Seasonal Dynamics of Minerals in Forages at the Texas Experimental Ranch

L.W. GREENE, W.E. PINCHAK, AND R.K. HEITSCHMIDT

Abstract

Range livestock derive the bulk of their dietary mineral intake from forages that are often deficient in one or more essential minerals. The objective of this study was to quantify the seasonal dynamics of phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) concentrations in the dominant native forages at the Texas Experimental Ranch. Concentrations were estimated by class of tissue (live and dead) for 5 species/species groups: sideoats grama (*Bouteloua curtipendula* Michx.), Texas wintergrass (*Stipa leucotricha* Trin. and Rupr.), annual grasses, other warm-season grasses, and forbs. The study spanned a period of 2 years and included 16 sample dates. Although P, Mg, and K concentrations varied significantly among species and date, they varied primarily as a function of class of tissue. Averaged across dates and species, concentrations of P, Mg, and K in live tissue averaged 0.12, 0.13, and 2.02%, respectively, while concentrations in dead tissue averaged 0.04, 0.09, 0.57%, respectively. As a result, seasonal differences in whole plant concentrations of P, Mg, and K were closely linked to seasonal growth dynamics as they affect live/dead ratios. Ca concentrations were affected more by species than class of tissue. Averaged across dates, Ca concentrations in live tissue averaged 0.55, 0.40, 0.42, 0.35, and 1.80% in annual grasses, Texas wintergrass, sideoats grama, other warm-season grasses and forbs, respectively, while concentrations in dead tissue averaged 0.41, 0.40, 0.41, 0.36, and 0.96%, respectively. It is concluded that considerations must be given to the potential effect that a given treatment may have on plant growth dynamics to properly interpret its effect on whole plant concentrations of minerals.

Key Words: phosphorus, magnesium, potassium, calcium

Livestock production from range resources is variously constrained by both the quantity and quality of forage produced and consumed. Previous forage quality research has focused on quantifying the crude protein (Cook and Harris 1968, Heitschmidt et al. 1982) and energy (Urness et al. 1983, Jung et al. 1985) content of range forages with only limited research focused on quantifying the seasonal dynamics of minerals (Rauzi et al. 1969, Everitt et al. 1980, Huston et al. 1981, Lambacher 1983). Furthermore, much of the research has focused on whole plant concentrations which probably do not accurately reflect their nutritional value to livestock because of diet selection processes. For example, cattle express varying degrees of selectivity for live over dead tissue (Stuth et al. 1986) and leaf over stem (Poppi et al. 1981) all of which have intrinsically different nutrient concentrations.

This study was initiated as part of a multi-disciplinary research effort to quantify the effects of rotational grazing on livestock production at the Texas Experimental Ranch. The objectives of this paper are to characterize the seasonal concentration dynamics of phosphorus (P), magnesium (Mg), potassium (K), and calcium (Ca) in the dominant forages growing at the ranch.

Authors are assistant professor, Department of Animal Science, Texas A&M University, College Station 77843; assistant professor and associate professor, Texas Agricultural Experiment Station, Box 1658, Vernon 76384.

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Study Area and Methods

The Experimental ranch is located (99° 14′ W, 33° 2-′ N) in the eastern portion of the Rolling Plains of Texas. Weather patterns are characterized by mild, dry winters; warm, wet springs and falls; and hot summers. Maximum daily temperatures range from 13° C in January to 36° C in July. Long-term average annual precipitation is 690 mm with approximately 70% occurring from April through September (Fig. 1). The average frost-free growing period of 233 days extends from March to November.

