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Decomposition of blue grama and rough fescue roots in prairie soils

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Abstract

The mass of grass roots of blue grama (*Bouteloua gracilis* (HBK.) Lag. ex Steud) and rough fescue (*Festuca campestris* Rydb.) to a depth of 13 cm is similar but the carbon contents of their respective soils are quite different. The objective of the present study was to determine some of the physical and chemical changes of blue grama and rough fescue root masses during decomposition under both Brown (Mixed Prairie) and Black Chernozemic (Fescue Prairie) soil-forming conditions. Roots of each species in fine-mesh nylon bags were buried in the Ah horizon of both a Brown and a Black Chernozemic soil. Sixteen collections were made between November 1987 and June 1989 to determine diminution, loss of dry matter and gross energy, and changes in the concentration of carbon, nitrogen, methoxyl groups, alkaline-soluble organic acids and phenols, structural and nonstructural carbohydrates, lignin, and monosaccharides. Differences in substrate quality were only partially responsible for the increased decomposition of root mass in the Brown Chernozemic soil-forming environment. Comminution of root mass was significantly greater under the Mixed Prairie than under the Fescue Prairie conditions for both species. The nitrogen content of blue grama roots increased (from 1.17 to 1.56%) while that of rough fescue decreased (from 1.53 to 1.26%) significantly over the duration of the experiments at both sites. Methoxyl group content and energy levels were not useful parameters. Organic acid, phenols, and nonstructural carbohydrate contents decreased with time. Lignin concentration displayed a significant upward trend for both species (from 232 to 280 for blue grama and for 205 to 247 mg/g for rough fescue) in the Black Chernozemic soil only.

Key Words: Alberta, Chernozemic soils, litter bags, comminution of roots, root quality, Mixed Prairies, Fescue Prairies

R.R. James assisted with the laboratory analyses, and J. Elder conducted the GC-MS analyses.
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In grassland ecosystems, most of the organic matter input into soil is through root biomass. While decomposition of litter and straw has been the subject of numerous investigations, few studies have been published on decomposition of grassland roots and its effect on the quality of soil organic matter. Although Weaver (1947) reported on the decomposition of roots in situ of 12 range and pasture grasses over a 3-year period, a comprehensive review of information on the soil of drier regions (Dregne 1976) contained little about soil organic matter per se or about its quality.

Under pure stands of blue grama (*Bouteloua gracilis* (HBK.) Lag. ex Steud) (Brown Chernozemic soil) the Ah horizon contained considerably more organic matter that was readily decomposable (Dormaar 1975) and less resistant to thermal decomposition (Lutwick and Dormaar 1976) than that under pure stands of rough fescue (*Festuca campestris* Rydb.) (Black Chernozemic soil). 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).

The mass of grass roots of blue grama and rough fescue, to a depth of 13 cm, was similar at 12,180 and 12,606 kg/ha, respectively (Lutwick and Dormaar 1976). Conversely, the carbon (C) contents of their respective soils were 2.5 and 11.1%. The quality of organic matter and the duration of biological processes in different Chernozemic soils is probably affected by such factors as hydrothermal conditions and chemical composition of the vegetation. Humus is the relatively biodegradation-resistant fraction of soil organic matter. Humification, the biological, microbial, or chemical conversion of organic residues to humus (Tate 1987), increases from arid to humid soil environments (Konovoa 1966, Anderson 1972, Karmanov 1974, Dormaar 1977) resulting in an increase in humified organic matter content across the gradient from Brown to Black Chernozemic soils (Dormaar 1975). This increased humification in the Black Chernozemic soil environment has been shown to relate, among other factors, to high soil moisture and periods of pseudo-gley conditions in the spring (Dormaar 1979).

Volkovintser (1969) noted that drought reduced biological decomposition, and thus, rates of biologically induced mineralization, which would lead to an accumulation of undecomposed organic matter. Fuller (1974), on the other hand, observed that the relatively low humus content of semiarid soils was due chiefly to intense activity of biogenic soil processes, and not, as previously proposed, to the low amount of plant material entering the soil. However, the exact conditions under which this occurred were not specified.

Although increasing aridity results in a decrease in the rate of the biologically controlled humification process, there is an increase in the mineralization process. Root mass likely goes through a similar series of physical and chemical transformation pathways that may differ only in rate in different soil types and grass species. The objective of the present study was to determine some of the physical and chemical changes of blue grama and rough fescue root masses during decomposition under both Brown and Black Chernozemic soil-forming conditions.

