

## Genetic Variability of Mineral Concentrations in *Festuca arundinacea* Schreb.\*

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**Summary.** Nine randomly chosen clones of tall fescue (*Festuca arundinacea* Schreb.) were mated in all possible combinations to determine the nature of genetic variation for Mg, Ca, K, and P concentrations in a broad genetic base population. General combining ability mean squares were significant for most variables, whereas specific combining ability mean squares were not significant in most instances indicating that additive genetic variance was more important. Genotype  $\times$  year interactions were significant for most variables, suggesting that selection should be evaluated over many environments. Broad-sense heritability estimates based on parental and progeny variance components were generally high for P, K, Ca, and Mg but low for the ratio  $K/(Ca + Mg)$ . Narrow-sense heritabilities for these minerals were close to the broad sense values since the additive genetic variance was the largest component of the total genetic variation. Correlations between mineral concentrations and herbage dry matter yield were low. It was concluded that adequate genetic variation exists to improve mineral concentration without altering herbage dry matter yields.

**Key words:** Tall fescue – Forage grass breeding – Diallel analyses – Forage quality – Grass tetany

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### Introduction

Grass tetany or hypomagnesaemia is a metabolic disorder of ruminants associated with low blood serum Mg levels. Grass tetany has been observed most frequently in ruminants grazing lush cool season forage grasses, including tall fescue (*Festuca arundinacea* Schreb.), in the spring or autumn (Grunes et al. 1970).

Increasing the intake of Mg by the ruminant will generally prevent the occurrence of grass tetany. Kemp (1960) demonstrated that no cases of clinical grass tetany occurred at blood serum Mg levels above 9 ppm, or at a herbage Mg level above 0.19%. Kemp and t'Hart (1957) and Butler (1963) concluded that with a  $K/(Ca + Mg)$  ratio of less than 2.2 (meq/100 g dry matter) the incidence of hypomagnesaemia was reduced. Pasture fertilization and Mg supplementation were discussed by Wilkinson and Stuedemann (1979) as methods of preventing grass tetany. Reducing the incidence of grass tetany by providing grazing animals with forage grasses having higher concentrations of Mg and 'balanced' mineral concentrations through plant breeding appears worthwhile.

Hill and Guss (1976) and Sleper (1979) reported that accumulation of minerals in many forages appears to be under genetic control and that breeding for certain mineral concentrations should be possible. Hill and Jung (1975) and Hovin et al. (1978) found significant genetic variation for mineral elements in alfalfa (*Medicago sativa* L.) and reed canarygrass (*Phalaris arundinacea* L.), respectively. Additive genetic variances were most important in the plant materials studied.

Sleper et al. (1977) reported genetic variation for Mg, Ca, K, and P concentration in herbage of selected tall fescue clones at three different harvest dates. Estimates of general combining ability were more important than estimates of specific combining ability in the inherited uptake of these minerals. Heritability estimates based on parent-offspring regression appeared to be adequate to breed tall fescue plants for improved Mg, Ca, and K levels in this material.

The breeder must realize that genes controlling mineral concentrations may not be inherited independently of each other. Hovin et al. (1978) discovered that breeding for improved levels of Mg and Ca in reed canarygrass would increase concentrations of P and K. Butler et al. (1962) found that in ryegrass (*Lolium*) Ca was positively correlated with K. Hill and Jung (1975) found significant positive genetic correlations between P and K and between Ca and Mg in alfalfa. Sleper et al. (1977) found that Mg was correlated significantly with Ca in the spring and fall harvest in tall fescue. Correlations between Mg and K in the same series of studies were generally low and nonsignificant.

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In this experiment, the genetic variability of mineral concentration in tall fescue plants derived from a broad genetic germplasm base was investigated. Objectives were (1) to determine the genetic variation and heritability of Mg, Ca, K, P, and the ratio K/(Ca + Mg); and (2) to examine the interrelationships among these minerals in tall fescue forage.