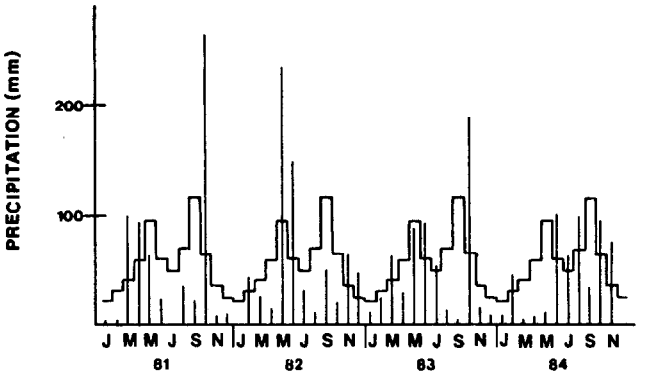

Fig. 1. *Long-term average monthly (continuous lines) and actual (vertical lines) precipitation (mm) from 1981 through 1984 at the Texas Experimental Ranch.*

Vegetation is characterized as a southern mixed-grass prairie with a dominant honey mesquite (*Prosopis glandulosa* var. *glandulosa* Torr.) over-story. Dominant perennial grasses include: sideoats grama [*Bouteloua curtipendula* (Michx.) Torr.], a warm-season midgrass; Texas wintergrass (*Stipa leucotricha* Trin. and Rupr.), a cool-season midgrass; and buffalograss [*Buchloe dactyloides* (Nutt.) Engelm.], a warm-season shortgrass. Japanese brome (*Bromus japonicus* Thurb.) is the dominant annual grass.

The period of study extended from August 1982 through August 1984. Herbaceous standing crop was harvested at ground level in forty, 0.25-m^2 quadrats approximately every 45 days. Ten quadrats each were randomly located inside permanent 0.25-ha study areas located in 4 paddocks in a 16-paddock rotational grazing treatment initiated in 1981. All 4 study areas were located on a clay loam fine-silty, mixed, thermic Typic Calciustolls soil. Range condition of all study areas was good.

The herbaceous standing crop was clipped by dominant species/species group. Species/species groups were annual grasses (Angr), Texas wintergrass (Stle), sideoats grama (Bocu), other warm-season grasses (Wsgr), and forbs (Forbs). Following drying (60° C) and weighing, amounts of live and dead tissue were estimated for each species/species group by paddock via hand separation of subsamples. Samples within a date were then combined across paddocks for laboratory analyses. For a more complete description of field sampling procedures see Heitschmidt et al. (1987a, 1987b).

A 1-g subsample was wet digested with nitric and perchloric acid following the procedures outlined by Sandel (1950). Digested samples were analyzed for Mg, K, and Ca by atomic absorption

spectrophotometry (Varian AA6). Phosphorus was determined colorimetrically, following the procedures of Fiske and Subarrow (1925). Subsamples were ashed at 500° C for 3 hours for organic matter determination.

Mineral concentration data were statistically analyzed using various factorial and 2-way analysis of variance (AOV) models (SAS 1985). The 3-way factorial AOV used for each mineral included tissue type (live vs. dead), species (species/species group) and date as main effects and all 2-way interactions. The 3-way interaction was used as the error term. Because of seasonal growth dynamics, no sample date included both live and dead tissue for all species. Consequently, a series of analyses was done for various date combinations including all grasses (2 dates) and perennial grasses only (12 dates). Two-way AOV were used where possible to assist in the interpretation of statistical differences in mineral concentrations between either class of tissue, species, or date. Significant main effect means were separated using a protected Student-Neuman-Keuls test. Unless otherwise noted, the level of significance of an effect is $P<.05$.

Results and Discussion

Class of tissue (live vs. dead) was the major factor affecting mineral concentrations (Table 1) when averaged across all species/species groups. This was also true for P, Mg, and K in perennial grass species (Table 2). Ca concentrations, however, did not vary as a function of class of tissue. Results from the 3-way AOV of all grasses indicated the same basic trends except the effect of date was of greater significance relative to Ca concentrations. Subsequent analyses of all species indicated relationships among main effects and interactions were similar to those observed in the perennial grass models (Table 2). Graphic presentation of the 3-way interactions of date, class of tissue, and species (Fig. 2) confirm the validity of these generalized conclusions.

Table 1. Average concentrations (%) of phosphorous (P), magnesium (Mg), calcium (Ca), and potassium (K) in live and dead tissues of 5 species/species groups.

Mineral	Tissue	
	Live	Dead
P	0.12[1]	0.04
Mg	0.13	0.09
K	2.02	0.57
Ca	0.73	0.52

[1]All means in a row were significantly different at 0.05 level.

