plots to eliminate edge effect in fall and spring over a 3-year period, beginning in the fall of 1993, at the *Stipa-Agropyron-Bouteloua* and *Festuca campestris* sites, and over a 2-year period, beginning in the fall of 1994, at the *Stipa-Bouteloua* site (Table 1). Three subsamples from the Ah (=A1) soil horizon were taken by spade, composited, and hand-sieved in the field through a 2-mm screen. The samples were stored in sealed, double polyethylene bags at 4° C.

All analyses were made using moist soil and carried out within 3 weeks of arrival at the laboratory. Moisture content was determined gravimetrically. Mineralizable-N, as an index of biological N availability, was determined as described by Keeney (1982). Dehydrogenase activity, a common enzymatic activity to estimate microbial activity, was determined at pH 7.6 on fresh, moist soil 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 (0.5 M) at 30° C for 5 hours (Ross 1971). Phosphatase activity, an indicator of capability to cleave phosphate esters, was determined at pH 6.5 on fresh, moist soil by measuring p-nitrophenol produced when soil was incubated with buffered disodium *p*-nitrophenyl phosphate tetrahydrate solution (0.115 M) and toluene at 37° C for 1 hour (Tabatabai and Bremner 1969).

Statistical Analyses

Each variable was analysed in a whole model as an unbalanced 3 (sites) x 7 (treatments) x 2 (seasons) x 2 or 3 (years) x 4 (replicates) split-split-split plot design (Table 2) using the GLM Procedure of SAS (1989). The potential bias resulting from repeated measurements over years was alleviated using the Box Correction Procedure (Milliken and Johnson 1984). The data were unbalanced because there were only 2 years for the *Stipa-Bouteloua* site and the grass species were combined as 1 treatment to yield 2 x the plot number for the new treatment. This was done to account for the differences in species among sites. The variables were highly responsive to the factors tested and meaningful interpretation required a more detailed examination of the data. This was accomplished by analysing the data by individual site, and the grass species as individual treatments, as a 7 (treatments) x 2 (seasons) x 2 or 3 (years) x 4 (replicates) split-split plot design. Further analyses consisted of evaluating only the first year effects in a 7 (treatments) x 4 (replicates) design for each season. The yearly trend of each index was also evaluated, for each

Table 1. Study site descriptions.

Location	Soil Zone	Soil Canada (Chernozemic)	Soil U.S. (Haploboroll)	Average Precipitation (mm)	Started	Soil Sampling Dates 1993	1994		1995		1996
Onefour	Brown	Orthic Brown	Aridic	310	6 Apr. 1994			1 Nov.	20 Apr.	28 Sep.	22 Apr.
ADRI	Dark Brown	Orthic Dark Brown	Typic	420	1 Apr. 1993	29 Sep.	21 Apr.	10 Oct.	8 Apr.	11 Oct.	1 May
Stavely	Black	Orthic Black	Udic	550	13 Apr. 1993	3 Oct.	22 Apr.	19 Sep.	17 May	14 Sep.	6 Jun.

Table 2. Analyses of variance for the whole model and by site of 4 variables to examine the influence of modified plant communities, site, season, and year on selected soil parameters.

