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Variation in Mineral Concentration and Grass Tetany Potential among Russian Wildrye Accessions

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ABSTRACT

Grass tetany or hypomagnesemic tetany in cattle (*Bos taurus*) is caused by an imbalance of K, Ca, and Mg in the diet. Indications of grass tetany range from reduced milk yield or weight gain to severe convulsions and death. The risk of grass tetany dramatically increases when the K/(Mg + Ca) ratio of forage exceeds 2.2, especially for dams during early lactation. Russian wildrye [*Psathyrostachys juncea* (Fisch.) Nevski], a valuable forage species, has ratios well above this level. Our objectives were to determine the mineral concentration and ratio values for 65 accessions of Russian wildrye to select germplasm sources with low tetany ratio and to determine the effects of year, location, and their interactions with accessions. Seedlings of each accession and two checks, Syn A and Mankota, were established in replicated space-plant nurseries at Logan, UT, Mandan, ND, and Swift Current, Saskatchewan, Canada. Years-within-location effects generally produced the largest variance component, while the accession variance was larger than location × accession and location × accession × year interaction variances for K, Ca, Mg, K/(Mg + Ca) ratio, and Reduced Tetany Potential (RTP) index. Selection for these traits in Russian wildrye germplasm will require multiple years to characterize adequately accessions, breeding lines, or synthetics. The K/(Ca + Mg) ratio of the accessions tested ranged from 2.2 to 3.0 when averaged across sites and years for V4 growth stage. A similar range of ratio values and ranking of the accessions was observed at the E2 growth stage. The three tetraploid accessions evaluated were among the five accessions with the highest tetany ratios. Previously reported forage yield and seed yield means were significantly correlated with K, Mg, and N concentrations and K/(Ca + Mg) ratio. The RTP index was not correlated with forage yield, seed yield, or N concentration. Therefore, selection in Russian wildrye should be based on increased RTP index rather than K concentration or K/(Ca + Mg) ratio to avoid concomitant unintentional selection of reduced forage yield and seed yield.

Russian wildrye grass is a valuable cool-season, ceaspitose forage species of the Northern Great Plains and Intermountain regions of North America (Rogler and Schaaf, 1963). It has higher forage quality, both protein and digestibility, in the summer and fall than crested wheatgrass [*Agropyron cristatum* (L.) Gaertner] (Knipfel and Heinrichs, 1978; Holt, 1996) and is used for summer and fall season grazing of stockpiled forage by beef cattle. Spring grazing in twice-over rotational grazing systems may increase forage quality by reducing seed head density and increasing the proportion of leaf tissue in forage biomass stock-piled for summer or fall use (Holt, 1996).

Grass tetany or hypomagnesemic tetany is characterized by low Mg concentrations in plasma or cerebrospinal fluid of cattle that results in reduced milk production of lactating females, reduced weight gain of feeders on pasture, or, in acute cases, convulsions, coma, and death of affected animals (NRC, 1996). Tetany occurs most often in early-lactating cows because of the large demand for Mg during lactation and the limited ability to mobilize Mg reserves. Magnesium content of the diet must be adequate on a daily basis to avoid chronic hypomagnesemic symptoms. Many environmental and edaphic factors may affect grass tetany but mineral concentrations of Mg, Ca, and K in the ruminant diet are important to determining the risk of occurrence (Mayland and Grunes, 1979). Kemp and 't Hart (1957) reported that tetany symptoms rarely occurred when the tetany ratio of K/(Mg + Ca), in equivalent units, was less than 2.2, but the incidence of tetany increased rapidly when ratio values exceeded this threshold.

Tetany ratio of Russian wildrye was highest in early June and declined for the remainder of the growing season at Swift Current, Saskatchewan (Lawrence et al., 1982). The ratio values observed in that study were above the threshold level from the first sampling date in mid-May to the early-July date and ranged from 2.20 to 2.78. Karn et al. (1983) also reported tetany ratios greater than 2.2 for Russian wildrye sampled in May and June at Mandan, ND. Asay and Mayland (1990) found that Russian wildrye had tetany ratio values of 3.2 to 4.6 suggesting that lactating beef cattle grazing it in spring will be at risk of developing grass tetany.

