Genetic variability for elements associated with grass tetany in Russian wildrye

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Abstract

Grass tetany (hypomagnesemia) may be an important factor limiting productivity of animals grazing Russian wildrye [*Psathyrostachys juncea* (Fisch.) Nevski]. This malady is associated with relatively low concentrations in the forage of Mg and Ca, and high values for K and K/(Ca+Mg). We studied the genetic variablity in a Russian wildrye breeding population for mineral elements that relate to grass tetany in ruminants. Forty-five progeny lines, established as spaced plants in a randomized complete block, were sampled at the pre-boot and boot stages in each of 2 years and analyzed for Mg, Ca, K, and P. Although seasonal variation was evident, K/(Ca+Mg) of the progeny lines ranged from 3.2 to 4.6, well above the 2.2 level at which a 5% incidence of grass tetany has been found in dairy cattle. With few exceptions, progenies differed for all traits evaluated. Differences among progenies were relatively consistent over harvests for all traits. A reduced tetany potential (RTP) was computed as the sum of normalized Mg and reciprocal of K/(Ca+Mg) values, providing an estimate of the grass tetany risk for individual progeny lines. The variation among progenies, and the magnitude of broad-sense heritability estimates for RTP (0.48) and K/(Ca+Mg) values (0.31), indicate that mineral ion composition of this breeding population can be altered through breeding. The high K/(Ca+Mg) values in the population suggest that it may be helpful to introduce genetic factors conditioning lower grass tetany potential from other sources. Intercharacter correlations suggest that breeding for higher levels of Mg will be accompanied by increased Ca and, to a lesser extent, increased K.

Key Words: *Psathyrostachys juncea,* hypomagnesemia, broad-sense heritability, grass breeding, Mg, Ca, K, P

Russian wildrye [(*Psathyrostachys juncea* (Fisch.) Nevski] is a valuable cool-season perennial grass for improvement of rangelands in western North America. Established plants of this C-3 caespitose grass are resistant to drought and have moderate salinity tolerance (Rauser and Crowle 1963). Because Russian wildrye retains its nutritive value better than most other range grasses during later stages of maturity, it is regarded as an excellent source of forage during late summer and fall (Knipfel and Heinrichs 1978, Heinrichs and Carson 1956, Lawrence and Troelsen 1964, Mayland 1988, Smoliak and Slen 1975).

Grass tetany (hypomagnesemia) is a deficiency of available Mg in grazing ruminants. Clinical deficiencies (<18 mg Mg liter^{-1} blood plasma) may result in reduced weight gain, milk production, and conception (Vogel et al., Unpublished; Stuedemann et al. 1983). Severe deficiencies produce tetanic convulsions, coma, and death of affected animals. Tetany occurs most often in early-lactating cows because of large secretory losses of Mg in milk. Because body reserves of Mg in soft tissue generally have a half-life of 24 to 30 hours, Mg must be replaced on a daily basis.

Forage that promotes grass tetany has low concentrations of Mg, Ca, carbohydrates, and dry matter. Such forage also contains high concentrations of K, nonprotein N, fatty acids, and organic acids along with a relatively high K/(Mg+Ca) ratio (Mayland 1988). Grass tetany occurs predominately in animals grazing C-3 grasses and only rarely with legume-grass mixtures. Low Mg and high K and N concentrations in the forage are the most prominent factors in the etiology of the ailment. Potassium interferes with translocation of Mg from the roots to other parts of the plant (Ohno and Grunes 1985).