Source of variation	Df	Probabilities/Means			
		Moisture	Mineralizable-N[1]	Dehydrogenase Activity[2]	Phosphatase Activity[3]
Whole model[4]		(%)			
Site		------------------	Means	------------------	
Stipa-Bouteloua		12	43	63	867
Stipa-Agropyron-Bouteloua		16	75	103	566
Rough Fescue Prairie		40	205	198	2914
Partial Models (by site)					
Stipa-Bouteloua[5]		------------------	P	------------------	
Treatment (T)	6	< 0.01	< 0.01	< 0.01	< 0.01
R x T (Error 1)	21				
Season (Se)	1	< 0.01	0.02	0.10	< 0.01
T x Se	6	< 0.01	0.02	< 0.01	0.06
R x T x Se (Error 2)	21				
Year (Y)	1	< 0.01	0.10	< 0.01	< 0.01
Se x Y	1	< 0.01	< 0.01	< 0.01	< 0.01
T x Y	6	< 0.01	< 0.01	< 0.01	0.22
T x Se x Y	6	< 0.01	< 0.01	< 0.01	0.02
R x T x Se x Y (Error 3)	111				
Year		------------------	Means	------------------	
1994/95		15	42	68	914
1995/96		12	43	63	867
Stipa-Agropyron-Bouteloua[6]		------------------	P	------------------	
Treatment (T)	6	< 0.01	< 0.01	< 0.01	< 0.01
R x T (Error 1)	21				
Season (Se)	1	< 0.01	0.02	< 0.01	0.14
T x Se	6	< 0.01	< 0.01	< 0.01	< 0.01
R x T x Se (Error 2)	21				
Year (Y)	2	< 0.01	< 0.01	< 0.01	< 0.01
Se x Y	2	< 0.01	< 0.01	< 0.01	< 0.01
T x Y	12	< 0.01	< 0.01	< 0.01	< 0.01
T x Se x Y	12	< 0.01	< 0.01	< 0.01	< 0.01
R x T x Se x Y (Error 3)	167				
Year		------------------	Means	------------------	
1993/94		19	95	68	719
1994/95		16	75	103	566
1995/96		18	83	106	466
Fescue Prairie[7]		------------------	P	------------------	
Treatment (T)	6	< 0.01	< 0.01	< 0.01	< 0.01
R x T (Error 1)	21				
Season (Se)	1	< 0.01	< 0.01	< 0.01	0.03
T x Se	6	< 0.01	< 0.01	< 0.01	< 0.01
R x T x Se (Error 2)	21				
Year (Y)	2	< 0.01	< 0.01	< 0.01	< 0.01
Se x Y	2	< 0.01	< 0.01	< 0.01	< 0.01
T x Y	12	< 0.01	< 0.01	< 0.01	< 0.01
T x Se x Y	12	< 0.01	< 0.01	< 0.01	< 0.01
R x T x Se x Y (Error 3)	167				
Year-		------------------	Means	------------------	
1993/94		50	306	189	4933
1994/95		40	205	198	2914
1995/96		40	197	180	2728

[1]NH_4^+-N released, mg kg^{-1} dry soil h^{-1}.
[2]Formazan released, nmole g^{-1} dry soil h^{-1}.
[3]P-nitrophenol formed, mg kg^{-1} dry soil h^{-1}.
[4]All effects were significant (<0.01) for each variable: Site (Si); Treatment (T); Si x T; Season (Se); Si x Se; Si x T x Se; Year (Y); Si x Y; Se x Y; Si x T x Y; T x Se x Y; Si x T x Se x Y.
[5]Brown Chernozemic soil.
[6]Dark Brown Chernozemic soil.
[7]Black Chernozemic soil.

site, as either the difference between 2 years with a t-test (*Stipa-Bouteloua* site) or with simple linear regression over 3 years (*Stipa-Agropyron-Bouteloua* and *Festuca campestris* sites). The trends were evaluated by subtracting the native soil (control) value for each indicator. This was done to remove the effect of environment at the time of sampling by assuming its effect on the control was the same as on the treatments (Table 4). Trends were thus established for each season, treatment, and replicate that were then evaluated by analysis of variance to test for the effect of season. Since the season by treatment interaction was significant ($P < 0.05$), in all but one case, (phosphatase activity on the *Stipa-Bouteloua* site), the data were reported by season and treatment. Mean separation was achieved using single degree of freedom contrasts (Steel and Torrie 1980).

Results

The indices of soil quality selected, i.e., mineralizable-N, and dehydrogenase and phosphatase activities, were highly responsive ($P < 0.01$) to the agronomic treatments and were influenced ($P < 0.01$) by site, season and year (Table 2). The main effects all influenced ($P < 0.01$) one another necessitating a more detailed examination to discern constituent response (Tables 3 and 4). The indices of soil quality tended to increase across sites with *Stipa-Bouteloua* < *Stipa-Agropyron-Bouteloua* < *Festuca campestris*. This response corresponded to increased soil moisture at the time of sampling (Table 2). Only phosphatase activity was lower on the *Stipa-Agropyron-Bouteloua* site than on the *Stipa-Bouteloua* site (Table 2).

The unadjusted (with the control) indices of soil quality tended to decrease with years since cultivation (Table 2). These means include the control (native prairie), so the trend describing the effect of years since cultivation was partially obscured by this analysis.

In the first year, cultivation and seeding affected the indices of soil quality ($P < 0.05$) in both fall and spring on each site (Table 3). The mineralizable-N and dehydrogenase activity were reduced by all treatments in both seasons on the *Stipa-Bouteloua* site and in spring only on the *Stipa-Agropyron-Bouteloua* and *Festuca campestris* sites (Table 3); however, both indices increased ($P < 0.05$) in response to treatment in fall on the *Stipa-Agropyron-Bouteloua* and *Festuca campestris* sites. Phosphatase activity tended to follow a similar pattern of response as the biological index and dehydrogenase activity, but with 1 exception in fall where the response to cultivation was less clear on the *Stipa-Bouleloua* site. Among the treatments in the first year, grass species tended to have lower mineralizable-N, and lower or simi-

Table 3. The influence of cultivation and modified plant communities on selected soil parameters in the year after establishment.

