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Water-extractable organic matter from plant litter and soil of rough fescue grassland

JOHAN F. DORMAAR AND WALTER D. WILLMS

Authors are soil scientist and range ecologist, respectively, Agriculture Canada Research Station, Lethbridge, Alta. T1J 4B1.

Abstract

Little is known about the chemical composition of throughfall, or the water that falls through, and drips from, the grass canopy of Rough Fescue Grassland during the grazing season. Water-extractable C, N, organic acids, and monosaccharides from litter and from soil in the upper 2 cm of the Ah horizon collected at monthly intervals in 1988 were assessed at Stavely, Alberta. Rough fescue (*Festuca campestris* Rydb.) grasslands were stocked at either light (1.2 AUM/ha) or very heavy (4.8 AUM/ha) fixed rates for 39 years or were ungrazed in exclosures located within each field for an equal period of time. At the high grazing intensity, the soil and litter N was less water-extractable. The C/N ratios of the water-extractable organic matter from litter and soil averaged 11.2 and 2.3, respectively. Soil monosaccharides were essentially not water-extractable. The quality of the litter as reflected by the water-extractable constituents often differed over the season between fields. Observations at regular time intervals are essential. The effect of the quality of leachates of litter on soil was not predictable. The 3 major long-chain fatty acids identified, palmitic, stearic, and arachidic acids, from soil in grasslands that are in good condition because of the low grazing pressure, could well contribute to the resistance of those grasslands to the encroachment of invading species.

Key Words: soil quality, soil chemical properties, monosaccharides, organic acids, stocking rate, chernozemic.

Litter is that part of the forage resource not produced in the current year. Dead plant material, found in the plant canopy (standing litter) or on the soil (fallen litter), has a large influence on the productivity, biomass accumulation, and species composition of plants and animals (Knapp and Seastedt 1986). The microenvironment of grasslands is significantly modified by plant litter (Willms et al. 1986, Willms 1988), which increases water infiltration, reduces radiation density, and insulates the soil surface, thereby keeping soil temperatures cooler in spring and summer while reducing evaporation.

Grazing affects the quantity and quality of litter on grasslands. Its long-term effect, the alteration of species composition, is achieved by shifting the competitive advantage to species that are smaller, more shallow rooted, and less productive, but more resistant to grazing and more tolerant of drier soil conditions resulting from litter removal. Therefore, while litter accumulation is affected by grazing over the short term, litter production and, presumably, quality are affected over the long term by the new species composition. Litter quantity on the rough fescue grassland was reduced from 12,403 kg/ha on ungrazed range to 247 kg/ha on heavily grazed range (Peake and Johnston 1965) while the average percentage basal area of the dominant rough fescue (*Festuca campestris* Rydb.) decreased from 7.5 to 0.6 for the same grazing treatments, respectively (Johnston et al. 1971).

Plant canopies in the natural environment can alter the chemical composition of precipitation falling through them. For example, litter affects the chemistry of nitrogen in rainwater passing through it (Knapp and Seastedt 1986, Gilliam 1987). The chemical properties of soil under litter will be affected both by the quality and quantity of litter aboveground and by the chemical composition of the rainwater falling through the litter. During the decomposition of litter by abiotic and biotic agents, many hydroxyl- and carboxyl-containing compounds are released and leached into the soil by precipitation. Their presence in the soil has both detrimental and beneficial ecological consequences (Whittaker 1970, Rice 1984). Components of extracts from grassland litter exhibit phytotoxic effects on the germination of various range grasses (Johnston 1961, Bokhari 1978) and affect competition among species (Rice 1984).

Little is known about the chemical composition of the water that falls through, and drips from, the grass canopy (throughfall) of rough fescue grassland during the grazing season, particularly as it is affected by different grazing pressures. Also there is little information available on possible differences between water extracts of litter and of soil immediately below the surface. This study was conducted to examine the potential contribution of litter to the chemical composition of water extracts during the grazing season, and to assess the relationship of water-extractable constituents from litter and the top 2 cm of soil under various grazing pressures.

Materials and Methods

Sampling Sites

The study site was at the Agriculture Canada Research Substation, Stavely, Alberta, situated in the Porcupine Hills, an area managed primarily for grazing by cattle. The vegetation is typical of the Fescue Grassland Association (Coupland and Brayshaw

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1953). The soils are members of the Orthic Black Subgroup of the Chernozemic Order (Udic Haploboroll) developed on till overlying sandstone, and have a clay-loam to loam texture. The climate is dry subhumid and annual precipitation averages about 500 mm. Details of the overall grazing trial ongoing since 1949 have been given by Johnston et al. (1971) and Willms et al. (1985).

