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GROWTH AND MAGNESIUM UPTAKE OF TALL FESCUE CLONES WITH VARYING ROOT DIAMETERS

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

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ABSTRACT:

A cool season perennial grass with a root system capable of penetrating hardpans and which can accumulate adequate Mg to prevent deficiencies in forage is needed in the Coastal Plain region. A greenhouse experiment was conducted to determine the effects of magnesium (Mg) concentration in nutrient solution and root diameter on Mg uptake and growth of tall fescue (*Festuca arundinacea* Schreb.). Propagules of two fescue clones with large root diameter (LDR >1 mm), two clones with small root diameter (SDR <0.8 mm), and a single clone from 'Kentucky 31' (Ky-31) were transferred into 12-liter tanks containing Mg concentrations of 3, 21, 42, 125, 250, and 500 μM as $MgSO_4$ and grown for 39 or 70 days. Leaf Mg concentration was increased linearly with Mg solution concentration in LDR clones for a 39-day growth period (Harvest 1), but increased according to a cubic equation in the SDR clones and the Ky-31. Predicted leaf Mg concentration as a

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function of solution Mg followed a cubic equation for a 70-day growth period (Harvest 2) in all clones. Predicted root Mg concentration was linearly related to Mg solution concentration for the LDR clones and the Ky-31, but followed a cubic equation for the SDR clones for the first growth period. For the second growth period, the root Mg concentration of the SDR clones and the Ky-31 was increased linearly, while the LDR clones followed a quadratic equation. Magnesium uptake followed a cubic equation with Mg solution concentration for both growth periods on all tall fescue clones. This nonlinear variation of Mg uptake and plant Mg concentration with respect to solution Mg concentration strongly suggests that a dual uptake mechanism might have been present in tall fescue clones. Root volume was greater in the SDR than LDR clones or Ky-31 for both growth periods. The Ky-31 had the greatest leaf and root dry weight for both growth periods, while the LDR clones had the lowest.

INTRODUCTION

Most soils in the southern Coastal Plain region have sandy surface horizons that are highly susceptible to compaction. The formation of compacted layers often prevents adequate root development and keeps roots from growing into available moisture and nutrients in the subsoil horizons[1]. Williams et al.[2] demonstrated that morphological differences in roots exist among tall fescue genotypes (*Festuca arundinacea* Schreb.), and these differences were associated with drought resistance due to differential penetration of plowpans. In this study, tall fescue clone with large root diameter (LDR) penetrated to soil depths beyond 1 m, while a tall fescue clone with small root diameter (SDR) was limited to the top 25 cm.

In greenhouse experiments, SDR had greater water-use efficiency and forage and dry matter production than did LDR when Lance (*Hoplolaimus* spp.) nematodes were present[3]. However, under field conditions, LDR had a higher percent survival than SDR because of its ability to penetrate the plowpan, permitting a larger percentage of the total root system to grow out of nematode-infested soil.

Root morphology of tall fescue clones undoubtedly influences more than soil penetration ability. However, no information regarding the effects of tall fescue root morphology (root and xylem diameter) on nutrient uptake is available. Considerable research has been directed towards selecting tall fescue lines that will accumulate adequate Mg to prevent hypomagnesemic tetany in ruminants[4,5,6,7,8], and this Mg accumulative ability should be maintained or improved in selecting tall fescue clones for root types that will penetrate the compacted soils of the Southeast. Thus, the objectives of this study were: 1) to determine the effects of root diameter on the Mg-absorbing ability of tall fescue at various Mg solution levels, and 2) to characterize tall fescue root and xylem diameter under repeatable, controlled conditions.

MATERIALS AND METHODS

Mg Uptake and Plant Growth

Five clonal lines of tall fescue were used in this study. Two were classified as LDR, and two as small SDR 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 unknown root diameter, selected from 'Kentucky 31' (Ky-31) 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 12-liter tanks in the greenhouse.

