Pasture type and fertilization effects on soil chemical properties and nutrient redistribution

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Chen, W., McCaughey, W. P., Grant, C. A. and Bailey, L. D. 2001. **Pasture type and fertilization effects on soil chemical properties and nutrient redistribution.** Can. J. Soil Sci. **81**: 395–404. Soil samples were collected from beef pastures varying in species composition and fertilizer inputs after being grazed by cow-calf pairs for 4 yr (1995–1998) near Brandon, Manitoba. The objective of this experiment is to examine the impact of 4 yr of continuous rotational grazing on soil chemical properties and nutrient redistribution in mixed alfalfa-grass and pure-grass pastures with or without fertilization. Pastures were established on an Orthic Black Chernozemic, fine sandy-loam soil. Compared with N-fertilized pure-grass pastures, alfalfa-grass pastures had greater seasonal soil mineral-N supply, and tended to have higher total soil C, N and organic C. In grazed systems in this environment, the use of alfalfa as the primary N source may be more profitable and sustainable than using fertilizer N. However, considering the seasonal changes in soil nitrification rate observed in alfalfa-grass pastures, caution needs to be taken when stands with high legume content are used to maximize animal performance, because this may increase the risk of N losses into the environment. Fertilization over a 5-yr period (1994–1998) tended to lower surface soil pH. Application of P significantly increased soil "extractable" P levels in the top 15-cm soil layer. However, K fertilization only increased surface soil "extractable" K slightly compared with unfertilized pastures. There was also no effect of S application on soil "extractable" S. Zone effects on soil mineral N and soil "extractable" P, K and S were limited to the surface (0–7.5 cm). For mineral N, the zone effect seemed to be more pronounced in first rotation than in second rotation. The magnitude of K redistribution was greater than for S and P due to higher K intake and excretion. Use of rotational stocking with short grazing periods appears to have resulted in a relatively even redistribution of nutrients derived from animal excreta.

Key words: Grazing, beef pasture, nitrogen dynamics, sustainability.

Chen, W., McCaughey, W. P., Grant, C. A. et Bailey, L. D. 2001. **Incidence du type de pâturage et de la fertilisation sur les propriétés du sol et la redistribution des éléments nutritifs**. Can. J. Soil Sci. **81**: 395–404. Les auteurs ont prélevé des échantillons de sol dans les pâturages pour bovins de boucherie recouvert d'une végétation variable et fertilisés de diverses façons après quatre années de paissance par des couples vaches-veaux, près de Brandon, au Manitoba. L'expérience devait établir l'incidence de 4 années de paissance continue, en rotation, sur les propriétés chimiques du sol et la redistribution des éléments nutritifs dans les champs de luzerne et de graminées et les champs de graminées bonifiés ou pas. Les pâturages reposaient sur un loam sableux fin de type tchernoziom noir orthique. Comparativement aux pâturages de graminées fertilisés avec de l'engrais azoté, les pâturages de luzerne et de graminées disposent d'une plus grande réserve saisonnière de N minéral et leur sol a tendance à contenir plus de carbone total, d'azote et de carbone organique. Dans de telles conditions, l'usage de luzerne comme principale source d'azote, au lieu d'engrais azotés, pourrait s'avérer plus rentable et plus soutenable. Puisque le taux de nitrification du sol connaît des fluctuations saisonnières dans les pâturages de luzerne et de graminées, on doit néanmoins se montrer prudent en recourant à un peuplement très dense de légumineuses pour maximiser le rendement des animaux. En effet, pareille pratique peut accroître les risques de perte d'azote dans le milieu. Au cours de la période de cinq ans à l'étude (1994–1998), la fertilisation a eu tendance à diminuer le pH du sol de surface. L'application de P augmente sensiblement la concentration de P extractible dans le sol, jusqu'à 15 cm de profondeur. Les engrais potassiques n'accroissent toutefois que légèrement la concentration de K extractible dans le sol de surface, comparativement aux pâturages non traités. L'utilisation d'un engrais S n'a aucune influence sur la concentration de S extractible. Les effets de zone sur la concentration de N minéral et sur celle de P, de K et de S extractibles ne s'observent que dans la couche superficielle du sol (de 0 à 7,5 cm). Ces effets semblent plus prononcés lors de la première rotation que lors de la seconde, pour le N minéral. Le K est mieux redistribué que le S et le P à cause d'une plus grande absorption et excrétion de cet élément. Un régime de mise en pâturage rotatif avec de courtes périodes de paissance semble conduire à une redistribution relativement uniforme des éléments nutritifs par les excréments des animaux.

Mots clés: Paissance, pâturages pour bovins de boucherie, dynamique de l'azote, pérennité

In western Canada, producers are expected to diversify their farms in response to the elimination of grain transportation subsidies and uncertain agriculture commodity prices. Establishing tame pastures for beef production is an important way to diversify farm income and also produce economic value of marginal land (Popp et al. 1997). Tame pastures are important feed resources for livestock production. However, as these pastures have been developed by sowing desirable grass and legume species for animal production, they can be unstable so that even small changes in

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environmental conditions, soil nutrient status or grazing management can lead to rapid changes in botanical composition and thus productivity (Snaydon 1987). A better understanding of the effects of grazing on soil chemical properties and their subsequent influence on nutrient cycling through the soil-plant-animal system is necessary to maintain productivity and sustainability of pastures.