## Materials and Methods

Nine clones of tall fescue were randomly chosen from a broad based population for use in a diallel mating design. Crosses were made in the greenhouse by mutual pollination, and reciprocal seeds were bulked to provide 36 full-sib  $F_1$  families. The nine parental clones were I5-7 (South Africa), I7-6 (Turkey), I38-1 (Sweden), I56-30 (Netherlands), I80-11 (Greece), I96-559 (France), I97-8 (USSR), V6-647 (USA), and V10-225 (New Zealand). These parents were not previously selected for any agronomic trait.

Parental clones and  $F_1$  seedlings were transplanted into a randomized complete block design with three replications in the fall of 1974 at the Agronomy Research Center, Columbia, Mo. Each plot was  $0.9 \times 2.4 \text{ m}^2$ , consisting of three rows with 16 seedlings (progeny) or clonal segments (parents) planted 15 cm apart in each row. 'Kentucky 31' and 'Fawn' cultivars were included as checks. By fall of 1975 all plots were well established swards.

Prior to transplanting fertilizer was applied according to soil test at rates of 112, 30, and 85 kg/ha of N, P, and K, respectively. In the fall of 1975, 1976, and 1977 106 kg/ha N were applied each year. Spring applications were 106, 25, and 139 kg/ha of N, P, K, respectively, for 1975 and 1976. Only 106 kg/ha of N was applied in the spring of 1977.

Parents and progenies were evaluated for P, K, Ca, and Mg concentrations in the regrowth forage (1975, 1976, and 1977) and herbage dry matter yield (1976 and 1977). Plots were cut to a height of approximately 8 cm with a flail-type harvester in May, June, August, and October each year. At each regrowth harvest, plant material was immediately weighed after cutting on a spring balance. A grab sample of herbage was dried at 40 C for 48 hours for herbage dry matter yield determination and laboratory analyses.

Prior to the determination of mineral concentrations, ground forage samples were dry ashed at 500 C in porcelain crucibles according to the magnesium nitrate method (Horwitz 1975), and then solubilized in boiling 6N HCl. The 6N HCl (redistilled) and enough  $\text{La}_2\text{O}_3$  solution to make 1,000 ppm La (chloride form) in the final solution were added to appropriate dilutions of the samples before analyzing for Ca and Mg (Slavin 1968). Calcium and Mg concentrations were determined using an atomic absorption spectrophotometer equipped with a Ca-Mg hollow cathode ray lamp.

Potassium concentrations were determined using the same solutions that were tested for Ca and Mg. The solution that contained 1,000 ppm La was tested with a flame ionization spectrometer using an air acetylene flame (Pickett and Koirtjohann 1969). Horwitz's (1975) micromethod (colorimetric) was used to test the samples for P. Absorbance was read at 630 nm.

The data were analyzed as a split-plot in time with years as the subplots according to Steel and Torrie (1960). Analyses of variance were computed separately for parents and crosses using plot means. Expected mean squares were based on a mixed linear model with years having fixed effects and parents and crosses random. The sum of squares for crosses was partitioned by least squares analysis into general (GCA) and specific combining ability (SCA) according to method 4 of Griffing (1956). Variance components

were estimated by computing appropriate linear functions of the mean squares as determined from the mean square expectations (Table 1). Variances of the variance components were approximately estimated according to Kempthorne (1957).

Broad-sense heritabilities were estimated based on the parental variance components ( $Hb_1$ ) (Eberhart and Newell 1959) and on the  $F_1$  progeny variance components ( $Hb_2$ ) (Kehr 1961). Narrow-sense heritabilities ( $h_n$ ) were estimated from the variance components due to GCA, SCA, and their interactions with years, according to a digenic model with non-inbred parents selected from a random mating population. Epistasis was assumed absent (Kempthorne 1957; Gardner 1963). All heritabilities were estimated on the phenotypic mean basis, averaging over replications and years as follows:

$$Hb_1 = \frac{s_p^2}{s_p^2 + \frac{s_{PY}^2}{y} + \frac{s_{RP}^2}{r} + \frac{s_e^2}{yr}}$$

$$Hb_2 = \frac{s_C^2}{s_C^2 + \frac{s_{CY}^2}{y} + \frac{s_{RC}^2}{r} + \frac{s_e^2}{yr}}$$

