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GROWTH AND MAGNESIUM UPTAKE OF TALL FESCUE LINES AT HIGH AND LOW POTASSIUM LEVELS[1]

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Key Words: Root diameter, xylem diameter, nutrient concentration, relative growth rate, nutrient solution, mineral nutrition, *Festuca arundinacea*.

ABSTRACT:

Five tall fescue (*Festuca arundinacea* Schreb.) clonal lines with diverse root and xylem diameters were grown in nutrient solutions with magnesium (Mg) concentrations of 42, 125 and 250 µM and potassium K concentrations of 133 and 333 µM. Leaf Mg concentrations increased with increasing Mg rates at both low and high K concentrations. The tall fescue line with the largest root and xylem diameters had low leaf Mg concentrations, indicating a possible increased Mg tetany potential when consumed by cattle. The response of the K/(Mg+Ca) ratio in the plant, an indicator of tetany potential, to varying solution Mg at low and

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high K was determined for each of the five lines. No Mg effects or interactions were significant. Line, K, and line x K effects were all significant for the K/(Mg+Ca) ratios. The line with the largest root and xylem diameters had the highest tetany potential (highest cation ratio). Higher solution K gave higher K/(Mg+Ca) ratios.

INTRODUCTION

Two important features of breeding tall fescue (*Festuca arundinacea* Schreb.) for the Coastal Plain region of the Southeastern United States are that: 1) tall fescue must be persistent; and 2) tall fescue should accumulate adequate Mg to prevent deficiences in forage for consuming ruminants. Accumulation of minerals in forage appears to be under genetic control,[3,4] with relatively high heritability estimates for Ca, Mg and the cation ratio K/(Ca+Mg) in *Loluim-Festuca* hybrids[5]. However, with randomly chosen tall fescue clones, low heritability estimates were obtained for K/(Ca+Mg)[6,7]. Previous experiments dealt with the foliar portion and no consideration was given to root morphological differences in tall fescue.

Williams et al.[8] demonstrated that morphological differences in roots existed among tall fescue genotypes, and these differences were associated with drought resistance due to differential penetration of plowpans. In their study, a tall fescue clone with large root diameter (LRD) penetrated to soil depths beyond 1 m, while a tall fescue clone with small root diameter (SRD) was limited to the top 25 cm. In greenhouse experiments, SRD had greater water-use efficiency and forage and dry matter production than did LRD when lance (*Hoplolaimus* spp.) nematodes were present. However, under field conditions, LRD had a higher percentage of survival than SRD because of its ability to penetrate the plowpan, permitting a larger percentage of the total root system to grow beneath the nematode-infested soil[8].

With nutrient solution experiments in the greenhouse, root morphology of tall fescue clones influenced Mg uptake and growth of selected tall fescue cones[9]. In greenhouse experiments, reduced Mg concentration in the leaf and roots was associated with elevated K levels[10,11]. However, limited information is available regarding the effects of tall fescue root morphology (root and xylem diameter) on Mg uptake at different K levels. Considerable research has been directed towards selecting tall fescue lines that will accumulate adequate Mg to prevent hypomagnesemic tetany in ruminants[4,6,7,12,13]. Magnesium accumulative ability should be maintained or improved when selecting tall fescue clones for root types that will penetrate compacted soils. Thus, the objectives of this study were to determine the effects of: 1) root diameter on the Mg-and K-absorbing ability of tall fescue at various Mg and K concentrations; and 2) root and xylem diameter on K/(Mg+Ca) ratio in forage.

MATERIALS AND METHODS

Five clonal lines of tall fescue were used in this study. Two were classified as LRD (AU 7 and AU 264) and two as SRD (AU 5 and AU 718) in an earlier study (C. B. Williams. 1982. Root system morphology of tall fescue, _Festuca arundinacea_ Schreb.: The evaluation of selected genotypes for cultivar improvement. Ph.D. Thesis, Auburn University, Alabama). A single clone of previously undetermined root diameter, selected at random from 'Kentucky 31' (Ky 31) tall fescue, was included for comparison. The clonal material was preconditioned in nutrient solution to produce propagules with roots free of soil contamination. Uniform single shoot propagules were removed from the 'parent' clones, washed for 2 hours in distilled water, and transferred into individual 12-liter tanks in the greenhouse.

Nutrient concentrations were 0.25 m$\underline{M}$ NaH_2PO_4, 0.25 m$\underline{M}$ NH_4NO_3, 0.5 m$\underline{M}$ $CaCl_2$, 180 µ$\underline{M}$ FeDTPA (diethylene triamine-pentacetic acid), 46 µ$\underline{M}$ B, 9 µ$\underline{M}$ Mn, 0.8 µ$\underline{M}$ Zn, 0.3 µ$\underline{M}$ Cu, and 0.05 µ$\underline{M}$ Mo. When the tall fescue propagules were transferred into the tanks, Mg concentrations of 42, 125, and 250 µ$\underline{M}$, and K concentration of 133 and 333 µ$\underline{M}$ were imposed on individual tanks by the addition of $MgSO_4$ and KCl. Nutrient concentrations were monitored every two days by removing 50 ml of solution from each tank and determining the nutrient concentrations by standard methods. Nutrient concentrations were maintained by addition of nutrients as required. Nutrient concentrations did not vary more than 5% from their specified concentration during the course of the experiment.