Alfalfa (*Medicago sativa* L.) is an important forage crop on the Canadian prairies as its yield, protein content and palatability are greater than other forage legumes (Simons et al. 1995). Introducing alfalfa into pastures is an effective way to improve livestock production. Experiments conducted at the Brandon Research Centre have shown that by introducing alfalfa into pasture mixtures, nutrition of grazing cattle is substantially improved and yearling beef cattle can gain at rates of up to 1.6 kg d^{-1} (Popp et al. 1997). On alfalfa-grass pastures, calf average daily gains have been observed to be 6–11% higher than on the grass-only pastures (Kopp et al. 1997). Although enhanced beef cattle productivity has been well documented when grazing on sown legume-grass mixed pastures in western Canada, no information exists that documents the impact of intensive grazing on soil chemical properties, nutrient redistribution and their subsequent influence on pasture productivity and environmental sustainability.

In grazed pastures, returns of livestock excreta represent an important recyclable source of soil nutrients because 60–90% of plant nutrients consumed by grazing livestock pass through the digestive tract and return to the pasture in the form of dung and urine (Haynes and Williams, 1993). However, spatial variability of soil nutrients is a major factor affecting recycling of the returned nutrients and the usefulness of soil test results for fertilizer recommendations. Furthermore, when soil nutrients become spatially concentrated on pastures, potential exists for environmental problems due to nutrient losses through volatilization, leaching and runoff. This is particularly true for pastures established on light-textured sandy soils with limited capacity to retain nutrients. The effects of grazing on soil nutrient redistribution in pastures has been reviewed by Mathews et al. (1996), from the soil perspective, and by Peterson and Gerrish (1996), from the livestock perspective. Most published research has compared either the impact of grazing systems (continuous vs. rotational stocking systems) or paddock design (shade and water locations) on soil nutrient redistribution. To date, little information is available on the impact of pasture type and pasture fertilization on soil chemical properties and horizontal and vertical nutrient redistribution. Obtaining this information is important to improve management practices, to ensure efficient nutrient cycling in soil-plant-animal systems and to reduce nutrient losses into the environment while maintaining pasture and animal productivity. The object of this experiment was to examine the impact of 4 yr of rotational grazing on soil chemical properties and nutrient redistribution in mixed alfalfa-grass and pure-grass pastures with or without fertilization.

MATERIALS AND METHODS

Location, Climate and Experimental Design

The experimental site was located 2 km north east of Brandon, Manitoba (49°52′ N; 99°59′ W; 363 m above sea level) on an Orthic Black Chernozemic soil with generally level to very gently sloping terrain. Over the course of the experiment (1995–1998), air and soil temperature (0–5 cm) increased from 11–12°C in May to 20°C in August and then declined to 5–7°C in October. Monthly rainfall varied significantly between years, but in general, rainfall during 1995–1997 (accumulated rainfall from April to October was 283, 334, and 301 mm for 1995, 1996 and 1997, respectively) was much lower than in 1998 (accumulated rainfall in the same period was 533 mm). The plots (3.7 ha each) were used to examine the effects of pasture type and fertility on beef cow-calf production since 1995. The details of experimental plots layout are presented in Fig. 1. Each plot was divided into five paddocks using portable electric fences and grazed rotationally by beef cow-calf pairs, and all plots were arranged side by side; paddock size was 100 m by 74 m

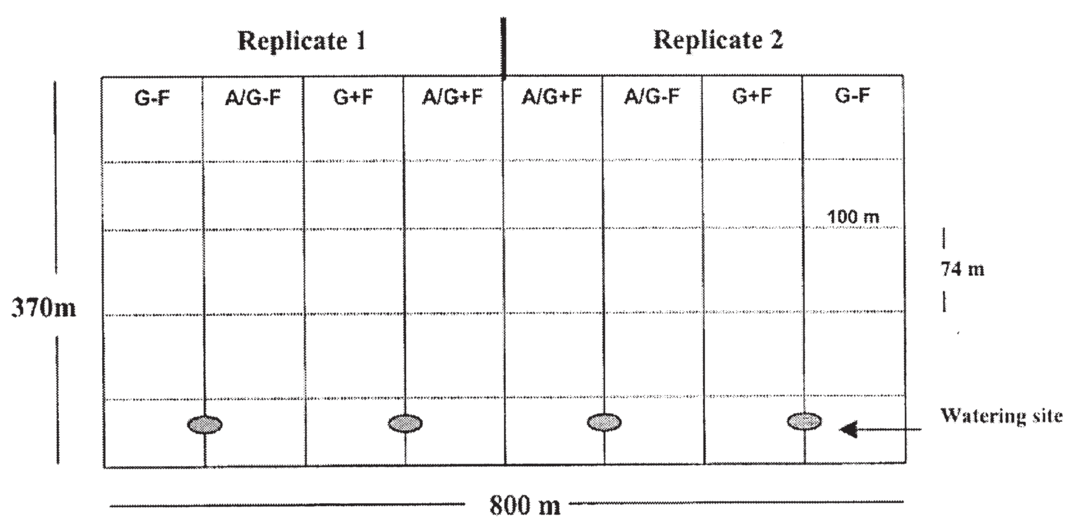

Fig. 1. Layout of experimental plots.

Table 1. Summary of fertilizer application on alfalfa/grass and grass-only pastures during 1994–1998

	Grass-only pasture				Alfalfa/grass pasture			
Year	N[z]	P_2O_5	K_2O	S	N	P_2O_5	K_2O	S
	(kg ha^{-1})[y]							
1994	0	0	50	0	11	50	77	0
1995	95	4	0	30	29	20	0	30
1996	110	22	0	0	9	43	0	0
1997	110	10	0	0	5	22	0	0
1998	68	22	21	0	44	31	16	10

[z]N as urea, P_2O_5 as MAP, K_2O as potash and S as $(NH_4)_2SO_4$.
[y]Application rates based on soil test.