Materials and Methods

Description of Sites

The study sites were at the Agriculture Canada Research Substations at Onefour and Stavely, Alberta. The Onefour site is located in southeastern Alberta with a semiarid climate and average annual precipitation of about 310 mm. The vegetation is representative of the *Stipa-Bouteloua* fasciation of the Mixed Prairie Association (Coupland 1961). The soil is a member of the Orthic Brown Subgroup of the Chernozemic Order (Aridic Haploboroll) and has a loam texture. The Stavely site is located within the Porcupine Hills of southwestern Alberta, about 290 km north-west of Onefour, having a dry subhumid climate and average annual precipitation of about 500 mm. The vegetation is representative of the Fescue Grassland Association (Coupland and Brayshaw 1953, Moss and Campbell 1947). The soil is a member of the Orthic Black Subgroup of the Chernozemic Order (Udic Haploboroll) and has a clay-loam to loam texture.

Brown Chernozemic soils occur in the most arid segment of the climatic range of Chernozemic soils in Alberta (Agriculture Canada Expert Committee on Soil Survey 1987). The soil climate of this Great Group is typically cold (mean annual soil temperature of 2 to 8° C), rarely mild, and subarid to semiarid. The Ah horizon is brown (10YR 5/3). These soils are associated with xerophytic and mesophytic grass and forb vegetation. Conversely, Black Chernozemic soils occur in cool to cold subhumid grassland and parkland regions. The soil climate of this Great Group is typically cold, rarely mild, and subhumid. The Ah horizon is black (10YR 2/1). These soils are associated with a native vegetation of mesophytic grasses and forbs or with mixed grass, forb, and tree cover. The major difference between the 2 soil-forming environments is their soil moisture and soil temperatures over winter. Brown Chernozem soil water contents are typical of subarid or semiarid conditions with water deficits of 13 to 38 cm. Subhumid conditions on Black Chernozemic soils result in water deficits of 6.5 to 13 cm. The Onefour and Stavely sites represent Mixed Prairie and Fescue Prairie with Brown and Black Chernozemic soils, respectively.

Root Sample Preparation

Roots were collected in June 1987 from the upper 10 cm of the Ah horizon of pure stands of blue grama and rough fescue. The roots were carefully washed (Lauenroth and Whitman 1971) to include all nonsuberised roots (Ares 1976), dried at room temperature, and 10 g portions were placed in 16 × 10 cm nylon bags with a mesh size of 0.2 mm. Four 10-g samples of each species were retained to represent the initial, unburied state (time 0). For each species, 32 randomly assigned bags were buried at each site in October 1987. The bags were buried at both the Mixed Prairie and Fescue Prairie sites within the upper 10 cm of the Ah horizons by cutting 4 narrow 2-m-long slits, 1 m apart, and closing the opening by pressing the sod together. Each slit contained 16 bags of a single species and, at each time of sampling, a single bag was randomly selected and removed from each slit to yield duplicate samples for each species. Samples were collected in mid-November 1987, at monthly intervals until October 1988, and at bimonthly intervals until June 1989, for a total of 16 collections.

The samples were carefully taken out of the bags, placed on trays, and dried at 60° C to a constant mass. The dried material consisted of fine and coarse fractions, which were weighed separately. Following weighing, fractions were milled to pass a 1-mm sieve and pooled for chemical analyses. Subsamples were analyzed for moisture (24 hours at 105° C) and ash contents (4 hours at 700° C). This allowed for all data to be expressed on an oven-dry, ash-free basis.

Chemical Analyses

Decomposition of roots is regulated, among other factors, by their chemical nature. To examine the decomposition process one can measure changes in a number of chemical parameters. Those selected for this study, based on previous work (Dormaar 1975, Herman et al. 1977, Dormaar et al. 1981), were C, N, methoxyl groups, gross energy, alkaline-soluble organic acids and phenols, lignin, and structural and nonstructural carbohydrates. Not all these parameters may be meaningful under the conditions of the experiment.

Since nitrogen content has different effects on carbohydrate and lignin decomposition, carbon mineralization is much better predicted by a combination of the C/N ratio and lignin/carbohydrate ratio than by the C/N ratio alone (Herman et al. 1977). This index of decomposibility, when applied to blue grama roots collected in the field, established that roots collected in May were potentially more resistant to decomposition than those collected in October (Dormaar et al. 1981).