Treatment	Fall			Spring		
	Mixed prairie[1]	Mixed prairie[2]	Fescue prairie[3]	Mixed prairie[1]	Mixed prairie[2]	Fescue prairie[3]
			Moisture (%)			
1 Native	17 a[4]	24 bc	62 a	17 a	21 a	72 a
2 Grass 1[5]	15 ab	24 c	50 cd	13 c	8 e	36 cd
3 Grass 2[6]	15 b	25 abc	53 bc	13 c	8 e	32 d
4 Wheat Fallow	16 ab	26 ab	62 a	14 bc	13 c	48 b
5 Wheat continuous	17 a	25 abc	60 a	15 b	15 b	45 b
6 Alfalfa	16 ab	25 abc	48 d	13 c	9 e	35 cd
7 Abandoned	17 a	26 a	55 b	13 c	12 d	37 c
			Mineralizable-N[7]			
1 Native	68 a	57 e	313 b	64 a	116 a	556 a
2 Grass 1[5]	44 de	118 a	322 b	26 c	84 d	207 bcd
3 Grass 2[6]	47 cd	104 c	380 a	24 c	75 e	163 e
4 Wheat Fallow	51 bc	116 ab	398 a	34 b	96 b	244 b
5 Wheat continuous	53 b	111 b	380 a	34 b	88 cd	228 bc
6 Alfalfa	53 b	103 c	335 b	36 b	91 bc	200 cde
7 Abandoned	41 e	92 d	374 a	17 d	77 e	181 de
			Dehydrogenase activity[8]			
1 Native	106 a	44 d	104 e	97 a	87 a	431 a
2 Grass 1[5]	65 c	69 a	135 bc	52 de	70 b	210 bc
3 Grass 2[6]	68 c	60 c	149 a	52 de	63 c	202 c
4 Wheat Fallow	67 c	63 bc	136 b	55 cd	86 a	223 bc
5 Wheat continuous	73 bc	67 ab	125 d	62 c	82 a	202 c
6 Alfalfa	78 b	72 a	152 a	72 b	74 b	222 bc
7 Abandoned	68 c	59 c	129 cd	45 e	56 d	228 b
			Phosphatase activity[9]			
1 Native	1083 a	643 c	6962 a	922 a	826 a	9511 a
2 Grass 1[5]	986 b	796 ab	5407 b	789 bc	571 d	3059 c
3 Grass 2[6]	1007 ab	742 b	5635 b	702 e	571 d	2905 cd
4 Wheat Fallow	1091 a	830 a	6949 a	795 bc	689 b	3648 b
5 Wheat continuous	1082 a	795 ab	5408 b	770 cd	692 b	3465 b
6 Alfalfa	1049 ab	869 a	4870 c	834 b	692 b	2778 d
7 Abandoned	974 b	726 b	5732 b	718 de	620 c	2729 d

[1]*Stipa-Bouteloua*, Brown Chernozemic soil.
[2]*Stipa-Agropyron-Bouteloua*, Dark Brown Chernozemic soil.
[3]*Festuca campestris*, Black Chernozemic soil.
[4]Means having the same letter within a subset of the column do not differ significantly P>0.05.
[5]Grass species is crested wheatgrass in the mixed prairie and smooth brome in the fescue prairie.
[6]Grass species is Russian wildrye in the mixed prairie and orchard grass in the fescue prairie.
[7]NH_4^+-N released, mg kg^{-1} dry soil h^{-1}.
[8]Formazan released, nmole g^{-1} dry soil h^{-1}.
[9]P-nitrophenol formed, mg kg^{-1} dry soil h^{-1}.

lar dehydrogenase and phosphatase activities compared to wheat (Table 3). The 2 wheat treatments in the first year were identical and the differences ($P < 0.05$) detected between them (Table 3) are an anomaly likely produced by sampling.