(Fig. 1). The experimental treatments consisted of four combinations of two pasture types and two fertilizer application levels with two replications of each pasture treatment. The four treatments were **alfalfa-meadow bromegrass with fertilizer (A/G + F)**, **meadow bromegrass with fertilizer (G + F)**, **alfalfa/meadow bromegrass without fertilizer (A/G – F)** and **meadow bromegrass without fertilizer (G – F)**.

Fertilizer and Grazing Management

Two pastures, A/G + F and G + F were fertilized in April each year since 1994 at soil test recommended levels (Table 1). On each pasture, four "tester" cow/calf pairs were used for animal data collection and additional cow-calf pairs were used by putting them into experimental plots and taking them out periodically so as to achieve equal and uniform pasture utilization on each paddock of each treatment. Grazing commenced each spring when sufficient forage was available and ended each autumn. Pastures were grazed from 13 June to 21 August in 1995 (69 d), from 15 June to 9 September in 1996 (86 d), from 5 June to 27 August in 1997 (83 d) and from 28 May to 17 September in 1998 (112 d).

Soil Sampling Procedures

Soil samples were taken using a truck-mounted soil probe when cow-calf pairs exited the first and third paddocks in a five-paddock rotation after 4 yr grazing in 1998. Each paddock was divided into three equal-sized zones, based on distance from water (zone distance is 33 m each). Zone 1 was closest to the fence line where water was located and Zone 3 was furthest away from the water, but close to the other fence line within a paddock (Fig. 1). The samples were collected from each zone of each pasture treatment. A well-mixed composite of 12 soil cores was collected along a zigzag line and depth within each zone (Mathews et al. 1994a). Areas where water was located were avoided so that small areas with high concentrations of excreta would not be included in the sample. Soil samples were collected at three depths i.e., 0–7.5 cm, 7.5–15 cm and 15–30 cm during the grazing season. However, sampling depth was extended down to 30–60 cm and 60–100cm at the end of grazing season in September. All soil samples were stored in a cool room with temperature close to 0°C. Surface dead materials and roots were removed as much as possible from soils prior to soil mineral N determination.

Soil Sample Preparation and Chemical Analysis

Soil Mineral N (NH_4^+ + NO_3^-)

Mineral N was determined for all soil samples at field moisture conditions using 2 M KCl extract. A 5.0-g soil sample at field moisture was weighed directly into plastic bottle without pre-treatment and 25 mL 2 M KCl solution was added (soil/solution ratio of 1:5). The bottle was shaken on a horizontal shaker for 30 min at 25°C. The supernatant was filtered through a Whatman 42 filter paper. The NO_3-N and NH_4-N in the extract were determined colorimetrically by autoanalyzer using cadmium reduction and indophenol blue procedures, respectively (Maynard and Kalra 1993). Soil mineral N (NH_4^+ + NO_3^-) was expressed as mg N kg^{-1} soil after field moisture content was corrected, based on oven-drying soil at 105°C overnight.

Soil pH and "Extractable P, K and S

After samples were taken for soil mineral N determination, all samples were oven-dried at 30°C for 48 h. The samples taken at the end of grazing season (September 1998) down to 1 m were ground to pass through a 2-mm sieve prior to soil pH and "extractable" P, K and S determinations. Soil pH was determined in water for all samples (1:5 soil:water). Soil "extractable" P and K were extracted using a solution containing 1 N ammonium acetate, 0.005 N acetic acid and 0.015 N ammonium fluoride. The PO_4-P concentrations were determined colorimetrically using an autoanalyzer, whereas K concentrations were determined using a flame photometer (Ashworth and Mrazek 1995). Soil "extractable" S was extracted with 0.001 M calcium chloride solution and analyzed colorimetrically by autoanalyzer.

Total Soil C, N and Organic C

Following the analysis of soil pH, extractable P, K and S, soil samples from the top 15-cm soil layers collected in September were sub-sampled and further ground to pass a 100-mesh screen using a Ball Grinder [Retsch/Brinkmann Mixer Mill, Model MM 2000, Brinkmann Instruments, (Canada) Ltd., Mississauga, ON]. Soil samples were treated with 2 M HCl to remove inorganic C prior to analyses of organic C. Total soil C, N and organic C were determined using a combustion technique with an elemental analyzer (Carlo Erba Instrument, NCS 2500 Elemental Analysis).

Table 2. Total mineral N (mg N kg^{-1} soil, % of total mineral N as ammonium in parentheses) over time and down soil profile in 1998

	Pastures[z]					Contrasts		
Sampling time	A/G + F (T_1)	G + F (T_2)	A/G – F (T_3)	G – F (T_4)	SEM[y]	T_1 vs. T_3	T_2 vs. T_4	T_1T_3 vs. T_2T_4
		0–7.5 cm						
June	10.7 (50)	10.0 (20)	7.0 (45)	2.8 (17)	2.6	*	*	NS
July	21.0 (4)	6.3 (14)	15.1 (10)	4.7 (17)	4.8	NS	NS	**
August	21.9 (4)	9.0 (8)	9.6 (7)	5.5 (9)	3.1	**	NS	**
September	9.7 (85)	3.5 (72)	6.5 (84)	2.0 (43)	4.1	NS	NS	NS
		7.5–15 cm						
June	1.8 (1)	2.0 (2)	1.7 (4)	1.3 (5)	0.1	**	**	NS
July	6.2 (17)	2.9 (37)	2.9 (40)	2.7 (41)	1.1	NS	NS	NS
August	4.6 (9)	2.5 (17)	2.7 (16)	2.6 (15)	1.7	NS	Ns	NS
September	1.2 (26)	1.0 (38)	1.2 (32)	1.8 (22)	0.2	NS	**	NS
		15–30 cm						
June	1.8 (10)	2.0 (3)	1.4 (4)	0.8 (8)	0.4	NS	*	NS
July	2.4 (61)	1.5 (100)	1.8 (91)	2.0 (78)	0.8	NS	NS	NS
August	1.9 (29)	1.2 (49)	1.3 (46)	1.4 (38)	0.5	NS	NS	NS
September	0.8 (0)	0.6 (0)	0.7 (0)	0.8 (0)	0.3	NS	NS	NS
		30–60 cm						
September	0.9 (0)	0.6 (0)	1.0 (0)	0.8 (0)	0.2	NS	NS	NS
		60–100 cm						
September	1.1 (0)	0.9 (0)	1.4 (0)	1.3 (0)	0.8	NS	NS	NS