The study was conducted in 1988 in 2 fields stocked from mid-May to mid-November, at either light (field L) or very heavy (field VH) rates, and in their ungrazed exclosures (fields E) to provide 3 grazing treatments. Field L has been stocked at 1.2 animal unit months (AUM)/ha since 1949; field VH was stocked at 4.8 AUM/ha from 1949 to 1958. Since 1959, the stocking rate on field VH averaged 3.2 AUM/ha and varied, depending on annual precipitation, from 2.4 to 4.8 AUM/ha. Cattle were removed from field VH when utilization was about 80% of annual production. Average utilization in field L was about 25%. The exclosures, 0.5 ha in area, were constructed in 1948 and have been protected from livestock grazing since then. Percent composition (basal area) of fields L and VH and of the exclosures was presented in a previous study (Willms et al. 1985).

Sampling

Grassland litter, consisting of all dead herbage, standing as well as the accumulated mulch, and soil from the upper 2 cm of the Ah horizon immediately below the litter were sampled each month from May to November, 1988, in 3 randomly located sub-plots in each field and within each exclosure. To reduce the number of samples requiring analysis, 3 subsamples from 1 exclosure were randomly paired with 3 subsamples from the second exclosure and pooled to give 3 common exclosure subsamples.

The soil samples were dried and ground to pass a 0.5-mm sieve. At the time of sieving, roots and other debris were removed from the soil and discarded. The litter was dried at 60° C for 24 hours and ground in a Wiley mill to pass through a 100-mesh sieve. Ash content of the ground litter was determined on a portion of each sample by ignition at 700° C for 4 hours.

Analyses

Chemical

Total C and N were determined to enable the calculation of water-extractable C and N as a percentage of litter and soil C and N. Total organic C was determined by dry combustion at 900° C for 15 min; the evolved CO_2 was collected and weighed. Total N was determined by the Kjeldahl procedure as outlined by the Association of Official Agricultural Chemists (1950).

To simulate maximum leachates of organic acids from litter and soil, 1 gram of material and 15 ml of distilled water were placed in 50-ml polypropylene centrifuge tubes. After shaking in a circulating shaker for 48 hours, the mixture was centrifuged and filtered. The remaining litter or soil was washed with an additional 15 ml of water, centrifuged, and filtered. The 2 supernatant solutions were combined and the pH recorded. The combined filtrates were extracted with 60 ml dichloromethane (CH_2Cl_2) in a separatory funnel. The lower fraction, consisting of CH_2Cl_2, was drawn off and dried over anhydrous Na_2SO_4; the upper water layer was saved for a second CH_2Cl_2 extraction at pH 2.5.

The water-extractable organic acids were determined by a modification of a procedure outlined by Dormaar and Willms (1990). This first CH_2Cl_2-extracted fraction was reduced to about 3 ml, transferred to a small vial and further reduced to 250 μl. Fifty microliters of a vanillic acid solution at a concentration of 0.2 $\mu g/\mu l$ was added to serve as internal standard. The mixture was then evaporated to dryness at 40° C with a stream of nitrogen. To obtain silylation, 150 μl pyridine and 50 μl N,0-bis(trimethylsilyl) tri-fluoroacetamide (BSTFA) were added and mixed. After standing for 10 min in the closed vial, the sample was ready for gas chromatographic analysis.

The pH of the water phase, after the first CH_2Cl_2 extraction was drawn off, was readjusted to pH 2.5 with HCl and extracted once again with CH_2Cl_2 after which this second CH_2Cl_2 extract was processed like the first CH_2Cl_2 extract in preparation for gas chromatographic analysis.

The quantitative analyses were carried out with a Hewlett Packard GC 5840A using a 30-m long fused silica capillary column wall-coated with cross-linked methylsilicone at a film thickness of 0.5 μ. Total water-extractable organic acids were calculated up to retention time 27.05 minutes. The cumulative (pH as extracted and pH at 2.5) quantitative output of the 3 major peaks, 2 of which were easily identified, also were calculated.

For water-extractable carbohydrates, the initial water extraction from the litter and the soil was similar to that described under water-extractable organic acids. After the pH values of the extracts were recorded, the pH was adjusted to 7.5 with 0.1 *N* HCl. Sugars in the solution were reduced, acetylated, and analyzed as outlined by Dormaar (1984). Fucose acetate was used as internal standard because significant amounts of sugar alcohol inositol were present in the water extracts of the litter. Deoxyhexoses (rhamnose), pentoses (ribose + arabinose + xylose), hexoses (mannose + galactose + glucose), and inositol were expressed as $\mu g/g$, but their totals were expressed as mg/g.