Increasing K content from 6 to 24 and 48 g kg^{-1} resulted in decreased Mg absorption by 24 and 61%, respectively, in wether lambs (Greene et al., 1983). Plasma Mg content was reduced by 7 and 10%, respectively. When additional Mg was fed in combination with additional K, higher Mg concentration flowed into the intestinal tract and was excreted than at low Mg and K concentrations. The addition of 1 g kg^{-1} of Mg had no effect on the urinary excretion of K. These results not only indicate the antagonistic absorption and retention of these minerals in ruminants but also suggest that Mg

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Abbreviations: GRIN, Genetic Resources Information Network; PI, Plant Introduction; RTP, reduced tetany potential.

supplementation may not be as effective in reducing the tetany risk as reduced K concentration or reduced tetany ratio in the forage.

Mineral supplementation of grazing beef cattle to increase dietary Ca and Mg consumption can be difficult on extensive rangelands with low stock density. Magnesium supplements are unpalatable and may not be consumed in sufficient quantity, even if mixed with salt or grain (Sleper, 1979). A tall fescue (*Festuca arundinacea* Schreber) cultivar with altered mineral content resulting from selection for increased Mg concentration, HiMag, exhibited similar preference by grazing cattle compared with other cultivars (Shewmaker et al., 1997). If mineral content is under genetic control and there is sufficient genetic variation, then altering K/(Ca + Mg) values by plant breeding can be an effective, alternative means to reduce grass tetany potential (Sleper, 1979). Heritability for K/(Ca + Mg) values in a population of Russian wildrye was 31% (Asay and Mayland, 1990) which is sufficient to achieve genetic gain from selection. Successful selection for tetany ratio value below 2.2 would require Russian wildrye germplasm with ratio values lower than those reported by Asay and Mayland (1990). The genetic variation, heritability, and response to selection for K/(Ca + Mg) values that have been reported in crested wheatgrass indicate that plant breeders could develop cultivars for grazing with low tetany risk (Mayland and Asay, 1989; Vogel et al., 1989; Asay et al., 1996).

Mayland and Asay (1989) proposed a Reduced Tetany Potential (RTP) selection index that would be more effective in crested wheatgrass than direct selection for mineral concentration or tetany ratio. The index is calculated from the sum of Studentized Mg concentration, the Studentized inverse of K/(Ca + Mg) tetany ratio, and the integer 10. The last term ensured that all index values would be positive since 99% of the values from the first two terms of the equation would range from −3 to +3 standard deviation units about a mean of zero. Asay and Mayland (1990) reported that Russian wildrye RTP index values were positively correlated with Ca and Mg concentrations but negatively correlated with K/(Ca + Mg) ratio values. Potassium concentration and K/(Ca + Mg) ratio were weakly correlated with forage yield (Asay and Mayland, 1990), suggesting that selection for decreased K concentration or decreased tetany ratio could result in reduced forage yield. However, selection for increased RTP index should increase Mg and Ca concentrations, or reduce K/(Ca + Mg) ratio without concomitant changes in K concentration.

The objectives of this study were to: (i) determine if genetic variation exists among accessions of Russian wildrye germplasm for K, Ca, Mg, grass tetany ratio [K/(Mg + Ca)], and RTP index; and (ii) determine the magnitude of genotype × environment interaction effects for mineral concentrations, grass tetany ratio, and RTP index.

MATERIALS AND METHODS

The sample Russian wildrye germplasm consisted of 62 diploid ($2n = 2x = 14$) and three tetraploid ($2n = 4x = 28$) accessions, a 21 clone synthetic (Syn-A) developed at Logan UT, and the cultivar Mankota (Berdahl et al., 1992). Origin of accessions can be obtained from the passport data of the Genetic Resources Information Network (GRIN) system (http://www.ars-grin.gov/npgs/; verified October 26, 2000) Agronomic performance of these accessions and a brief description of them has been reported by Berdahl et al. (1999). Seed of these accessions were provided by the USDA Western Regional Plant Introduction Station, Pullman, WA, and breeder seed was used for the cultivar and synthetic strain.

Test locations were Logan, UT (41° 46′ N, 107° 50′ W), Mandan, ND (46° 48′ N, 100° 46′ W), and Swift Current, Saskatchewan, Canada (50° 17′ N, 107° 50′ W), which represented three diverse environments within the region of adaptation for Russian wildrye in North America. Soil type was a fine, mixed, mesic, semiactive Aquic Argiustolls (silty, clay loam) at Logan, a fine-silty, mixed Pachic Haploborolls (silty loam) at Mandan, and a fine, mixed, mesic, Aridic Haploborolls (sandy loam) at Swift Current. Soils were sampled in spring, 1990 at Swift Current and Mandan and in spring, 1991 at Logan. Soil characteristics and mineral content (saturated paste extract) are shown in Table 1.