Total C and N were measured by dry combustion in a Carlo Erba NA 1500 Analyzer. Methoxyl (OCH_3) groups were determined by a modified Zeisel technique (Technical Association of the Pulp and Paper Industry 1972). Gross energy of roots was determined on 0.6-g samples by combustion in a Parr 1241 adiabatic oxygen bomb calorimeter.

For detailed analysis of root material, 1 g of each root sample was first extracted in a Soxhlet apparatus for 24 hours with ethyl ether and, after drying of the root mass, the reflux was repeated with a 50/50 methanol/chloroform mixture for another 24 hours. To obtain alkaline soluble organic acids and phenols, a 0.5-g subsample of this extracted root mass was hydrolyzed under nitrogen in 25 ml of 0.1 N NaOH for 24 hours on an orbital shaker and processed as outlined by Dormaar and Willms (1990). Lignin and the monosaccharide components of nonstructural as well as structural carbohydrates were obtained on the remainder of the ethyl ether and methanol/chloroform extracted root material as outlined by Morgenlie et al. (1988).

Qualitative analyses were carried out with a Hewlett Packard 5985B gas chromatograph-mass spectrometer (GC-MS). Identifications were based on a search of the GC-MS data system and authentic samples. Quantitative analyses were conducted with a Hewlett Packard 5840A gas chromatograph, using a 25-m capillary column wall-coated with cross-linked methyl silicon (HP-1) for organic acids and phenols, and a 30-m capillary column wall-coated with 5% diphenyl/95% dimethyl polysiloxane (DB-5) for monosaccharides (Morgenlie 1975).

A decomposibility index was calculated according to Herman et al. (1977) as (C:N) × (% lignin)/(% total carbohydrate$^{-0.5}$). Total carbohydrate was estimated as the sum of soluble and structural carbohydrates.

All data were analyzed statistically using nonparametric tests because the observations varied considerably with sampling time. Trends over time were evaluated with the Mann-Whitney-Wilcoxon test (Lehmann and D'Abrera 1975). Comparisons were made between specific treatments with the Wilcoxon's signed rank test and executed using the univariate procedure in SAS (SAS Institute 1990).

Results

Particle Size and Mass

The comminution of root mass from coarse to fine was significantly ($P<0.01$) greater on the Mixed Prairie site than on the Fescue Prairie for both species (Fig. 1a, Table 1). The extent of this process was greater ($P=0.021$) for rough fescue than blue grama on the Mixed Prairie site but similar ($P=0.659$) for the 2 species on the Fescue Prairie site (Table 1).

Over the duration of the experiment, root mass of blue grama decreased more than that of rough fescue (Fig. 1b). The coarse to fine ratios of blue grama and rough fescue under Mixed Prairie conditions were 1.2 and 1.0, respectively, and under Fescue Prairie were 27 and 54, respectively. The difference was significant ($P=0.012$) within the Black Chernozemic soil-forming conditions on the Fescue Prairie (16.1 vs 12.4%), but not Mixed Prairie ($P=0.156$) under Brown Chernozemic soil-forming conditions (17.5 vs 15.5%). Site affected dry matter losses of only rough fescue

