The Effect of Formulation and Amount of Potassium Fertilizer on Macromineral Concentration and Cation-Anion Difference in Tall Fescue

M. L. Swift,^{*1} S. Bittman,[†] D. E. Hunt,[†] and C. G. Kowalenko[†]

^{*}Abbotsford Veterinary Clinic, 200-33648 McDougall Avenue, Abbotsford, British Columbia, Canada V2S 5Z5

[†]Pacific Agri-Food Research Centre, Agriculture and Agri-Food Canada, Box 1000 Agassiz, British Columbia, Canada V0M 1A0

ABSTRACT

This study investigated the feasibility of altering the dietary cation-anion difference (DCAD) in grass by altering the grass variety and the amount and formulation of K fertilizer application. In experiment 1, treatments were combinations of 2 varieties (Barcel and HiMag) of tall fescue (*Festuca arundinacea* Schreb); 2 rates of K (0 and 250 kg/ha), supplied as KCl; and 2 rates of Mg (0 and 60 kg/ha), supplied as MgO. In experiment 2, K fertilizer was applied at 0 or 125 kg/ha as KCl or K₂SO₄. There was no difference between HiMag and Barcel tall fescue in the concentrations of Mg, S, and Cl. Application of K fertilizer decreased concentrations of Mg, but the magnitude of the decrease was not consistent across harvests. Conversely, application of Mg fertilizer increased Mg concentrations, but again, the magnitude of the increase was not consistent across harvests. The concentrations of Ca were higher in HiMag than in Barcel tall fescue, with the magnitude of the difference increasing from first to last harvest. Potassium fertilizer decreased Ca concentrations in the first, fourth, and fifth harvests only. Calcium concentration was decreased by a greater magnitude in HiMag tall fescue as a result of Mg fertilization. The HiMag tall fescue contained lower concentrations of K than did Barcel tall fescue in the first, second, and third harvests. Application of K fertilizer increased the K concentration in all 5 harvests but did not affect Na concentrations except in the last harvest. The HiMag tall fescue contained less Na than did Barcel, but the magnitude of the difference was affected by K and Mg fertilization. Application of K fertilizer decreased S concentrations in first-harvest grass, increased concentrations in second- and third-harvest grasses, and had no effect in fourth- or fifth-harvest grasses. Application of Mg fertilizer decreased S concentrations of tall fescue. Application of K fertilizer increased DCAD values for grass harvested

from the second through fifth harvests. The increase in DCAD attributable to K fertilizer was less in HiMag than in Barcel tall fescue. Application of K fertilizer as K₂SO₄ increased dry matter yield and S concentrations of HiMag tall fescue, whereas K applied as KCl increased concentrations of K and Cl. There was no effect of fertilizer formulation on Na concentrations. The DCAD was lower in HiMag tall fescue fertilized with K₂SO₄ compared with that fertilized with KCl. This study showed that DCAD of grass can be manipulated by the choice of grass variety, fertilizer formulation, and fertilizer application rate.

Key words: fertilizer, macromineral, cation-anion difference, grass

INTRODUCTION

Milk fever is a costly metabolic disease in terms of lost milk production and expenses incurred for veterinary treatment. In addition, indirect costs may be incurred because of increased risk of associated health problems and culling. Studies have helped both to elucidate the etiology and effects of milk fever (Kamgarpour et al., 1999; Gröhn et al., 2003; Østergaard et al., 2003) and to provide strategies for reducing the incidence of milk fever (Horst et al., 1997; Sörensen et al., 2002). Both the concept of DCAD and its manipulation have been investigated to prevent the occurrence of milk fever postpartum (Block, 1994; Moore et al., 2000). The concept of DCAD, based on increasing dietary anion concentrations relative to cations, has been calculated as milliequivalents of (Na + K) – (Cl + S) (Block, 1994). Increasing dietary anion concentrations reduces blood and urine pH, and this reduction is associated with a reduced incidence of milk fever (Horst et al., 1997). Dietary anion concentrations are typically increased by adding anionic salts such as calcium chloride, magnesium chloride, magnesium sulfate, and calcium sulfate or by adding hydrochloric acid (Goff et al., 2004).

Grass-based feeding programs can present unique challenges to the successful implementation of the DCAD concept. The high concentrations of K that can be found in grass herbage (Fisher and Bates, 1986;

Received July 11, 2005.

Accepted September 14, 2006.

¹Corresponding author: pacificagri@shaw.ca

Moore et al., 2000; Roche et al., 2002) necessitate feeding large amounts of anionic salts, which can decrease the palatability of the diet (Oetzel and Barmore, 1993). In some cases, decreasing the DCAD of grass-based diets to negative values, as recommended in the literature (NRC, 2001), is impractical.

The scientific literature contains several reports on the success of breeding forage grasses to increase the concentrations of Mg to alleviate hypomagnesemia, commonly known as grass tetany (Moseley and Baker, 1991; Wilkinson and Mayland, 1997; Crawford et al., 1998). In the studies reported by Wilkinson and Mayland (1997) and Sabreen et al. (2003), the concentrations of K were reduced in the grasses bred to contain higher concentrations of Mg. In addition, the concentrations of Ca and Mg were increased, which resulted in a lower grass tetany ratio, defined as the ratio of K to the sum of Ca and Mg (Smith et al., 1999).

Pehrson et al. (1999), investigating the effect of applying different formulations and amounts of K fertilizers on DCAD levels in primary and first-regrowth harvests of grass, reported that KCl fertilizer had the greatest effect on DCAD because it doubled the concentrations of Cl in the herbage. In contrast, Roche et al. (2002) reported that, although addition of KCl fertilizer increased K concentrations in pastures, there was no consistent effect on DCAD balance because of a concomitant decrease in Na and increase in Cl concentrations. Calcium and Mg were not affected by the K fertilizer treatment (Roche et al., 2002). This study investigated the feasibility of altering DCAD in grass forages by altering the amount and formulation of K and Mg fertilizer applied to 2 tall fescue varieties, one selected for high Mg concentration.

MATERIALS AND METHODS

Plot Design and Treatments

Trial plots were located at the Agriculture and Agri-Food Canada Research Centre in Agassiz, British Columbia. Plots for each of 2 experiments were planted in 1995 in a randomized complete block design. In experiment 1, treatment combinations (replicated 4 times) included 2 varieties of tall fescue (*Festuca arundinacea* Schreb.), Barcel and HiMag, the latter selected for high Mg concentration (Sleper et al., 2002). Both varieties received all combinations of 2 fertilizers, KCl and MgO, each applied at zero or soil test-based rates of 250 kg/ha of K and 60 kg/ha of Mg. All plots received 100 kg/ha of N, applied each spring and after the first 3 harvests each year of the trial. Phosphorus was applied at 100 kg/ha as P₂O₅ in the spring of each year.