Rogler and Lorenz (1970) found that although beef production was similar for yearling steers consuming Russian wildrye and crested wheatgrass [*Agropyron desertorum* (Fisch. ex Link)], apparent metabolic disorders were observed in animals grazing Russian wildrye. The symptoms, which consisted of scouring, frequent urination, and reduced weight gains, were observed in the steers during the spring or early summer when grass tetany usually occurs. Later work (Karn et al. 1983) did not conclusively identify the cause of the malady, although they found low forage Ca and P during both years of their study and low Mg during 1 year. Potassium levels in the forage may have been high enough to interfere with Mg absorption. The K/(Ca+Mg) ratios were generally higher than 2.2, a level previously reported to be associated with the incidence of grass tetany (Kemp and t'Hart 1957). High levels of K have been measured in Russian wildrye in Mayland (unpublished). Lawrence et al. (1982) reported Russian wildrye had higher K/(Mg+Ca) values than crested wheatgrass. They concluded that, particularly under heavy fertilization, supplementation of diets with Mg and/or Ca might be required to prevent grass tetany and assure good performance. The potential of inducing grass tetany in grazing animals would substantially reduce the value of Russian wildrye on semiarid rangeland.

Based on the magnitude of genetic variation and narrow-sense heritability values in a breeding population of tall fescue (*Festuca arundinacea* Schreb.), Sleper et al. (1977) concluded that substantial progress should be possible in breeding for low hypomagnesemia potential in this species. This conclusion was later confirmed by Sleper and Mayland (Unpublished). Hides and Thomas (1981) increased the level of Mg in a breeding population of Italian ryegrass. The derived high-Mg line resulted in greater dry matter intake by sheep and increased Mg availability (Moseley and Griffiths 1984).

Our objectives were to evaluate the grass tetany potential and extent of genetic variation for mineral elements associated with this disorder in a Russian wildrye breeding population.

Materials and Methods

Plant materials consisted of 45 open pollinated (OP) progeny lines selected from 2 closely related synthetic strains of diploid (2n = 14) Russian wildrye. The population was originally derived from named cultivars and plant introductions; 38% from an introduction from the USSR, PI 440627 (Asay et al. 1985). Although the parentage had been subjected to selection for characters associated with forage and seed yield potential, seedling vigor, and resistance

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to environmental stress and plant pests, no selection pressure had been applied for mineral ion uptake of Mg, Ca, K, and P.

The progeny lines were established during April 1986 as spaced plants on 1-m centers. Plots consisted of a single row of 10 plants each and were arranged in a randomized complete block design with 4 replications. The experimental area was about 2 km south of Logan, Utah, on the Utah State University Evans Research Farm (41 45′ N, 111 48′ W, 1,350 m a.s.l.). The soil was a Nibley silty clay loam series that is classified as a fine mixed mesic aquic Argiustoll. The area was fertilized with 50 kg N ha^{-1} in mid-September of the establishment year (1986) and in 1987. No supplemental water was applied during the course of the experiment.

Forage from the first 2 plants in each plot were sampled for analyses at pre-boot and boot growth stages during 1987 and 1988. Samples were taken at a 5-cm stubble height at the pre-boot stage on 27 April 1987 and 4 May 1988 and at the boot stage on 5 May 1987 and 13 May 1988. The samples were dried in forced draft ovens at 60° C for 48 hours. Dried samples were ground to pass through a 40-mesh Wiley screen. Subsamples of the forage were digested in 3:1 nitric:perchloric acid and diluted with 1 g La l^{-1} as $LaCl_2$. Analyses for Mg and Ca were made by atomic absorption and K by flame emission. Phosphorus was determined colorimetrically using the Vanadomolybdate procedure. Green weights were measured at the post-anthesis stage (22 June) in 1988.

An in-house alfalfa sample was analyzed with the grass series to typify the analytical precision. This sample was analyzed to contain 3.4 ± 0.3 mg Mg g^{-1}, 14.5 ± 0.8 mg Ca g^{-1}, 23.5 ± 1.0 mg K g^{-1}. The K/(Ca+Mg) ratio was computed on an equivalent basis. Data from mineral analyses were expressed on a dry matter basis.