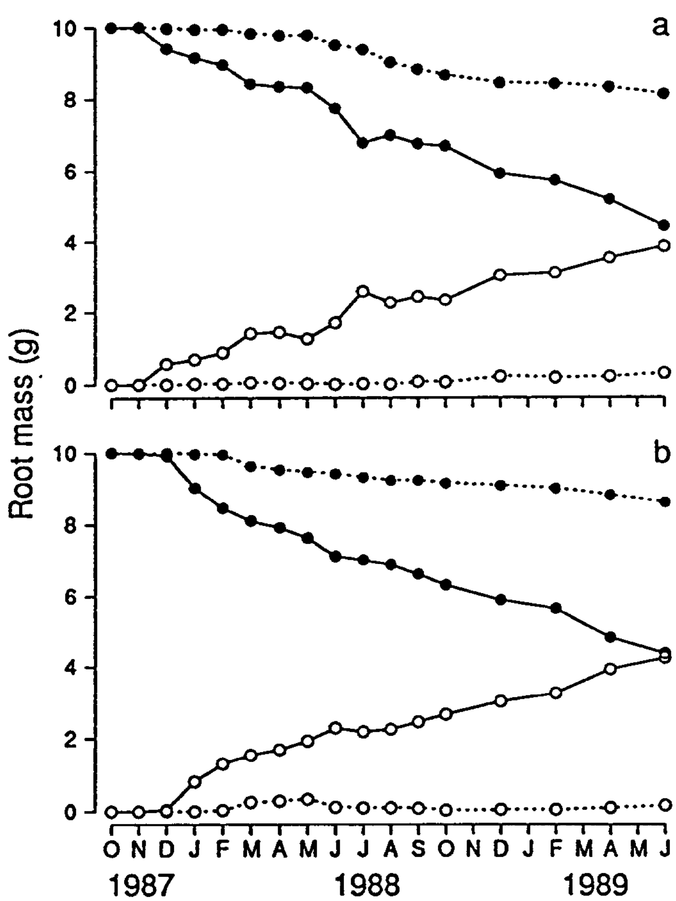

Fig. 1. Root mass (g) of blue grama (Fig. 1a) and rough fescue (Fig. 1b) buried in Mixed (——) and Fescue Prairie (---) Ah horizons (•••• coarse; oooo fine).

Table 1. Statistical probabilities associated with effect of species and site on chemical constituents of buried root mass.

Characteristic	Trends over time[1] Chernozemic soil: Brown, Blue grama A	Brown, Rough fescue B	Black, Blue grama C	Black, Rough fescue D	Comparisons between paired treatments[2]: AB	CD	AC	BD
Coarse (g)	<0.001	<0.001	<0.001	<0.001	0.015	0.131	<0.001	<0.001
Fine (g)	<0.001	<0.001	<0.001	0.045	0.021	0.659	<0.001	<0.001
Loss (g)	<0.001	<0.001	<0.001	<0.001	0.156	0.012	0.501	<0.001
Nitrogen (%)	<0.001	0.009	<0.001	<0.001	0.002	0.811	<0.001	0.049
Carbon (%)	0.043	0.131	0.031	0.363	<0.001	0.006	0.022	0.303
OCH_3 (%)	0.066	0.378	0.004	0.081	0.034	0.074	0.007	0.076
Energy (kJ/g)	0.069	0.209	0.298	0.295	0.018	0.001	0.001	<0.001
Organic acids and phenols (μg/g)	<0.001	<0.001	0.009	0.034	<0.001	<0.001	<0.632	0.940
Structural carbohydrates (mg/g)	<0.001	<0.001	0.078	0.452	0.315	0.537	0.571	0.571
Non-structural carbohydrates (mg/g)	<0.001	0.016	<0.001	<0.001	0.006	<0.001	0.225	0.055
Lignin (mg/g)	0.201	0.075	0.001	0.012	<0.001	<0.001	0.017	0.087
Decomposibility index	0.001	0.005	0.102	0.005	<0.001	<0.001	0.056	0.752

[1]Test against a trend with an adaptation of the Mann-Whitney-Wilcoxon test (Lehmann and D'Abrera 1975).
[2]Wilcoxon's signed rank test (SAS Institute 1990).

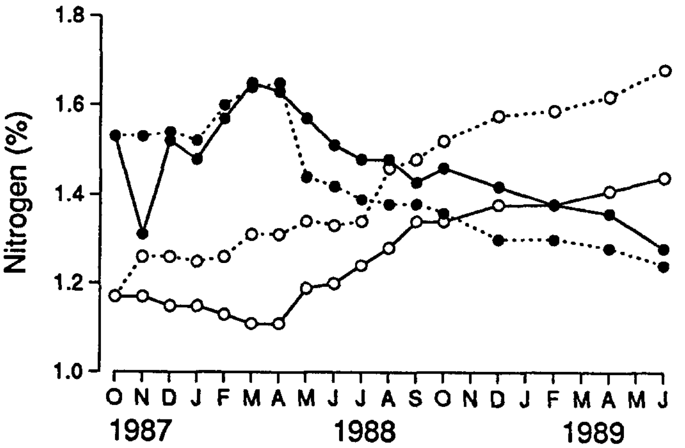

Fig. 2. Total nitrogen content (dry, ash-free) of root mass of rough fescue (••••) and blue grama (oooo) buried in Mixed (—) and Fescue Prairie (---) Ah horizons.

(P<0.01) with greater losses occurring at the Mixed Prairie location.

Nitrogen and Carbon

The N content of blue grama roots increased (P<0.01) over the duration of sampling in both Mixed Prairie and Fescue Prairie sites (Fig. 2, Table 1). Over the same period, N content of rough fescue decreased (P<0.01) despite peaking in late winter of the first year (Fig. 2, Table 1). The N content of blue grama increased more (P<0.01) and that of rough fescue decreased more (P=0.049) on the Mixed Prairie site.