To ascertain the effect of the type of K fertilizer, a second experiment was conducted with 2 treatments

(each replicated 4 times) of HiMag tall fescue fertilized with zero or soil test-based rates. Application rates were 125 kg/ha of K as KCl or as K₂SO₄. Nitrogen, Mg, and P fertilization was as described for experiment 1.

Harvesting

Five harvests of grass were done on May 8 (first), June 16 (second), July 21 (third), August 20 (fourth), and October 6 (fifth) in 1997. The fresh weight of harvested material from each plot was recorded in the field, and subsamples were retained for DM determinations and chemical analyses.

Chemical Analysis

Subsamples were dried in a forced-air oven at 60°C to constant weight and then ground to pass through a 1-mm screen. Samples from 3 of the 4 replicates were submitted to a commercial laboratory (Griffin Laboratories, Kelowna, British Columbia, Canada) for quantification of Ca, P, Mg, K, Na, and S using inductively coupled plasma optical emission spectroscopy after perchloric-nitric acid digestion. Ten milliliters of a perchloric-nitric acid mixture (3 vol of 72% perchloric and 7 vol of concentrated nitric) was combined with 0.5 g of ground plant material and allowed to stand overnight before gradual heating to 70°C over 1 h and then increasing to 203°C over 4 h (John, 1972). After cooling, 2.5 mL of 1 N hydrochloric acid was added, and the solution was made up to 12.5 mL in preparation for inductively coupled plasma analyses. Chloride was first extracted from the samples using nitric acid (0.25-g sample in 25 mL of 0.5 M nitric acid) and then measured using a Cl selective electrode.

Calculation of DCAD

The DCAD index was calculated according to the equation of Ender et al. (1971) as presented in NRC (2001), in which the milliequivalents of the anions Cl and S are subtracted from the milliequivalents of the cations Na and K:

$$\text{DCAD} = (\text{Na} + \text{K}) - (\text{Cl} + \text{S}) \text{ (mEq/kg of DM)}.$$

Statistical Analysis

Concentrations of Mg, Ca, Na, K, Cl, and S are expressed as grams per kilogram of DM, DCAD as milliequivalents per kilogram of DM, and DM yield as kilograms per hectare. Data from both experiments were analyzed in a similar manner using the mixed-models procedure (Littell et al., 1996). In experiment 1, data analysis investigated main effects, namely, block, har-

vest, grass variety, and K and Mg fertilizer treatments, and the following interactions: harvest $\times$ variety, harvest $\times$ K fertilizer, harvest $\times$ Mg fertilizer, harvest $\times$ variety $\times$ K fertilizer, harvest $\times$ variety $\times$ Mg fertilizer, harvest $\times$ variety $\times$ K fertilizer $\times$ Mg fertilizer, harvest $\times$ K fertilizer $\times$ Mg fertilizer, variety $\times$ K fertilizer, variety $\times$ Mg fertilizer, variety $\times$ K fertilizer $\times$ Mg fertilizer, and K fertilizer $\times$ Mg fertilizer. Harvests were considered repeated measurements on each experimental block and were analyzed using the repeated statement with a compound symmetry covariance structure. The critical level of significance was set a priori at $P < 0.05$. Block and harvest $\times$ variety $\times$ Mg fertilizer, harvest $\times$ variety $\times$ K fertilizer $\times$ Mg fertilizer, harvest $\times$ K fertilizer $\times$ Mg fertilizer, variety $\times$ K fertilizer $\times$ Mg fertilizer, and K fertilizer $\times$ Mg fertilizer interactions were not significant and are not reported. In experiment 2, the data analysis investigated the main effects of block, harvest, and type of K fertilizer and the interaction of harvest $\times$ type of K fertilizer. Harvests were considered as repeated measures and were analyzed as in experiment 1.

Ration Evaluation

To evaluate the effect of using a grass bred for mineral concentration in transition diets, rations were formulated using the CPM-Dairy nutrition model (Version 3.06; Cornell-Penn-Miner; Cornell University, Ithaca, NY). Diets were balanced to provide 10.5 kg of DM using 9.1 kg of corn silage, 13.6 kg of grass silage, and a grain mix consisting of 2.1 kg of ground barley, 0.42 kg of canola meal, 0.42 kg of corn distillers grains, 0.21 kg of limestone, 0.21 kg of a vitamin-mineral premix, and 0.08 kg of MgO. Nutrient values for all ingredients were taken from the feed tables within CPM-Dairy except for grass silage, for which nutrient values of HiMag or Barcel tall fescue (Table 1, first-harvest data) were used.

RESULTS AND DISCUSSION

Dry matter yield was consistent with previous records collected in the south coastal region of British Columbia (BCMAFF, 2002). There was a difference in mean DM yield between harvests (Table 1), but the response of each variety to K fertilization within each harvest was not consistent ($P = 0.014$). Application of K fertilizer increased the DM yield of the first ($P = 0.007$) and fourth harvests ($P = 0.001$) of Barcel but had no effect on the DM yield from the second ($P = 0.859$), third ($P = 0.061$), and fifth harvests ($P = 0.112$; Table 2). In HiMag tall fescue, application of K fertilizer had no effect ($P = 0.888$) on DM yield of the first harvest

and increased the DM yield of each of the second through fifth harvests by approximately 400 kg/ha (Table 2). In general, HiMag yielded less DM than did Barcel tall fescue, with the exception of grass harvested in the first harvest (Table 2). Although the 2 varieties of tall fescue were chosen to be similar in maturity, HiMag reached maturity earlier than did Barcel, resulting in a greater yield from the first harvest (Table 2).

Values observed for Ca, Mg, and K concentrations (Table 1) are consistent with those reported for grasses (Cathcart et al., 1980; Fisher and Bates, 1986; NRC, 2001). Sodium and Cl concentrations (Table 1) were less than those commonly published for grasses (NRC, 2001) but are consistent with previous measurements of grass forage harvested in this geographical region (BCMAFF, 2002; M. L. Swift, unpublished data). Values for DCAD are within the ranges reported by Roche et al. (2000), Pehrson et al. (1999), and Gagnon et al. (2003).