A reduced tetany potential index (RTP) was computed according to Mayland and Asay (1989) as follows:

$$RTP_u = \frac{Mg_i - Mg_p}{S\ Mg_p} + \frac{\frac{Ca + Mg}{K}_i - \frac{Ca + Mg}{K}_p}{S\ \frac{Ca + Mg}{K}_p}$$

The subscript ‘i’ is the value for the individual plant, the subscript ‘p’ is the mean value for the population, and ‘s’ denotes the square root of the error mean square in the analysis of variance for the appropriate trait at a given harvest date. The RTP_u value as calculated above is a normalized function with a mean of 0 for a given harvest date. To avoid negative numbers in the statistical analyses, RTP_u values were adjusted to $RTP_u + 10$.

Data were subjected to standard regression and analysis of variance procedures. Variance components and F tests were computed with progeny lines and years considered as random variables and harvests as fixed. Percent genetic variability was computed on a mean basis as the ratio $\sigma^2_p/\sigma^2_{\overline{ph}}$, where σ^2_p is the variance component among the progeny lines or total genetic variance, and $\sigma^2_{\bar{p}h}$ is the variance of a progeny mean or phenotypic variance among progeny lines (Comstock and Robinson 1952). This ratio provides an estimate of heritability in the broad sense (H_b).

Correlations between forage yield and P and other measured variables were made to determine if selection for grass tetany potential could be done independently of forage yield potential and P concentration in this Russian wildrye breeding population.

Results and Discussion

Based on observed K/(Ca+Mg) ratios, a high potential for grass tetany outbreaks is evident in this breeding population of Russian wildrye. Mean K/(Ca+Mg) ratios for each of the 45 progeny lines were well above the 2.2 level, established by Kemp and t’Hart (1957) to be associated with incidence of grass tetany (Table 1). In 1987, K/(Ca+Mg) ratios for the progenies (averaged over harvests) ranged from 2.36 to 3.13 with a mean of 2.70. The apparent danger was greater in 1988, with ratios ranging from 3.87 to 6.25 and averaging 4.74. The corresponding values for the data combined over years were 3.19 to 4.55 and 3.72 for the range and mean, respectively.

Table 1. Summary of data for elemental traits for each year combined over harvests and combined over years and harvests for 45 Russian wildrye half-sib families.

Traits[1]	Ca	Mg	K	P	K/(Ca+Mg)	RTP
1987:						
Range						
Min.	2.91	1.61	31.01	----	2.36	8.05
Max.	3.94	2.01	36.37	----	3.13	12.09
Mean	3.47	1.80	33.31	----	2.70	10.00
SE	0.21	0.08	1.18	----	0.13	0.64
σ^2_p	0.02	0.01	0.71	----	0.01	0.19
H_b[3]	0.35	0.34	0.34	----	0.30	0.32
1988						
Range						
Min.	1.74	1.03	25.20	2.61	3.87	7.20
Max.	2.84	1.47	31.60	3.19	6.25	12.73
Mean	2.29	1.23	28.91	2.94	4.74	10.00
SE	0.19	0.06	0.99	0.10	0.31	0.72
σ^2_p	0.04	0.01	1.15	0.01	0.17	0.78
H_b	0.55	0.62	0.54	0.49	0.64	0.60
1987-88						
Range						
Min.	2.44	1.37	28.58	----	3.19	8.34
Max.	3.32	1.69	33.79	----	4.55	11.77
Mean	2.88	1.52	31.11	----	3.72	10.00
SE	0.17	0.05	0.90	----	0.18	0.53
σ^2_p	0.02	0.01	0.75	----	0.03	0.33
H_b	0.43	0.44	0.46	----	0.31	0.48

[1] Traits expressed in mg g^{-1} except H_b, which is a ratio.
[2] σ^2_p = Variance component among progeny means.
[3] H_b = heritability in the broad sense on a mean basis.