Statistical

All analytical results were expressed on the basis of oven-dried, ash-free weight of litter and oven-dried weight of soil.

Although replication and application of current statistical analyses to newly established, replicated field plot experiments is common and undeniably desirable and useful, valid information and data can still be gained from early established, unreplicated field experiments including long-term grazing trials, by virtue of their antiquity (Ridley and Hedlin 1968, Dormaar and Pittman 1980).

The concentration of each organic constituent was compared across grazing treatments using analysis of variance with the experimental error derived from the sampling error. Single degree of freedom contrasts (Steel and Torrie 1980) were used to test for differences between paired means. Individual analyses were made by sampling month and medium type (soil or litter).

The relationship between specific organic constituents in litter and soil was examined within each grazing treatment using regression analysis. Simple coefficients were calculated for concentrations from paired litter (x) and soil (y) samples over subsamples (3) and sampling months (6) for a total of 18 paired values after accounting for the effect of time (month). The effect of time (month) on the concentration of each constituent was examined with 1st or 2nd degree polynomial regressions.

Results

Tables 1, 2, and 3 present the original data and the results of the contrast tests for differences between selected means and 1st and 2nd degree polynomial regressions over month. Generally, all data show seasonal trends and many of the contrasts are either significant ($P<0.05$) or highly significant ($P<0.01$). Most regressions were 2nd degree polynomials, with mid-seasonal maxima.

The pH of the water extracts of the litter showed more significant contrasts than that of the soil (Table 1). The C content of the soil extracts showed the same trends as in a previous study examining the whole Ah horizon (Dormaar et al. 1984) but with larger values because this study examined only the upper 2 cm of the Ah horizon. As grazing intensity increased, the concentration of total N generally increased and the water-extractable N as a percent of total N decreased.

Table 1. Carbon and nitrogen contents (%) of litter and soil and of their water extracts sampled in 1988 from 2 fields stocked at either light or heavy rates and from their exclosures (n=3).

	Litter						Soil					
	Exclosures	Stocking rate[1]		Contrasts			Exclosures	Stocking rate		Contrasts		
	(E)	L	VH	E vs. L	E vs. VH	L vs. VH	(E)	L	VH	E vs. L	E vs. VH	L vs. VH
Total C												
May	45.9	46.9	45.3	0.006	0.050	<0.001	16.6	15.6	14.2	0.006	<0.001	0.001
June	45.6	46.1	45.1	0.054	0.066	0.004	16.5	15.5	13.1	0.012	<0.001	<0.001
July	45.5	46.1	45.1	0.031	0.095	0.003	15.0	13.7	11.4	0.006	<0.001	<0.001
August	44.6	46.4	44.5	<0.001	0.725	<0.001	14.9	12.3	10.6	<0.001	<0.001	<0.001
September	44.3	46.8	44.1	<0.001	0.261	<0.001	15.2	12.7	11.9	<0.001	<0.001	0.020
October	45.4	46.8	45.0	0.003	0.173	0.001	15.3	13.9	12.5	0.001	<0.001	0.001
P[2]	*	**	*[3]				**	**	**			
Water-extractable C as % of total C												
May	3.1	4.2	3.4	0.001	0.144	0.003	0.84	1.13	1.16	<0.001	<0.001	0.057
June	3.5	4.6	3.9	<0.001	0.029	<0.001	0.88	1.14	1.18	<0.001	<0.001	0.201
July	4.4	5.2	4.8	0.003	0.063	0.048	0.92	1.14	1.19	<0.001	<0.001	0.018
August	4.9	5.8	5.6	0.004	0.011	0.343	0.97	1.42	1.58	<0.001	<0.001	<0.001
September	3.9	4.7	4.1	0.002	0.382	0.005	0.68	1.16	1.21	<0.001	<0.001	0.076
October	3.0	3.6	3.2	0.011	0.353	0.040	0.68	1.05	1.15	<0.001	<0.001	0.016
P	**	**	**				**	**	*			
Total N												
May	1.28	1.06	1.92	0.002	<0.001	<0.001	1.44	1.43	1.32	0.854	0.014	0.017
June	1.15	1.34	1.96	<0.001	<0.001	<0.001	1.35	1.32	1.31	0.260	0.138	0.657
July	0.90	1.89	2.04	<0.001	<0.001	0.001	1.31	1.31	1.47	1.000	0.009	0.009
August	0.89	1.96	2.13	<0.001	<0.001	0.001	1.07	1.25	1.43	0.001	<0.001	0.001
September	0.82	1.04	2.23	0.001	<0.001	<0.001	1.06	1.27	1.31	<0.001	<0.001	0.201
October	0.70	0.89	2.12	0.001	<0.001	<0.001	1.25	1.27	1.31	0.372	0.048	0.180
P	*	**	*				**	**	**			
Water-extractable N as % of total N												
May	11.6	10.1	7.4	<0.001	<0.001	<0.001	1.17	0.74	0.52	<0.001	<0.001	<0.001
June	16.4	12.9	8.4	<0.001	<0.001	<0.001	0.96	0.74	0.44	<0.001	<0.001	<0.001
July	18.8	15.7	8.9	<0.001	<0.001	<0.001	0.78	0.63	0.43	0.004	<0.001	0.001
August	22.0	20.6	9.8	0.008	<0.001	<0.001	0.51	0.41	0.16	0.010	<0.001	<0.001
September	18.2	12.7	11.2	<0.001	<0.001	<0.001	0.56	0.40	0.63	0.003	0.070	<0.001
October	17.8	12.4	9.6	<0.001	<0.001	<0.001	0.63	0.80	0.65	0.002	0.642	0.004
P	**	**	**				**	**	**			
pH of the water extract												
May	5.8	5.9	6.2	0.604	0.001	0.002	7.0	7.0	7.1	0.725	0.310	0.488
June	6.0	5.8	6.1	0.001	0.506	0.001	7.3	7.1	7.1	0.005	0.009	0.604
July	5.9	5.5	5.8	0.001	0.152	0.005	7.5	7.5	7.6	0.604	0.315	0.604
August	5.9	5.4	5.8	<0.001	0.071	<0.001	7.4	7.7	7.5	0.035	0.522	0.088
September	5.6	5.7	5.8	0.315	0.034	0.152	7.3	7.3	7.6	1.000	0.010	0.010
October	5.6	5.9	6.1	0.001	<0.001	0.005	7.2	7.3	7.3	0.315	0.152	0.604
P	**	**	**				**	**	**			