**Table 1.** Expectations from analysis of variance for single-cross progenies and parents

Source	Mean square expectations <sup>a</sup>
<i>Single-crosses</i>	
Crosses (C)	$\sigma_e^2 + y \sigma_{RC}^2 + ry \sigma_C^2$
GCA	$\sigma_e^2 + y \sigma_{RC}^2 + ry \sigma_S^2 + ry (p-2) \sigma_G^2$
SCA	$\sigma_e^2 + y \sigma_{RC}^2 + ry \sigma_S^2$
Reps (R) × C	$\sigma_e^2 + y \sigma_{RC}^2$
C × Years (Y)	$\sigma_e^2 + \frac{ry}{y-1} \sigma_{CY}^2$
GCA × Y	$\sigma_e^2 + \frac{ry}{y-1} \sigma_{SY}^2 + \frac{ry(p-2)}{y-1} \sigma_{GY}^2$
SCA × Y	$\sigma_e^2 + \frac{ry}{y-1} \sigma_{SY}^2$
Residual	$\sigma_e^2$
<i>Parents</i>	
Parents (P)	$\sigma_e^2 + y \sigma_{RP}^2 + ry \sigma_P^2$
R × P	$\sigma_e^2 + y \sigma_{RP}^2$
P × Y	$\sigma_e^2 + \frac{ry}{y-1} \sigma_{PY}^2$
Residual $\sigma$	$\sigma_e^2$

<sup>a</sup> r, y = number of replications and years, respectively; p = number of parents

$$Hn = \frac{4 s_G^2}{4 s_G^2 + 4 s_S^2 + 4 \frac{s_{GY}^2}{y} + 4 \frac{s_{SY}^2}{y} + \frac{s_{RC}^2}{r} + \frac{s_e^2}{yr}}$$

where

$s_P^2$ ,  $s_C^2$ ,  $s_G^2$ , and  $s_S^2$  = variance component due to parents, crosses, GCA, and SCA, respectively.

$s_{PY}^2$ ,  $s_{CY}^2$ ,  $s_{GY}^2$ , and  $s_{SY}^2$  = variance component due to parent  $\times$  year, cross  $\times$  year, GCA  $\times$  year, and SCA  $\times$  year interaction, respectively.

$s_{RP}^2$  and  $s_{RC}^2$  = variance component due to replication  $\times$  parent and replication  $\times$  cross, respectively.

$s_e^2$  = corresponding residual variance component.

$r$ ,  $y$  = number of replicates and years, respectively.

Negative variance components were set equal to zero in calculating heritabilities.

Simple linear regression coefficient of progeny means on their midparent values was calculated to use this statistic as an estimate of narrow-sense heritability from the point of view of predicting genetic gain from selection on a phenotypic mean basis (Hanson 1963). Simple correlation coefficients among the characters were also calculated using progeny data.

## Results and Discussion

### Means

The means of P, K, Ca, and Mg concentrations were generally similar for parents and  $F_1$  progenies at each harvest (Table 2). All Mg concentrations were above the critical value of 0.2%, as established by Kemp (1960), at three

harvest dates. For both parents and progenies, Ca and Mg levels were generally lowest at the October harvest. Phosphorus concentrations generally decreased as the season progressed. Potassium increased from the June to October harvest.

The ratio of K/(Ca + Mg) (calculated on a milliequivalent basis) in the regrowth herbage of both parents and progenies was below 2.2 in every case. The highest ratio of K/(Ca + Mg) generally was found in the October harvest, and the lowest ratio generally was found in the August harvest.

### Genetic Variances and Combining Ability

Most  $s_p^2$  variance components were significantly greater than zero (Table 3), suggesting the existence of genetic variation for the mineral concentrations in the parental population. Parent  $\times$  year interaction variance components were significant for all cases except for K at the third harvest, indicating that multi-year testing is necessary. The replication  $\times$  parent variances were not significantly greater than zero in all cases.

Variances due to progenies (crosses) were significant for all minerals at each harvest date. Variance components for GCA were highly significant for all traits at each harvest. Variance components for SCA were significant only for Ca at the third harvest (Table 3). The estimates of GCA variance had much higher magnitude than that of SCA variance for most variables studied as indicated by the ratios of  $s_S^2/s_C^2$  (Table 3).