Nutrient concentrations were: 0.25 mM KCl, 0.25 mM KH_2PO_4, 0.25 mM NH_4NO_3, 0.5 mM CaCl, 180 µM FeDTPA (diethylene triamine-pentacetic acid), 46 µM B, 9 µM Mn, 0.8 µM Zn, 0.3 µM Cu, and 0.05 µM Mo. When the tall fescue propagules were transferred into the tanks, Mg concentrations of 3, 21, 42, 125, 250, and 500 µM were imposed on individual tanks by the addition of $MgSO_4$. The SO_4 concentration was adjusted with K_2SO_4 to give a constant SO_4 concentration of 500 µM. Nutrient concentations were monitored every 2 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% 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. All tanks were vigorously aerated, and nutrient solutions were changed every 7 days. Temperature was maintained at 24° ± 5°C, and sunlight was supplemented with fluorescent light to produce a minimum of 250-300 μEm^{-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 tank cover. After growing for 39 days, one propagule was harvested. The other propagule was harvested at 70 days. Roots were washed in diluted Ca solution (10^{-4} M) for 15 minutes to remove all Mg 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. Concentrations of Mg in the tissue were determined by Inductively Coupled Argon Plasma (ICAP). Magnesium uptake rates were calculated from the change in total Mg content and the change in fresh weight of tall fescue propagule roots using the following equation:

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

where I_m is uptake 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 three replications. Treatments were arranged in a factorial design (5 clones x 6 Mg concentrations). Data were analyzed using standard analysis of variance and regression analysis.

Roots for characterization were grown in the 12-liter tanks as previously described. Each tank contained 10 propagules of a single tall fescue clone. The experiment was replicated 10 times (50 tanks) with a completely randomized arrangement of the tanks in the greenhouse. The nutrient solution was the same as the standard solution, with 84 $\mu\underline{M}$ of Mg as $MgSO_4$. Twenty random roots were selected from each tank of propagules (a total of 200 roots) for characterization of each of the five clones. Roots removed were maintained in a petri dish with moist filter paper. All root diameters were determined within 4 hours of removal from the clone. A cross-sectional slice of each root, taken 7.5 cm behind the root apex, was examined under the microscope. A scaled eyepiece was used to measure root and xylem diameters.

RESULTS AND DISCUSSION

Root Characterization

The five tall fescue clones clearly separated into three groups on the basis of root diameter and xylem organization. Two clones had large diameter roots (Table 1), with root diameters averaging 0.90 mm. The two clones expected to exhibit small root diameters had roots averaging 0.72 mm. Th Ky-31 also had small root diameter, averaging 0.68 mm. The repeatability of the root-diameter methods was excellent, with C.V.'s averaging 20%. Root cross-sectional area of the LDR clones was 58% greater than in the SDR clones or Ky-31.

Xylem organization was distinctly different for the LDR, SDR, and Ky-31 (Fig.1). The LDR xylem elements were approximately the same diameter, and were arranged in a polyarch pattern. The average SDR xylem diameters were less than the LDR diameters, but several SDR xylem elements were approximately the same size as those in the LDR. In general, the xylem vessels of the SDR were less organized than the LDR xylem vessel. The xylem diameter in Ky-31 was also small. The xylem organization in

TABLE 1.

Root Morphology of Tall Fescue Clones

Clones	Avg. root diam.	Root diam. range	Xylem diam.	Root x-sec area	Xylem x-sec area
	(mm)	(mm)	(mm)	$(mm)^2$	$(mm)^2$
LDR	0.90	1.04-0.76	0.17	0.69	0.03
SDR	0.72	0.77-0.68	0.14	0.43	0.02
Ky-31	0.68	0.73-0.64	0.11	0.40	0.01