Trends in the indices of soil quality over years since cultivation and seeding (Table 4) were, with a few exceptions, affected ($P < 0.05$) by treatment, season, and their interaction. On the *Stipa-Bouteloua* site, the trend of dehydrogenase activity was not ($P > 0.05$) influenced by either treatment or season while phosphatase activity was not ($P > 0.05$) influenced by treatment or the interaction of treatment with season. On the *Stipa-Agropyron-Bouteloua* site, only dehydrogenase activity was not ($P > 0.05$) influenced by season.

Over years since cultivation and seeding, mineralizable-N tended to decline in fall and increase in spring (Table 4). The treatment response, and differences between season, became greater from the *Stipa-Bouteloua* to the *Festuca campestris* sites. Dehydrogenase activity increased in both spring and fall in a similar manner ($P < 0.05$) across treatments on the *Stipa-Bouteloua* site. In the *Stipa-Agropyron-Bouteloua* site, dehydrogenase activity was mostly unaffected by years since cultivation and seeding while on the *Festuca campestris* site, dehydrogenous activity increased ($P < 0.05$) over all treatments in spring and tended to decrease in fall except where orchard grass was seeded (Table 4). In the fall, phosphatase activity decreased over years since cultivation and seeding on both the *Stipa-Bouteloua* and *Stipa-Agropyron-Bouteloua* sites but increased on the *Festuca campestris* site. In spring, phosphatase activity increased on the *Festuca campestris* site, but remained mostly constant on the other 2 sites (Table 4).

Discussion

Initial effect of cultivation

Cultivation and seeding had a dramatic effect on the indices of soil quality as measured by mineralizable-N, dehydrogenase activity, and phosphatase activity. These effects were mediated by site, season and treatment and influenced by time after cultivation and seeding. Since the first time measurement was made only 180 days after cultivation and seeding, we speculate that cultivation stimulated a rapid release of organic compounds through microbial decomposition of existing soil organic matter that was readily decomposed and was not replenished under the newly established cultivated species.

How are the indices related to soil organic matter and soil quality?

Site differences appear to be related to the decomposable nature of the organic matter. That is, the Ah horizon of Brown Chernozemic soils contained considerably more organic matter that was readily decomposable (Dormaar 1975) and less resistant to thermal decomposition (Lutwick and Dormaar 1976) than that under Black Chernozemic soils. Up to 39% of the organic matter of Brown Chernozemic soils was still in an undecomposed form compared with 5% in Black Chernozemic soils (Dormaar 1977). Comminution of root mass is significantly greater under Mixed Prairie than under the fescue prairie (Dormaar and Willms 1993).

It is clear that the variables of the 3 sites are different even in response to the treatments. For the 4 comparisons of the first 2 years, the phosphatase activities were consistently lower for the Dark Brown than for the Brown Chernozemic soil. Conversely, under growth chamber conditions phosphatase activity was Brown<Dark Brown<Black Chernozemic soils (Dormaar 1988). Although the rea-

Table 4. Trends of selected soil quality variables in 3 plant communities over a 2 or 3 year period since cultivation and reseeding, or abandonment, in both fall and spring after adjustment for the composition in native soil.

		Crested wheat-grass	Russian wild rye	Wheat-fallow	Continuous wheat	Alfalfa	Abandoned
Stipa-Bouteloua[1]							
Soil Moisture (%)	Fall	-0.25	0.5	5.50*[3]	4.25*	0.75	2.00
	Spring	1.5	1.25	0	0.25	3.25	1.25
Mineralizable-N[4]	Fall	3	-0.2	-1.2	-7	-7.2	3.5
	Spring	23.0*	27.0*	11.8	13	25.8*	31.5*
Dehydrogenase[5]	Fall	29.0*	18.5*	42.5*	35.75*	19.5	28.0*
	Spring	27.0*	30.8*	22.5*	17	28.5*	30.0*
Phosphatase[6]	Fall	-55*	-106*	-137*	-105	-19	-68
	Spring	29	70	22	67	50	19
Stipa-Agropyron-Bouteloua[2]							
Soil Moisture (%)	Fall	-1.88	-3.38*	-2.38	-3.25*	-3.75*	-3.25*
	Spring	0.12	0.88	0.5	0	0.62	0.5
Mineralizable-N	Fall	-31.1*	-21.6*	-34.4*	-35.6*	-25.8*	-23.2
	Spring	7.9	9.9*	-4.2	3.5	10.0*	13.6*
Dehydrogenase	Fall	3.6	-1.2	7.5	-5.5	1.4	3.2
	Spring	7.8	0	-8.1	-6.5	5.8	13.1
Phosphatase	Fall	-191*	-134*	-152*	-184*	-160*	-118*
	Spring	12	-38	-78	-120*	-37	-34
Fescue Prairie[2]							
		Orchard Grass	Smooth Brome				
Soil Moisture (%)	Fall	1.62	-4	-5.12*	-2.5	2	-3
	Spring	13.00*	11.50*	3.12	4.38	8.88	4.62
Mineralizable-N	Fall	-60.0*	-132.0*	-129.4*	-93.1*	-101.0*	-136.6*
	Spring	121.9*	103.0*	56.8*	80.0*	73.4*	87.6*
Dehydrogenase	Fall	33.6*	-15	-25.6*	10.1	-25.4	-7.4
	Spring	134.0*	123.2*	121.9*	146.1*	128.6*	151.4*
Phosphate	Fall	69*	342	-235	614*	809*	258*
	Spring	2176*	1949*	1655*	1661*	1945*	1679*

