Factors Influencing Magnesium in High Plains Forage

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Abstract

Greenhouse and field experiments were conducted at the High Plains Grasslands Research Station to determine what might cause tetany-prone forage. The soil was analyzed for ammonium acetate-extractable cations, cation exchange capacity, and alkaline earth carbonates; and the successive harvests of forage plants were analyzed for magnesium (Mg), calcium (Ca), potassium (K), and nitrogen (N). Forages used in the study included legumes: 'Lutana' Cicer milkvetch *(Astragalus cicer* L.), 'Remont' sainfoin *(Onobrychis viciafolia* Scop.), 'Dawson', 'Vernal', 'Team', and 'Fremont' alfalfas (*Medicago sativa* L.); and grasses: 'Latar' orchardgrass (*Dactylis glomerata* L.), 'Fawn' tall fescue (Festuca *arundinacea* Schreb), 'Regar' bromegrass Bromus biebersteinii Roem & Schult.), 'Manchar' smooth bromegrass (*Bromus inermis* Leyss), 'Garrison' creeping foxtail (*Alopercurus pratensis* L.), 'Luna' pubescent wheatgrass [*Agropyron trichophorum* (Link) Richt.], and 'Greenar' intermediate wheatgrass [*Agropyron intermedium* (Host) Beauv.]. Forage Mg level increased when average soil temperature increased from 16.6 to 22.7° C. Fertilization with 1,134 kg of Mg as $MgSO_4$/ha did not increase forage Mg level. Latar orchardgrass and Fawn tall fescue consistently produced forage containing more than 0.20% Mg, whereas wheatgrass species produced forage with Mg levels as low as 0.11%. All legumes had Ca levels ranging from 1.0 to 2.5%. One field crop of Latar orchardgrass produced forage with a high K accumulation (K/Ca + Mg ratio of 2.7). Predication of blood-serum Mg from forage nutrient content indicated values from 17 to 31 mg/l in lactating cows.

To increase efficiency in the production of beef on the High Plains, irrigated forages are grown for use as hay or rotation pasture. Under this management system, forage can be harvested several times each season. Increased production intensity can decrease the nutrient concentration in successive forage crops. A decrease in magnesium (Mg) concentration would increase the grass tetany hazard in cattle (Grunes et al. 1970).

A review of earlier research has shown that plant nutrient uptake is very responsive to temperature (Grunes et al. 1970; Grunes 1972). Grass tetany generally occurs during periods of cool weather or when cool weather is followed by warmer weather that causes rapid forage growth. Since grass tetany is sometimes a problem in the High Plains area during the spring season, (personal communication with practicing veterinarians and ranchers) a study was made to determine the potential for producing tetany-prone forages (below .2% magnesium) (Grunes 1972) and the response of these forages to magnesium fertilization.

Soil Description

All experimental work was done on Archerson fine sandy loam soil, which belongs to the mixed mesic family of Aridic Arguistols (Young and Singleton 1977). These soils are on nearly level to gently sloping fans and terraces and are of granitic origin. Typically, Archerson soil has an A horizon of dark brown fine sandy loam from 0–15 cm, a B2t horizon of dark brown fine sandy clay loam from 15–45 cm, a B3 horizon of brown sandy clay loam from 45–60 cm, and a C horizon of coarse sand and gravel below the 60-cm depth. Most areas of Archerson soil at the High Plains Grasslands Research Station have a cation exchange capacity (CEC) of 28.0 meq/100 g for the 0–30 cm soil depth. However, some small isolated areas have a CEC of 17.0 meq/100 g. Archerson soil is moderately permeable with a relatively low water holding capacity. The top 1.2 m of the soil profile holds about 12.5 cm of water available to plants. Major uses of the Aridic Arguistol soils in the High Plains area include rangeland, irrigated and dryland crops, and wildlife habitat.

Materials and Methods

The experimental work included three separate studies, two in the greenhouse and one in the field. The soil was analyzed for CEC by the ammonium acetate method and atomic absorption spectrophotometry, and for alkaline-earth carbonates by acid neutralization (U.S. Salinity Laboratory Staff 1954). Atomic absorption spectrophotometry was used to determine magnesium (Mg), calcium (Ca), and potassium (K) in dry ashed plant materials. Nitrogen (N) in the plants was determined by a micro-kjeldahl method developed by Schuman et al. (1973).

In the first greenhouse study, three replicates of three grasses and three legumes were grown in 18 metal cans of soil. The cans had a diameter of 40 cm and a height of 60 cm and contained about 98 kg of soil with a CEC of 28 meq/100 g. Plastic liners were placed between the soil and the cans. The grasses studied were 'Latar' orchardgrass (*Dactylis glomerata* L.), 'Regar' bromegrass (*Bromus biebersteinii* Roem & Schult.), and 'Garrison' creeping foxtail (*Alopecurus pratensis* L.), while legumes were 'Dawson' alfalfa (*Medicago sativa* L.), 'Lutana' Cicer milkvetch (*Astragalus cicer* L.), and 'Remont' sainfoin (*Onobrychis viciaefolia* Scop.). Thus, a total of six forage treatments were used. Day length was adjusted to 15 hours with artificial light at an intensity of 13,455 lux. The light source was both incandescent and fluorescent. Soil water was monitored with tensiometers and maintained near 30 centibars at the 30-cm depth. The legumes were treated with appropriate inocculants at planting. Grasses were fertilized with 38 kg N/ha as ammonium nitrate for each crop, but the legumes were not fertilized. All treatments were harvested when the alfalfa was at 25% bloom. Forages were harvested 23 times between October 23, 1974, and February 11, 1977. After harvest 10, two replicates of each treatment were fertilized with 1,134 kg Mg/h (145 g/can) as magnesium sulfate and one replicate of each treatment was saved for a control. Greenhouse temperatures were recorded by a hygrothermograph.