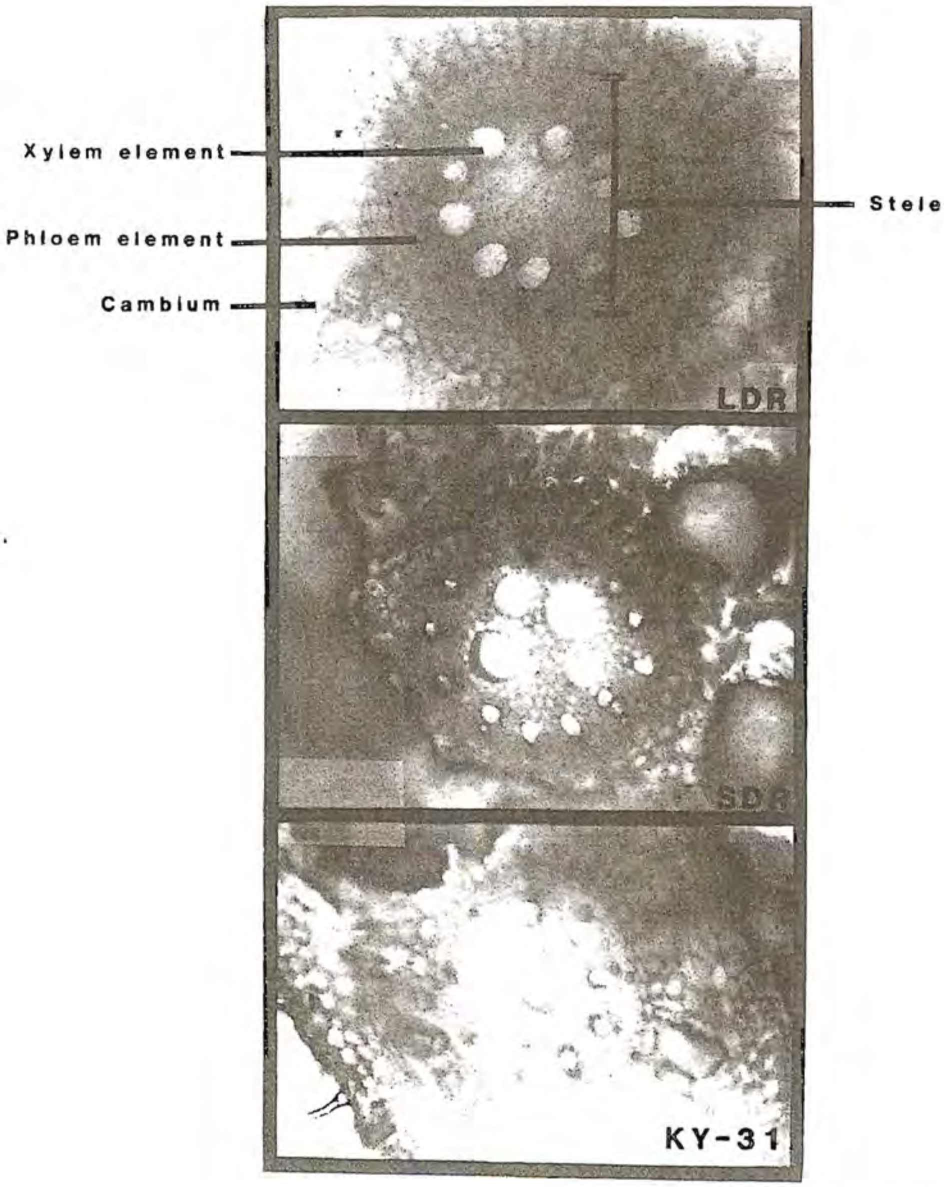

Figure 1. Cross-section of mature roots from LDR, SDR, and the Ky-31 selection 7.5 cm behind root apex.

Ky-31 was strikingly different from that in the SDR or LDR clones, with a monarch pattern of xylem arrangement have a relatively large xylem element in the center of the xylem. Average xylem cross-sectional area of the LDR clones was 49 and 107% greater than that of the SDR and Ky-31, respectively (Table 1). These differences in tall fescue root xylem diameter and arragement may be associated with differences in its ability to absorb and translocate water and nutrients.