Table 2. Mean concentrations of minerals in the regrowth forage of parents and single-crosses of tall fescue

Mineral <sup>a</sup>	Harvest	Parents				Crosses			
		1975	1976	1977	Mean SE <sup>b</sup>	1975	1976	1977	Mean SE <sup>b</sup>
P	First	0.303	0.336	0.365	0.335 $\pm$ 0.007	0.322	0.354	0.371	0.349 $\pm$ 0.010
	Second	0.264	0.377	0.341	0.327 $\pm$ 0.007	0.321	0.390	0.347	0.352 $\pm$ 0.010
	Third	0.287	0.268	0.293	0.283 $\pm$ 0.009	0.302	0.265	0.291	0.286 $\pm$ 0.009
K	First	2.453	1.881	1.634	1.989 $\pm$ 0.055	2.549	1.966	1.699	2.072 $\pm$ 0.059
	Second	2.295	1.927	2.262	2.161 $\pm$ 0.085	2.301	2.075	2.226	2.201 $\pm$ 0.064
	Third	2.373	2.345	2.478	2.399 $\pm$ 0.089	2.454	2.273	2.335	2.354 $\pm$ 0.074
Ca	First	0.449	0.567	0.581	0.532 $\pm$ 0.014	0.461	0.586	0.586	0.544 $\pm$ 0.014
	Second	0.527	0.657	0.564	0.582 $\pm$ 0.014	0.540	0.657	0.575	0.591 $\pm$ 0.014
	Third	0.458	0.417	0.389	0.421 $\pm$ 0.013	0.463	0.420	0.384	0.422 $\pm$ 0.012
Mg	First	0.322	0.256	0.300	0.293 $\pm$ 0.007	0.327	0.268	0.309	0.301 $\pm$ 0.010
	Second	0.305	0.351	0.425	0.360 $\pm$ 0.009	0.309	0.371	0.434	0.371 $\pm$ 0.009
	Third	0.310	0.241	0.260	0.270 $\pm$ 0.006	0.317	0.255	0.267	0.280 $\pm$ 0.009
K/ (Ca + Mg)	First	1.295	0.965	0.786	1.015 $\pm$ 0.046	1.319	0.983	0.798	1.033 $\pm$ 0.038
	Second	1.152	0.801	0.920	0.958 $\pm$ 0.044	1.128	0.843	0.887	0.953 $\pm$ 0.032
	Third	1.274	1.482	1.562	1.439 $\pm$ 0.057	1.286	1.393	1.463	1.381 $\pm$ 0.058

<sup>a</sup> Concentrations: Mg, Ca, K, and P (%) and K/(Ca + Mg) (meq/100 g dry matter)

<sup>b</sup> Mean and standard error of the mean averaged over 3 years

Table 3. Estimates of variance components for indicated traits in parents and single-cross progenies of tall fescue<sup>a</sup>