Experiment 1

Varietal Effects. There was no difference ($P = 0.681$) in the concentrations of Mg between the 2 varieties of tall fescue (Table 1). This observation does not agree with work previously published for HiMag tall fescue (Crawford et al., 1998; Sabreen et al., 2003; Shewmaker et al., 2004). Crawford et al. (1998) reported an increase (22%) in the concentration of Mg when HiMag was compared with other tall fescue varieties. The current study is the first to evaluate HiMag tall fescue in a system in which K fertilization approximated that applied through the spring application of manure and in which multiple harvests (>2) are taken each crop year.

The concentrations of Ca were higher in HiMag than in Barcel tall fescue, with the magnitude of the difference increasing from 0.36 to 1.10 g/kg from the first to last harvest (Table 2). Crawford et al. (1998) reported an increase of 18.5% in Ca concentration of HiMag vs. other tall fescue varieties. Other studies (Moseley and Baker, 1991; Wilkinson and Mayland, 1997; Shewmaker et al., 2004) also reported increased Ca concentrations in grass bred for a higher Mg concentration.

The HiMag tall fescue contained lower concentrations of K than did Barcel in the first ($P = 0.024$), second ($P = 0.001$), and third ($P = 0.006$) harvests, with no difference in the fourth ($P = 0.107$) and fifth harvests ($P = 0.517$; Table 2). Previous reports detailing K concentrations of HiMag, as compared with other varieties of tall fescue, have been inconsistent. Crawford et al. (1998) found no difference in K concentrations of 4 varieties of tall fescue, including HiMag. Sabreen et al. (2003) conducted 3 growth-chamber experiments comparing HiMag with 2 other varieties of tall fescue. Po-

Table 1. Dry matter yield; concentrations of Mg, Ca, Na, K, Cl, and S; and DCAD¹ in 2 varieties of tall fescue fertilized with 2 levels each of K fertilizer (Kfert) and Mg fertilizer (Mgfert; experiment 1)

Item	Yield, kg/ha	Mg, g/kg	Ca, g/kg	K, g/kg	Na, g/kg	S, g/kg	Cl, g/kg	DCAD, mEq/kg
Harvest (H)								
May 8	2,729 ^c ± 64.1 ²	1.72 ^a ± 0.051	3.12 ^a ± 0.090	25.3 ^a ± 0.36	0.08 ^a ± 0.007	1.90 ^{ab} ± 0.037	1.78 ^d ± 0.158	485 ^a ± 6.8
June 16	3,705 ^d ± 81.0	2.46 ^b ± 0.066	3.50 ^b ± 0.088	28.7 ^d ± 0.96	0.09 ^a ± 0.008	1.82 ^a ± 0.042	1.60 ^{bc} ± 0.138	583 ^c ± 19.9
July 21	2,706 ^c ± 59.1	2.75 ^c ± 0.073	3.26 ^a ± 0.096	28.3 ^{cd} ± 0.84	0.07 ^a ± 0.010	1.89 ^a ± 0.045	1.50 ^{ab} ± 0.119	572 ^c ± 17.4
August 20	1,755 ^a ± 72.0	3.56 ^d ± 0.118	4.63 ^d ± 0.183	26.7 ^b ± 0.87	0.10 ^a ± 0.011	1.81 ^a ± 0.042	1.41 ^a ± 0.102	536 ^b ± 19.1
October 6	1,915 ^b ± 76.7	3.59 ^d ± 0.096	4.23 ^c ± 0.178	27.5 ^{bc} ± 0.53	0.18 ^b ± 0.028	1.96 ^b ± 0.048	1.66 ^{cd} ± 0.124	543 ^b ± 10.3
Variety (V)								
Barcel	2,646 ± 103.8	2.81 ± 0.106	3.34 ± 0.084	28.2 ± 0.55	0.14 ± 0.013	1.92 ± 0.028	1.60 ± 0.084	566 ± 12.0
HiMag	2,477 ± 96.9	2.83 ± 0.106	4.15 ± 0.114	26.4 ± 0.40	0.07 ± 0.005	1.85 ± 0.027	1.58 ± 0.082	521 ± 8.3
Kfert ³								
0	2,392 ± 106.9	3.07 ± 0.107	4.02 ± 0.123	24.5 ± 0.23	0.12 ± 0.014	1.84 ± 0.028	0.99 ± 0.017	491 ± 5.8
250	2,731 ± 89.5	2.57 ± 0.95	3.47 ± 0.090	30.2 ± 0.39	0.08 ± 0.006	1.93 ± 0.028	2.18 ± 0.040	597 ± 10.0
Mgfert ⁴								
0	2,605 ± 99.3	2.57 ± 0.107	3.85 ± 0.115	27.4 ± 0.47	0.12 ± 0.013	1.94 ± 0.030	1.58 ± 0.083	544 ± 11.3
60	2,518 ± 102.4	3.07 ± 0.113	3.64 ± 0.109	27.2 ± 0.52	0.09 ± 0.007	1.83 ± 0.024	1.60 ± 0.083	544 ± 10.1
Source of variation	<i>P</i> -value							
Harvest	0.001	0.001	0.001	0.001	0.001	0.011	0.001	0.001
Variety	0.001	0.681	0.001	0.001	0.001	0.066	0.594	0.001
H × V	0.001	0.108	0.001	0.041	0.100	0.502	0.752	0.129
Kfert	0.001	0.001	0.001	0.001	0.001	0.018	0.001	0.001
H × Kfert	0.058	0.001	0.001	0.001	0.048	0.005	0.001	0.001
V × Kfert	0.630	0.055	0.840	0.001	0.047	0.577	0.291	0.001
H × V × Kfert	0.014	0.504	0.091	0.323	0.756	0.322	0.982	0.161
Mgfert	0.052	0.001	0.001	0.465	0.009	0.002	0.478	0.985
H × Mgfert	0.178	0.001	0.733	0.656	0.392	0.694	0.625	0.726
V × Mgfert	0.510	0.597	0.029	0.548	0.040	0.140	0.123	0.235

^{a-d}Yield and concentration means within a column followed by superscripts differ.

¹DCAD calculated as (Na + K) – (S + Cl).

²Values following ± represent SEM.

³Potassium fertilization at 0 or 250 kg/ha.

⁴Magnesium fertilization at 0 or 60 kg/ha.