[z]A/G + F alfalfa/meadow bromegrass with fertilizer; G + F meadow bromegrass only with fertilizer; A/G – F without fertilizer; G – F without fertilizer.
[y]SEM, Standard error of mean (*n* = 6 three zones and two reps).
*, ** $P < 0.05$ and $P < 0.01$, respectively; NS, not significant.

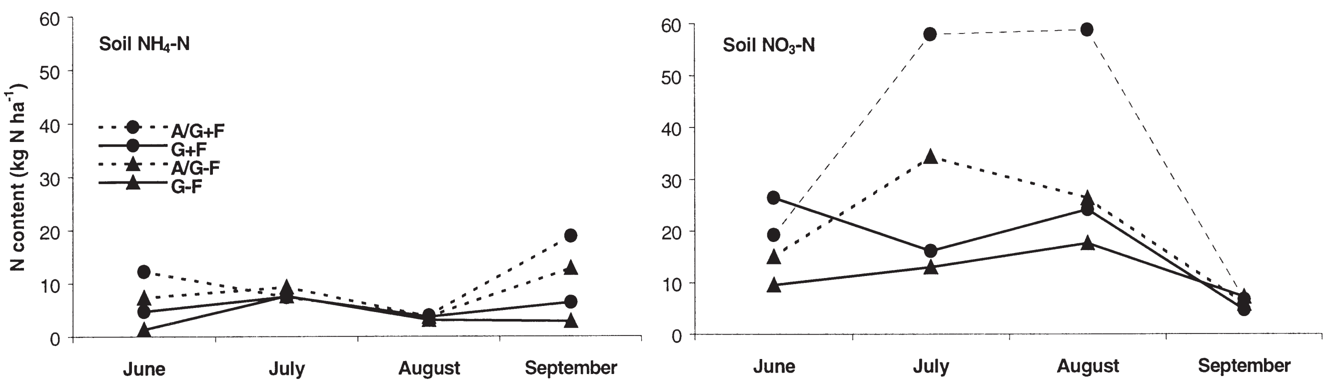

Fig. 2. Soil mineral N content and transformation in the top 30 cm soil layer over 1998 growing season.

Plant Sampling, Preparation and Analysis

Before cow/calf pairs entered paddock 3 of each pasture, hand clippings of quadrats (0.25 m^2) were taken to estimate forage productivity and collect plant samples for N analysis from 1995 to 1997. The samples collected in paddock 3 of each pasture, were oven-dried at 60°C for 48 h and grounded to pass a 0.5-mm sieve for N analysis (Association of Official Analytical Chemists [AOAC] 1984, method no. 7.025). However, in 1998, to estimate N_2 fixation by alfalfa, plant N concentration was measured using an automated combustion technique with a continuous flow mass spectrometer, and using the plant samples collected from six microplots (1 m by 0.5 m) established in the paddock 3 of each pasture (Chen et al. 1999). Plant N content in all treatments was calculated based on dry matter yield and plant N concentration.

Data Analysis

Soil mineral N was analyzed separately for each sampling time at each soil depth with repeated measures using GLM procedure of the SAS Institute (SAS Institute, Inc. 1989). In the analysis, a completely randomized design was used with pasture as the main treatment and zone as repeated measure. Similar analysis was also used for soil pH and "extractable" P, K and S, and total soil C, N, and organic C data at the end of the grazing season. For plant N data, a mixed model was used for AOV analysis with pasture as fixed effect and year as random effect (SAS Institute, Inc. 1989).

RESULTS

Soil Mineral N Dynamics

Differences between the four pasture treatments in soil mineral N in the top 15 cm of the soul profile depended on sampling time (Table 2). In June, mineral N concentrations in the fertilized pastures (A/G + F, G + F) were significantly higher than in the unfertilized pastures (A/G – F, G – F). However, in the summer (July and August), soil mineral N concentrations in the mixed pastures (A/G + F, A/G – F)