Table 2. F-values for factorial AOV models used to statistically analyze phosphorous (P), magnesium (Mg), calcium (Ca), and potassium (K) concentrations in perennial grass species/species groups.

Source	d.f.	Mineral			
		P	Mg	K	Ca
Tissue class	1	824**	408**	317**	<1
Date	15	8**	9**	9**	4*
TC * D	15	8**	6*	8*	4
Species	2	16*	18**	9*	11*
Sp * TC	2	4*	0	3	<1
Sp * D	30	<1	2	1	1
Residual	30				

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

Phosphorus

When averaged across all species and dates, P concentrations in dead tissue were about 60% less than live tissue (Table 1). Although absolute age and physiological condition of tillers within a class of tissue were not monitored, it was apparent P concentrations did vary within tissue class (Fig. 2), particularly in live tissue, and that this variation was closely associated with seasonal growth dynamics. For example, Forbs and Angr consistently attained their greatest concentrations (Fig. 2) during the fall and winter periods of active vegetative growth (Heitschmidt et al. 1987a). Similarly, P levels in live Stle tissue were greater during fall, winter, and spring than during summer. Characteristic annual minimum and maximum P concentrations for live Stle ranged from 0.08% in July 1983 and May 1984 to 0.17% in November 1983 (Fig. 2). Likewise, P concentrations in live tissue of Bocu and Wsgr ranged from 0.07 to 0.13 and 0.16%, respectively, with peak concentrations in both groups occurring during periods of active vegetative growth in spring and fall. Minimums occurred during periods of drought and winter dormancy. As a result, P concentration in live tissue varied less among groups of similar seasonal growth patterns and ontogeny, than among phenologically dissimilar groups (Table 3). Moreover, based on the growth dynamics data presented by Heitschmidt et al. (1987a), it would appear peak P concentrations in live tissue precede peak live biomass by about 30–45 days. Studies by Huston et al. (1981), Everitt et al. (1980), and Rauzi et

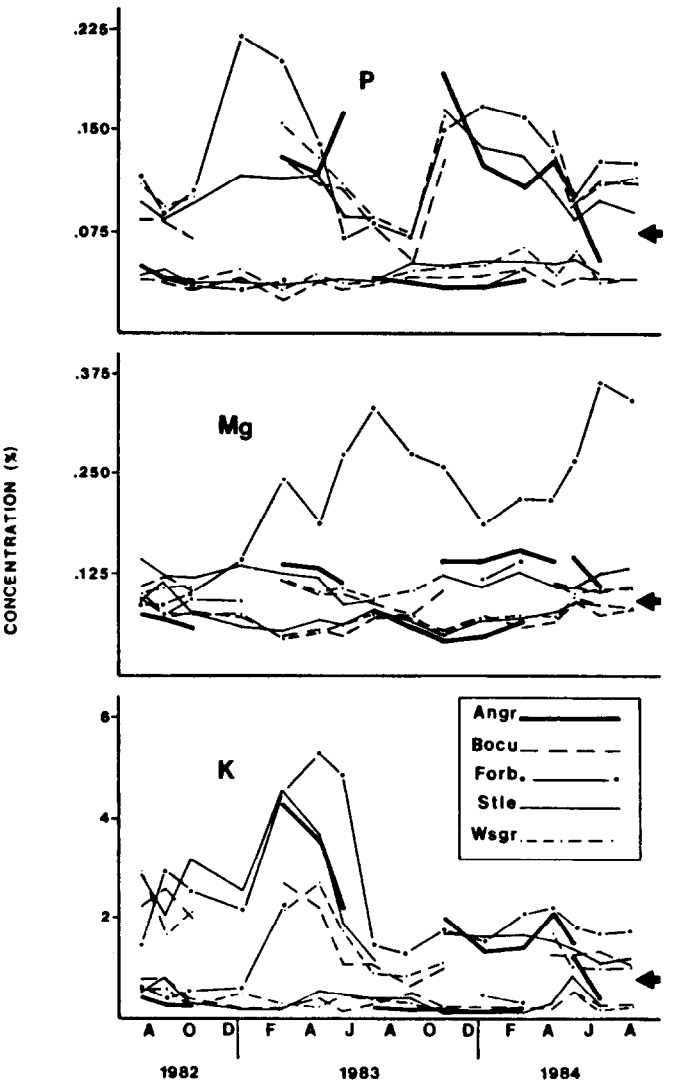

Fig. 2. *Concentrations (%) of phosphorus (P), magnesium (Mg), and potassium (K) in live and dead tissue of 5 species/species groups from August 1982 through August 1984. Arrow on right side of figures approximates line separating live (above arrow) and dead (below arrow) tissue concentrations.*