The experimental design was a randomized complete block with four replicates at each site. An individual plot consisted of a single row of eight plants that were space planted on 0.91- or 1.0-m centers in spring 1990 at Mandan and Swift Current and 1991 at Logan. Two plants per plot were utilized for forage mineral determination while others were used for plant height, vigor, forage DM yield, seed yield, and other agronomic evaluations (Berdahl et al., 1999).

In 1991 and 1992 at Swift Current and Mandan and in 1992 and 1993 at Logan, two plants were sampled at the V4 (vegetative tillers with four leaves) and E2 (seed head palpable at the second node) growth stages (Moore et al., 1991). One vertical half of the biomass of each plant was sampled at each growth stage and combined from both plants. Samples were dried at 60°C for 48 h or until a constant dry weight. They were then ground to pass a 0.5-mm stainless-steel screen and

Table 1. Water content, pH of saturated soil, electrolytic conductivity (EC), cation concentration and cation ratios of saturated-soil extract at three locations.

Location	Soil	Depth	pH	EC	Ca	Mg	K	Na	Mg/K	(Ca + Mg)/K
		mm		mSm^{-1}		mmoles L^{-1}				
Logan, UT	Aquic Argiustolls	0–300	7.72	–	4.94	3.58	0.15	0.95	24	57
		300–600	7.94	65	1.90	2.96	0.09	1.11	32	54
Mandan, ND	Pachic Haploborolls	0–300	5.76	62	3.49	2.12	0.51	0.17	4	11
		300–600	6.56	74	4.97	3.16	0.16	0.25	20	50
		600–900	7.27	88	4.96	3.97	0.11	0.47	36	81
Swift Current, Saskatchewan	Aridic Haploborolls	0–300	7.28	70	2.34	1.48	0.33	0.35	4	12
		300–600	7.60	66	1.94	1.48	0.17	0.45	9	20
		600–900	7.78	138	1.64	1.70	0.31	1.11	5	11

Table 2. Tests of significance for locations (fixed effect) and variance component estimates of random effects for K, Ca, and Mg concentrations, K/(Ca + Mg) ratio, and reduced tetany potential (RTP) index for Russian wildrye harvested for 2 yr at V4 and E2 growth stages at Logan, UT; Mandan, ND; and Swift Current, SK.

	K		Ca		Mg		K/(Ca + Mg)		RTP	
Source of Variation	**V4**	**E2**	**V4**	**E2**	**V4**	**E2**	**V4**	**E2**	**V4**	**E2**
Locations (L)	ns	*	ns	ns	ns	ns	ns	ns	ns	ns
Variance components										
Years within Locations (Y)	4.39	5.80	0.62	0.32	0.10	0.04	0.48	0.08	0†	0
Accessions (A)	3.67	3.02	0.02	0.01	0.01	0.01	0.02	0.02	0.27	0.21
L × A	0.91	0.72	0.02	0.00	0.00	0.00	0.01	0.00	0.22	0.14
L × A × Y	0.29	0.33	0.00‡	0.01	0.00	0.00	0.00	0.00	0.16	0.14

* Significant at $P = 0.05$.

† Estimates were forced to zero.

‡ Positive estimates rounded to zero.

stored in labeled kraft envelopes closed with a paper clip. Samples from all three locations were analyzed for mineral concentration at one laboratory.

Nitric-perchloric acid (3:1 v/v) digestion of 0.5 g of forage subsamples preceded analysis for Ca, K, Mg, Fe, and P. Phosphorous was measured colorimetrically using the vanadomolybdate procedure (Greweling, 1976). Potassium was determined by flame emission. Calcium, Fe, and Mg were measured by atomic absorption spectrophotometry. Samples for K, Ca and Mg analysis were prepared in 0.1% lanthanum (La) prior to analysis. The Fe concentration of forage samples was determined to check for exogenous soil contamination. Normal Fe content values were deemed to be 90 to 140 mg kg^{-1} depending on soil pH and fertility. Any samples producing Fe content >500 mg kg^{-1} were treated as contaminated and sample mineral data corrected to account for mineral soil content. A standard plant sample was included as a check on analytical procedures. All 3216 samples were analyzed and the cation ratio, K/(Ca + Mg) was calculated on an equivalent (moles of charge) kg^{-1} basis. Nitrogen content was determined by the micro Kjelldahl procedure at Mandan. There were 75 missing samples for N content because samples were used in an earlier determination. Reduced tetany potential index was calculated as proposed by Mayland and Asay (1989) as follows:

$$RTP = \frac{Mg_i - Mg_p}{s(Mg)} + \frac{[1/R]_i - [1/R]_p}{s[1/R]} + 10$$

where the subscript i is the value for the individual plant, the subscript p is the mean value for the accessions, and the s is the square root of the error mean square, and $1/R = (Ca + Mg)/K$ at a given harvest date for each site-year combination. The first two terms of the RTP index would each have a mean value of zero for a given population with 99% of values ranging from −3 to +3. To avoid negative values of the index, the integer value of 10 was added so that all RTP values are positive. The RTP index is the difference between two Studentized functions.

The Residual Maximum Likelihood (REML) directive in Genstat (Genstat 5 Committee, 1993) was used to fit a mixed linear model to Ca, K, Mg, Fe, P, K/(Ca + Mg), and RTP variates for each harvest. Effects of location (L) were considered fixed, while those for replicates within locations, years within locations, accessions, accessions × locations, accessions × replicate within locations, accessions × replicate within location, and accessions × years within locations were considered random. The estimated variance components were used to calculate broad-sense heritability for the mineral concentrations, K/(Ca + Mg) ratio and the RTP index (Allard, 1966). Accession means were best linear unbiased predictors estimated by REML in Genstat.

Pearson phenotypic correlation coefficients were determined by JMP software (SAS Institute Inc. 1997, Network JMP, version 3.2). Mean mineral concentrations, tetany ratio and RTP index for the 67 entries were correlated with forage DM yield, and seed yield data that was previously reported by Berdahl et al. (1999). Mineral concentrations were also correlated with tetany ratio and RTP index with recognition of the risk of auto-correlation between K/(Ca + Mg) tetany ratio and K, Ca, and Mg concentrations. However, because these correlations have been previously reported (Mayland and Asay, 1989; Asay and Mayland, 1990), we concluded that they could be useful for comparison to the previous results.

RESULTS AND DISCUSSION

Location affected only K concentration at the E2 growth stage (Table 2) despite the apparent differences among sites in soil mineral concentrations (Table 1). The K concentration for E2 growth stage at Mandan was 24% greater than at the other two locations (Table 3). This was consistent with the apparent higher soluble soil K concentration determined at that site (Table 1).

The largest variance component from the random effects was found for years within locations (Table 2). It was consistently the largest variance component for the three mineral variables and the K/(Ca + Mg) ratios for both growth stages. This variance was zero for the

Table 3. Mineral content and K/(Ca + Mg) ratio of Russian wildrye forage from two maturity dates in two years at three locations.

Maturity†	Location	Year	K	Ca	Mg	K/(Ca + Mg)
			g kg^{-1}			
V4	Logan, UT	1992	33.8	2.24	2.00	3.20
		1993	30.4	3.15	2.31	2.27
	Mandan, ND	1991	31.9	3.82	2.54	2.07
		1992	35.3	2.20	1.83	3.51
	Swift Current, SK	1991	28.3	2.39	2.27	2.41
		1992	29.9	2.93	2.26	2.34
	SE		0.1	0.02	0.1	0.02
E2	Logan, UT	1992	27.1	2.05	2.00	2.66
		1993	28.1	2.75	2.26	2.27
	Mandan, ND	1991	36.3	2.95	2.12	2.93
		1992	30.5	2.05	1.83	3.12
	Swift Current, SK	1991	26.5	1.89	1.93	2.74
		1992	26.5	2.68	2.18	2.20
	SEM		0.1	0.02	0.01	0.02

† V4 - four leaves per vegetative tiller; E2 - seed head palpable at second node (Moore et al., 1991).

RTP index because the index was calculated from normalized data. Precipitation and temperature can influence forage mineral concentration and grass tetany potential (Mayland and Grunes, 1979) and may have contributed to the year effects we observed.