Solution pH was measured daily and maintained at 5.6 to 5.8 by adding HCl or NaOH. To minimize the fluctuation of the solution pH, the sodium salt of 2-(N-Morpholino) ethanesulfonic acid (pH 6.15) was added to the nutrient solution to a final concentration of 1 m$\underline{M}$. All tanks were vigorously aerated, and nutrient solutions were changed every seven days. Temperature was maintained at 24° $\pm$ 5°C, and sunlight was supplemented with fluorescent light to produce a minimum of 250-300 uEm^{-2} s^{-1} at the canopy for a 16-hour day.

An experimental unit consisted of two propagules (paired) of each clonal line at each Mg level. Individual propagules were supported by foam rubber collars in No. 6 plastic stoppers in a 0.5-cm-thick black plexiglass[16] tank cover. After growing for 41 days, one propagule was harvested. The other propagule was harvested at 83 days. Roots were washed in diluted Ca solution (10^{-4} $\underline{M}$) for 15 minutes to remove all Mg and K in the free space of root cells. The propagules were separated into shoots (leaf blades, leaf sheaths, and stems) and roots, freeze-dried, weighed, and ground to pass a 40-mesh screen. Root volume was determined at harvest using a water-displacement method prior to freeze drying. Concentrations of Mg and K in the tissue were determined by Inductively Coupled Argon Plasma. Magnesium and K uptake rates were calculated from the change in total Mg and K contents and the change in fresh weight of tall fescue propagule roots using the following equation:

$$I_m = \frac{M_2 - M_1}{WR_2 - WR_1} \cdot \ln \frac{(WR_2/WR_1)}{t_2 - t_1}$$

where I_m is influx rate per gram fresh weight of root, M is total elemental content in tall fescue propagule (leaves + roots), WR is fresh root weight, and t is time (days). I_m for the first growth period (subscripts 1 and 2) denotes initial and first harvest, and for the second growth period denotes initial and second harvest.

The experimental design was a randomized complete block with four replications. Treatments were arranged in a factorial design (5 clones x 3 Mg concentrations x 2 K concentrations). Data were analyzed using standard analysis of variance and regression analysis.

RESULT AND DISCUSSION

Growth

Shoot dry matter (leaf blades, leaf sheaths, and stems) accumulation was not affected by Mg or K solution concentration at either the 41- or 83-day growth period (Table 1). Differences in shoot dry matter production due to tall fescue lines were observed at both the 41- and 83-day growth period with the Ky 31 clone having the highest dry matter accumulation. The tall fescue line AU-5 with small root diameter out yielded the large root diameter (AU-7 and AU-264) lines for both growth periods. However, the dry matter production of the SRD AU-718 line was

TABLE 1

Means of shoot dry matter accumulation of five tall fescue lines at high and low solution K concentration.

Fescue lines	Harvest 1 K concentration 133	Harvest 1 K concentration 333	Line mean	Harvest 2 K concentration 133	Harvest 2 K concentration 333	Line mean
	g/propagule					
AU-7 (LRD)	1.15	1.43	1.29	2.53	2.55	2.54
AU-264 (LRD)	1.43	1.37	1.40	4.54	4.23	4.39
AU-5 (SRD)	1.72	1.87	1.80	5.74	5.01	5.38
AU-718 (SRD)	1.42	1.57	1.49	3.67	3.94	3.81
Ky 31	1.96	2.26	2.10	7.95	6.27	7.11
K mean	1.54	1.70		4.89	4.40	
$FLSD_{05}$ K	ns			ns		
$FLSD_{05}$ L	0.31			0.87		

TABLE 2

Means of root volume of five tall fescue lines at high and low solution K concentration.

Fescue lines	Harvest 1 K concentration 133	Harvest 1 K concentration 333	Line mean	Harvest 2 K concentration 133	Harvest 2 K concentration 333	Line mean
	CM^3					
AU-7 (LRD)	7.6	10.3	9.0	18.1	16.2	17.2
AU-264 (LRD)	9.0	9.3	9.2	51.0	37.4	44.2
AU-5 (SRD)	14.2	16.0	15.2	66.7	54.2	60.5
AU-718 (SRD)	15.3	13.6	14.5	29.3	32.3	30.8
Ky 31	17.3	17.1	17.2	47.2	41.3	44.6
K mean	12.7	13.3		42.6	36.3	
$FLSD_{05}$ K	ns			ns		
$FLSD_{05}$ L	2.31			10.64		

similar to the two LRD lines. There was no significant interaction at either growth period.

Root volume was not affected by Mg or K solution concentration at either the 41- or 83-day growth period and none of the interactions were significant. The root volume of the SRD and the single selection of Ky 31 fescue clone were appproximately two-fold larger than the LRD lines (Table 2) for the first growth period (41 days). The root volume of the AU-5 line was two times the root volume of the LRD for the 83-day growth period. The AU-7 line consistently had the smallest root volume at both growth periods. One of the possible reasons for the larger root volume of the SRD (AU-5 and AU-718) fescue lines was a result of them having a greater number of secondary roots/cm of primary root than the LRD (AU-7 and AU-264) fescue lines.