[1]Light (L) — stocked at 1.2 AUM/ha; Very Heavy (VY) — stocked at 4.8 AUM/ha.
[2]Level of significance (* = $P<0.05$, ** = $P<0.01$) of 2nd degree polynomial regressions of the constituent concentration over month.
[3]Only 1st degree polynomial regression.

The C/N ratios of litter when averaged over the season were 49.2, 37.4, and 21.8 for fields E, L, and VH, respectively. These values were, respectively, 11.8, 10.6, and 9.1 for the soil; 10.6, 12.9, and 10.1 for water-extractable organic matter from the litter; and 1.4, 2.2, and 3.2 for water-extractable organic matter from the soil.

There were more nonsignificant contrasts for organic acids at the pH as extracted from the soil than for the subsequent pH-modified extract (Table 2). Most of the water-extractable organic acids were obtained at the pH of the original extract; additional organic acids for the soil extracts were obtained at pH 2.5.

The quality of the litter in terms of water-extractable quantities of monosaccharides differed significantly among grazing treatments (Table 3). Generally, pentoses > hexoses > deoxyhexoses, which meant low galactose + mannose/xylose + arabinose ratios. There was also, generally, more mannose and galactose from the litter of field L than from field VH, while the reverse was true for arabinose and xylose. Conversely, the soil essentially did not release any measurable water-extractable monosaccharides; hence, the data are not presented in Table 3.

Effect of month was highly significant for each constituent shown in Tables 1 and 2 and particularly for those shown in Table 3. Only 6 regressions of constituent in soil vs. litter were significant after removing the effect of time (Table 4). The coefficient describing the relationship between constituent in soil vs. litter was often negative, but significant ($P<0.05$) in only 2 instances, (water-extractable N as % of total N for lightly grazed; organic acids at pH 2.5 for exclosure).

Discussion

The effect of grazing on basal cover under various grazing pressures has been well-documented (Peake and Johnston 1965,

Table 2. Organic acids ($\mu g/g$) in water extracts of litter and soil sampled in 1988 from 2 fields stocked at either light or very heavy rates and from their exclosures (n=3).