[1]Mean differences of adjusted values between the first and second years after establishment of qualitative constituents, n=8.
[2]Coefficients of linear regression equations of adjusted values over 3 years (n=12); average change of the coefficients over the 3 years.
[3]Asterisk denotes a significant (P>0.05) mean difference or coefficient (n=12).
[4]NH_4^+-N released, mg kg^{-1}dry soil h^{-1}.
[5]Dehydrogenase activity: Formazan released, nmole g^{-1} dry soil h^{-1}.
[6]Phosphatase activity: P-nitrophenol formed, mg kg^{-1} dry soil h^{-1}.

sons for this are not fully understood, a tentative explanation, for the spring differences at least, in the field, can be offered. If the ratio of soil organic carbon (C)/NaOH-extractable organic phosphorus (P) increases, it means more inorganic P bound to the soil organic matter complex has been released by the phosphatases present in the soil (Dormaar 1972, Dormaar et al. 1984). This leads to decreased levels of phosphatase activity and increased levels of available inorganic P. This available inorganic P, however, is immediately being taken up by the roots as the plant actively starts to grow again in the spring (Dormaar 1972). When the spring 1996 samples were obtained for this study, other samples were collected for a 1-time, early comparison of the various treatments (unpublished data). The ratios of total organic soil C over NaOH-extractable organic P for the average of all 28 samples (7 treatments x 4 replicates) per site are 248, 425, and 156 for the Brown, Dark Brown, and Black Chernozemic soils, respectively. Obviously, timing, i.e., attempting to sample at equivalent biological activity stages, would be desirable; however, weather conditions generally do not permit this. In addition, there are numerous other factors, such as soil moisture, depth of Ah horizon and chemical properties, that influence soil phosphatase activities (Speir and Ross 1978).

On the whole, with some exceptions at the *Stipa-Agropyron-Bouteloua* site, once native prairie has been disturbed, in spite of replacement with introduced grass species, biological activity in the soil has decreased in the first 2 or 3 years. Time will tell if the various treatments will be able to rebuild biological activity to the level of native prairie. This will depend on root mass and plant contributions to the rhizosphere ecosystem. The rhizosphere of the plant provides a surface for microbiological colonization which uses root exudates as an energy source. A major problem is to quantify the amounts of photosynthate that enters the rhizosphere and to identify the composition of root exudates. Only 1 study, and that in a growth chamber, quantified the amounts of photosynthate that enters the rhizosphere of 1 of the native grass species involved, i.e., *Bouteloua gracilis* (H.B.K.) Lag. (Dormaar and Sauerbeck 1983). Attempts have also been made to determine the impact of the interaction of root systems of 4 different plant species on the quantities and composition of root exudates. Dormaar (1988) and McKenzie et al. (1995) concluded that the properties of rhizosphere soil are system specific, that is, rhizosphere changes are a function of plant species, soil type, and time.

Dick (1994) noted that the primary value of measuring soil enzyme activities may not be to estimate biological activity per se, but rather as an integrative indicator of a change in the biology and biochemistry of soil. This may be due to the external management, such as monoculture of various crops or abandonment, or to environmental factors, such as location and time of the year. The study presented indeed has shown that the 3 biological activity parameters selected were quite sensitive to not only time following external management, but also to seasonal fluctuations. Comparing between sites does not seem realistic, since it is difficult to have each site at the same climatic conditions at the time of sampling. Comparing within sites supports the conclusions on a field scale that were obtained under growth chamber conditions by Dormaar (1988) and McKenzie et al. (1995). Biological activity parameters can be used as soil quality indicators on a routine basis to follow within-site temporal and botanical changes.

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