Plant Growth

Shoot dry weight, root dry weight, and root volume were analyzed by regression, where Mg concentration was the independent variable, with no significant relationship for the LDR and SDR clones. There was a trend for Ky-31 root volume and root dry weight ($P = 0.09$) to decrease linearly with Mg concentration. Root dry weight and root volume were affected by Mg concentration and tall fescue clones for the first growth period (Tables 2 and

TABLE 2.

Root dry weight of tall fescue clones after 39 days of growth in nutrient solution containing selected Mg concentrations.

Tall fescue clones	Mg concentration, μM						Clone means
	3	21	42	125	250	500	
	-------- Root dry wt., g/propagules---------						
LDR	0.46	0.46	0.38	0.44	0.42	0.43	0.432
SDR	0.91	0.90	0.83	0.64	0.71	0.71	0.784
Ky-31	1.46	1.63	1.26	1.05	1.31	1.40	1.350
Concentration Means	0.845	0.874	0.740	0.640	0.713	0.736	
FLSD 5% concentration			= 0.161				
FLSD 5% clones			= 0.074				

3). Maximum root dry weight occurred at the 3 and 21 µM Mg treatment for the LDR and SDR clones, and decreased at Mg concentrations greater than 21 µM. The Ky-31 root dry weight was greater than LDR or SDR clones at all Mg concentrations for both growth periods. There was no clone x Mg concentration interaction for root dry weight for the first harvest period (39 days after initiation of Mg treatments).

Maximum root volume occurred at Mg concentrations of 3 and 21 µM but was decreased at higher Mg concentration (Table 3). The SDR root volume was greater than LDR or the KY-31 for all Mg concentrations. There was no Mg concentration x clone interaction for root volume for the first harvest period.

Leaf dry weight varied for tall fescue clones during the first harvest period (Table 4), and tall fescue clones x Mg concentration interaction was evident during the second growth period (Table 5). For both harvest periods, Ky-31 had the

TABLE 3.

Root volume of tall fescue clones after 39 days of growth in nutrient solution containing selected Mg concentrations.

Tall fescue clones	Mg concentration, µM						Clone means
	3	21	42	125	250	500	
	Root volume, cc						
LDR	7.67	7.33	7.00	5.83	6.33	6.67	6.81
SDR	17.50	15.67	13.50	11.17	12.67	14.50	14.17
Ky-31	11.67	14.33	10.33	8.67	10.67	10.00	10.94
Concentration Means	12.40	12.07	10.27	8.53	9.73	10.47	

FLSD 5% concentration = 2.697

FLSD 5% clones = 0.781

highest leaf dry weight and the LDR clone had the lowest. A significant Mg concentration x clone interaction occurred for leaf dry weight for the second growth period. Significant interaction occurred between the SDR and Ky-31 at the 500 µM Mg concentration. In the SDR clone, leaf dry weight increased with Mg concentration greater than 250 µM, while leaf dry weight for Ky-31 decreased at the Mg concentration of 500 µM (Table 5). The leaf dry weight of the LDR clone was lower than the SDR clone and Ky-31 at all Mg concentrations for both growth periods.

Tissue Mg Concentration

The predicted Mg concentration in the shoots and roots of the tall fescue clones was determined by regression analysis (Table 6). Predicted leaf Mg concentration in the SDR clones and Ky-31 followed a cubic equation, while the LDR clones were linearly related to the Mg solution concentration for the first growth period. All three followed a cubic equation for leaf Mg concentration in the second harvest. Predicted root Mg concentration response to Mg solution concentration was linear for

TABLE 4.

Leaf and Rot dry weight and root volume of tall fescue clones after 39 or 70 days of growth in nutrient solution containing selected Mg concentrations.

Tall fescue clones	Harvest 1	Harvest 2	
	Leaf dry weight	Root dry weight	Root volume
	(g/propagule)	(g/propagule)	(cc)
LDR	1.70	1.81	26.75
SDR	2.26	3.18	45.08
Ky-31	3.29	5.01	36.44
FLSD 5% clones	0.186	0.330	4.518

LDR clones and the Ky-31 in the first harvest, and for SDR clones and the Ky-31 during the second harvest. Predicted root Mg concentration followed quadratic equation for LDR clones in the second harvest, and a cubic equation for SDR clones in the first harvest.