Table 2. Harvest $\times$ variety, harvest $\times$ K fertilizer (Kfert), and harvest $\times$ Mg fertilizer (Mgfert) interactions for DM yield; concentrations of Mg, Ca, K, Na, S, and Cl; and DCAD¹ in experiment 1

Item	Harvest				
	May 8	June 16	July 21	August 20	October 6
	(DM yield, kg/ha)				
Barcel	2,570 $\pm$ 85.3 ²	3,915 $\pm$ 87.8	2,859 $\pm$ 70.3	1,822 $\pm$ 118.5	2,065 $\pm$ 106.9
HiMag	2,887 $\pm$ 73.1	3,496 $\pm$ 108.4	2,554 $\pm$ 73.9	1,688 $\pm$ 82.8	1,757 $\pm$ 94.3
<i>P</i>	0.003	0.001	0.004	0.201	0.004
Barcel, 0 Kfert ³	2,376 $\pm$ 93.4	3,927 $\pm$ 180.8	2,724 $\pm$ 87.9	1,459 $\pm$ 75.0	1,952 $\pm$ 169.0
Barcel, 250 Kfert	2,764 $\pm$ 90.8	3,902 $\pm$ 33.5	2,992 $\pm$ 82.7	2,186 $\pm$ 57.8	2,179 $\pm$ 128.3
<i>P</i>	0.007	0.859	0.061	0.001	0.112
HiMag, 0 Kfert	2,877 $\pm$ 107.2	3,242 $\pm$ 96.6	2,365 $\pm$ 86.7	1,456 $\pm$ 73.0	1,542 $\pm$ 115.1
HiMag, 250 Kfert	2,897 $\pm$ 109.6	3,749 $\pm$ 129.2	2,742 $\pm$ 47.4	1,922 $\pm$ 55.4	1,971 $\pm$ 86.4
<i>P</i>	0.888	0.001	0.009	0.001	0.003
	(Mg, g/kg)				
0 Kfert	1.93 $\pm$ 0.033	2.63 $\pm$ 0.087	3.01 $\pm$ 0.083	3.93 $\pm$ 0.142	3.83 $\pm$ 0.114
250 Kfert	1.51 $\pm$ 0.042	2.29 $\pm$ 0.074	2.49 $\pm$ 0.059	3.20 $\pm$ 0.117	3.36 $\pm$ 0.123
<i>P</i>	0.001	0.001	0.001	0.001	0.001
0 Mgfert ⁴	1.64 $\pm$ 0.075	2.23 $\pm$ 0.065	2.55 $\pm$ 0.076	3.17 $\pm$ 0.107	3.25 $\pm$ 0.087
60 Mgfert	1.80 $\pm$ 0.065	2.70 $\pm$ 0.063	2.95 $\pm$ 0.097	3.97 $\pm$ 0.133	3.94 $\pm$ 0.096
<i>P</i>	0.001	0.001	0.001	0.001	0.001
	(Ca, g/kg)				
Barcel	2.93 $\pm$ 0.110	3.13 $\pm$ 0.064	2.88 $\pm$ 0.066	4.07 $\pm$ 0.225	3.68 $\pm$ 0.144
HiMag	3.29 $\pm$ 0.125	3.87 $\pm$ 0.054	3.63 $\pm$ 0.009	5.15 $\pm$ 0.180	4.78 $\pm$ 0.241
<i>P</i>	0.026	0.001	0.001	0.001	0.001
0 Kfert	3.35 $\pm$ 0.116	3.48 $\pm$ 0.131	3.34 $\pm$ 0.142	5.18 $\pm$ 0.164	4.73 $\pm$ 0.214
250 Kfert	2.88 $\pm$ 0.107	3.52 $\pm$ 0.121	3.18 $\pm$ 0.129	4.07 $\pm$ 0.237	3.72 $\pm$ 0.203
<i>P</i>	0.001	0.748	0.200	0.001	0.001
	(K, g/kg)				
Barcel	26.2 $\pm$ 0.48	30.3 $\pm$ 0.16	29.5 $\pm$ 0.13	27.3 $\pm$ 0.14	27.8 $\pm$ 0.81
HiMag	24.4 $\pm$ 0.39	27.1 $\pm$ 0.10	27.3 $\pm$ 0.94	26.0 $\pm$ 0.11	27.3 $\pm$ 0.70
<i>P</i>	0.024	0.001	0.006	0.107	0.517
0 Kfert	24.3 $\pm$ 0.40	24.7 $\pm$ 0.43	24.8 $\pm$ 0.42	23.0 $\pm$ 0.59	25.6 $\pm$ 0.50
250 Kfert	26.4 $\pm$ 0.44	32.8 $\pm$ 0.85	32.0 $\pm$ 0.64	30.4 $\pm$ 0.53	29.5 $\pm$ 0.45
<i>P</i>	0.012	0.001	0.001	0.001	0.001
	(Na, g/kg)				
0 Kfert	0.09 $\pm$ 0.011	0.10 $\pm$ 0.012	0.08 $\pm$ 0.017	0.12 $\pm$ 0.20	0.24 $\pm$ 0.050
250 Kfert	0.07 $\pm$ 0.009	0.08 $\pm$ 0.011	0.06 $\pm$ 0.011	0.08 $\pm$ 0.013	0.013 $\pm$ 0.019
<i>P</i>	0.357	0.473	0.234	0.153	0.001
	(S, g/kg)				
0 Kfert	1.99 $\pm$ 0.058	1.72 $\pm$ 0.049	1.78 $\pm$ 0.065	1.78 $\pm$ 0.048	1.93 $\pm$ 0.057
250 Kfert	1.81 $\pm$ 0.026	1.92 $\pm$ 0.058	2.00 $\pm$ 0.048	1.85 $\pm$ 0.069	2.06 $\pm$ 0.075
<i>P</i>	0.025	0.014	0.008	0.351	0.122
	(Cl, g/kg)				
0 Kfert	1.05 $\pm$ 0.037	0.95 $\pm$ 0.019	0.99 $\pm$ 0.026	0.94 $\pm$ 0.044	1.08 $\pm$ 0.040
250 Kfert	2.52 $\pm$ 0.069	2.25 $\pm$ 0.038	2.01 $\pm$ 0.105	1.88 $\pm$ 0.033	2.25 $\pm$ 0.040
<i>P</i>	0.001	0.001	0.001	0.001	0.001
	(DCAD, mEq/kg)				
0 Kfert	475 $\pm$ 9.0	504 $\pm$ 10.9	501 $\pm$ 9.4	457 $\pm$ 15.1	514 $\pm$ 13.0
250 Kfert	494 $\pm$ 9.9	661 $\pm$ 20.2	642 $\pm$ 16.8	615 $\pm$ 13.1	572 $\pm$ 11.2
<i>P</i>	0.221	0.001	0.001	0.001	0.001