We chose the V4 and E2 growth stages for sampling because they were similar to or slightly earlier than the phenological stages used by Asay and Mayland (1990). They observed that the tetany ratio increased from the preboot to boot growth stage in Russian wildrye. This was consistent with changes in tetany ratio reported by Lawrence et al. (1982). They showed that K/(Ca + Mg) ratio increased from mid-May (2.2) to early-June (3.0) and declined again in early July (2.3). These dates would correspond to vegetative, stem-elongation, and postanthesis growth stages at the Swift Current site. We did not observe a consistent increase in tetany ratio at E2 compared with V4. The ratio increased at Mandan and Swift Current in 1991 but decreased at Mandan, Swift Current, and Logan in 1992 (Table 3). There was no apparent change in tetany ratio with growth stage at Logan in 1993. This result may be attributed to the short time difference between these growth stages. Sampling at the E2 growth stage was 7 to 10 d after the V4 growth stage. As a result of the inconsistent effect of growth stage, and to reduce the complexity of the statistical model, we analyzed the location, year, and accession effects separately for each growth stage.

The variance component for accessions was the next largest estimate for K, Ca, and Mg concentration, tetany ratio and RTP index. It was much smaller than the year within location component estimate for Ca, Mg, and tetany ratio. The Location × Accession and the Location × Accession × Year interaction variance components were significant for all variables (Table 2). However, the interaction variances ranged from equality with accession variance estimates, such as the L × A interaction for Ca concentration at the V4 harvest, to one-tenth of the accession variance such as the L × A × Y interaction for K concentration at the V4 stage. These results are consistent with those of Asay and Mayland (1990) who observed significant year and genotype × year interaction effects on K/(Ca + Mg) tetany ratio for Russian wildrye. While preliminary selection among diverse accessions or breeding accessions may be conducted over several years within one site, it is apparent from our study and previous studies that selection for any of these traits in Russian wildrye breeding programs will require multiple years and sites to account for the genotype × environment interaction effects on observed K/(Ca + Mg) ratio values.

The K/(Ca + Mg) ratios ranged from 2.24 to 2.98 among the accessions at the V4 growth stage (Table 4). No accession exhibited a tetany ratio below the threshold value of 2.2. The ten accessions with the lowest tetany ratios ranged from 2.24 to 2.47. The small number of genotypes sampled within an accession was necessary due to the large number of accessions as well as growth stages, locations and years. Resource limitations on the number of analytical procedures required some reduction in sample numbers and we chose to combine forage tissue collected from the two plants at each site. If we had been able to sample a larger number of plants (genotypes) within these accessions, then we might have found some genotypes with tetany ratio below the threshold value. On the basis of our results, the selection of low

Table 4. Mean mineral concentration, K/(Ca + Mg) tetany ratio, and RTP index of 67 Russian wildrye accessions sampled at the V4 growth stage averaged over two years and three sites. The ten accessions ranked highest and lowest for tetany ratio are presented along with check cultivars and the range of values for the remaining 45 accessions. The rank of K, Ca, Mg and ratio is presented (lowest to highest) after the mean.

	K		Ca		Mg		K/(Ca + Mg)		RTP
Accession	Mean $\bar{x}$	Rank	$\bar{x}$	Rank	$\bar{x}$	Rank	$\bar{x}$	Rank	$\bar{x}$
	g kg^{-1}		g kg^{-1}		g kg^{-1}				
PI 314671	25.0	1	2.65	13	2.07	11	2.24	1	10.55
PI 314669	25.8	2	2.68	20	2.05	8	2.30	2	10.41
PI 499673	32.9	53	3.22	67	2.56	67	2.33	3	12.14
PI 502576	29.8	9	3.03	62	2.24	42	2.38	4	10.77
PI 406469	30.2	10	3.13	66	2.23	36	2.38	5	10.76
PI 429798	30.7	20	2.96	59	2.28	55	2.44	6	10.70
PI 369234	29.7	7	2.74	29	2.31	62	2.44	7	10.88
PI 314670	27.3	3	2.70	23	1.98	1	2.44	8	9.82
PI 430863	31.2	25	3.06	65	2.27	51	2.46	9	10.68
PI 222050	32.4	48	3.04	63	2.45	66	2.47	10	11.38
Minimum value (*n* = 45)	28.6	4	2.54	3	2.02	2	2.48	11	8.92
Maximum value (*n* = 45)	34.6	64	3.04	64	2.44	65	2.80	57	10.56
Syn-A	34.4	63	2.89	51	2.31	61	2.72	53	10.17
Mankota	32.2	41	2.78	32	2.23	39	2.68	41	10.03
PI 370672	32.7	51	2.67	17	2.18	28	2.80	58	9.48
PI 499672	30.6	19	2.58	7	2.04	7	2.81	59	9.06
PI 314082	32.2	40	2.58	6	2.16	21	2.83	60	9.53
PI 502572	33.0	56	2.66	14	2.16	22	2.83	61	9.39
PI 502573	33.4	59	2.68	19	2.17	25	2.87	62	9.35
PI 565068	36.0	66	2.70	25	2.30	60	2.91	63	9.77
PI 565070	35.7	65	2.65	12	2.23	38	2.94	64	9.50
PI 565071	36.5	67	2.66	15	2.26	49	2.97	65	9.56
PI 430872	33.8	61	2.49	1	2.14	18	2.98	66	9.06
PI 430868	32.3	44	2.50	2	2.03	3	2.98	67	8.63
LSD (0.05)	1.3		0.19		0.12		0.18		0.86