The C content of root mass peaked in late spring and decreased (P<0.05) over the duration of sampling for blue grama on both sites (Fig. 3, Table 1). The C content of blue grama was greater

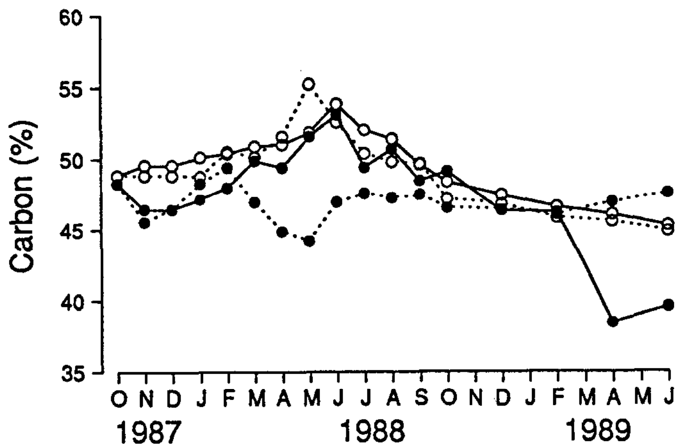

Fig. 3. Total carbon content (dry, ash-free) of root mass of rough fescue (••••) and blue grama (oooo) buried in Mixed (—) and Fescue Prairie (---) Ah horizons.

(P<0.01) than that of rough fescue on both sites and, for blue grama, was greater (P=0.22) on the Mixed Prairie than the Fescue Prairie site.

Methoxyl Groups and Energy

The methoxyl group content varied in a cyclical manner (Fig. 4) and only blue grama on the Fescue Prairie site showed a significant (P=0.004) increase (Table 1). The cycles on the Mixed Prairie site appeared to be inverse to those on the Fescue Prairie site, over the first year, while changes in blue grama tended to lag behind those of rough fescue (Fig. 4). The methoxyl group content in blue grama

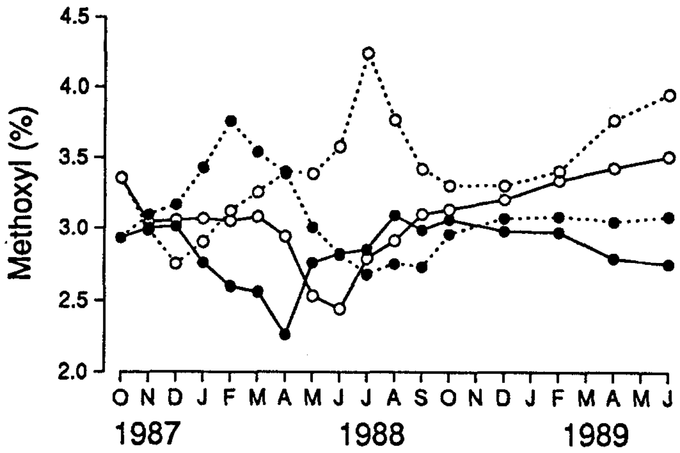

Fig. 4. Methoxyl group content, (dry, ash-free) of root mass of rough fescue (••••) and blue grama (oooo) buried in Mixed (—) and Fescue Prairie (---) Ah horizons.

on the Mixed Prairie site was greater (P=0.034) than in rough fescue and blue grama on the Fescue Prairie site (P<0.01). Decreasing methoxyl content is considered to indicate an increasing degree of humification.

Since cyclical patterns in the energy content of roots of both species were observed (Fig. 5), a linear trend over the duration of the trial was not detected (Table 1). For each species, the energy

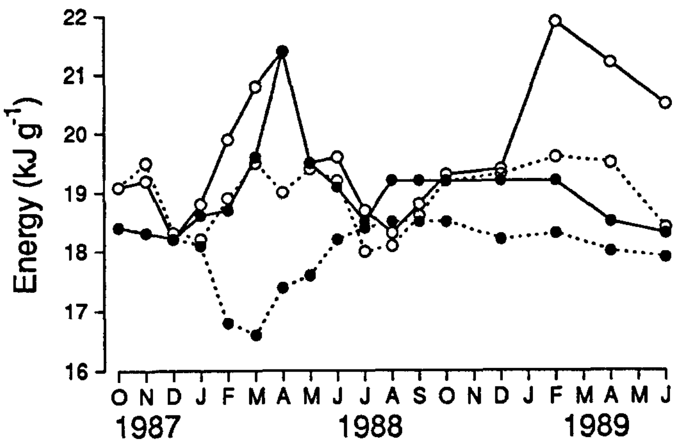

Fig. 5. Energy content (dry, ash-free) of root mass of rough fescue (••••) and blue grama (oooo) buried in Mixed (—) and Fescue Prairie (---) Ah horizons.

content of roots buried in the Mixed Prairie site was greater (P<0.01) than those at the Fescue Prairie site and, at each site, the energy content of blue grama was greater (P<0.05) than that of rough fescue (Fig. 5, Table 1).