Trait	Parents			Crosses							$\frac{s_b^2}{s_G^2}$
	Harvest	$s_P^2$	$s^2_{PY}$	$s_e^2$	$s_G^2$	$s_S^2$	$s_{GY}^2$	$s_{SY}^2$	$s_e^2$		
P	First	1.016 ± 0.476**	0.328 ± 0.138**	0.378 ± 0.091	0.249 ± 0.117**	0.004 ± 0.031	0.085 ± 0.034**	0.051 ± 0.026	0.362 ± 0.043	2	
	Second	0.489 ± 0.244**	0.262 ± 0.133**	0.574 ± 0.139	0.193 ± 0.096**	0.063 ± 0.048	0.029 ± 0.019**	0.066 ± 0.038	0.547 ± 0.065	33	
	Third	0.495 ± 0.256**	0.119 ± 0.063**	0.283 ± 0.068	0.174 ± 0.083**	-0.006 ± 0.028	0.026 ± 0.010		0.312 ± 0.037	0	
K	First	14.793 ± 8.056**	15.784 ± 6.799**	19.678 ± 4.771	4.783 ± 2.441**	1.208 ± 1.390	3.458 ± 1.546**	1.196 ± 1.729	30.918 ± 3.671	25	
	Second	10.079 ± 8.101	19.517 ± 8.288**	22.858 ± 5.542	6.895 ± 3.276**	-0.910 ± 1.077	3.557 ± 1.485**	0.075 ± 1.385	27.680 ± 3.286	0	
	Third	26.552 ± 15.643**	4.680 ± 3.998	28.729 ± 6.966	16.347 ± 7.720**	1.391 ± 2.004	3.118 ± 1.345**	1.067 ± 1.346	23.617 ± 2.804	8	
Ca	First	1.602 ± 0.813**	1.027 ± 0.451**	1.387 ± 0.336	0.403 ± 0.193**	-0.007 ± 0.065	0.254 ± 0.099**	0.015 ± 0.070	1.362 ± 0.161	0	
	Second	0.472 ± 0.301*	0.864 ± 0.488*	2.463 ± 0.597	0.146 ± 0.084**	0.108 ± 0.083	0.089 ± 0.045**	0.045 ± 0.066	1.197 ± 0.142	74	
	Third	1.939 ± 0.943**	1.016 ± 0.387**	0.633 ± 0.153	0.521 ± 0.254**	0.186 ± 0.091**	0.127 ± 0.050**	0.014 ± 0.039	0.737 ± 0.087	36	
Mg	First	0.704 ± 0.338**	0.761 ± 0.272**	0.246 ± 0.059	0.302 ± 0.140**	-0.003 ± 0.031	0.078 ± 0.029**	0.007 ± 0.017	0.329 ± 0.039	0	
	Second	1.117 ± 0.539**	0.238 ± 0.140*	0.742 ± 0.179	0.383 ± 0.178**	0.038 ± 0.033	0.055 ± 0.025**	0.044 ± 0.029	0.451 ± 0.053	10	
	Third	0.798 ± 0.373**	0.324 ± 0.126**	0.239 ± 0.058	0.338 ± 0.155**	-0.007 ± 0.023	0.038 ± 0.015**	-0.002 ± 0.124	0.258 ± 0.030	0	
K/ (Ca + Mg)	First	2.915 ± 2.341	12.294 ± 5.415**	16.775 ± 4.068	0.416 ± 0.306**	0.371 ± 0.526	3.010 ± 1.165**	0.510 ± 0.729	13.021 ± 1.546	89	
	Second	2.056 ± 1.890	4.885 ± 2.387**	9.505 ± 2.305	0.950 ± 0.503**	0.225 ± 0.363	1.442 ± 0.553**	0.261 ± 0.327	5.728 ± 0.680	24	
	Third	6.031 ± 4.292*	17.016 ± 6.498**	10.828 ± 2.625	3.872 ± 2.071**	1.944 ± 1.499	2.575 ± 0.995**	-0.356 ± 0.670	14.646 ± 1.739	50	

\* \*\* Mean square associated with variance component was significant at the 0.05 and 0.01 probability levels, respectively

<sup>a</sup> Values were multiplied by 10<sup>3</sup><sup>b</sup> Expressed in %

These results suggest the importance of additive genetic variance in this broad genetic base population of tall fescue. Non-additive genetic variance appeared less important. Sleper et al. (1977) found that additive genetic effects were important in the inheritance of P, K, Ca, and Mg content in a set of narrow genetic based tall fescue clones. Hovin et al. (1978) reported that additive genetic variances were present for concentrations of those minerals in reed canarygrass. Cross  $\times$  year interactions were highly significant for all traits except for P at the third harvest date. The GCA  $\times$  year interaction was highly significant, whereas none of the SCA  $\times$  year variance components were significantly greater than zero. These significant interactions indicated differential expression of genetic effects in different environments. However, in general, the estimates of GCA  $\times$  year variances were much lower than estimates of GCA variances (Table 3).

Breeding procedures such as phenotypic restricted recurrent selection or simple mass selection, which utilize the additive genetic variance, are expected to result in improvements in selection for P, K, Ca, Mg, and the cation ratio in this population. Multi-year testing seems necessary in the breeding program on the basis of significant genotype  $\times$  year interaction variance components.