In 1987, concentrations of Ca and Mg were significantly higher at the earlier stage of development (harvest 1) than later at harvest 2 (Table 2). The K/(Ca+Mg) ratio was higher at harvest 2, even though levels of K were significantly higher at harvest 1 (35.8 vs 30.9). Although the trend was reversed for Ca and Mg in 1988, levels of K and the K/(Ca+Mg) ratio were significantly higher at harvest 2. This inconsistency is reflected by a year × harvest interaction for Ca, Mg, K, and the K/(Ca+Mg) ratio in the analyses combined over years (Table 3). The magnitude of K/(Ca+Mg) ratios suggests, however, that the potential for grass tetany increases during the week from the pre-boot to the boot stage in this population of Russian wildrye. This is in accordance with previous findings in crested wheatgrass (Mayland and Asay 1989. ans.

[3] H_b = heritability in the broad sense on a mean basis.

Table 2. Calcium, Mg, and K concentrations and the K/(CA+Mg) ratio in 45 Russian wildrye progeny lines at 2 harvest dates and during 2 years, and concentrations of P at 2 harvest dates for 1 year.

Harvest	Year	Ca	Mg	K	P	K/(Ca+Mg)
		---------- mg g^{-1} ----------				
1	1987	3.83	1.95	35.8	----	2.64
	1988	2.24	1.20	29.3	2.94	3.66
	Mean	3.03	1.58	32.5	----	3.15
2	1987	3.11	1.65	30.9	----	2.75
	1988	2.34	1.26	28.5	2.93	5.83
	Mean	2.72	1.45	29.7	----	4.29

Table 3. Mean squares from analyses of variance of elemental traits for each year combined over harvests and combined over years and harvests for 45 Russian wildrye half-sib families.

Source	DF	Mean squares					
		Ca	Mg	K	P	K/(Ca+Mg)	RTP
1987							
Rep	3	1.032	0.407**	56.4	----	0.1408	11.629
Progeny (P)	44	1.092*	0.137*	33.6*	----	0.3713	9.524*
Error a	132	0.707	0.090	22.3	----	0.2584	6.484
Harvest (H)	1	94.178**	16.592**	4321.3**	----	2.4140**	0.000
P × H	44	0.102	0.016	11.2	----	0.0676	1.607
Error b	135	0.128	0.020	10.3	----	0.0755	1.711
1988							
Rep	3	0.4371	0.1821*	141.05**	0.0456	2.31	5.630
Progeny (P)	44	1.2461**	0.1433**	34.02**	0.3362**	4.25**	20.729**
Error a	132	0.5562	0.0552	15.56	0.1722	1.54	8.227
Harvest (H)	1	1.7900**	0.6361**	113.05**	0.0458	844.87**	0.000
P × H	44	0.1694	0.0186	5.51	0.1253	1.42**	5.007**
Error b	135	0.1511	0.0146	5.80	0.0931	0.47	2.105
1987-88							
Rep	3	0.43	0.37**	74.7*	----	1.5	9.466
Progeny (P)	44	1.81*	0.21*	51.7*	----	2.9	21.908**
Error a	132	0.89	0.10	26.1	----	1.0	8.846
Year	1	498.08**	116.22**	6979.3**	----	1505.5**	0.000
P × Y	44	0.52	0.07	15.9	----	1.7**	8.345
Error b	135	0.39	0.05	14.2	----	0.8	5.907
Harvest (H)	1	35.00	5.37	2916.1	----	468.8	0.000
P × H	44	0.12	0.02	9.9	----	0.7	3.120
Y × H	1	60.97**	11.86**	1518.2**	----	378.5**	0.000
P × H × Y	44	0.15	0.02	6.8	----	0.8**	3.495**
Error c	270	0.14	0.17	8.1	----	0.3	1.908

*,**Significant at 0.05 and 0.01 probability levels, respectively.

The RTP index values were normalized within each harvest; consequently mean squares were 0 and means were 10 for harvests and years for this trait.