¹DCAD calculated as (Na + K) – (S + Cl).²Values following $\pm$ represent SEM.³Potassium fertilization at 0 or 250 kg/ha.⁴Magnesium fertilization at 0 or 60 kg/ha.

tassium concentrations were lower in shoots of HiMag in 2 of the 3 experiments reported. Whitehead (2000) reported that K competes with Ca, Mg, and Na for

uptake by the plant and that some grass species have a greater tendency for uptake of divalent cations relative to monovalent cations depending on the cation ex-

Table 3. Variety $\times$ K fertilizer (Kfert) and variety $\times$ Mg fertilizer (Mgfert) interactions for Ca, K, Na, and DCAD¹ (experiment 1)

Item	Barcel	HiMag
	(Ca, g/kg)	
Low Mgfert	3.38 $\pm$ 0.118 ²	4.32 $\pm$ 0.158
High Mgfert	3.29 $\pm$ 0.121	3.98 $\pm$ 0.160
P	0.001	0.001
	(K, g/kg)	
0 Kfert ³	24.9 $\pm$ 0.34	24.1 $\pm$ 0.31
250 Kfert	31.6 $\pm$ 0.56	28.8 $\pm$ 0.41
P	0.001	0.001
	(Na, g/kg)	
0 Kfert	0.18 $\pm$ 0.023	0.08 $\pm$ 0.008
250 Kfert	0.11 $\pm$ 0.010	0.06 $\pm$ 0.005
P	0.001	0.173
0 Mgfert ⁴	0.17 $\pm$ 0.023	0.07 $\pm$ 0.007
60 Mgfert	0.12 $\pm$ 0.010	0.06 $\pm$ 0.007
P	0.001	0.677
	(DCAD, mEq/kg)	
0 Kfert	501 $\pm$ 9.1	480 $\pm$ 6.7
250 Kfert	631 $\pm$ 14.5	562 $\pm$ 10.7
P	0.001	0.001

¹DCAD calculated as (Na + K) – (S + Cl).²Values following $\pm$ represent SEM.³Potassium fertilization at 0 or 250 kg/ha.⁴Magnesium fertilization at 0 or 60 kg/ha.

change capacity of their root system. In particular, tall fescue is reported to have higher concentrations of Ca and Mg but lower K, compared with orchardgrass (*Dactylis glomerata* L.) and reed canary grass (*Phalaris arundinacea* L.; Odom et al., 1980).

In general, HiMag tall fescue contained less Na than did Barcel, but the magnitude of difference in Na concentrations between the 2 varieties was affected by K and Mg fertilization (Table 3). Application of K fertilizer decreased Na concentrations in Barcel ($P = 0.001$) but not in HiMag ($P = 0.173$) tall fescue (Table 3). Similarly, application of Mg fertilizer decreased Na concentrations in Barcel ($P = 0.001$) but not in HiMag ($P = 0.677$) tall fescue (Table 3). Previous publications detailing the mineral composition of HiMag relative to other varieties of tall fescue have not reported Na concentration data (Wilkinson and Mayland, 1997; Crawford et al., 1998; Sabreen et al., 2003). Moseley and Baker (1991) reported a decrease in the Na concentration of a high-Mg ryegrass as compared with a standard ryegrass variety but did not attempt to explain the reported difference. Adams (1973) reported a decrease in Na concentration in response to K fertilization in 22 out of 30 harvests of grass harvested over 3 yr. Likewise, Reith et al. (1964) reported that increasing K fertilization from none to 412 kg/ha decreased the Na concentration of grass. The low Na accumulation in HiMag may be of importance on soils with higher Na concentrations.

The variety of tall fescue had no effect ($P = 0.066$) on the concentrations of S (Table 1). Previous studies investigating mineral concentration differences in HiMag tall fescue vs. other grass species have not reported the S concentration (Wilkinson and Mayland, 1997; Crawford et al., 1998; Sabreen et al., 2003).

Chloride concentrations were not different ($P = 0.594$) between HiMag and Barcel tall fescue (Table 1). Previous reports detailing the macromineral concentration of HiMag tall fescue in comparison with other varieties of tall fescue have not discussed Cl. Whitehead (2000) reported that differences in Cl concentration among cool-season grass species are small.

The increase in DCAD attributable to K fertilizer application was less in HiMag (82 mEq/kg) than in Barcel tall fescue (130 mEq/kg; Table 3). This was in large part due to the lower concentrations of K noted for HiMag vs. Barcel. Although lower in HiMag than in Barcel tall fescue, the concentrations of Na were too low in our trial to have a notable effect on DCAD.

K Fertilizer

In general, application of K fertilizer decreased concentrations of Mg in tall fescue, but the magnitude of the decrease was not consistent across the 5 harvests, resulting in a harvest $\times$ K fertilizer interaction ($P = 0.001$; Table 1). Brown and Sleper (1980) reported a decrease in Mg concentration in 2 varieties of tall fescue when 50, 150, or 250 mg/kg of K were applied to the soil. Roche et al. (2002) reported no decrease in Mg concentrations with increasing K fertilizer application rates up to 225 kg/ha. The inconsistent response of Mg concentrations in grass forages in response to K fertilization has been noted in the literature, as reviewed by Whitehead (2000), and may be explained by the rate of K fertilizer application in relation to the requirement. Application of K fertilizer in amounts greater than required for maximum yield decreased the Mg concentration in the forage (Whitehead, 2000). This would suggest that experimental treatments in this study provided excess K in terms of that required for maximum yield, and that the magnitude of this excess was greatest for the fourth harvest, which showed the greatest magnitude of decrease (0.7 g/kg) in Mg concentration (Table 2).

Application of K fertilizer decreased Ca concentrations in the first ($P = 0.001$), fourth ($P = 0.001$), and fifth harvests ($P = 0.001$), with no difference noted in the second ($P = 0.748$) and third ($P = 0.200$) harvests (Table 2). Roche et al. (2002) reported a linear decrease in Ca concentrations with increasing levels of K fertilizer application up to 225 kg/ha. However, when the

experiment was repeated, there was no response in Ca concentration to increased rates of K fertilizer application. Reith et al. (1964) illustrated a consistent depressing effect of K fertilizer on Ca concentration in the presence of N fertilization. In a summary of data from 3 harvests in each of 16 trials conducted over 3 yr, Adams (1973) found that K fertilizer application resulted in numerically lower Ca concentrations in 10 of the harvests, numerically higher concentrations in 34 of the harvests, and only significant (level of significance not given) decreases in 4 of the 48 harvests.