#### Heritability Estimates

Broad-sense heritability estimates based on parental variance components and  $Hb_2$  were in general high for P, K, Ca, and Mg concentrations and low for K/(Ca + Mg) (Table 4.). Each type of broad-sense heritability estimate

could be used according to the population involved in selection on a family mean basis. If parental or  $F_1$  clones are to be selected and reproduced vegetatively, improvement may be estimated directly from the broad sense heritability estimate and the clonal means. If clones are to be selected for inter-crossing to establish a new breeding population, then narrow-sense heritability should be used to predict genetic gain from selection. Narrow-sense heritabilities for these mineral concentrations were expected to be close to the broad-sense heritabilities, since the additive genetic variance was the largest component of the total genetic variation.

Narrow-sense heritabilities estimated from GCA and SCA variance components, based on a digenic model, were in some cases higher than the broad-sense heritability estimates (Table 4). For such cases, the assumptions as pointed out above obviously did not hold. This could be due to the presence of epistasis, linkage, and/or multiple allele effects in this population. Kempthorne (1957) demonstrated for a random mating population with no linkage that the covariance of half sibs =  $1/4 \sigma_A^2 + 1/16 \sigma_{AA}^2 + 1/64 \sigma_{AAA}^2 \dots$  and the covariance of full sibs =  $1/2 \sigma_A^2 + 1/4 \sigma_D^2 + 1/4 \sigma_{AA}^2 + 1/8 \sigma_{AD}^2 + 1/16 \sigma_{DD}^2 + \dots$  Thus the estimates  $\hat{\sigma}_A^2 = 4 \hat{\sigma}_G^2$  and  $\hat{\sigma}_D^2 = 4 \hat{\sigma}_S^2$  would be biased upward by the indicated epistatic variances. Narrow-sense heritability estimates therefore could be biased upward. Linkages, which affect covariance of half sibs and full sibs, can also magnify the biases (Cockerham 1956).

Linear regression of progeny means on mid-parent values was calculated in an attempt to use this statistic as an estimate of narrow-sense heritability (Table 4). The estimates were greater than 100 cases which may have

Table 4. Estimates of broad- and narrow-sense heritabilities and parent-offspring regression coefficient for mineral concentrations in the regrowth forage of tall fescue

Mineral	Harvest	Heritability estimate			Regression coefficient $\times$ 100		
		Hb <sub>1</sub>	Hb <sub>2</sub>	Hn %	1975	1976	1977
P	First	86	72	77	72	102	72
	Second	76	72	61	57	109	63
	Third	81	73	84	68	81	87
K	First	64	60	57	97	103	40
	Second	42	63	75	124	35	31
	Third	74	79	80	101	96	109
Ca	First	74	64	74	101	79	71
	Second	46	58	42	52	30	53
	Third	79	82	66	81	88	57
Mg	First	70	76	85	88	103	84
	Second	87	84	80	60	82	120
	Third	84	84	91	82	101	103
K/(Ca + Mg)	First	32	24	18	78	68	37
	Second	37	48	48	64	21	42
	Third	40	64	51	70	67	96

**Table 5.** Estimates of simple correlations among mineral concentrations of regrowth forage of tall fescue (n = 108)

Mineral	Harvest	K			Ca			Mg			K/(Ca + Mg)		
		1975	1976	1977	1975	1976	1977	1975	1976	1977	1975	1976	1977
P	First	0.51**	0.23*	0.18	-0.21*	0.02	0.08	-0.32**	-0.15	0.01	0.58**	0.20**	0.13
	Second	-0.17	0.27**	0.37**	0.08	-0.09	-0.01	-0.19	-0.09	-0.11	-0.11	0.31	0.35
	Third	0.52**	0.56**	0.53**	-0.24	-0.08	0.10	-0.28	-0.15	0.01	0.61**	0.60**	0.41**
K	First				-0.04	-0.24*	-0.16	0.12	0.23*	0.48**	0.68**	0.80**	0.77**
	Second				-0.20*	-0.25**	-0.13	0.45**	0.44**	0.18	0.85**	0.81**	0.74**
	Third				0.08	0.34**	0.19	0.18	0.31**	0.33**	0.69**	0.58**	0.63**
Ca	First							0.67**	0.26**	0.16	-0.66**	-0.67**	-0.61**
	Second							0.02	0.02	0.26**	-0.49**	-0.58**	-0.57**
	Third							0.74**	0.59**	0.58**	-0.59**	-0.46**	-0.54**
Mg	First										-0.59**	-0.22*	-0.07
	Second										0.01	-0.01	-0.43**
	Third										-0.53**	-0.49**	-0.42**