The 45 progeny lines differed significantly ($P<0.05$ or 0.01) for all traits evaluated except for the K/(Ca+Mg) ratio in 1987 and in the analysis combined over years (Table 3). Differences among the 45 progeny lines were relatively consistent at the 2 harvest dates as indicated by the nonsignificant progeny × harvest interaction in the analyses for all traits in 1987 and in the analysis combined over years. The tetany × harvest interaction was significant ($P<0.01$) only for the K/(Ca+Mg) ratio and RTP index in 1988.

Consistency among the progeny lines at the 2 harvests was verified by significant ($P<0.01$) correlation coefficients (r) between harvests (Table 4), which ranged from 0.56 to 0.84 in 1987, from 0.48 to 0.80 in 1988, and from 0.68 to 0.89 when the data were combined over years. The entry × year interactions were generally nonsignificant, although the correlations among entry means between years were of a lesser magnitude than the corresponding correlations between harvests.

Table 4. Correlations (r) between harvests and between years for Ca, Mg, K, P, K/(Ca+Mg), and RTP index based on 45 Russian wildrye progeny mean values.

	Harv 1 vs. Harv 2			1987 vs. 1988		
	1987	1988	1987-88	Harv 1	Harv 2	Harv 1-2
			r			
Ca	0.84**	0.79**	0.89**	0.47**	0.50**	0.55**
Mg	0.80**	0.80**	0.87**	0.37*	0.47**	0.47**
K	0.56**	0.72**	0.69**	0.39**	0.61**	0.53**
P	----	0.48**	----	----	----	----
K/(Ca+Mg)	0.70**	0.58**	0.68**	0.40**	0.34*	0.47**
RTP	0.71**	0.62**	0.76**	0.43**	0.35*	0.48**

[1] Degrees of freedom = 43

*,**r values significantly greater than 0 at 0.05 and 0.01 probability levels, respectively.

Variation among progeny lines was subtantially greater in 1988 than in 1987 (Table 3), possibly because plants were better established in 1988. The range among progeny lines for the K/(Ca+Mg) ratio was 29% and 50% of the mean in 1987 and 1988, respectively. When data were combined over years, the range in mean values for the K/(Ca+Mg) ratio was 37% of the mean. The magnitude of the variation is also demonstrated by the variance component among progeny lines (σ_p^2). This component, which provides an estimate of the total genetic variance among the progeny lines, was substantially larger in 1988 than in 1987 in all but 1 instance. For example, the genetic variance for the K/(Ca+Mg) ratio was 0.01 in 1987 compared to 0.17 in 1988.

A similar range of variation was observed for the RTP index. This index, which provides an estimate of the grass tetany producing potential of an individual progeny line, comprises information involving the interactions of Mg, Ca, and K (Mayland and Asay 1989, Mayland and Grunes 1979, Kemp and t'Hart 1957). The index gives additional weight to the Mg concentration in the forage and should be particularly useful in evaluating the progress in breeding programs to reduce the grass tetany hazard. The ranges in RTP values were 40, 55, and 34% of the mean in 1987, 1988, and 1987–88, respectively.

Broad-sense heritability values (H_b) also indicated that opportunities were available in the population for selection. Heritabilities for the K/(Ca+Mg) ratio were 0.30, 0.64, and 0.31 for the individual year and the analysis combined over years, respectively.

The corresponding values for the RTP index were 0.32, 0.60, and 0.48.

The variability among progenies for K/(Ca+Mg) and RTP values along with the magnitude of the heritability values suggests that the grass tetany potential of this breeding population can be altered through breeding. However, because the lowest mean K/(Ca+Mg) ratios were above the 2.2 threshold level, it would be appropriate to infuse genetic diversity from other sources. A logical procedure would be to assemble as much Russian wildrye germplasm as possible through plant exploration, from the National Plant Germplasm System, and from seed inventories in breeding programs. These plant materials would then be screened to establish a base from which the necessary genetic factors could be obtained.