	Litter						Soil					
	Exclosures	Stocking rate[1]		Contrasts			Exclosures	Stocking rate		Contrasts		
	(E)	L	VH	E vs. L	E vs. VH	L vs. VH	(E)	L	VH	E vs. L	E vs. VH	L vs. VH
Organic acids at pH as extracted												
May	210	101	125	<0.001	<0.001	0.002	62	60	66	0.387	0.090	0.025
June	264	207	193	<0.001	<0.001	0.004	120	118	78	0.627	<0.001	<0.001
July	425	207	284	<0.001	<0.001	<0.001	82	65	69	0.001	0.003	0.190
August	361	311	221	<0.001	<0.001	<0.001	53	50	52	0.065	0.482	0.184
September	299	219	223	<0.001	<0.001	0.194	46	33	38	<0.001	0.003	0.026
October	253	147	202	<0.001	<0.001	<0.001	27	26	27	0.715	0.715	0.473
P[2]	**	**	**				*	**[3]	**			
Organic acids at pH 2.5[4]												
May	51	32	49	<0.001	<0.001	0.012	21	12	9	<0.001	<0.001	0.076
June	89	76	81	0.001	0.011	0.071	114	25	18	<0.001	<0.001	0.043
July	93	79	112	0.001	<0.001	<0.001	57	23	23	<0.001	<0.001	0.680
August	91	81	110	0.010	0.001	<0.001	31	35	27	0.069	0.040	0.003
September	61	58	104	0.133	<0.001	<0.001	24	76	37	<0.001	0.002	<0.001
October	45	51	94	0.062	<0.001	<0.001	32	20	18	<0.001	<0.001	0.108
P	**	**	**				NS	*[3]	**			
Palmitic acid (at pH as extracted + at pH 2.5)[5]												
May	10	5	5	<0.001	<0.001	0.012	15	15	12	0.828	0.087	0.063
June	14	6	7	<0.001	0.001	0.453	33	21	14	<0.001	<0.001	0.006
July	16	15	21	0.258	0.018	0.004	19	19	15	1.000	0.020	0.020
August	21	12	17	<0.001	0.009	0.003	15	18	17	0.128	0.168	0.851
September	18	9	12	<0.001	<0.001	0.010	11	17	10	0.012	0.439	0.005
October	12	4	5	<0.001	<0.001	0.315	7	5	9	0.034	0.017	0.001
P	**	**	**				*	**	**			
Stearic acid (at pH as extracted + at pH 2.5)												
May	16	8	9	<0.001	<0.001	0.488	19	19	7	0.849	<0.001	<0.001
June	18	14	10	0.012	<0.001	0.005	36	21	18	<0.001	<0.001	0.275
July	24	16	18	0.004	0.002	0.160	25	21	17	0.090	0.006	0.071
August	24	24	17	0.665	0.004	0.002	20	31	20	<0.001	1.000	<0.001
September	19	16	15	0.057	0.024	0.546	12	20	7	<0.001	0.003	<0.001
October	12	12	13	1.000	0.134	0.134	4	3	5	0.152	0.071	0.009
P	**	**	**				**	**	**			
Arachidic acid (at pH as extracted + at pH 2.5)[5]												
May	28	19	19	<0.001	<0.002	0.550	5	6	7	0.537	0.153	0.364
June	48	35	25	0.002	<0.001	0.006	14	6	5	<0.001	<0.001	0.697
July	50	58	35	0.013	0.001	<0.001	13	7	10	0.001	0.019	0.019
August	94	47	36	<0.001	<0.001	0.194	7	19	16	<0.001	0.003	0.091
September	90	46	34	<0.001	<0.001	0.002	9	16	9	0.001	0.776	0.001
October	25	21	22	0.003	0.010	0.267	23	8	20	<0.002	0.215	0.001
P	**	**	**				*[3]	*	**[3]			

[1]Light (L) — stocked at 1.2 AUM/ha; Very Heavy (VH) — stocked at 4.8 AUM/ha.
[2]Level of significance (* = $P<0.05$, ** = $P<0.01$, NS = $P>0.05$) of 2nd degree polynomial regressions of the constituent concentration over month.
[3]1st degree polynomial regression.
[4]pH of water extract readjusted to 2.5 after first CH_2Cl_2 separation.
[5]Sum of the 2 CH_2Cl_2 separations.

Table 3. Monosaccharides and inositol in water extracts of litter sampled in 1988 from 2 fields stocked at either light or very heavy rates and from their exclosures (n = 3).