The predicted response of leaf Mg concentration for LDR, SDR, and Ky-31 is shown in Fig. 2. Predicted leaf Mg concentration in LDR clones increased linearly with increasing Mg in the solution during first growth period. The predicted leaf Mg concentration for SDR and Ky-31 was increased by the 3, 21, 42, and 125 μM Mg concentrations, decreased at the 250 μM, and increased again at the 500 μM Mg concentration. The leaf Mg concentration was greater for the SDR and Ky-31 at all Mg concentrations for the first growth period.

The predicted leaf Mg concentrations were similar for SDR and Ky-31 during the second growth period, and followed the same

TABLE 5.

Shoot dry weight of tall fescue clone after 79 days of growth in nutrient solution containing selected Mg concentrations.

Tall fescue clones	Mg concentration, μM						Clone means
	3	21	42	125	250	500	
				g/propagule			
LDR	5.35	4.54	3.38	5.07	4.15	4.55	4.50
SDR	6.01	6.96	6.35	5.20	5.60	8.21	6.39
Ky-31	10.87	8.41	11.47	8.09	9.87	7.34	9.34
Concentration Means	6.71	6.28	6.18	5.72	5.87	6.57	
FLSD 5% clones				= 0.549			

TABLE 6.

Leaf and root regression equation for prediction of Mg concentration after 39 or 70 days of growth in nutrient solution containing selected Mg concentrations.

Tall fescue clones	Equations	r^2
	Harvest 1	
	Leaves	
LDR	$Y^z = 1468 + 2.40X^y$	0.451
SDR	$Y = 1252 + 22.33X - 0.092X^2 + 1.10 \times 10^{-4}X^3$	0.871
Ky-31	$Y = 1378 + 22.64X - 0.105X^2 + 1.33 \times 10^{-4}X^3$	0.891
	Roots	
LDR	$Y = 499 + 0.533X$	0.371
SDR	$Y = 367 + 3.79X - 0.02X^2 + 1.97X^3$	0.698
Ky-31	$Y = 448 + 0.740X$	0.884
	Harvest 2	
	Leaves	
LDR	$Y = 642 + 25.51X - 0.12X^2 + 1.60 \times 10^{-4}X^3$	0.585
SDR	$Y = 778 + 35.53X - 0.15X^2 + 1.83 \times 10^{-4}X^3$	0.920
Ky-31	$Y = 890 + 37.19X - 0.17X^2 + 2.20 \times 10^{-4}X^3$	0.895
	Roots	
LDR	$Y = 130 + 3.16X - 4.04 \times 10^{-3}X^2$	0.784
SDR	$Y = 190 + 1.03X$	0.745
Ky-31	$Y = 290 + 1.05X$	0.733

^{z}Y = Predicted Mg concentration in each organ.
^{y}X = Mg concentration in the nutrient solution.