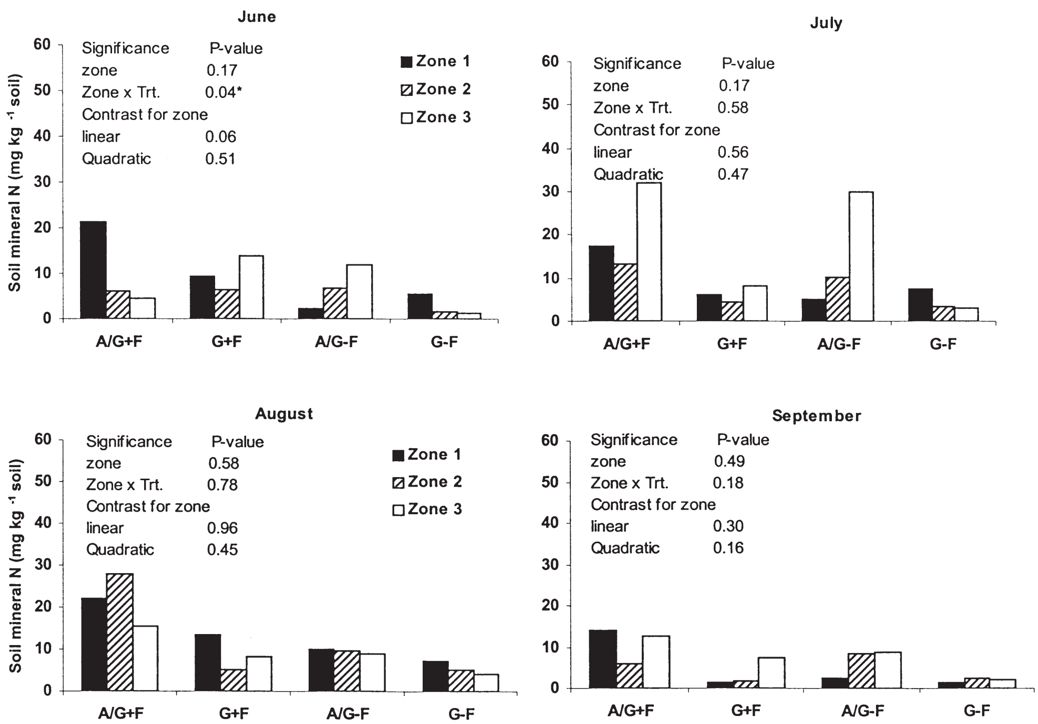

Fig. 3. Redistribution of soil mineral N in the top 7.5 cm layer over 1998 grazing season.

were significantly higher than in the pure grass pastures (G + F, G – F) in the top 7.5 cm of the soil profile (Table 2).

Total soil mineral N content (kg N ha^{-1}) in the top 30 cm of soil profile was calculated based on soil mineral N concentrations and a bulk density factor for sandy loam (2.2). The amount of soil mineral N, as NO_3-N, varied greatly over the season, particularly for the mixed pastures (A/G + F, A/G – F) with NO_3-N being predominant in the summer (Fig. 2). Although there was considerable variation in soil mineral N among the pastures, at the end of the grazing season (September 1998), soil NO_3-N concentrations down to 1 m were low (0.9–1.4 mg kg^{-1} soil) without any significant differences between the four pastures (Table 2).

There was no overall effect of zone on soil mineral N down the entire profile except for the top 0–75 cm soil layer where there was a significant interaction between pasture and zone in the June sampling period (Fig. 3). Also, soil mineral N tended to accumulate at the soil surface near the watering site and fence line (Zones 1 and 3) to a greater extent in the first rotation (June and July) than in the second rotation (August and September) (Fig. 3).

Soil pH and Soil “Extractable” P, K, and S

There was no significant effect on soil pH (Table 3). However, at the top 0–7.5 cm soil layer, soil pH in the fertilized pastures (A/G + F, G + F) tended to be numerically lower than in the unfertilized pastures (A/G – F, G – F) (Table 3). Overall, treatment effects on soil “extractable” nutrients were not significant except for P. For mixed pastures, soil “extractable” P in A/G + F was significantly higher than in A/G – F in the 0–7.5, 7.5–15 cm soil layers. However, for pure-grass pastures, soil “extractable” P in G + F was significantly lower than in G – F in the 7.5–15, 15–30 cm soil layers. Soil “extractable” P from 60 to 100 cm in the alfalfa-grass pastures (A/G + F, A/G – F) was significantly lower than in the pure grass pastures (G + F, G – F). Although there was no overall treatment effects on soil extractable K, K levels in the fertilized pastures (A/G + F, G + F) were numerically higher than in the unfertilized pastures (A/G – F, G – F) in the 0–7.5 cm soil layer. There was also no apparent treatment effects on soil “extractable” S (Table 3).

Soil “extractable” P, K and S did not differ significantly among zones throughout the soil profile. However, in the top 0–7.5 cm soil layer, there appeared to be high accumulations of soil “extractable” K and S near watering sites and fence lines (Zone 1 and 3), particularly for K in the fertilized pastures (Fig. 4).

Total Soil C, N and Organic C

In the 0–7.5, 7.5–15 cm soil layers, total soil C, N and organic C did not differ significantly among treatments. However, there appeared to be a trend that total soil C, N and organic C slightly increased when legume or fertilizer was introduced into these pastures (Table 4).

Plant N Content

There was a significant treatment effect with strong interactions between treatment and year in plant N content (Fig. 5). In general, using alfalfa in mixed and N fertilizer in pure pastures significantly increased plant N content (Fig. 5). There were no overall differences in plant N content

Table 3. Soil pH and "extractable" P, K and S (mg kg^{-1} soil) down soil profile at the end of the 4 yr grazing in 1998