<u>Tissue nutrient concentration</u>

Shoot K concentration was influenced by K levels and tall fescue lines for both the 41- and 83-day growth periods (Table 3). At the 41-day growth period, AU-5 (SRD) and AU-7 (LRD) tall fescue lines had 2.87 and 2.77% K at the 133 $\mu\underline{M}$ K level and 3.5% K at the the 333 $\mu\underline{M}$ K level. The other lines ranged from 2.51 to 2.62% K at the 133 $\mu\underline{M}$ and 3.0 to 3.2% K at the 333 $\mu\underline{M}$ level. After the 83-day growth period, shoot K concentration was reduced more than 50% at the low K level in all lines and by 4% at the high K level. However, AU-5 and AU-7 lines still contained an equal or higher K concentration at both K levels when compared to other lines.

Leaf Mg concentration was influenced by solution Mg and K, tall fescue lines and interactions of Mg x lines and K x lines. Regression analysis was determined for each line at each K level (Table 4 and Fig. 1). Predicted leaf Mg concentration was generally linearly related to the Mg solution concentration for the 41-day growth period. The one exception was the AU-7 at the high K level which followed a quadratic equation for predicting

TABLE 3
Means of shoot K concentration of five tall fescue lines at high and low solution K concentration.

Fescue lines	Harvest 1 K concentration 133	Harvest 1 K concentration 333	Line mean	Harvest 2 K concentration 133	Harvest 2 K concentration 333	Line mean
	g/kg					
AU-7 (LRD)	27.71	35.13	31.42	13.16	20.24	16.70
AU-264 (LRD)	26.25	30.34	28.90	12.98	19.20	16.09
AU-5 (SRD)	28.71	34.99	31.85	13.94	20.84	17.39
AU-718 (SRD)	26.00	30.88	28.45	13.15	18.71	20.84
Ky 31	25.19	32.60	28.89	11.23	18.66	14.94
K Mean	26.78	32.74		12.89	19.53	
$FLSD_{05}$ K	1.38			0.60		
$FLSD_{05}$ L	2.18			0.95		

leaf Mg concentration. At the low K level, the leaf Mg concentration of the LRD (AU-7 and AU-264) was lower when compared to the SRD (AU-5 and AU-718) and Ky 31.

The Mg x line interaction occurred with the AU-264 line at the low K level. When increasing the Mg concentration from 125 µM to 250 µM, little increase in leaf Mg concentration was observed in the AU-264 lines when compared to the other lines. The K x line interaction occurred with the AU-5 line at the 333 µM K level. A rapid increase in leaf Mg was observed when the Mg concentration was increased from 125 µM to 250 µM. A reduced leaf Mg concentration was associated with high solution K concentration in the 41-day growth period, indicating higher Mg tetany potenial under high K fertilization.

At the 83-day growth period, solution Mg and K concentration and lines gave significant differences in leaf Mg concentration (Table 5 and Fig. 2). Predicted leaf Mg concentration was generally linearly related to the Mg solution con-

TABLE 4
Leaf regression equation for prediction of Mg concentration after 41 days of growth in nutrient solution containing selected Mg and K concentration.

Fescue lines		Equations	r^2
		K 133 uM	
AU-7	(LRD)	$Y^z = 1568.91 + 6.21X^y$	0.85
AU-264	(LRD)	$Y = 3039.19 + 1.91 \times 10^{-2}X$.	0.95
AU-5	(SRD)	$Y = 3099.16 + 10.30X$	0.79
AU-718	(SRD)	$Y = 2789.45 + 7.71X$	0.88
Ky 31		$Y = 2333.69 + 16.79X$	0.97
		K 333 uM	
AU-7	(LRD)	$Y = 1465.68 + 1.91X$	0.83
AU-264	(LRD)	$Y = 2398.08 + 2.78X$	0.88
AU-5	(SRD)	$Y = 2808.49 + 1.91X$	0.90
AU-718	(SRD)	$Y = 2400.44 + 10.52X$	0.95
Ky 31		$Y = 2644.15 + 5.52X$	0.87

^{z}Y = predicted Mg concentration.
^{y}X = Mg concentration in leaf tissue.

centration. The two exceptions were AU-264 at the low K level and AU-7 at the high K level. In these instances, the LRD lines followed a quadratic equation for predicting leaf Mg concentration at both K levels. The AU-718 line was not influenced by Mg concentration. In the 83-day growth period, the leaf Mg concentration of LRD (AU-7 and AU-264) was lower when compared to the other lines. Also, the line AU-7 showed tissue Mg concentration at the 83-day growth period below the 1.9 g/kg level suggested by Kemp and t'Hart[14] as critical for causing Mg tetany.

Nutrient influx rate

The influx rate of K was influenced by K levels and tall fescue lines at both growth periods (Table 6). At the 41-day