Progeny means combined over years were used to compute a correlation matrix among the 6 traits within and combined over harvests (Table 5). Magnesium was significantly and positively correlated with Ca within each harvest and combined over harvests (r = 0.62** to 0.73**). A weaker positive relationship existed between Mg and K (r = 0.31* to 0.34*) and Ca and K (r = 0.29* for harvest 2). As expected, Mg and Ca were negatively correlated ($P<0.01$) with the K/(Ca+Mg) ratio and positively correlated with the RTP index. Although K was positively correlated with the K/(Ca+Mg) ratio (r = 0.32* to 0.35*), no relationship was detected between K and the RTP index. A strong negative association was found between the K/(Ca+Mg) ratio and the RTP index (r = -0.84** to -0.92**).

Table 5. Correlations (r) among Ca, Mg, K, P, K(Ca + Mg), and RTP index based on 45 Russian wildrye progeny mean values combined over two years.[1]

	Harvest	Ca	Mg	K	P	K/(Ca+Mg)
				r		
Mg	1	0.73**				
	2	0.62**				
	Combined	0.69**				
K	1	0.25	0.31*			
	2	0.29*	0.32*			
	Combined	0.27	0.34*			
P	1	0.10	0.31*	-0.07		
	2	-0.11	0.26	0.08		
	Combined	0.04	0.31*	-0.03		
K/(Ca+Mg)	1	-0.78**	-0.66**	0.32*	-0.25	
	2	-0.52**	-0.41**	0.34*	0.12	
	Combined	-0.66**	-0.55**	0.35*	-0.10	
RTP Index	1	0.82**	0.88**	-0.07	0.34*	-0.92**
	2	0.68**	0.82**	-0.01	0.07	-0.84**
	Combined	0.78**	0.88**	-0.02	0.25	-0.87**

[1] Degrees of freedom = 43; P values from 1988 only.

*,** r values significantly greater than 0 at the 0.05 and 0.01 probability levels, respectively.

Stepwise regression analyses showed that Mg accounted for 77% of the variation among the RTP index of the progeny lines. The second variable added was K, which along with Mg accounted for 89% of the variation. When Mg, K, and Ca were all included in the regression analysis, 95% of the variation was accounted for. This confirms that selection based on RTP places more emphasis on Mg than on Ca and K, as was initially reported by Mayland and Asay (1989).

A weak relationship was found between green weights of the progeny lines and K concentration (r = 0.28 to 0.37*) and between green weight and the K/(Ca+Mg) ratio (r = 0.23 to 0.41*). All other correlations involving green weight were low and nonsignificant. Although green weight was determined for only 1 year, the trends suggest that it should be possible to select Russian wildrye germplasm with high forage yield and low tetany potential.

Conclusions

Although seasonal variation was evident, chemical analyses indicate that cultivars developed from this breeding population of Russian wildrye would pose a high risk of producing grass tetany in grazing ruminants. Ratios were consistently above the previously established danger level of 2.2. Genetic progress could not be realistically predicted without parent-progeny data; however, the level of H_b values for the K/(Ca+Mg) ratio and the RTP index along with the variability observed among the progeny lines for all traits measured suggests that selection to reduce the grass tetany potential would be effective. Breeding to increase Mg levels would probably be accompanied by increases in the concentration of Ca and to a lesser extent increased K. Because of the relatively weak relationship found between Mg and Ca and K, it should be feasible to concurrently select for higher levels of Mg and Ca and lower levels K. Because of the relatively high K/(Ca+Mg) ratios found in this population, it would be advisable to identify other germplasm with attributes associated with low grass tetany potential (higher levels of Mg and Ca and lower concentrations of K). This would provide a germplasm pool from which genetic factors that condition low tetany potential could be transferred to this and other populations that possess the desirable attributes of Russian wildrye. Preliminary results from our studies suggest that reduced grass tetany potential may be accompanied by reductions in forage yield, unless selection for high yield potential is done concurrently. The relationship between grass tetany potential and forage yield and other important attributes in Russian wildrye merits additional study.

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