tetany potential Russian wildrye will be difficult without additional genetic variability.

Low tetany ratio appeared to result from a combination of low K concentration and high Mg and/or Ca concentration (Table 4). Three accessions, PI 314669, PI 314670, and PI 314671, exhibited K concentrations that averaged nearly 4 g kg^{-1} lower than the next highest accession. It would appear that these accessions might be useful parental accessions for selection. However, Berdahl et al. (1999) identified these accessions as exhibiting low forage yield and their agronomic limitations would need to be considered before their utilization for selection. Accessions PI 499673 and PI 222050 had high K concentrations but also had among the highest Mg concentrations producing tetany ratios of 2.33 and 2.47. These two accessions exhibited the highest RTP index values of 12.14 and 11.38. These two accessions had the highest Mg concentrations so their RTP index values reflected the inclusion of normalized Mg concentration in its calculation.

Among the 10 accessions with the highest ratio were PI565068, PI565070, and PI565071, three tetraploid accessions that had the highest K content of all 67 entries. These accessions averaged 36.1 g kg^{-1} and were 3 g kg^{-1} higher in K concentration than the next highest accession. These accessions were among the five accessions exhibiting the highest K/(Ca + Mg) tetany ratios. Whether the K concentration of these accessions is related to their ploidy level is worthy of further study of the impact of ploidy level on Russian wildrye mineral concentrations.

The ranking of accessions for K/(Ca + Mg) tetany ratio at the E2 growth stage (data not shown) were similar to the rankings at the V4 stage (Table 4). Nine of the 10 lowest ratio accessions were the same and seven of the 10 highest ratio accessions were the same. The tetany ratio of the two growth stages exhibited a significant correlation ($r = 0.87$, $P < 0.01$, df = 66).

We calculated broad-sense heritability values of 0.64 and 0.66 for the K/(Ca + Mg) tetany ratios at V4 and E2 growth stages. These values are higher than the 0.31 heritability reported by Asay and Mayland (1990) and likely reflects the greater genetic variability of accessions compared with their selected breeding accession. Our heritability values for K, Ca, and Mg concentrations (data not shown) were also higher than those reported by Asay and Mayland (1990). We calculated broad-sense heritability values of 0.50 and 0.47 for the RTP index at V4 and E2 growth stages which are very close to the 0.48 value reported by Asay and Mayland (1990).

The observed K, Ca, and Mg concentrations and K/(Ca + Mg) ratios were similar to those previously reported for Russian wildrye (Asay and Mayland, 1990) and the tetany ratio was higher than those observed in other grasses (Sleper, 1979). The maximum allowable K content for beef cattle diets is 30 g kg^{-1} (NRC 1996) and 43 accessions were at or above this level. This suggests that beef cattle grazing lush spring Russian wildrye pastures are at risk of reduced Mg absorption and reduced performance even when no acute symptoms of grass tetany are observed. Potassium concentration and tetany ratio will decline with maturity (Lawrence et al., 1982) and will likely be below the threshold value for summer or fall stock-piled grazing. However, if spring grazing is utilized to reduce seed head density of Russian wildrye and increase the forage quality of stock-piled regrowth (Holt, 1996), then caution should be raised about the risk of grass tetany. In southwestern Saskatchewan, beef cows lactate early, when the risk of grass tetany is highest. Spring blizzards, such as 27 to 29 May 1982 and 11 May 1999, were followed by reports of hypomagnesemic tetany to local veterinarian clinics or provincial extension staff (P. Jefferson, personal observation). While none of these reports was attributed solely to grazing Russian wildrye, it is clear that grass tetany is a recurring management issue for beef cow/calf producers of this region and the Northern Great Plains.