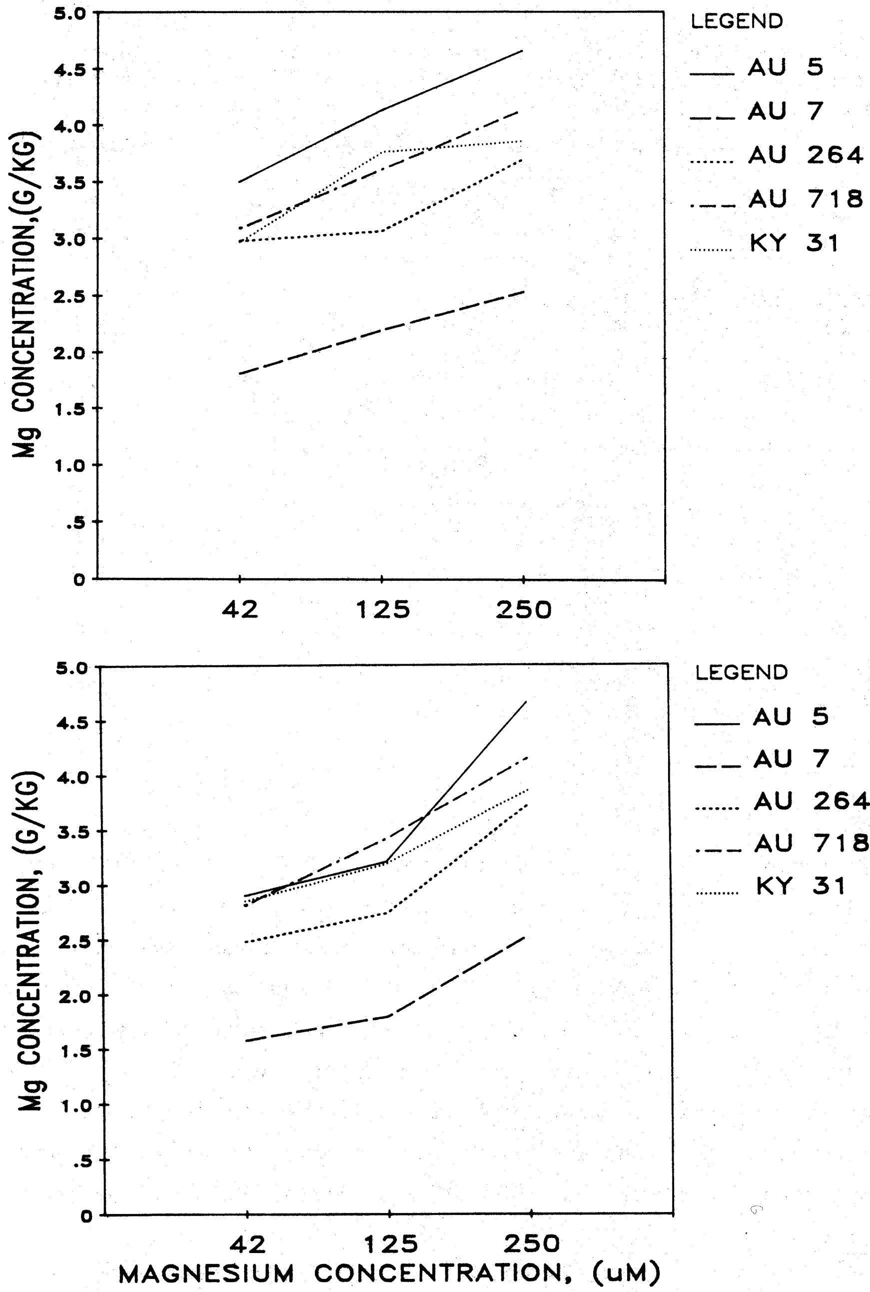

Figure 1. Leaf Mg concentration in five fescue lines after 41 days of growth in nutrient solution containing selected Mg and K concentration.