Application of K fertilizer increased the K concentration across all 5 harvests, but the magnitude of the increase ranged from 2.1 g/kg (first harvest) to 8.1 g/kg in the second harvest (Table 2). Increasing K concentrations in grass in response to increasing K fertilizer has been shown in many studies (Adams, 1973; Dampney, 1992; Whitehead, 2000). Application of K fertilizer increased K concentrations in HiMag ($P = 0.001$) and Barcel ($P = 0.001$), but the increase was smaller in magnitude in HiMag (4.7 g/kg) than in Barcel (6.5 g/kg) tall fescue (Table 3).

With the exception of grass harvested on October 6 (fifth harvest), K fertilization did not affect the Na concentration of grass (Table 1). Grass harvested on October 6 receiving no K fertilization contained greater ($P = 0.001$) concentrations of Na than did grass receiving K fertilization (Table 2). Pehrson et al. (1999) reported no effect of increasing the application rate of KCl fertilizer on Na concentration in first and second harvests of grass herbage. Application rates of K fertilizer were notably lower (7, 44, and 56 kg/ha) than used in the current study.

The response in S concentrations to K fertilizer was not consistent across harvests (Table 2). Application of K fertilizer decreased ($P = 0.025$) S concentrations in first-harvest grass, increased S concentrations in second- and third-harvest grasses ($P = 0.014$ and 0.008 , respectively), and had no effect on S concentrations in fourth- and fifth-harvest grasses ($P = 0.351$ and 0.122 , respectively). McLaren (1976) reported that regardless of harvest, the application of 78 or 314 kg/ha of KCl fertilizer reduced S concentrations in grass, and hypothesized this was attributable to dilution with increasing yield or, second, that S uptake was reduced because of competition for uptake with Cl in the K fertilizer. Roche et al. (2002) found that increasing KCl fertilizer application from 0 to 225 kg/ha of K did not affect the S concentration of pastures in either of 2 experiments.

In this study, KCl fertilizer application inherently increased application of Cl, which increased the Cl concentration of tall fescue, although the magnitude of the

response was not consistent across harvests (Table 2). This observation is similar to the reports of Whitehead (2000) and Roche et al. (2002). Application of Mg fertilizer had no effect ($P = 0.478$) on Cl concentrations (Table 1).

Application of K fertilizer did not affect ($P = 0.221$) the DCAD value of grass harvest on May 8 (first harvest) but did increase DCAD values by 157, 142, 158, and 58 mEq/kg of grass harvested for the second, third, fourth, and fifth harvests, respectively (Table 2). Roche et al. (2002) reported higher DCAD values when the rate of K fertilizer applied to pasture was increased from 0 to 225 kg/ha.

Mg Fertilizer

Application of Mg fertilizer increased ($P = 0.597$) Mg concentrations in HiMag and Barcel tall fescue, but the increase was not consistent across the 5 harvests of grass, resulting in a harvest $\times$ Mg fertilizer interaction ($P = 0.001$; Table 1). As shown in Table 2, the increase in Mg concentrations attributable to Mg fertilizer application ranged from 0.16 to 0.80 g/kg in the first and fourth harvests, respectively.

Application of Mg fertilizer decreased Ca concentrations in HiMag and Barcel tall fescue, but the magnitude of the decrease was much greater in HiMag than in Barcel (0.34 vs. 0.09 g/kg; Table 3). Previous studies comparing HiMag to other varieties of tall fescue did not include Mg fertilizer as an experimental variable (Wilkinson and Mayland, 1997; Crawford et al., 1998). Application of Mg fertilizer decreased ($P = 0.002$) the concentration of S regardless of variety or harvest (Table 1).

Experiment 2

Harvest date affected DM yield ($P = 0.001$) and concentrations of K ($P = 0.008$), Na ($P = 0.001$), Cl ($P = 0.013$), and the DCAD ($P = 0.009$) but had no effect on S concentrations ($P = 0.063$) in HiMag tall fescue (Table 4). The effects of K fertilizer formulation (KCl vs. K_2SO_4) on DM yield, concentrations of K, Na, Cl, and S (g/kg of DM), and the DCAD (mEq/kg of DM) in HiMag tall fescue are presented in Table 4. Application of K fertilizer as K_2SO_4 increased ($P = 0.011$) the yield over that realized with K fertilizer applied as KCl.

HiMag tall fescue fertilized with KCl had higher ($P = 0.047$) concentrations of K than did HiMag fertilized with K_2SO_4 , even though the amounts of each fertilizer were calculated to supply K at 125 kg/ha. The formulation of K fertilizer affected the concentrations of Cl and

Table 4. Dry matter yield; concentrations of Mg, Ca, Na, K, Cl, and S; and DCAD¹ in HiMag tall fescue fertilized with 2 types of K fertilizer (Kfert) at 125 kg/ha K (experiment 2)

Item	Yield, kg/ha	K, g/kg	S, g/kg	Na, g/kg	Cl, g/kg	DCAD, mEq/kg
Harvest						
May 8	3,027 ^b ± 90.5 ²	27.8 ^a ± 0.37	2.47 ± 0.175	0.07 ^b ± 0.005	1.59 ^b ± 0.147	518 ^a ± 12.9
June 16	3,704 ^c ± 139.1	30.5 ^b ± 0.42	2.32 ± 0.188	0.05 ^a ± 0.003	1.60 ^b ± 0.143	594 ^c ± 14.6
Aug 20	1,740 ^a ± 69.0	28.1 ^a ± 0.69	2.22 ± 0.150	0.05 ^a ± 0.004	1.44 ^{ab} ± 0.121	543 ^{ab} ± 22.4
Oct 6	1,854 ^a ± 109.9	29.4 ^{ab} ± 0.82	2.48 ± 0.146	0.10 ^c ± 0.006	1.33 ^a ± 0.167	567 ^{bc} ± 21.8
Kfert						
KCl	2,453 ± 177.6	29.5 ± 0.31	1.89 ± 0.067	0.07 ± 0.005	1.92 ± 0.052	588 ± 9.7
K ₂ SO ₄	2,709 ± 190.3	28.3 ± 0.57	2.86 ± 0.049	0.07 ± 0.006	1.06 ± 0.052	522 ± 14.3
Source of variation	P-value					
Harvest	0.001	0.008	0.063	0.001	0.013	0.009
Kfert	0.011	0.047	0.001	0.120	0.001	0.001
Harvest × Kfert	0.120	0.135	0.129	0.839	0.216	0.094

^{a-c}Yield and concentration means within a column followed by superscripts differ.