Table 3. Average (± 1 S.E.) concentration (%) of phosphorous (P), magnesium (Mg), calcium (Ca), and potassium (K) in live (L) and dead (D) tissue of annual grasses (Angr), Texas wintergrass (Stle), sideoats grama (Bocu), other warm season grasses (Wsgr), and forbs (Forb.) Mean is average for maximum of 16 sample dates.

Species	Tissue	Mineral			
		P	Mg	K	Ca
Angr	L	.133±.011	138.±.004	2.269±.375	.553±.033
	D	.047±.006	.075±.010	.338±.100	.409±.035
Stle	L	.107±.006	.120±.004	2.142±.257	.400±.023
	D	.045±.002	.076±.005	3.97±.054	.396±.021
Bocu	L	.101±.007	.104±.004	1.576±.186	.419±.018
	D	.039±.001	.070±.003	.361±.050	.414±.015
Wsgr	L	.114±.007	.105±.002	1.552±.200	.348±.014
	D	.046±.002	.073±.003	.364±.036	.359±0.19
Forb	L	.128±.011	.225±.021	2.457±.321	1.80 ±.203
	D	.039±.003	.130±.017	.754±.226	9.56±.112

al. (1969) also indicate P concentrations in live tissue are greatest during periods of active growth.

Phosphorous levels in dead tissue did not vary as much among dates (Fig. 2) and forages (Table 3) as they did in live tissue. Although the absence of seasonal variations in dead tissue concentrations may be attributed in part to the subjective method used to classify and separate live and dead tissue, we believe the data show most labile P had been translocated from or leached out of live tissue by the time full senesence occurred. This is in agreement with the findings of Lonengran (1973).

Weighted average or whole plant concentrations of P differed among species and dates (Fig. 3) and were primarily a function of live:dead mixing and relative age of live tissue. Peak whole plant P concentrations generally occurred in spring and late fall during periods of active growth when relative and absolute amounts of live tissue were greatest (Heitschmidt et al. 1987a). Mid-summer decreases were associated with the maturation of annual species, Stle senesence, and Bocu and Wsgr quiesence. Rauzi et al. (1969) found similar seasonal trends for P concentrations in blue grama [*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.] and western wheatgrass (*Agropyron smithii* Rydb.) in southeastern Wyoming.

Averaged across dates, whole plant P levels in Forbs were significantly greater than in Stle, Wsgr, and Bocu, but were comparable to those in Angr. Bocu had significantly lower P concentrations than Forbs or Angr.

Magnesium

Magnesium concentrations in live tissue were 44% greater than concentrations in dead tissue (Table 1), when averaged across dates and species. Concentrations in perennial grasses varied significantly as a function of class of tissue, species, and date (Table 2). But unlike P, Mg concentrations in live tissue varied little among sampling dates within species, with the exception of Forbs, while concentrations in dead tissue varied a slightly greater amount than P concentrations (Fig. 2). Forbs contained significantly greater concentrations of Mg in both live and dead tissue than did grasses when averaged across dates (Table 3). As a result, average whole plant Mg concentrations were generally greater in Forbs than grasses (Fig. 3).

Cool-season species tended to maintain greater whole plant Mg concentrations (0.13% vs. 0.11%) than warm-season species (Table 3). Peak concentrations of Mg in Angr occurred during winter and early spring when germination and initial vegetative growth occurred, while warm-season perennial grasses exhibited summer peaks (Fig. 3). Stle tended to attain maximum whole plant concentrations during spring. Like P, whole plant Mg concentrations in all species/species groups tended to coincide with periods of active growth when live/dead ratios were greatest (Heitschmidt et al. 1987a). These data agree closely with the seasonal dynamics of whole plant Mg concentrations reported by Everitt et al. (1980). They also reflect that Mg is a mobile mineral whose critical function is associated primarily with plant photosynthetic processes (Devlin 1966).