	Exclosures	Stocking rate[1]		Contrasts		
	(E)	L	VH	E vs. L	E vs. VH	L vs. VH
Total (mg/g)						
May	0.7	2.5	3.1	<0.001	<0.001	0.001
June	1.5	2.9	2.8	<0.001	<0.001	0.283
July	9.3	12.6	7.3	<0.001	<0.001	<0.001
August	6.5	3.0	6.5	<0.001	1.000	<0.001
September	2.1	2.5	5.6	0.008	<0.001	<0.001
October	0.8	0.5	2.5	0.005	<0.001	<0.001
P[2]	**	*[3]	**			
Deoxyhexoses (μg/g)						
May	26	49	122	<0.001	<0.001	<0.001
June	73	29	138	<0.001	<0.001	<0.001
July	467	378	147	<0.001	<0.001	<0.001
August	323	119	194	<0.001	<0.001	<0.001
September	147	253	223	<0.001	<0.001	0.002
October	38	10	74	<0.001	<0.001	<0.001
P	**	NS	**			
Pentoses (μg/g)						
May	237	1480	2331	<0.001	<0.001	<0.001
June	763	1848	1881	<0.001	<0.001	0.720
July	5227	7938	4620	<0.001	<0.001	<0.001
August	4591	2136	4527	<0.001	0.737	<0.001
September	1281	1875	4286	<0.001	<0.001	<0.001
October	399	355	2072	0.348	<0.001	<0.001
P	**	NS	**			
Hexoses (μg/g)						
May	267	863	337	<0.001	0.046	<0.001
June	543	997	581	<0.001	0.393	<0.001
July	3080	4032	2053	<0.001	<0.001	<0.001
August	1229	653	1487	<0.001	0.004	<0.001
September	567	304	891	<0.001	<0.001	<0.001
October	322	125	222	<0.001	0.001	0.001
P	**	NS	**			
Inositol (μg/g)						
May	27	74	276	<0.001	<0.001	<0.001
June	88	59	166	0.008	<0.001	<0.001
July	560	252	513	<0.001	0.002	<0.001
August	323	59	259	<0.001	<0.001	<0.001
September	105	101	167	0.386	<0.001	<0.001
October	8	10	99	<0.001	0.001	0.001
P	*	NS	**			
(Galactose + mannose)/(xylose + arabinose) (mg/g)						
May	0.72	0.55	0.12	<0.001	<0.001	<0.001
June	0.67	0.50	0.29	<0.001	<0.001	<0.001
July	0.56	0.47	0.41	0.006	0.001	0.048
August	0.24	0.28	0.30	0.017	0.002	0.104
September	0.41	0.14	0.18	<0.001	<0.001	0.006
October	0.78	0.32	0.09	<0.001	<0.001	<0.001
P	**	**[3]	**			

[1]Light (L)—stocked at 1.2 AUM/ha; Very Heavy (VH)—stocked at 4.8 AUM/ha.
[2]Level of significance (* = $P<0.05$, ** = $P<0.01$, NS = $P>0.05$) of 2nd degree polynomial regression of the constituent concentration over month.
[3]1st degree polynomial regression.

Johnston et al. 1971, Willms et al. 1985). The vegetation changes, both qualitative and quantitative, on the grazed fields represent the effect by the various grazing pressures. Conversely, potential productivity of the vegetation within the exclosures will be affected by its protection (Tueller and Tower 1979). Naturally, the reduction in productivity of range plants resulting from a lack of grazing is always a legitimate concern when comparing grazed fields with exclosures. However, the difference particularly between field L and its exclosure in terms of the results of the study under discussion will be quantitative rather than qualitative, since the only actual species composition differences (percent composition basal area) were trace vs. 0 and 0.2 vs trace for *Artimisia frigida* and *Oxytropis gracilis,* respectively (Willms et al. 1985, Table 1 vs. Table 2).

Materials leached from aboveground live and dead herbage by rain-wash include a diversity of metabolically important compounds, such as amino acids, phenols, other organic acids and carbohydrates, and inorganic nutrients (Tukey 1969). Compounds synthesized by microbial activity will, of course, also be part of the leachates. The plant materials in this study, representing dead herbage only, were macerated. These water extracts of litter, therefore, represented the maximum potential effect of the chemical composition of precipitation percolating through dead herbage on rangeland soils. Although grazing superimposes other sets of

Table 4. Regression coefficients in the concentration of chemical constituents between litter (x) and soil (y) after removing the effect of month[1], for the period from May to October.