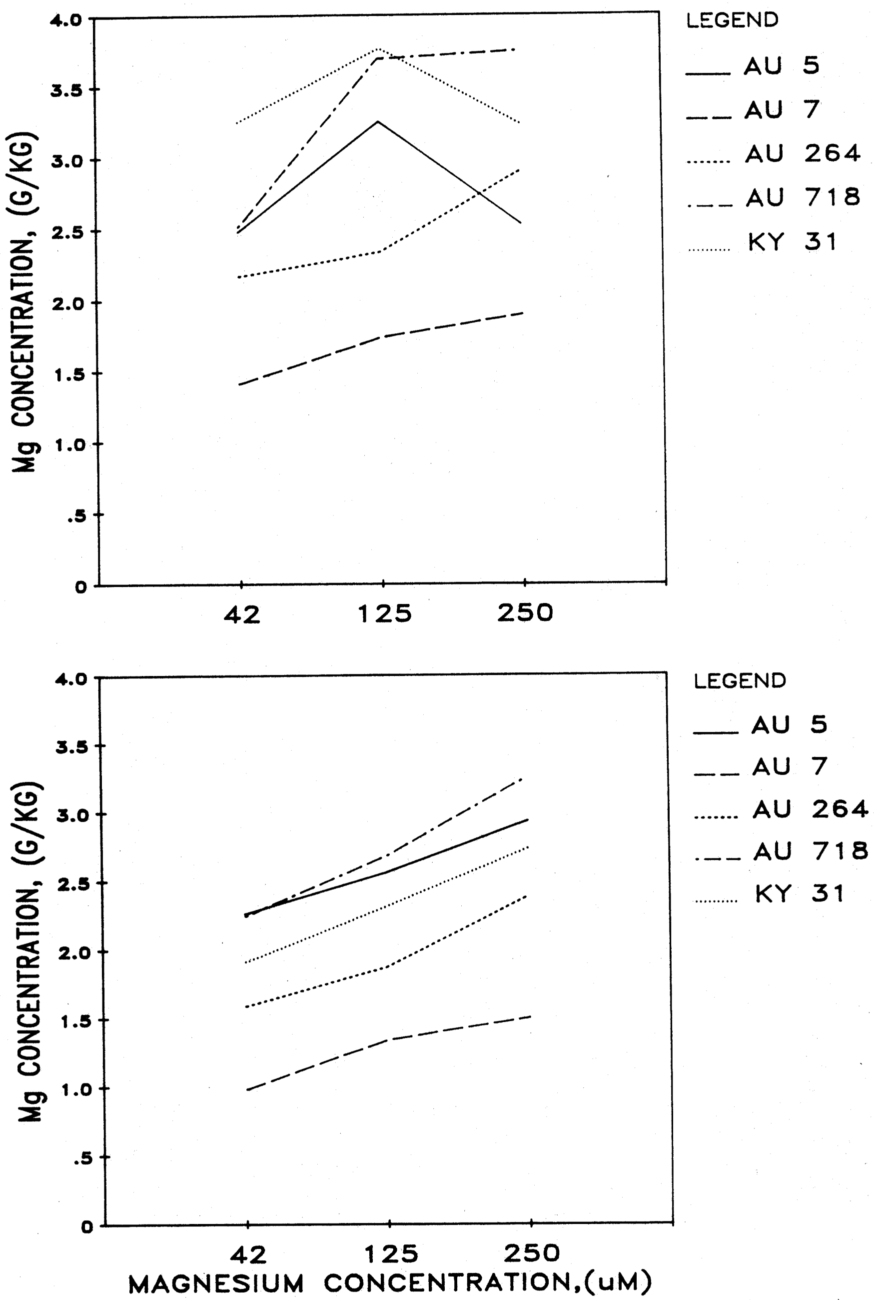

Figure 2. Leaf Mg concentration in five fescue lines after 83 days of growth in nutrient solution containing selected Mg and K concentration.

TABLE 5
Leaf regression equation for prediction of Mg concentration after 83 days of growth in nutrient solution containing selected Mg and K concentration.

Fescue lines	Equations	r^2
	K 133 uM	
AU-7 (LRD)	$Y^z = 1184.12 + 6.08X^y$	0.77
AU-264 (LRD)	$Y = 2156.82 + 3.22 \times 10^{-2}X$	0.86
AU-5 (SRD)	$Y = 1968.12 + 13.45X$	0.92
AU-718 (SRD)	$Y = 1560.47 + 25.41X$	0.71(ns)
Ky 31	$Y = 1681.50 + 5.11X$	0.89
	K 333 uM	
AU-7 (LRD)	$Y = 724.24 + 6.88X - 1.51 \times 10^{-2}X^2$	0.96
AU-264 (LRD)	$Y = 1482.77 + 2.61X$	0.77
AU-5 (SRD)	$Y = 2103.74 + 4.03X$	0.95
AU-718 (SRD)	$Y = 2007.22 + 5.93X$	0.84
Ky 31	$Y = 1667.94 + 6.19X$	0.90

^{z}Y = predicted Mg concentration.
^{y}X = Mg concentration in leaf tissue.

TABLE 6
Means of K influx rate of five tall fescue lines at high and low solution K concentration.

Fescue lines	Harvest 1 K concentration 133	Harvest 1 K concentration 333	Line mean	Harvest 2 K concentration 133	Harvest 2 K concentration 333	Line mean
	---------uMoles/g fr root wt/day-------------					
AU-7 (LRD)	13.1	18.7	15.9	3.67	6.58	5.13
AU-264 (LRD)	14.8	17.3	16.1	3.33	6.34	4.83
AU-5 (SRD)	11.2	15.2	13.2	2.66	5.01	3.84
AU-718 (SRD)	11.4	16.2	13.8	3.47	6.00	4.73
Ky 31	13.0	20.1	16.6	4.49	7.27	5.88
K mean	12.7	17.5		3.52	6.24	
$FLSD_{05}$ K	1.01			0.352		
$FLSD_{05}$ L	1.60			0.557		

TABLE 7
Magnesium influx regression equation for prediction of Mg uptake rates after 41 days of growth in nutrient solution containing selected Mg and K concentration.

Fescue lines	Equations	r^2
	K 133 uM	
AU-7 (LRD)	$Y^z = 1.48 - 3.10 \times 10^{-3}X^y$	0.81
AU-264 (LRD)	$Y = 2.15 + 9.59 \times 10^{-3}X$	0.40(ns)
AU-5 (SRD)	$Y = 2.09 + 1.13 \times 10^{-3}X$	0.49(ns)
AU-718 (SRD)	$Y = 1.27 + 7.84 \times 10^{-3}X$	0.73
Ky 31	$Y = 1.85 + 4.44 \times 10^{-3}X$	0.74
	K 333 uM	
AU-7 (LRD)	$Y = 0.69 + 9.22 \times 10^{-2}X - 2.13 \times 10^{-5}X^2$	0.90
AU-264 (LRD)	$Y = 1.92 - 1.96 \times 10^{-3}X$	0.81
AU-5 (SRD)	$Y = 1.17 + 6.65 \times 10^{-3}X$	0.91
AU-718 (SRD)	$Y = 1.30 + 9.32 \times 10^{-3}X$	0.79
Ky 31	$Y = 1.12 + 1.94 \times 10^{-2}X$	0.84

^{z}Y = predicted Mg influx rate.
^{y}X = actual Mg influx rate.

growth period, the K influx rate ranged from 11 to 15 uMoles/g fr root wt/day at the low K level and from 15 to 20 uMoles/g fr root wt/day at the 333 µM K level. However, for the 83-day growth period, K influx rate was three-fold lower at both K levels in all lines. A possible reason for the decrease in shoot K concentration with physiological age is that tall fescue roots are not able to absorb K at a rate sufficient to meet their needs; or the K that occurs in the old shoots (leaf blades, leaf sheaths, and stems) is being mobilized to actively growing apical areas. As a result, the shoot demands are reduced and subsequently the influx rate of K is reduced.