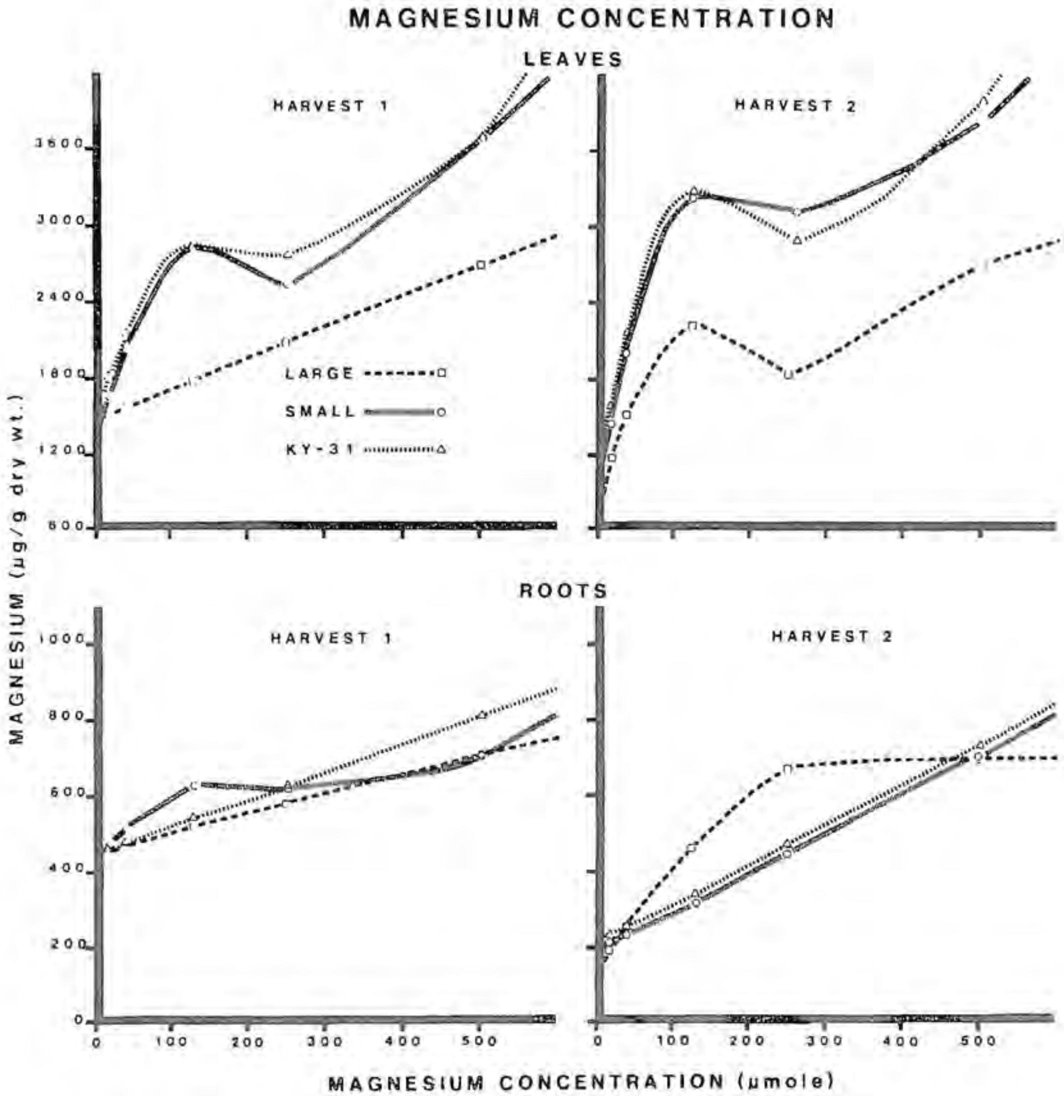

Figure 2. Predicted regression curves for leaf and root Mg concentration for tall fescue clones after 39 or 70 days of growth in nutrient solution containing selected Mg concentrations.

trends as in the first growth period. The LDR followed the same trends as SDR and Ky-31 during the second growth period, but were considerably lower in leaf Mg concentration (Fig. 2).

The predicted Mg concentration in the SDR and the Ky-31 leaves exceeded the 0.20%, which is considered to be adequate for hypomagnesemia prevention at soluton Mg concentration of 21 μM, while the LDR required a Mg solution concentration of 250 μM to attain 0.2% of the herbage. This was a very important consideration in determining the nutrient efficiency of these tall fescue clones since the Mg concentration found in solution of representative soils in the Southeast Coastal Plain ranged from 210 μM to 750 μM10. However, as the physiological age of the LDR increased (harvest 2), the solution Mg concentration needed to attain the 0.2% Mg concentration of the forage declined to 125 μM, but the solution Mg concentration remained constant in SDR and Ky-31.