	Pastures[z]					Contrasts		
Soil depth	A/G + F (T_1)	G + F (T_2)	A/G – F (T_3)	G – F (T_4)	SEM[y]	T_1 vs. T_3	T_2 vs. T_4	T_1T_3 vs. T_2T_4
		Soil pH						
0–7.5	7.3	7.3	7.6	7.6	0.3	NS	NS	NS
7.5–15	7.6	7.6	7.6	7.7	0.4	NS	NS	NS
15–30	8.1	8.2	8.1	8.1	0.2	NS	NS	NS
30–60	8.3	8.4	8.4	8.4	0.2	NS	NS	NS
60–100	8.6	8.7	8.6	8.5	0.2	NS	NS	NS
		Soil "extractable" P						
0–7.5	25.8	17.0	11.8	20.2	2.3	***	NS	NS
7.5–15	9.5	6.0	4.0	10.3	1.5	**	**	NS
15–30	3.7	3.0	3.3	5.8	1.3	NS	*	NS
30–60	5.5	5.0	5.2	6.7	0.5	NS	NS	NS
60–100	3.7	5.2	3.7	5.8	1.2	NS	NS	*
		Soil "extractable" K						
0–7.5	187.5	184.3	169.5	135.0	38.9	NS	NS	NS
7.5–15	68.2	76.8	66.2	80.0	25.3	NS	NS	NS
15–30	76.2	87.3	79.8	78.7	19.6	NS	NS	NS
30–60	66.0	69.5	70.7	74.5	10.8	NS	NS	NS
60–100	45.7	68.2	59.0	66.3	15.3	NS	NS	NS
		Soil "extractable" S						
0–7.5	10.7	7.0	7.0	8.3	2.1	NS	NS	NS
7.5–15	6.7	6.7	5.5	6.7	3.4	NS	NS	NS
15–30	4.7	4.2	2.8	4.3	2.0	NS	NS	NS
30–60	4.2	1.8	1.8	2.0	1.0	*	NS	NS
60–100	3.3	3.0	2.5	1.8	2.1	NS	NS	NS

[z]A/G + F alfalfa/meadow bromegrass with fertilizer; G + F meadow bromegrass only with fertilizer; A/G – F without fertilizer; G – F without fertilizer.
[y]SEM, Standard error of mean (*n* = 6 three zones and two reps).
*, **, *** $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively; NS, not significant.

between A/G – F and G + F. Compared with A/G – F, P-based fertilization in alfalfa/grass pasture (A/G + F) significantly increased plant N content only in 1995 and 1998. Total seasonal plant N uptake was calculated after N_2 fixation by alfalfa being taken into account. N_2 fixation by alfalfa was estimated using ^{15}N-enriched isotope dilution method (Chen et al. 1999). Total plant N uptake was comparable to soil NO_3-N supply (Table 5).

DISCUSSION

Soil and Plant N Dynamics

In pasture soils, the amount of soil mineral N that is present at any time, is dependent upon the balance of inputs (e.g., fertilizer, fixations by legume, mineralization of soil organic matter and recycled N in excreta returns) and removal in animal and plant products and other losses (Ryden 1984). Monitoring seasonal changes in soil mineral N under grazed systems is important to evaluate the synchronization between the soil N supply and N demand by pasture species.

At the beginning of the grazing season (June), soil mineral N (0–15 cm) was higher in the fertilized pastures than in the unfertilized pastures (Table 2) due to N fertilizer broadcast in the spring (Table 1). A large increase in soil mineral N in the top 30-cm layer over the summer (July and August) was observed, particularly for the alfalfa-grass pastures (Fig. 2). High soil mineral N in the alfalfa-grass pastures during the summer (Fig. 2) may be closely related to high plant N content (Fig. 5), and the subsequent rapid turnover rate of alfalfa litter and root in soil. It has been documented that for decomposing materials, the lower the C:N ratio the more rapid is the mineralization (Wedin and Tilman 1990). The roots and herbage of legumes usually have C:N ratios in the range of 13:1 to 20:1 (Marstorp and Kirchman 1991) and thus will tend to mineralize N more readily than grasses. Mytton et al. (1993) also suggest that the presence of legumes such as white clover (*Trifolium repens* L.), in swards could improve soil structure, which, in turn, may increase mineralization rate.

The seasonal change of soil mineral N observed in our experiment was also associated with seasonal change in soil conditions in this environment. It has been reported that soil mineralization rate varies with season of the year, mainly in response to soil temperature and moisture status (Standford and Epstein 1974; Jarvis et al. 1996). Variations in summer rainfall during our experiment often result in soil wetting/drying sequences. This, in turn, would also favor soil mineralization (Campbell et al. 1988) particularly for soils with high N return from litter and roots, as wetting/drying cycles could increase the availability of substrates for microbial activity (Jarvis et al. 1996).

Nitrification is a particularly important process as it reflects the transfer rate from the large pool of relatively immobile NH_4-N through to NO_3-N, which is vulnerable to leaching and denitrification. In our experiment, high accumulations of NO_3-N in the top 30-cm soil layer in the summer, particularly for the mixed pastures (Fig. 2), indicate short-term excessive NO_3-N supply, presumably due to the favorable soil conditions for nitrification (Harrison et al. 1994; Whitehead 1995) during the summer, rather than low