At the 41-day growth period, the influx of Mg was increased linearly by Mg solution concentration in all tall fescue lines

TABLE 8
Magnesium influx regression equation for prediction of Mg uptake rates after 83 days of growth in nutrient solution containing selected Mg and K concentration.

Fescue lines	Equations	r^2
	K 133 uM	
AU-7 (LRD)	$Y^z = 0.70 - 8.95 \times 10^{-5}X^y$	0.45(ns)
AU-264 (LRD)	$Y = 0.76 + 4.90 \times 10^{-5}X$	0.70
AU-5 (SRD)	$Y = 0.39 + 9.10 \times 10^{-3}X$	0.83
AU-718 (SRD)	$Y = 0.71 + 6.88 \times 10^{-3}X$	0.45(ns)
Ky 31	$Y = 0.61 + 1.24 \times 10^{-2}X$	0.86
	K 333 uM	
AU-7 (LRD)	$Y = 0.33 + 2.47 \times 10^{-3}X$	0.95
AU-264 (LRD)	$Y = 0.98 - 6.64 \times 10^{-3}X$	0.68(ns)
AU-5 (SRD)	$Y = 0.49 + 1.49 \times 10^{-3}X$	0.90
AU-718 (SRD)	$Y = 0.66 + 4.04 \times 10^{-3}X$	0.73
Ky 31	$Y = 0.51 + 1.04 \times 10^{-2}X$	0.75(ns)

^{z}Y = predicted Mg influx rate.
^{y}X = actual Mg influx rate.

that responded to solution Mg concentration (Table 7 and Fig. 3). The only exception was the AU-7 line which followed a quadratic equation for predicting Mg influx rate. The two lines that did not respond to solution Mg concentration were the AU-264 (LRD) and AU-5 (SRD) at the 133 uM K level.

At the 83-day growth period, lines that responded to solution Mg concentration responded linearly (Table 8 and Fig. 4). The lines AU-7 (LRD) and AU-718 (SRD) at the low K level did not respond to Mg concentration. The only significant interaction was Mg x line. The AU-264 had a higher Mg influx rate when the Mg concentration was increased from 125 µM to 250 µM as compared to the other lines. Relative differences in Mg influx were reflected in the Mg tissue differences. This is important since