¹DCAD calculated as (Na + K) – (S + Cl).

²Values following ± represent the SEM.

S differently in that Cl concentrations were increased ($P = 0.001$) in grass samples fertilized with KCl, whereas the S concentrations were increased ($P = 0.001$) in grass receiving the K₂SO₄ fertilizer. This finding agrees with that of Pehrson et al. (1999), who reported that Cl concentrations approximately doubled in grass fertilized with KCl over that fertilized with K₂SO₄. There was no effect ($P = 0.120$) of formulation of K fertilizer on Na concentrations.

The DCAD was lower ($P = 0.001$) in grass fertilized with K₂SO₄ compared with that fertilized with KCl. This finding is in contrast with the results of Pehrson et al. (1999), who reported that the DCAD was decreased with the application of KCl fertilizer, and attributed this result to the increased Cl concentration in the grass. In the current study, the application of K fertilizer as KCl did not elicit the magnitude of positive response in Cl concentration reported by Pehrson et al. (1999). The average response in this study was 81%, in comparison with the 100% reported by Pehrson et al. (1999). The largest difference between the 2 studies was in the response of S concentrations in grass fertilized with KCl vs. K₂SO₄. In the current study, K₂SO₄ fertilizer application supported a mean increase in S concentration of 51%, whereas Pehrson et al. (1999) reported a small increase of 8% in S concentration for first-harvest grass. This can be explained by the difference in fertilizer regimens between the 2 studies. In the current study, the amount of KCl or K₂SO₄ fertilizer applied was based on K application, whereas in the study by Pehrson et al. (1999), the amounts and types of fertilizer applied were based on N application. Therefore, in the current study plots fertilized with KCl received no supplemental form of S, whereas in the study by Pehrson et al. (1999) grass fertilized with KCl also

received S in the form of ammonium sulfate. The large increase in S concentrations in grass fertilized with K₂SO₄ noted in the current study, coupled with the numerically lower K concentration, resulted in a lower DCAD for HiMag tall fescue fertilized with K₂SO₄ compared with that fertilized with KCl.

Implications for Feed Formulation

Grass silage is often not included in the diets for transition (21-d prepartum) dry cows in the south coastal region of British Columbia because of its high K concentration and the subsequent need for anionic salts or products containing HCl to be included in the diet. To evaluate the effect of grass bred for mineral concentration in transition diets, rations were formulated using HiMag or Barcel tall fescue.

Diets containing HiMag had a calculated DCAD index of 26 vs. 28 for the diet containing Barcel tall fescue. To decrease the DCAD to a value of –50 mEq/kg (Goff, 2004), NutriChlor 18-8 (Nutritech Solutions, Abbotsford, British Columbia, Canada) was added to the diet at the expense of barley, canola, and corn distillers grains. Amounts of limestone and MgO were adjusted to account for the Ca and Mg concentration of NutriChlor 18-8. The diet containing HiMag required approximately 8% less NutriChlor 18-8 (1,361 vs. 1,474 g, respectively) than the diet containing Barcel tall fescue.

A duplicate exercise to evaluate the effect of fertilizer formulation was evaluated using nutrient values for HiMag tall fescue fertilized with KCl or K₂SO₄ (Table 2, harvest 1). The diet containing HiMag fertilized with K₂SO₄ required approximately 10% less NutriChlor 18-8 to be added to the ration to achieve a DCAD value of –50 mEq/kg (1,600 vs. 1,450 g).

CONCLUSIONS

Under the growing and fertilizer regimens used in this study, HiMag tall fescue contained higher concentrations of Ca but lower concentrations of Na and K, with no difference in the concentration of Mg compared with Barcel tall fescue. Because of decreased concentrations of Na and K, the calculated DCAD index was lower in HiMag than Barcel tall fescue. Increasing the rate of KCl fertilizer increased the DCAD index because of an increasing concentration of K in the grass. Application of KCl vs. K_2SO_4 fertilizer altered the Cl and S concentrations in samples of HiMag tall fescue. In contrast to other studies, the DCAD index was lower in grass fertilized with K_2SO_4 because of the large increase in S concentration. Other commercially available fertilizer formulations containing S and Cl could also be used to enhance the concentrations of S and Cl in grass forage. Both elements have benefits for crop production. In summary, DCAD can be manipulated by choice of grass variety, fertilizer formulation, and fertilizer application rate.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to R. Blades, J. Forbes, M. Schaber, and X. Wu for their technical assistance. Funding for this project was provided by Terralink Horticulture Inc. (Abbotsford, British Columbia, Canada) and the Matching Initiatives Fund of Agriculture and Agri-Food Canada.