The accessions that had the five highest Mg content were PI 499673, PI 222050, PI 315080, PI 406468, and PI 430876. These accessions had Mg concentrations of 2.56, 2.45, 2.44, 2.32, and 2.32 g kg^{-1} but K/(Ca + Mg) ratios of 2.44, 2.47, 2.61, 2.57 and 2.62, respectively. This suggests that selection for increased Mg concentration alone will not reduce the tetany ratio.

Potassium concentration was significantly correlated with Mg concentration and tetany ratio but not Ca or RTP index (Table 5). Calcium concentration was correlated with Mg concentration, tetany ratio and RTP index. Mg concentration was not correlated with tetany ratio but was correlated with RTP index. These are generally similar correlations to those reported by Asay and Mayland (1990) and those calculated from the data of Lawrence et al. (1982). Phosphorus concentration has been reported to be correlated with K and Mg content for Russian wildrye (Asay and Mayland, 1990). Phosphorus concentration has also been reported to be corre-

Table 5. Phenotypic correlation coefficients among mineral content, K/(Ca + Mg) ratio, RTP index, forage and seed yield of 67 Russian wildrye accessions averaged over two growth stages, two years, and three sites.

	Ca	Mg	K/(Ca + Mg)	RTP	N	P	Forage	Seed g m^{-2}
K g kg^{-1}	0.06	0.62**	0.70**	−0.04	0.66**	0.20	0.67**	0.49**
Ca g kg^{-1}		0.48**	−0.58**	0.71**	0.19	0.03	−0.05	−0.02
Mg g kg^{-1}			−0.06	0.73**	0.48**	0.00	0.47**	0.38**
K/(Ca + Mg)				−0.71**	0.41**	0.24	0.48**	0.35**
RTP					<0.01	−0.23	<0.01	0.01
N g kg^{-1}						0.70**	0.52**	0.52**
P g kg^{-1}							0.15	0.25*
Forage g m^{-2}								0.72**

*, ** Denote statistical significance at $P = 0.05$ and 0.01, respectively.

lated with Ca and Mg in perennial ryegrass (Blevins and Sanders, 1994). However, we did not observe any correlations of K, Ca, Mg concentrations, tetany ratio, or RTP index with P concentration.

Forage DM yield and seed yield were positively correlated with K and Mg concentrations and the K/(Ca + Mg) ratio (Table 5). Potassium plays an important physiological role in stomatal control of transpiration and a biochemical role in protein synthesis. Magnesium is an essential mineral for photosynthesis. Thus, these significant correlations to biomass productivity were expected but are higher than the correlation value reported by Asay and Mayland (1990). These results also suggest that selection for reduced K concentration or reduced K/(Ca + Mg) ratio will risk a concomitant, unintentional reduction in forage and seed yield. Selection for higher Ca and Mg content will have no effect and a positive association with forage yield, respectively. The use of the RTP index for selecting lower tetany breeding materials should not be associated with changes to forage yield or seed yield (Table 5). Thus the RTP index value would be a more effective selection criterion than mineral concentration or tetany ratio per se.

There were significant, positive correlations between N and association between N concentration and K and Mg concentration and between N and K/(Ca + Mg) tetany ratio (Table 5). A significant relationship between N concentration and Mg concentration has been reported for crested wheatgrass (Asay et al., 1996). However, they reported no relationship between N and K while our results, and those of Lawrence et al. (1982), for Russian wildrye indicated a positive association. On the basis of our results, selection for reduced K concentration or reduced tetany ratio could result in lower protein (N) concentration and that could have negative effect on animal nutrition. However, selection for altered RTP index would not cause altered protein content.

CONCLUSIONS

There was significant variation for K, Ca, and Mg concentrations and K/(Ca + Mg) tetany ratio among these Russian wildrye accessions but all accessions exhibited tetany ratios above the threshold value. Selection for reduced tetany risk in Russian wildrye will require the discovery of genetic materials with tetany ratios below those exhibited by these accessions. Selection must be conducted at multiple sites and years to account for genotype × environment interaction effects on mineral content and tetany ratio. The RTP index will be more useful than K, Ca, or Mg concentration or tetany ratio for selection because of its independence from N concentration, forage DM yield, and seed yield.

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