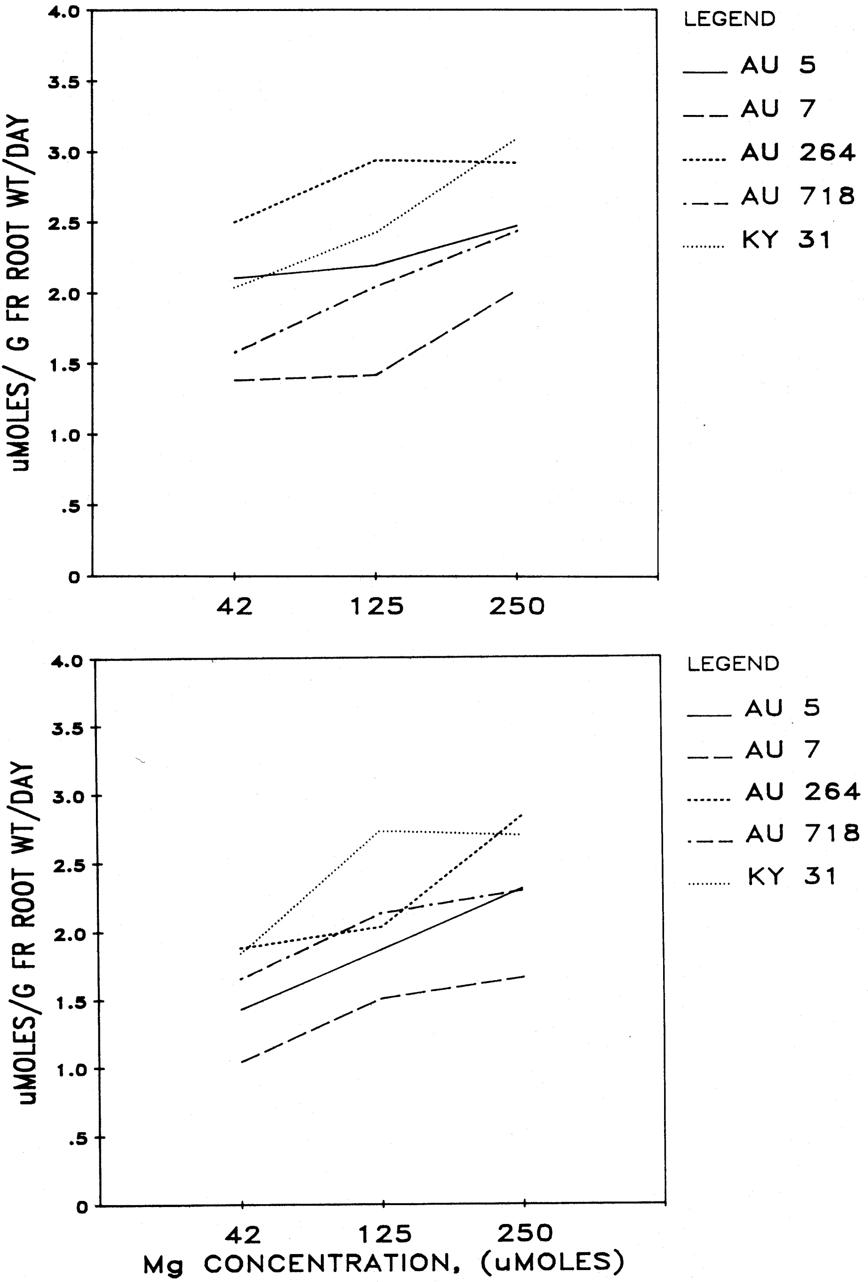

Figure 3. Magnesium influx rate in five fescue lines after 41 days of growth in nutrient solution containing selected Mg and K concentration.

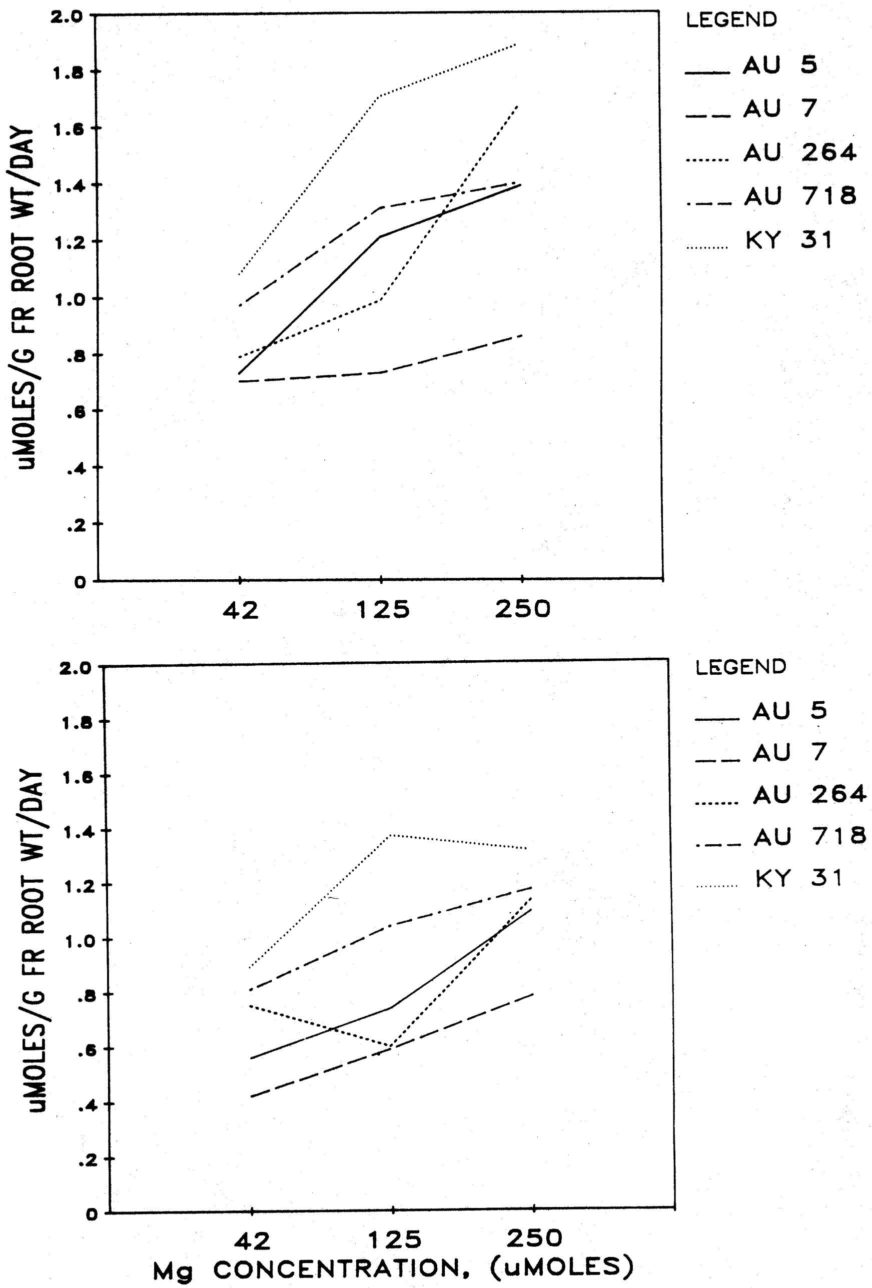

Figure 4. **Magnesium influx rate in five fescue lines after 83 days of growth in nutrient solution containing selected Mg and K concentration.**

TABLE 9
Means of K/(Ca + Mg) ratios of five tall fescue lines at high and low solution K concentration.