	Exclosure		Grazed			
			Light		Very heavy	
Chemical constituent	Coefficient	*P*	Coefficient	*P*	Coefficient	*P*
Total C	–0.267	0.230	–0.225	0.633	0.088	0.796
Water-extractable C (% of total C)	–0.022	0.482	0.079	0.254	0.106	0.027
Total N (%)	–0.235	0.304	0.059	0.784	0.498	0.211
Water-extractable N (% of total N)	0.026	0.199	–0.077	0.040	0.063	0.131
Organic acids (at pH as extracted)	0.484	0.001	0.047	0.804	0.405	0.010
Organic acids (at pH 2.5)	–0.715	0.001	0.252	0.335	–0.048	0.785
Palmitic acid (at pH 2.5)	0.621	0.079	0.577	0.224	–0.278	0.552
Stearic acid (at pH 2.5)	0.430	0.235	–0.545	0.174	1.021	0.009
Arachidic acid (at pH 2.5)	0.034	0.849	0.054	0.802	0.098	0.691

[1]The effect of month was significant ($P<0.01$) in each case.

dynamics through additions of saliva and excreta, and through trampling, which exposes cell contents of fresh tissue, and through the change in species composition, none of these effects were considered in this study.

No water-extractable carbohydrates were present in the soils under consideration. Free sugars provide a rich source of available energy for metabolic use by microorganisms. Litter in July and August produced the greatest amount of water-extractable carbohydrates. Only traces of free sugars in water extracts were extractable from the Chernozemic soil studied, since the sugars are immediately incorporated into microbial tissue, mineralized, polymerized, or adsorbed on the soil itself. However, Gupta (1967) and Haynes and Swift (1990) did find small amounts of free sugars in water extracts of soils formed in higher rainfall areas.

Although many phenolic acids have been found in leachates from a number of grasses (Whitehead et al. 1982, Hartley and Whitehead 1985), Shindo and Kuwatsuka (1975) established that they were rapidly adsorbed by the soil. That is, once the throughfall has reached the soil, its contents are subjected to various processes that reduce or eliminate their concentration in the soil solution. To extract phenols and carbohydrates from the soil, more drastic extractions, such as the use of hot water at 80° C (Haynes and Swift 1990) or of NaOH or H_2SO_4, are required (Whitehead et al. 1981, Dormaar 1984).

Wang et al. (1971) found the predominant free fatty acids under various crops to be myristic, palmitic, palmitoleic, stearic, oleic and arachidic. Three major fatty acid peaks were present in the present study. Two were palmitic and stearic acid; the third peak was tentatively accepted as arachidic acid.

The soil close to the surface is a sink for nutrients (Christie 1979) and likely also for organic compounds leached into the soil from standing and fallen litter (Dormaar and Willms 1990). Repeated overgrazing reduces litter yield (Christie 1979, Willms 1988). Consequently, the quantity of C, N, organic acid, and carbohydrate mass entering the soil of field VH was considerably smaller than that in field L or in the exclosures.

Water-soluble constituents followed a nonlinear relationship over time with a maximum occurring in midsummer. Although site differences for specific months existed, the trends among sites were generally the same. There were also differences over the season for total leachable palmitic and arachidic acids, particularly between the exclosures and the grazed fields. That is, rain-induced leachates from plants differ between grazing pressures, and thus litter quality differs due to the various grazing pressures. Observations at regular time interval are therefore essential.

The relationship of constituents in soil vs. litter was less clear. Although water-extractable constituents from litter sometimes affected the equivalent soil chemical properties, either positively or negatively, no predictions on litter or soil constituents were possible under the conditions of the experiment.

AlSaadawi et al. (1983) showed that among the long-chain fatty acids extracted from *Polygonum aviculare* residue, palmitic, stearic, and arachidic acids had strong allelopathic action against various test plants. The organic acids obtained at pH 2.5 were released from larger complexes by acid hydrolysis. In reality, they would thus be somewhat protected and released, if at all, more slowly into the soil solution. Nevertheless, the significantly greater quantities of water-extractable organic acids, at pH 2.5, taken from soil in grasslands that are in good condition because of low grazing pressure (Table 2: E vs. L and E vs. VH) might well contribute to the resistance of those grasslands to encroachment by invading species. For a deeper understanding as to the ecological balance between litter leachate and the organization of natural and transformed plant communities both root exudates and litter leachates of individual plants will have to be evaluated.

Literature Cited

AlSaadawi, I.S., E.L. Rice, and T.K.B. Karns. 1983. Allelopathic effects of *Polygonum aviculare* L. III. Isolation, characterization, and biological activities of phytotoxins other than phenols. J. Chem. Ecol. 9:761–774.

Association of Official Agricultural Chemists. 1950. Official methods of analysis. 7th ed., Washington, D.C.