REFERENCES

- Adams, S. N. 1973. The response of pastures in Northern Ireland to N, P and K fertilizers and to animal slurries. II. Effects of mineral composition. *J. Agric. Sci. (Camb.)* 81:419–428.
- BCMAFF (British Columbia Ministry of Agriculture, Food and Fisheries). 2002. Forage quality in the South Coastal Region in 2001. Factsheet 2002. BCMAFF, Victoria, British Columbia, Canada.
- Block, E. 1994. Manipulation of dietary cation-anion difference on nutritionally related production diseases, productivity, and metabolic responses of dairy cows. *J. Dairy Sci.* 77:1437–1450.
- Brown, J. R., and D. A. Sleper. 1980. Mineral concentration in two tall fescue genotypes grown under variable soil nutrient levels. *Agron. J.* 72:742–745.
- Cathcart, E. B., J. A. Shelford, and R. G. Peterson. 1980. Mineral analyses of dairy cattle feed in the upper Fraser Valley of British Columbia. *Can. J. Anim. Sci.* 60:177–183.
- Crawford, R. J., Jr., M. D. Massie, D. A. Sleper, and H. F. Mayland. 1998. Use of an experimental high-magnesium tall fescue to reduce grass tetany in cattle. *J. Prod. Agric.* 11:491–496.
- Dampney, P. M. R. 1992. The effect of timing and rate of potash application on the yield and herbage of grass grown for silage. *Grass Forage Sci.* 47:280–289.
- Ender, F., I. W. Dishington, and A. Helgebostad. 1971. Calcium balance studies in dairy cows under experimental induction and prevention of hypocalcaemic paresis puerperalis. The solution of the aetiology and the prevention of milk fever by dietary means. *Z. Tierphysiol. Tierernaehr. Futtermittelkd.* 28:233–256.
- Fisher, L. J., and D. Bates. 1986. The relationships between mineral elements and quality factors in forages. *Can. J. Anim. Sci.* 66:1198. (Abstr.)
- Gagnon, B., G. Bélanger, M. C. Nolin, and R. R. Simard. 2003. Relationships between soil cations and plant characteristics based on spatial variability in a forage field. *Can. J. Plant Sci.* 83:343–350.
- Goff, J. P. 2004. Common syndromes affecting transition cows. Page 109–132 in *Proc. Intermountain Nutr. Conf.*, Utah State University, Salt Lake City, UT.
- Goff, J. P., R. Ruiz, and R. L. Horst. 2004. Relative acidifying activity of anionic salts commonly used to prevent milk fever. *J. Dairy Sci.* 87:1245–1255.
- Gröhn, Y. T., P. J. Rajala-Schultz, H. G. Allore, M. A. DeLorenzo, J. A. Hertl, and D. T. Galligan. 2003. Optimizing replacement of dairy cows: Modelling the effects of diseases. *Prev. Vet. Med.* 61:27–43.
- Horst, R. L., J. P. Goff, T. A. Reinhardt, and D. R. Buxton. 1997. Strategies for preventing milk fever in dairy cattle. *J. Dairy Sci.* 80:1269–1280.
- John, M. K. 1972. Automated digestion system for safe use of perchloric acid. *Anal. Chem.* 44:429–430.
- Kamgarpour, R., R. C. W. Daniel, D. C. Fenwick, K. McGuigan, and G. Murphy. 1999. Post partum subclinical hypocalcaemia and effects on ovarian function and uterine involution in a dairy herd. *Vet. J.* 158:59–67.
- Littell, R. C., G. A. Milliken, W. W. Stroup, and R. D. Wolfinger. 1996. SAS System for Mixed Models. SAS Inst., Inc. Cary, NC.
- McLaren, R. G. 1976. Effects of fertilizers on the sulphur content of herbage. *J. Br. Grassl. Soc.* 31:99–103.
- Moore, S. J., M. J. VandeHaar, B. K. Sharma, T. E. Pilbeam, D. K. Beede, H. F. Bucholtz, J. S. Liesman, R. L. Horst, and J. P. Goff. 2000. Effects of altering dietary cation-anion difference on calcium and energy metabolism in peripartum cows. *J. Dairy Sci.* 83:2095–2104.
- Moseley, G., and D. H. Baker. 1991. The efficacy of a high magnesium grass cultivar in controlling hypomagnesaemia in grazing animals. *Grass Forage Sci.* 46:375–380.
- NRC (National Research Council). 2001. Nutrient Requirements of Dairy Cattle. 7th rev. ed. Natl. Acad. Sci., Washington, DC.
- Odom, J. W., R. L. Haaland, C. S. Hoveland, and W. B. Anthony. 1980. Forage quality response of tall fescue, orchardgrass and *Phalaris* to soil fertility level. *Agron. J.* 72:401–402.
- Oetzel, G. R., and J. A. Barmore. 1993. Intake of a concentrate mixture containing various anionic salts fed to pregnant, nonlactating dairy cows. *J. Dairy Sci.* 76:1617–1623.
- Østergaard, S., J. T. Sørensen, and H. Houe. 2003. A stochastic model simulating milk fever in a dairy herd. *Prev. Vet. Med.* 58:125–143.
- Pehrson, B., C. Svensson, I. Gruvaeus, and M. Virkk. 1999. The influence of acidic diets on the acid base balance of dry cows and the effect of fertilization on the mineral content of grass. *J. Dairy Sci.* 82:1310–1316.
- Reith, J. W. S., R. H. E. Inkson, W. Holmes, D. S. Maclusky, D. Reid, R. G. Heddle, and G. J. F. Copeman. 1964. The effect of fertilizers on herbage production II. The effect of nitrogen, phosphorus and potassium on botanical and chemical composition. *J. Agric. Sci.* 63:209–219.
- Roche, J. R., D. Dalley, P. Moate, C. Grainger, M. Hannah, F. O'Mara, and M. Rath. 2000. Variations in the dietary cation-anion difference and the acid-base balance of dairy cows on a pasture-based diet in south-eastern Australia. *Grass Forage Sci.* 55:26–36.
- Roche, J. R., J. Morton, and E. S. Kolver. 2002. Sulfur and chlorine play a non-acid base role in periparturient calcium homeostasis. *J. Dairy Sci.* 85:3444–3453.
- Sabreen, S., S. Saiga, H. Saitoh, M. Tsuiki, and H. F. Mayland. 2003. Performance of high-magnesium varieties of three cool-season grasses grown in nutrient solution culture. *J. Plant Nutr.* 26:589–605.
- Shewmaker, G. E., D. A. Johnson, H. F. Mayland, S. A. Martin, and S. B. Hansen. 2004. Elemental uptake in relation to root characteristics of tall fescue. *Commun. Soil Sci. Plant Anal.* 35:1339–1355.

- Sleper, D. A., H. F. Mayland, R. J. Crawford, G. E. Shewmaker, and M. D. Massie. 2002. Registration of HiMag tall fescue germplasm. *Crop Sci.* 42:318.
- Smith, K. F., G. J. Rebetzke, H. A. Eagles, M. W. Anderson, and H. S. Easton. 1999. Genetic control of mineral concentration and yield in perennial ryegrass (*Lolium perenne* L.), with special emphasis on mineral related to grass tetany. *Aust. J. Agric. Res.* 50:79–86.
- Sørensen, J. T., S. Østergaard, H. Houe, and J. Hindhede. 2002. Expert opinions of strategies for milk fever control. *Prev. Vet. Med.* 55:69–78.
- Whitehead, D. C. 2000. *Nutrient Elements in Grassland: Soil-Plant-Animal Relationships*. CABI Publishing, New York, NY.
- Wilkinson, S. R., and H. F. Mayland. 1997. Yield and mineral concentration of HiMag compared to other tall fescue varieties grown in the Southern Piedmont. *J. Plant Nutr.* 20:1317–1331.