Predicted root Mg concentration was linearly related to Mg concentration in solution for the LDR and Ky-31 for the first growth period. However, Mg concentration in roots of SDR clones increased with the 125 μM Mg concentration, and then decreased for the 250 and 500 μM Mg concentrations. During the second growth period, Mg concentration of the SDR and Ky-31 was linearly related to Mg concentration in solution. Predicted root Mg concentration of the LDR clone was increased by Mg concentration up to 250 μM, but then leveled off.

Predicted Mg Uptake Rates

The Mg uptake rates for the tall fescue clones during both growth periods were predicted by regression analysis (Table 7). The Mg uptake rates for each fescue clone and for both growth periods followed a cubic equation with significant r2 values. The Mg uptake of LDR and the Ky-31 increased for 3, 21, 42, and

125 μM Mg concentrations, and decreased for the 250 μM Mg concentration for the first growth period (Fig. 3). Magnesium uptake rates of LDR and Ky-31 both increased when Mg concentration reached 500 μM Mg with Mg uptake of the LDR clone increasing at a faster rate than that of the Ky-31. The only exception was at the 500 μM Mg concentration where the Mg uptake rates were similar for the LDR and Ky-31. Magnesium uptake of the SDR clone increased lineraly at 3, 21, 42, and 125 μM Mg concentrations and linearly increase at the 250 and 500 μM Mg concentrations but the rate of increase was lower. Magnesium uptake for the SDR clone was greater than for the LDR clone at all Mg

TABLE 7.

Magnesium uptake regession equations for prediction of Mg uptake after 39 or 70 days of growth in nutrient solution containing selected Mg concentrations.

Tall fescue clones	Equations	r^2
	Harvest 1	
LDR	$Y^z = 0.798 + 0.18X^y - 8.37 \times 10^{-5}X^2 + 1.09 \times 10^{-7}X^3$	0.577
SDR	$Y = 1.00 + 0.178X - 6.32 \times 10^{-5}X^2 + 7.33 \times 10^{-8}X^3$	0.694
Ky-31	$Y = 1.09 + 0.20X - 9.44 \times 10^{-5}X^2 + 1.00 \times 10^{-7}X^3$	0.802
	Harvest 2	
LDR	$Y = 0.271 + 0.02X - 6.89 \times 10^{-5}X^2 + 8.74 \times 10^{-8}X^3$	0.651
SDR	$Y = 0.37 + 0.2X - 7.75 \times 10^{-5}X^2 + 9.81 \times 10^{-8}X^3$	0.869
Ky-31	$Y = 0.45 + 0.02X - 7.40 \times 10^{-5}X^2 + 8.75 \times 10^{-8}X^3$	0.843

[z]Y = Predicted Mg uptake for each harvest.