Organic Acids and Phenols

The content of organic acids and phenols, representing the sum of the GC outputs, peaked during the first year of study in winter on the Mixed Prairie site and in spring on the Fescue Prairie site (Fig. 6). Over the trial period, their levels decreased significantly (P<0.05, Table 1). Rough fescue had significantly (P<0.01) less organic acids and phenols than blue grama at each site; however, site differences for each species were not detected (P>0.05).

Structural and Non-structural Carbohydrates and Lignin

Structural carbohydrates of rough fescue and blue grama decreased (P<0.01) on the Mixed Prairie site but showed no apparent trend on the Fescue Prairie site although a well-defined

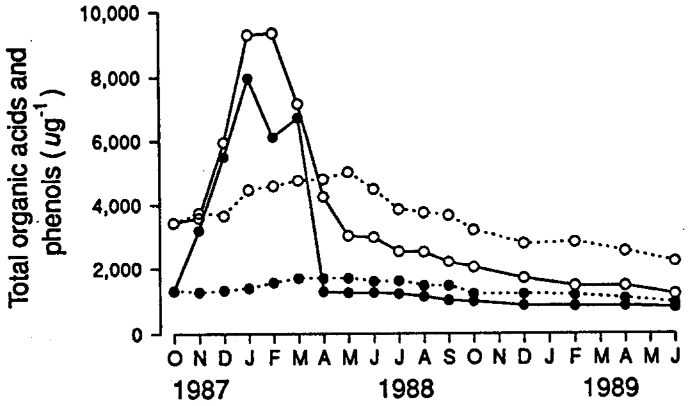

Fig. 6. Total organic acid and phenol content (dry, ash-free) in the alkaline-soluble fraction of solvent-washed root mass of rough fescue (••••) and blue grama (oooo) buried in Mixed (——) and Fescue Prairie (---) Ah horizons.

depression was observed during summer (Fig. 7, Table 1). Structural carbohydrate content did not differ ($P>0.05$) between species by site or between sites by species (Table 1).

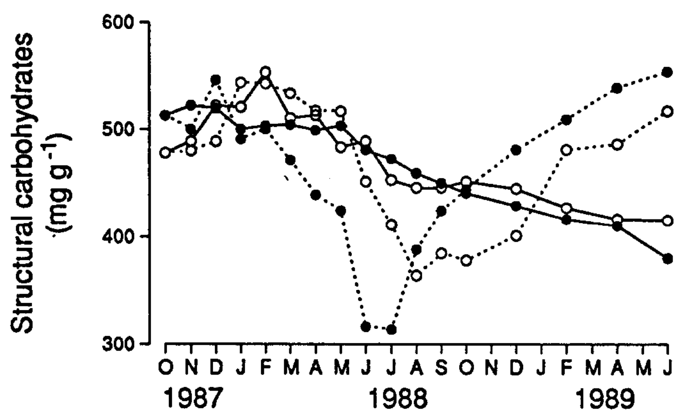

Fig. 7. Structural carbohydrate content (dry, ash-free) of root mass of rough fescue (••••) and blue grama (oooo) buried in Mixed (——) and Fescue Prairie (---) Ah horizons.

Nonstructural carbohydrates decreased for both blue grama ($P<0.01$) and rough fescue ($P<0.05$) (Fig. 8, Table 1). Rough fescue had a greater ($P<0.01$) concentration of nonstructural carbohydrates than blue grama on both sites but the concentration within species did not differ ($P>0.05$) between sites.