Bokhari, U.G. 1978. Allelopathy among prairie grasses and its possible ecological significance. Ann. Bot. 42:127–136.

Christie, E.K. 1979. Ecosystem processes in semiarid grasslands. II. Litter production, decomposition and nutrient dynamics. Austr. J. Agr. Res. 30:29–42.

Coupland, R.T., and F.C. Brayshaw. 1953. The fescue grassland of Saskatchewan. Ecology 34:386–405.

Dormaar, J.F. 1984. Monosaccharides in hydrolysates of water-stable aggregates after 67 years of cropping to spring wheat as determined by capillary gas chromatography. Can. J. Soil Sci. 64:647–656.

Dormaar, J.F., and U.J. Pittman. 1980. Decomposition of organic residues as affected by various dryland spring wheat-fallow rotations. Can. J. Soil Sci. 60:97-106.

Dormaar, J.F., and W.D. Willms. 1990. Effect of grazing and cultivation on chemical properties of soils in the mixed prairie. J. Range Manage. 43:456-460.

Dormaar, J.F., A. Johnston, and S. Smoliak. 1984. Seasonal changes in carbon content, and dehydrogenase, phosphatase, and urease activities in mixed prairie and fescue grassland Ah horizons. J. Range Manage. 37:31–35.

Gilliam, F.S. 1987. The chemistry of wet deposition for a tallgrass prairie ecosystem: Inputs and interactions with plant canopies. Biogeochemistry 4:203–217.

Gupta, U.C. 1967. Carbohydrates, p. 91–118. *In:* A.D. McLaren and G.H. Peterson (eds.), Soil Biochemistry. Marcel Dekker, Inc., New York.

Haynes, R.J., and R.S. Swift. 1990. Stability of soil aggregates in relation to organic constituents and soil water content. J. Soil Sci. 41:73–83.

Hartley, R.D., and D.C. Whitehead. 1985. Phenolic acids in soils and their influence on plant growth and soil microbial processes, p. 109–149. *In:* D. Vaughan and R.E. Malcolm (eds.), Soil Organic Matter and Biological Activity. Martinus Nijhoff/Dr. W. Junk Publishers, Dordrecht, Netherlands.

Johnston, A. 1961. Some factors affecting germination, emergence, and early growth of three range grasses. Can. J. Plant Sci. 41:59–70.

Johnston, A., J.F. Dormaar, and S. Smoliak. 1971. Long-term grazing effects on fescue grassland soils. J. Range Manage. 24:185–188.

Knapp, A.K., and T.R. Seastedt. 1986. Detritus accumulation limits productivity of tall grass prairie. BioScience 36:662–668.

Peake, R.W., and A. Johnston. 1965. Grazing effects on fescue grassland in western Canada. Proc. 9th Int. Grassl. Congr., Brazil: 1627–1630.

Rice, E.L. 1984. Allelopathy. 2nd ed. Academic Press, Inc., N.Y.

Ridley, A.D., and R.A. Hedlin. 1968. Soil organic matter and crop yields as influenced by the frequency of summerfallowing. Can. J. Soil Sci. 48:315–322.

Shindo, H., and S. Kuwatsuka. 1975. Behavior of phenolic substances in the decaying process of plants. III. Degradation pathway of phenolic acids. Soil Sci. Plant Nutr. 21:227–238.

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

Tueller, P.T., and J.D. Tower. 1979. Vegetation stagnation in three-phase big game exclosure. J. Range Manage. 32:128–203.

Tukey, Jr., H.B. 1969. Implications of allelopathy in agricultural plant science. Bot. Rev. 35:1–16.

Wang, T.S.C., P.T. Hwang, and C.Y. Chen. 1971. Soil lipids under various crops. Soil Sci. Soc. Amer. Proc. 35:584–587.

Whitehead, D.C., H. Dibb, and R.D. Hartley. 1981. Extractant pH and the release of phenolic compounds from soils, plant roots and leaf litter. Soil Biol. Biochem. 13:343–348.

Whitehead, D.C., H. Dibb, and R.D. Hartley. 1982. Phenolic compounds in soil as influenced by the growth of different plant species. J. Appl. Ecol. 19:579–588.

Whittaker, R.H. 1970. The biochemical ecology of higher plants p. 43–70. *In:* E. Sandheimer and J.B. Simeone (eds.), Chemical Ecology. Academic Press, N.Y.

Willms, W.D. 1988. Response of rough fescue *(Festuca scabrella)* to light, water, temperature, and litter removal, under controlled conditions. Can. J. Bot. 66:429–434.

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.

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.