[y]X = Mg concentration in the nutrient solution

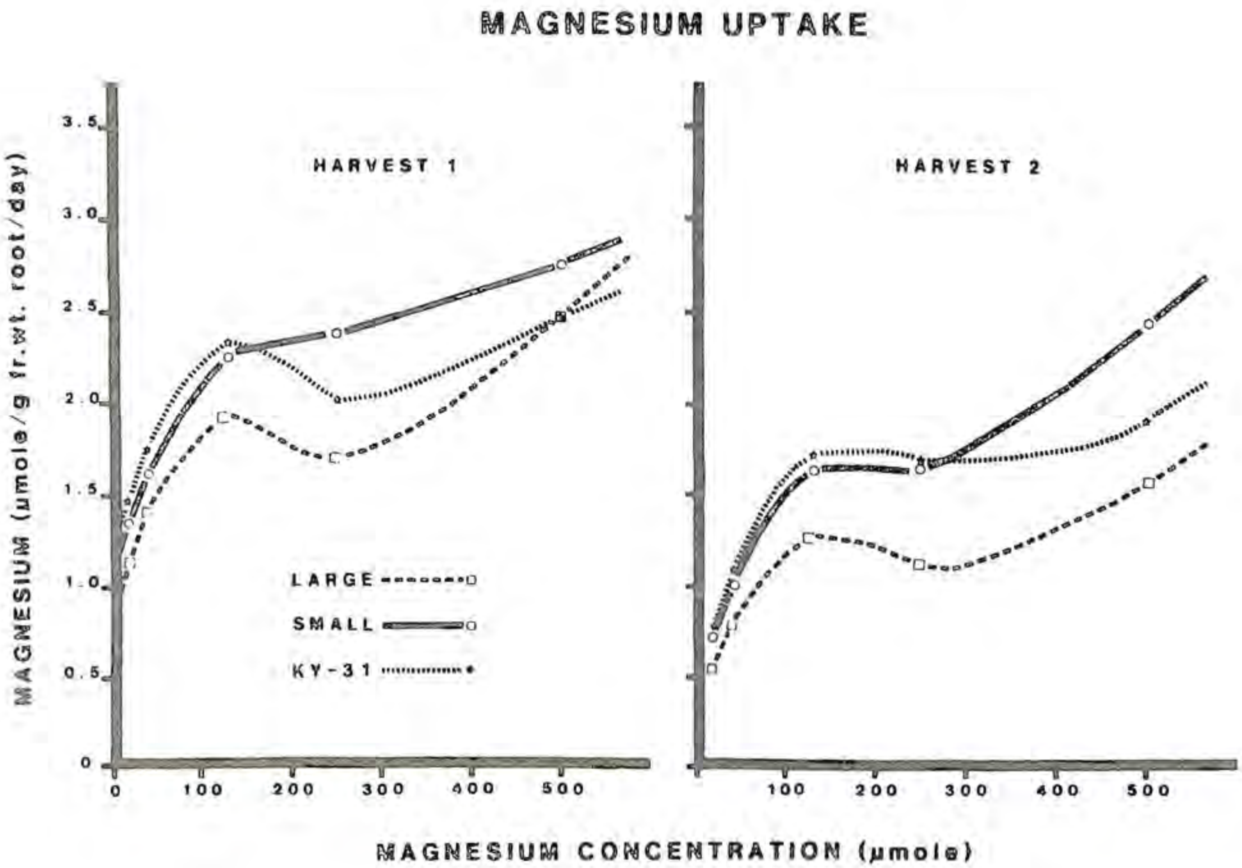

Figure 3. Predicted magnesium uptake curves for tall fescue clones after 39 or 70 days of growth in nutrient solution with selected Mg concentrations.

concentrations and for Ky-31 at low solution Mg concentrations.

The Mg uptake rate for all three tall fescue clone followed similar patterns of increase for the second growth period (Fig. 3). Magnesium uptake of the SDR and the Ky-31 was higher than for LDR at all Mg concentrations, and Mg uptake rate for the SDR clone was greater than the Ky-31 at the 500 μM Mg concentration.

The Mg uptake in the LDR, SDR, and the Ky-31 appears to follow a dual mechanism of uptake[11,12,13]. The component active at low Mg concentration is the movement of Mg from the external solution into the cytoplasmic organelles. At Mg concentrations $\geq$ 250 μM, the rate-limiting step is the movement of external Mg through the cytoplasm into the xylem. When the external Mg concentration is less than 125 μM, competition between organelles in the cytoplasm and the xylem vessels is the rate-limiting step. Thus, Mg uptake and Mg concentration did not increase until external Mg was high enough to saturate the organelle uptake mechanism. Xylem organization could certainly influence the efficency of Mg movement into xylem vessels of the tall fescue clones at low Mg concentration by reducing the path length the Mg has to move before being translocated to the shoots.

From our uptake calculations, SDR and Ky-31 have higher Mg uptake rates and maintained higher Mg concentration in the shoots than the LDR. Reduced Mg uptake and Mg shoot Mg concentration may be a deterrent to its acceptance as a tall fescue clone for soil penetration. However, this problem must be corrected when selecting tall fescue clones for soil penetration in the Southeast Coastal Plain. Additional research will be required to explore the variation in root xylem diameter of this species, and to delineate effects on nutrient uptake processes and ability to penetrate soil with high soil strength in this important forage crop for soils of the Southeast.

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