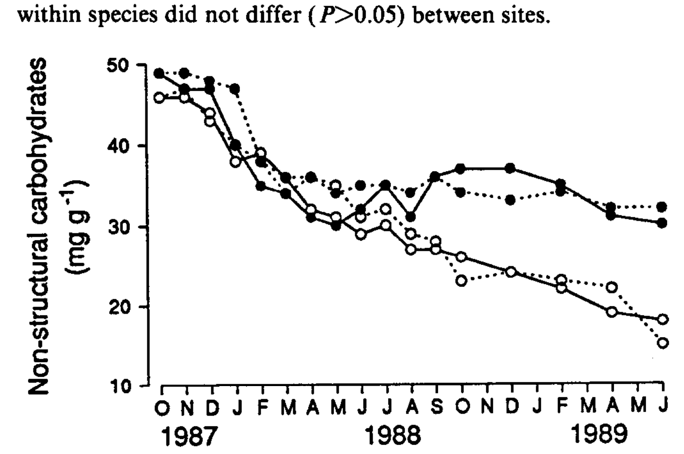

Fig. 8. Nonstructural carbohydrate content (dry, ash-free) of root mass of rough fescue (••••) and blue grama (oooo) buried in Mixed (——) and Fescue Prairie (---) Ah horizons.

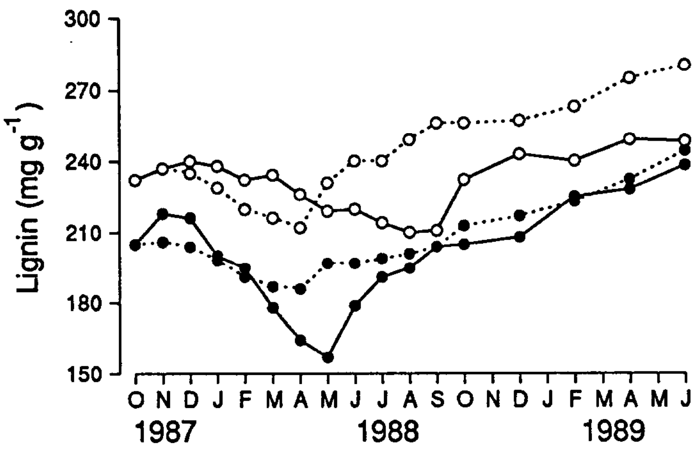

Fig. 9. Lignin content (dry, ash-free) of root mass of rough fescue (••••) and blue grama (oooo) buried in Mixed (——) and Fescue Prairie (---) Ah horizons.

The lignin content was depressed in spring or summer of the first year (Fig. 9) but displayed a significant ($P<0.05$) upward trend for both species only on the Fescue Prairie site (Table 1). Blue grama had a greater lignin content than rough fescue while the content was greater in blue grama on the Fescue Prairie site than the Mixed Prairie site ($P=0.017$).

Decomposibility Index

The decomposibility index of blue grama tended to decrease ($P<0.01$ on Mixed Prairie site and $P=0.102$ on Fescue Prairie site) while rough fescue tended to increase ($P<0.01$) (Fig. 10, Table 1). The index was greater for blue grama than for rough fescue ($P<0.01$) on both sites.

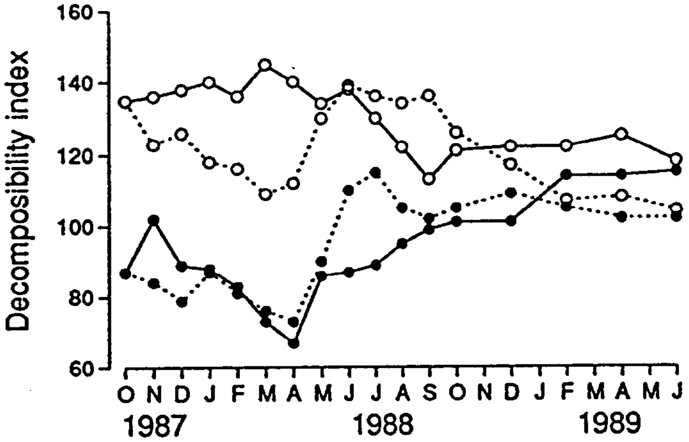

Fig. 10. Decomposibility indices of root mass of rough fescue (••••) and blue grama (oooo) buried in Mixed (—) and Fescue Prairie (---) Ah horizons.

Discussion

Root decomposition and transformation of chemical constituents followed significant trends that were influenced by species and site. The major difference between the soil-forming environments of the 2 sites is soil water content, distinguished by the subarid Mixed Prairie site and the semihumid to subhumid Fescue Prairie site. Even though the use of litter bags may underestimate actual decomposition due to reduced soil-root contact, and it estimates net decomposition only (Wieder and Lang 1982), it is assumed that the results would, nevertheless, reflect trends characteristic of unconfined decomposing root mass and, as such, allow for comparisons among species and sites. Root turnover in the Mixed Prairie has been estimated at 18% annually (Sims and Coupland 1979) while, in the first year of the present study, weight losses were 8.1 for blue grama and 9.1% for rough fescue roots on the Mixed Prairie.