Fescue lines		Harvest 1 K concentration 133	333	Line mean	Harvest 2 K concentration 133	333	Line mean
		----------Meq of (K /(Ca +.Mg)/100 g of shoot-----					
AU-7	(LRD)	1.74	2.49	2.11	0.91	1.73	1.32
AU-264	(LRD)	1.15	1.44	1.29	0.67	1.21	0.94
AU-5	(SRD)	0.99	1.49	1.24	0.54	0.98	0.76
AU-718	(SRD)	1.03	1.34	1.44	0.50	0.88	0.69
Ky 31		1.04	1.44	1.24	0.55	0.99	0.77
K mean		1.19	1.19		0.64	1.16	
$FLSD_{05}$	K	0.07			0.05		
$FLSD_{05}$	L	0.11			0.08		

screening for higher Mg influx appears possible by measuring tissue Mg concentration in fescue lines.

K/(Mg+Ca) ratio

The K/(Mg+Ca) ratio of the five lines was shown to vary with solution Mg concentration, solution K concentration, and lines at the 41-day growth period, and with only solution K and lines at the 83-day growth period (Table 9). The solution K x line interaction was significant in both growth periods. Butler[15] concluded that a ratio of less than 2.2 meq/100 g of dry matter reduced Mg tetany. No values greater than 2.2 were shown for this ratio in the 83-day growth period, agreeing with the commonly held concept that Mg tetany potential is usually highest during early growth. As would be expected, high solution K concentration consistently resulted in higher K/(Mg+Ca) ratios, indicating that high K fertility could contribute to Mg tetany potential, even though the magnitude of this response varied with lines. Solution K concentration and line effects were more important than solution Mg concentration in determining this ratio in the 83-day growth period, as shown by the lack of a solution Mg concentration effect on this trait (data not shown).

SUMMARY

Root morphology does influence tall fescue lines' ability to absorb Mg. The LRD lines contained less tissue Mg than the SRD or the clonal selection of Ky 31, and this effect is amplified as the plant ages. The concentration of K is also very important in determining the leaf tissue concentration of Mg. We can conclude from this work that, although harvest age and fertility are important in determining the Mg tetany potential of tall fescue, line effects are also important. Furthermore, it appears that the selection of tall fescue lines with LRD may at times increase the risk of Mg tetany in this species. Breeders selecting for altered root morphology in this, and possibly other species, should therefore continue to monitor the Mg potential of their lines via tissue analyses.

REFERENCES

1. Cooperative research between USDA, ARS, Soil-Plant Interaction Research Unit and Alabama Agricultural Experiment Station, Auburn University, AL 36849.

2. Soil Scientist, USDA-ARS-Soil-Plant Interaction Research Unit, Assistant Professor, Agronomy and Soils Department, Auburn University.

3. Hill, R. R. and S. B. Guss. 1976. Genetic variability for mineral concentrations in plants related to mineral requirements of cattle. Crop Sci. 16:680-685.

4. Sleper, D. A. 1979. Plant breeding, selection, and species in relation to grass tetany. p.63-77 In V. V. Rendig and D.L. Grunes (eds.) Grass tetany. Am. Soc. Agron., Madison, WI.

5. Buckner, R. C., P. B. Burris II, P. L. Cornelius, and L. P. Bush. 1981. Genetic variability and heritability of certain forage quality and mineral constituents in Lolium-Festuca hybrid derivatives. Crop Sci. 21:419-423.

6. Nyguyen, H. T., and D. A. Sleper. 1981. Genetic variability of mineral concentration in Festuca arundinacea Schreb. Theor. and Appl. Gen. 59:57-63.

7. Sleper, D. A., G. B. Garner, R. H. Asay, R. Boland, and E. E. Pickett. 1977. Breeding for Mg, Ca, K, and P content in tall fescue. Crop Sci. 17:433-438.

8. Williams, C. B., C. B. Elkins, R. L. Haaland, C. S. Hoveland, and R. Rodriguez-Kabana. 1983. Effect of root diameter, nematodes, and soil compaction on two tall fescue genotypes. Proc. XIV Inter. Grasslands Congr., Lexington, KY, June 15-24, 1981.

9. Torbert, H. A., J. H. Edwards, J. F. Pedersen. 1985. Growth and magnesium uptake of tall fescue clones with varying root diameters. J. Plant Nutrition 8(8): 731-749.

10. Hannaway, D. B., L. P. Bush and J. E. Leggett. 1982. Mineral composition of Kenhy tall fescue as affected by nutrient solution concentration of Mg and K. J. Plant Nutrition 5(3):137-151.

11. Hannaway, D. B., J. E. Leggett, L. P. Bush and P. E. Shuler. 1984. Magnesium (mg) and Rubidium (RB) absorption by tall fescue. J. Plant Nutrition 7(7):1127-1147.

12. Sleper, D. A., G. B. Garner, C. J. Nelson, and J. L. Sebaugh. 1980. Mineral concentration of tall fescue genotypes grown under controlled conditions. Agron. J. 72:720-722.

13. Haaland, R. L., C. B. Elkins, and C. S. Hoveland. 1978. A method for detecting genetic variability for grass tetany potential in tall fescue. Crop Sci. 18:339-340.

14. Kemp, A. and M. L. t'Hart. 1957. Grass tetany in grazing milking cows. Neth. J. Agric. Sci. 5:4-17.

15. Butler, E. J. 1963. The mineral element content of spring pasture in relation to the occurrence of grass tetany and hypomagnesaemia in dairy cows. J. Agric. Sci. 60:329-340.

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