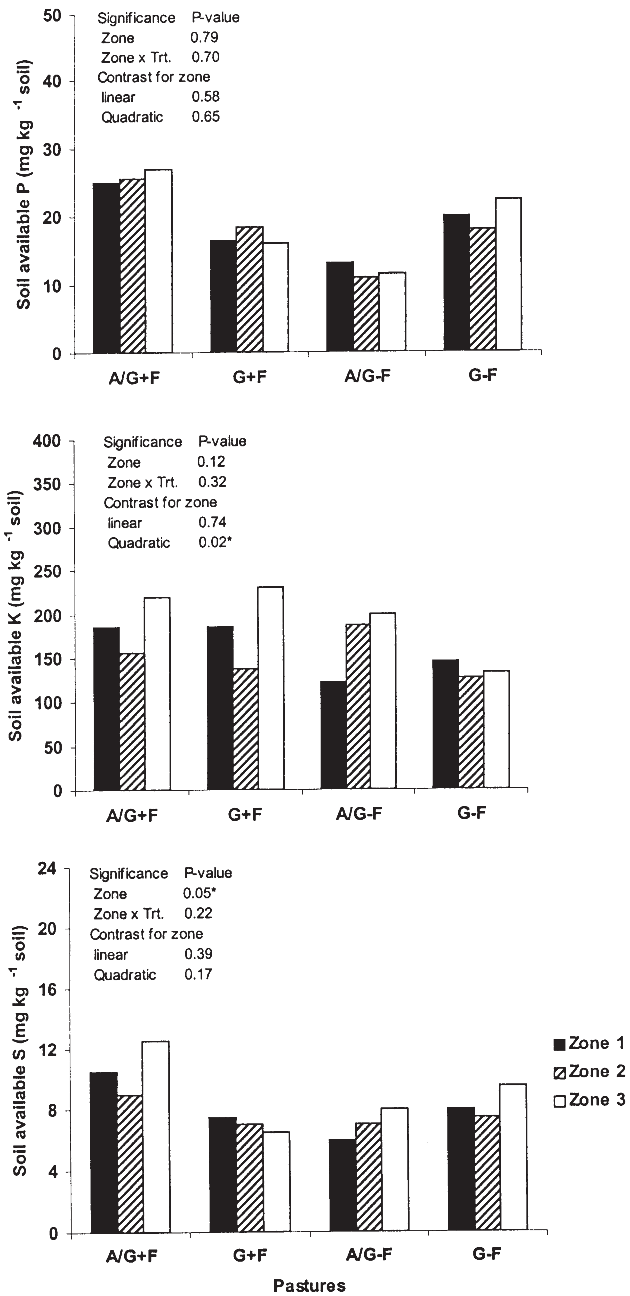

Fig. 4. Redistribution of the surface soil "extractable" P. K and S in pastures at the end of the four years grazing in 1998.

plant N uptake, as indicated in Table 5. Significant accumulations of NO_3-N in the top 30 cm soil layer observed in the present experiment (Fig. 2), could increase the risk of NO_3-N losses into the ground water (leaching) and the atmosphere (denitrification) if soil NO_3-N levels exceed pasture N demand and a significant rainfall event occurs. However, low NO_3-N concentrations (0.9–1.4 mg kg^{-1} soil) down to 1 m recorded at the end of the grazing season suggest that leaching of NO_3-N might be limited compared with other loss pathways being studied in our experiment. The comparison made in Table 5 suggest that total seasonal N uptake from soil by pasture species appeared to be comparable with soil NO_3-N levels in the top 30 cm soil layer and this could be the main mechanism limiting NO_3-N leaching in our environment. However, more research is needed to quantify N loss pathways in these pastures, particularly in relation to soil mineral N variation, transformation and interactions with N return from animal excreta.

Soil "Extractable" P, K and S

Higher soil "extractable" P in the top 15-cm layer in A/G + F than in A/G – F (Table 3) was directly attributed to the P fertilization over years (Table 1). Lower soil "extractable" P down to 1 m in A/G + F and A/G – F compared with G + F and G – F could be associated with the deep rooting depth of alfalfa and thus more P uptake at depth. In the 7.5–15 and 15–30 cm soil layers, lower soil " extractable" P in G + F than in G – F (Table 3) could result from greater subsoil P uptake by meadow bromegrass, presumably due to better root development from the N application in G + F than in G – F. Application of K at pasture establishment in 1994 and later in 1998 increased soil "extractable" K slightly in the top 7.5-cm soil layer in A/G + F and G + F (Table 3). Application of S on the pure-grass pastures in 1995 and on the alfalfa-grass pastures in both 1995 and 1998 (Table 1) did not affect soil "extractable" S levels (Table 3).

Redistribution of Soil Mineral N and "Extractable" P, K and S

By comparing a standard method of transect soil sampling and subsequent contour mapping with zone soil sampling (zones are determined by distance from water, shade and supplemental feeders, Mathew et al. (1994a) concluded that zone soil sampling was a useful and practical tool for describing nutrient redistribution in pastures. Zone soil sampling was used in this experiment to characterize the redistribution of soil nutrients.

Increased N inputs (derived from alfalfa N_2 fixation and N application) only affected redistribution of the surface soil mineral N early in the grazing season (Fig. 3). This observation could be related to higher pasture N intake by cows in the early grazing season (June and July) than in the later grazing season (August and September). Lack of zone effects on the surface soil mineral N could also indicate large urine N losses into the atmosphere as N from cow urine is vulnerable to ammonia volatilization and denitrification, particularly during the summer (Haynes and Williams 1993).

In this experiment, the zone effect appeared to be more profound for soil "extractable" K and S than P, particularly for K in the fertilized pastures (Fig. 4). This is consistent with the literature (Mathews et al. 1996; Peterson and Gerrish 1996). In intensively managed pastures, the magnitude of K redistribution is likely to be more than that of P and S due to high K intake and excretion. Also, K unlike N is not subject to gaseous losses. Relatively high K accumulations near watering sites and fence lines in A/G + F and G + F compared with A/G – F and G – F, may be partly related to a previous large applications of K at establishment in 1994 and a more recent K application in the spring of 1998

Table 4. Total soil C and N at the end of the 4 yr grazing in 1998

	Pastures[z]						
Soil depth (cm)	A/G + F	G + F	A/G – F	G – F	SEM[y]	CV (%)	*P*-value
		Total N (%)					
0–7.5	0.18	0.17	0.16	0.15	0.06	29	0.17
7.5–15	0.17	0.16	0.16	0.15	0.05	25	0.17
		Total C (%)					
0–7.5	1.99	1.86	1.77	1.64	0.68	32	0.14
7.5–15	1.87	1.74	1.74	1.75	0.60	28	0.14
		Organic C (%)					
0–7.5	1.83	1.80	1.61	1.60	0.70	30	0.12
7.5–15	1.71	1.66	1.60	1.61	0.54	24	0.04

[z]A/G + F alfalfa/meadow bromegrass with fertilizer; G + F meadow bromegrass only with fertilizer; A/G – F without fertilizer; G – F without fertilizer.
[y]SEM, Standard error of mean (*n* = 6 three zones and two reps).