Although soil temperatures were not measured over the duration of the experiment and site comparisons are scarce, greater temperature fluctuations in the soil are expected on the Mixed Prairie than on the Fescue Prairie because of less surface litter (Willms, unpublished data). Temperatures at the 7.5 cm depth in grassland near the Fescue Prairie site (D. Storr, unpublished data) were below 0° C from 25 November 1965 to 30 March 1966 and from 1 December 1966 to 23 March 1967, and varied between -0.3 and -9° C and between -0.7 and -6.1° C, during these periods. That is, the Ah horizon at that depth was frozen solid for about 4 months. Grassland near the Mixed Prairie study site had, during the winter of 1990/91, soil temperatures below 0° C at 0800 hours between 3 November and 14 March with 25 days of above 0° C temperatures scattered through this period. There were 42 days between 3 November and 6 March with temperatures above 0° C at 1600 hour. Although abiotic mechanisms may play only a minor role in the decomposition processes of buried litter (Moorhead and Reynolds 1989), physical breakdown in Brown Chernozemic soils is likely the result of abiotic fragmentation, such as the mechanical force of repeated freezing and thawing. This, together with low biological activity at the Mixed Prairie site vs the Fescue Prairie site (J.L. Neal, Jr., unpublished data), leads to a high proportion (up to 39%) of organic matter being in undecomposed, fragmented form (Dormaar 1977). The increase in surface area of the root mass during the initial stages enhances subsequent intense mineralization (Kononova 1966, Ares 1976) that occurs in arid soil environments. Mineralization, e.g., ammonification (O'Brien 1978), is certainly biotically driven, but is also partly abiotically driven, such as by photo-chemical degradation (Zepp 1988) and fluctuating temperature-moisture regimes (Nyhan 1976). Rain events superimposed on elevated summer soil temperatures are an important driving variable allowing pulses of microbially mediated ammonification (Wildung et al. 1975, Cameron and Kowalenko 1976, Steinberger and Whitford 1988). Similarly, litter left on the surface in deserts is macerated rather than humified, followed by rapid oxidation (West 1979, Montana et al. 1988).

Although, some trends are not statistically significant, several conclusions can be drawn. The present study can be summarized as follows: Physical comminution, regardless of type of root mass, was greatest at the semiarid site. Nitrogen content of rough fescue roots generally decreased while that of blue grama roots generally increased, regardless of site. The C/N ratio of the blue grama roots decreased over time due to increased N content, regardless of site, while that of rough fescue remained the same (semiarid) or even increased (subhumid). Levels of total organic acids and phenols generally decreased, although they increased initially, and under semiarid conditions the levels in blue grama were generally greater than those of rough fescue, regardless of site. Structural carbohydrates first decreased then increased for both species in the subhumid soil environment; conversely, they generally decreased in the semiarid soil environment. Nonstructural carbohydrates decreased at both sites although more slowly for the rough fescue root mass. Finally, lignin of roots of both species initially decreased and then increased at both sites.

It is clear that both soil environment, as determined by site, (A vs C and B vs D, Table 1) and root chemistry (A vs B and C vs D, Table 1) were significant discriminating variables in the complex process of root decomposition. In terms of site, abiotic characteristics, such as freezing/thawing (Environment Canada, Atmospheric Environment Service monthly record meteorological observations in Canada, Ottawa, Ontario) and rain events (Sala and Lauenroth 1982), may well be responsible for initiating breakdown of root mass in the Mixed Prairie. The former could be accepted as the cause of increased root diminution while the latter would allow for increased microbial activity (J.L. Neal, Jr., unpublished data) and hence increased mineralization regardless of species. In terms of substrate chemistry, some of the parameters, such as N, acted independent of site, while others, such as structural carbohydrates, interacted with site.

The organic fraction of the Brown Chernozemic Ah horizon has a large proportion of nonextractable organic constituents consisting of partially decomposed roots and relatively large amounts of clay-associated humus (Anderson 1972, Dormaar 1977). The incentive for the present study was to better understand the dynamics of root decomposition under 2 soil climatic environments. The trends observed underscore the importance of root diminution under Brown Chernozemic soil-forming factors. Differences in substrate quality played a lesser role under the conditions of the experiment. Based on soil moisture and temperature distributions over the summer months (Agriculture Canada Research Station, Lethbridge, Alberta, unpublished weather data file), it is also concluded that the "hydrothermal" conditions probably override, even though differently, substrate quality at both sites.

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