\*, \*\* Correlation coefficient was significantly different from zero at the .05 and .01 probability levels respectively, based on normal correlation model

been the result of an inadequate statistical or genetic model. Interpretation of regression coefficients as narrow-sense heritability estimates does involve a digenic model with no epistasis (Kempthorne and Tandon 1953). However, the parent-offspring linear regression coefficients indicated a moderate to strong relationship between parents and offsprings for P, K, Ca, and Mg concentration in this tall fescue population, suggesting that progress from selection is possible.

From this experiment, we suggest that more reliable breeding implications could be obtained from the estimates of variance components rather than from heritability estimates per se. The essential information needed by most forage grass breeders is the magnitude of GCA and SCA variance, and relative importance of those variances to total genetic variance. The magnitude of genotype  $\times$  environmental interactions as compared to that of the genetic variance is also of major concern in forage grass breeding.

Additive genetic variance appears to be the most important component of genetic variance for the mineral concentrations in this broad genetic base population. The simpler mating designs including polycross, open pollination, and top cross progeny tests would be recommended over the diallel cross in screening heterozygous clones for general combining ability for synthetic cultivar development with improved mineral concentrations.

#### Correlation Between Characters

In this broad genetic base material, significant positive correlations between Ca and Mg were found (Table 5), particularly at the third harvest in October, the coefficients

were moderate to high, suggesting that breeding for higher Mg concentrations in the fall could lead to higher Ca concentrations. Correlations between Mg and K and between Ca and K were generally low. However, a correlation coefficient of about 0.40 between Mg and K for some cases would suggest the possibility of correlated increase in K due to selection for higher Mg concentration. Correlations between P and K were above 0.50 at the third harvest for all three years.

The K/(Ca + Mg) ratio was more closely correlated to K than to Mg and Ca in this population. Thill and George (1975) examined the K/(Ca + Mg) ratio in nine cool-season grass species and concluded that K was largely responsible for plants having either a high or low ratio and that Mg and Ca contributed to the day to day variation in the ratio as influenced by temperature changes.

Information on the association between mineral element concentrations and forage dry matter yields is also of interest to the grass breeder. Statistically significant correlations between P, K, Ca, Mg and forage dry matter yield were found (Table 6). However, the magnitude of those correlations were generally low, giving further evidence that forage yields in tall fescue should not be altered significantly by modifying mineral levels. Sleper et al. (1977) reported that in tall fescue the association of minerals with yield was generally low and not significant over the entire growing season. They suggested that mineral concentrations could be altered through breeding without affecting forage yield. Similar results were reported in reed canarygrass by Hoving et al. (1978).

It appears that adequate genetic variation is available to modify mineral concentrations in this tall fescue material. It is necessary to note that the estimates of means and variance components may be influenced by the num-

**Table 6.** Estimates of simple correlations between mineral concentrations and dry matter yield of regrowth herbage of tall fescue

Mineral	Harvest	Yield	
		1976	1977
P	First	-0.12	-0.19
	Second	0.18	0.09
	Third	-0.08	-0.17
K	First	0.00	0.24*
	Second	0.75**	0.14
	Third	0.02	0.09
Ca	First	-0.28**	-0.05
	Second	-0.29**	0.03
	Third	-0.01	0.21*
Mg	First	-0.12	0.09
	Second	0.38**	0.06
	Third	0.31**	0.46**

\*, \*\* Correlation coefficient was significantly different from zero at the 0.05 and 0.01 probability levels, respectively, based on a normal correlation model,  $n = 108$

ber of parents used in the diallel mating design. A larger number of parents may have demonstrated greater genetic variability and the standard errors of estimates of variance components would likely have decreased, particularly if more replications were added. However, breeding for improved mineral concentrations, particularly Mg, appears to be a worthy objective.

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