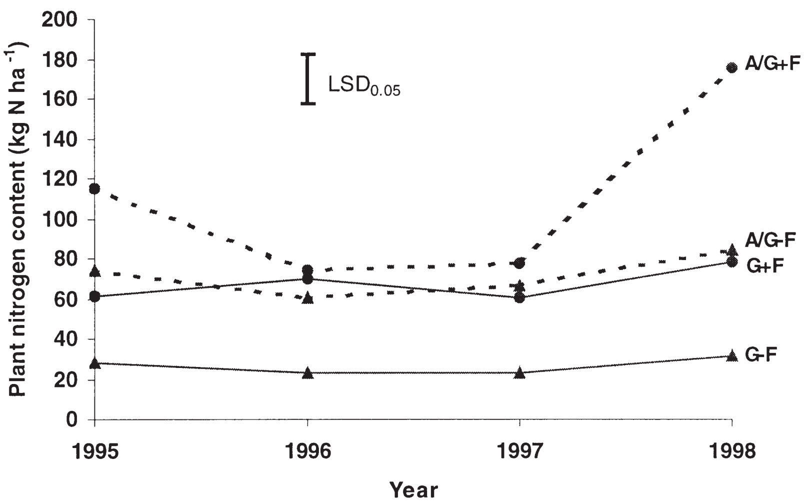

Fig. 5. Pasture plant N content on offer in four pasture systems during 1995–1998.

Table 5. Soil NO_3-N supply (top 30 cm layer) and total N uptake by pasture species

	Rotation 1	Rotation 2
	Soil NO_3-N cupply (kg N ha^{-1})	
A/G – F	34	26
A/G + F	58	59
	Total plant N uptake from soil (kg N ha^{-1})	
A/G – F	27	19
A/G + F	72	42

(Fig. 4, Table 1). Similarly, recent S application (10 kg S ha^{-1} in 1998) in A/G + F also led to S accumulations along the fence line (Fig. 4). S application in A/G + F could increase plant S concentration and thus result in high S intake by cows leading to more S excreted in urine (Chen 1998). Soil "extractable" P was evenly distributed in this experiment and this result was also supported by the two visual observations in the spring 1998 and 1999 that the dung from cows appeared to be evenly distributed across each paddock. The above observations suggest that nutrients predominantly or partly excreted in urine (K and S) appeared to be more likely to be spatially concentrated on pastures, particularly with increased inputs of these nutrients, than those predominantly excreted in dung such as P (Haynes and Williams 1993).

No clear trend of nutrient transfer to watering sites was observed. Compared with other experiments (Gerrish et al. 1993; Mathews et al. 1994a,b) relatively small amounts of nutrients were transferred to either the watering site or fence lines. This may be attributed to the rotational grazing system used in this experiment. Furthermore, the layout of the pasture plots, small paddock sizes and short distances to watering sites in this experiment (Fig. 1) could also contribute to relatively small magnitude of soil nutrient redistribution.

IMPLICATIONS TO PASTURE AND GRAZING MANAGEMENT

The findings from this experiment have several implications to pasture and grazing management. For tame pastures, N is the first limiting nutrient and it has the most profound effect on pasture productivity. This experiment suggests that alfalfa/grass pastures can increase soil mineral N supply through alfalfa N_2 fixation and improve pasture seasonal productivity. A recent experiment conducted at the Brandon Research Centre of Agriculture and Agri-Food Canada indicated that meadow bromegrass in alfalfa-grass pastures (approximately 30–40% alfalfa), with or without fertilizer, was able to produce dry matter yield similar to pure meadow bromegrass swards either receiving 0 or 100 kg N ha^{-1} fertilizer (Kopp J., personal communication). McCaughey and

Simons (1998) also suggested that fertilization of dryland grasses may not be profitable. However, considering the accumulations of soil NO_3-N over the growing season (June to September) in our experiment, caution needs to be taken when considering grazing of high-legume content swards to maximize animal productivity in this environment. This is because high-legume content pastures could increase the proportion of N in the cattle diet excreted in urine (Haynes and Williams 1993). Grazed swards with a high percentage of legumes could also lead to excessive soil NO_3-N carrying over at the end of grazing season, and increase the risk of N losses into the environment in the fall and early spring when plant N requirement is low.

Long-term productivity of legumes may be sensitive to soil P, K and S levels. Application of these nutrients is often necessary to maintain productivity and persistence of legumes in mixed swards. As inputs of these nutrients increase, managing nutrient redistribution on pastures should become the producer goal. This can reduce environmental degradation resulting from nutrient losses in small concentrated areas (e.g., near water, shade and supplement feeders), improve nutrient recycling and in the long-term will reduce fertilizer requirements (Mathews et al. 1996; Peterson and Gerrish 1996). This experiment demonstrates that rotational grazing with short grazing periods can be a useful management tool to achieve even excreta return and thus enhance uniformity of soil nutrient redistribution. In annually fertilized tame pastures, which have been intensively grazed over a number of years, zone sampling may be a useful tool to characterize soil nutrient status, particularly for K and S. This would allow paddocks to be fertilized accordingly or it may even be possible to vary fertilizer rate within a paddock if economically feasible.

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