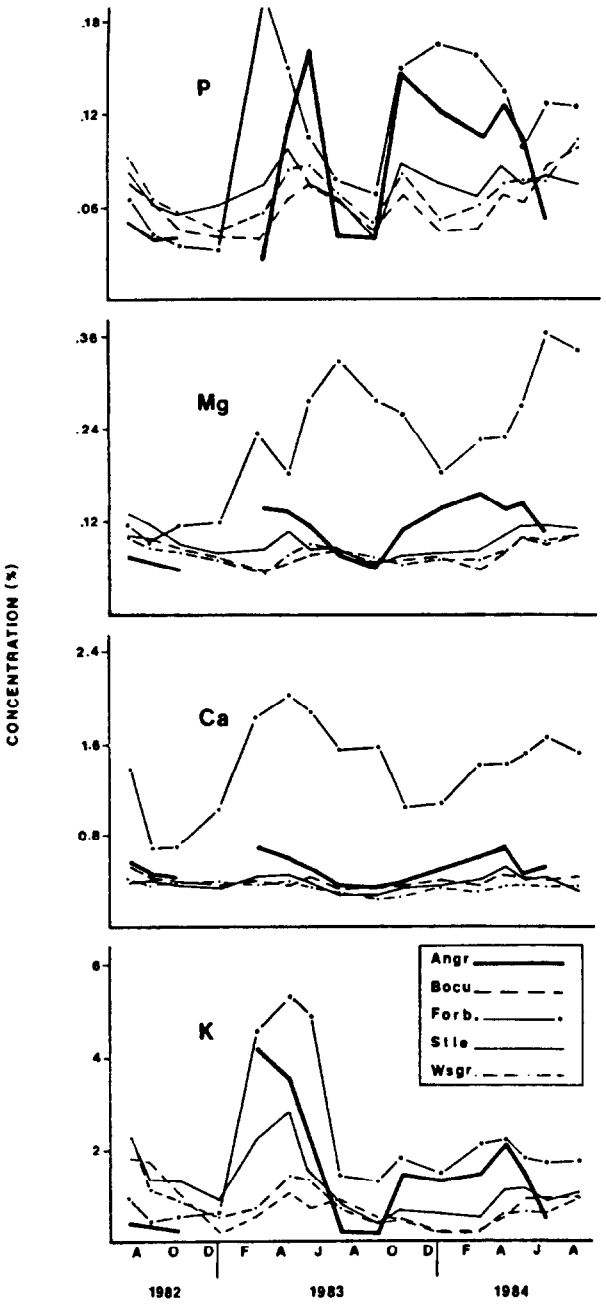

Fig. 3. *Whole plant concentrations (%) of phosphorus (P), magnesium (Mg), calcium (Ca), and potassium (K) for 5 species/species groups from August 1982 through August 1984.*

Potassium

Concentration of K in perennial grasses varied as a function of class of tissue, species, and date (Table 2) but as with P and Mg, class of tissue was the major factor influencing K concentration. Live tissue K levels were on the average about 3.5 times greater than in dead tissue (Table 1) and ranged from about 0.6 to 5.0% (Fig. 2). Potassium concentration in live tissue appeared to vary

among dates as a function of absolute age of leaf and environmental conditions and at a magnitude similar to P. For example, during 1982 and early 1983 when a "normal" distribution of precipitation occurred (Fig. 1), K levels in live tissue (Fig. 2) tended to vary as a direct function of growth activity as presented by Heitschmidt et al. (1987a). These changes apparently occurred because K, like P, is a labile mineral. Up to 60% of total plant K may be translocated to storage organs prior to senescence (Charley 1977) whereas leaching is the major avenue of loss from senesced tissue (Hinnant and Kothmann 1982, Lonengran 1973). Conversely, in 1984, very little variation in live tissue K concentrations was found (Fig. 2). This coincided with an extended spring/summer drought when only 13% of average precipitation was received (Fig. 1). Longengran (1973) and Charley (1977) state that root absorption of K is closely tied to available soil moisture. Under near optimal soil moisture conditions, K concentrations will usually exceed plant nutrient requirements. But under moisture stress, a K deficiency may develop. Perhaps the lack of seasonality in K concentrations of live tissues during 1984 was in part caused by the lack of sufficient soil moisture to facilitate maximum K uptake during periods of active growth.

Potassium concentrations in dead tissue varied little among dates or species (Fig. 2) and ranged from about 0.4 to 0.8%. Apparently, by the time tissue was classified as dead most labile K had either been translocated or leached. One exception to this was dead forbs, which usually had higher K levels than the grasses (Table 3).

Whole plant K concentrations (Fig. 3) varied among species and dates primarily as a function of amount of live:dead mixing. Forbs however, generally had the greatest K concentrations although during winter and spring, Angr contained comparable concentrations because of an abundance of live tissue. Peak concentrations of K occurred in late winter and spring in Angr and Stle. Concentrations then declined at a near uniform rate through early fall. Potassium concentrations in the warm-season perennial grasses peaked during spring and summer and subsequently declined through fall. Bocu K levels ranged from 0.41 to 1.16% and were below 0.8% from fall through winter. Concentrations in Wsgr ranged from 0.46 to 1.12% and were also below 0.8% from fall through winter.

Calcium

When averaged across dates and species, Ca concentration in live tissue was greater than in dead (Table 1). However, concentrations were highly variable (Tables 2 and 3, Fig. 2), and extremely difficult to interpret relative to seasonal dynamics. For example, major differences in Ca concentrations in live and dead tissue were only apparent in forbs when average concentrations in each species/species group were examined separately (Table 3). Live tissue Ca levels exhibited little seasonal variation in perennial grasses. For example, live Bocu and Wsgr concentrations ranged only from 0.28 to 0.59% over the entire study period. Based upon the magnitude of differences of Ca concentrations in live tissue between dates, we concluded age of live tissue was not a major factor affecting Ca concentrations in live tissue.

Likewise, dead tissue concentrations of Ca were similar among all forages except forbs (Table 3). Seasonal peaks tended to occur in fall and winter for warm-season grasses and in spring and summer for cool-season species (Fig. 2). Increases in the relative concentrations of Ca in dead tissue has been variously attributed to its immobility and the leaching and/or translocation of other minerals (Lonengran 1973, Fleming 1973).

Whole plant Ca concentrations were comparable among forages and seasons with the exception of forbs, which maintained significantly greater concentrations through all seasons (Fig. 3). Angr and Stle exhibited more inter-seasonal variation than did Bocu or Wsgr.

Summary and Conclusion

Macro-mineral dynamics of forages in this study varied primarily as a function of class of tissue and as secondary functions of species, absolute age of tissue, and environmental growth patterns. Forages of comparable phenology and ontogeny generally had similar seasonal patterns of mineral concentrations.

The concentrations of P, Mg, and K in live tissue were greater than in dead. However, concentration of Ca was generally unaffected by class of tissue except for forbs. Phosphorus and to a lesser extent K concentrations in live tissue had substantial seasonal variation. Phosphorus levels appeared to change in relation to tissue age and metabolic activity with peaks occurring during periods of active growth. Live tissue P levels were not adversely affected by an extended spring-summer drought in 1984. Conversely, K levels were significantly lower during the drought. This difference was attributed to K uptake by plants being limited by available soil moisture (Lonengran 1973). In comparison, Ca and Mg levels in live tissue were less variable among seasons, though peak concentrations still occurred during periods of active growth. Drought conditions also had little apparent effect on Mg and Ca concentrations of grass forage.

Dead tissue concentrations of P and K had little apparent seasonal variation probably because most translocation and leaching had occurred by the time tissues were classified as dead. The dead tissue concentrations of Ca and Mg increased as live tissue concentrations decreased. We would hypothesize this was caused by increased relative concentrations of these immobile minerals as more labile ones were either translocated or leached.

The results from this research emphasize the importance of determining the dynamics of mineral pools in both live and dead plant components. We suggest that when evaluating the effect that various management practices and/or soil types may have on whole plant mineral concentrations, the differential effects of treatments on plant growth and senescence be considered.

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