The second greenhouse study was done in 20 cm diameter crock pots, 23 cm high, filled with 10 kg of soil. The CEC of the soil was 28 meq/100 g in half of the pots and 17 meq/100 g in the other half. Latar orchardgrass and Dawson alfalfa were each replicated six times on both the high and low CEC soils. The plants were managed the same as those in the first greenhouse study except water

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Table 1. High and low levels of ammonium acetate extractable cations, cation exchange capacity, Ca/Mg ratio, Mg/K ratio, pH, and alakaline-earth carbonates with soil depth in Archerson soil.

Level of Soil constituent	Soil depth (cm)	Ca++	Mg++	K+	Na+	Cation exchange capacity	Ca:Mg ratio	Mg:K ratio	pH	Alkaline-earth carbonates (%)
		meq/100 g								
High	0–15	28.25	2.05	1.41	0.17	27.42	13.7	1.4	7.2	6.32
	15–30	27.28	2.15	0.98	0.15	29.19	12.9	2.2	7.4	14.91
	30–45	19.35	0.26	0.11	8.15	15.2	4.8	7.3		
	30–45	19.35	1.27	0.26	0.11	8.15	15.2	4.8	7.3	3.50
	45–60	21.95	1.51	0.31	0.11	11.55	14.5	4.8	7.3	5.03
Low	0–15	11.74	1.89	0.50	0.15	17.57	6.2	3.7	7.2	2.57
	15–30	14.24	3.54	0.51	0.14	14.88	4.0	6.9	7.1	2.63
	30–45	18.25	2.98	0.38	0.21	13.82	6.1	7.8	7.3	2.27
	45–60	23.79	2.51	0.30	0.19	8.94	9.5	8.3	7.4	2.79

was not monitored with tensiometers but was added daily as needed to maintain the soil between 0.3 and 1.0 bar of tension. Forage was harvested four times between April and September 1976.

The third study was done in the field and consisted of part of an ongoing experiment in which legumes and grasses were being observed for total yield under three different harvest treatments. These were a biweekly harvest at 5 and 10 cm cutting heights simulating intensive and moderate grazing, and a hay crop. The hay crops were harvested when the alfalfa was at 25% bloom and grasses on the first harvest were at boot or heading stage. Succeeding harvests of grass were made when the forage was 20–30 cm tall. The nutrient content of the hay harvest treatment was determined for inclusion in the forage magnesium study since the species or cultivars of the greenhouse experiments were also included in the field study. The forages consisted of six legumes and six grasses. The legumes were Lutana cicer milkvetch, Remont sainfoin, and four alfalfa cultivars—Dawson, 'Vernal', 'Team' and 'Fremont'. The six grasses were Latar orchardgrass, 'Fawn' Tall fescue (*Festuca arundinacea* Schreb.), 'Manchar' smooth bromegrass (*Bromus inermis* Leyss), 'Luna' pubescent wheatgrass [Agropyron trichophorum (Link) Richt.], Regar bromegrass, and 'Greenar' intermediate wheatgrass [*Agropyron intermedium* (Host) Beauv.]. The hay treatment for each species was replicated twice and three harvests were obtained in 1975. Grass species were fertilized with 75 kg N/ha as ammonium nitrate. Irrigation was applied at the rate of 2.0 cm each three to four days throughout the growing season. The irrigation water for the greenhouse and field experiments came from the same source and Mg, Ca, and K concentrations in ppm were 0.12, 2.22 and 0.17, respectively by atomic absorption spectrophotometry. Average soil temperature data from the Archer, Wyo., weather station (U.S. Dept. of Commerce 1975) was used as an indication of the temperature affecting field crops during the 1975 season.

Results and Discussion

The soil analysis indicated that cations in Archerson soil have relationships that could influence Mg content of forages (Table 1). Grunes (1972) listed research which showed herbage Mg may be depressed if soil exchangeable Mg does not equal 10–15% of the total exchangeable cations, or if the Ca/Mg ratio is above 5.0. Therefore, if effects from these relationships hold, low plant Mg levels could be expected in this study since Archerson soil has exchangeable Mg ranging from 6–13% of the total exchangeable cations and Ca:Mg ratios range from 6.2–13.7. However, forage Mg level reportedly (Hooper 1967) is more closely correlated with the soil Mg:K ratio than with either of the above relationships. The soil Mg/K ratio should be 1.2 or above to produce forage with .2% Mg or more in plant tissues. In the top 30 cm of the Archerson soil this ratio ranges from 1.4 to 6.9 which indicates Mg levels in the forage should be adequate to meet animal requirements. Thus, exchangeable cation relationships in Archerson soil do not seem to be consistent, nor dependable, as a basis for predicting forage Mg level. Grunes (1972, p 119) has suggested, "Additional research will be required to predict when soils will supply sufficient magnesium in plants to avoid grass tetany." His observation seems to be especially appropriate to the Archerson soil which has a large amount of alkaline-earth carbonates.

Data from the first greenhouse study (Fig. 1) do not include the milkvetch or sainfoin species since they went into dormancy during the winter months. All of the forages of this experiment had a Mg concentration of 0.2% or greater except Regar bromegrass. While this species had a concentration of 0.17% and 0.18% in the sixth and seventh harvests, respectively, it was not tetany-prone according to the findings of Bohman et al. (1977). The data of Figure 1 indicate two responses—Mg increased in all forage when the average temperatues were 20° C or above, and Mg concentrations were relatively high in Latar orchardgrass as compared with other species at all average temperatures. The increase in Mg at temperatures of 20° C or above may have been a Q_{10} response, which is a doubling of biological activity for every

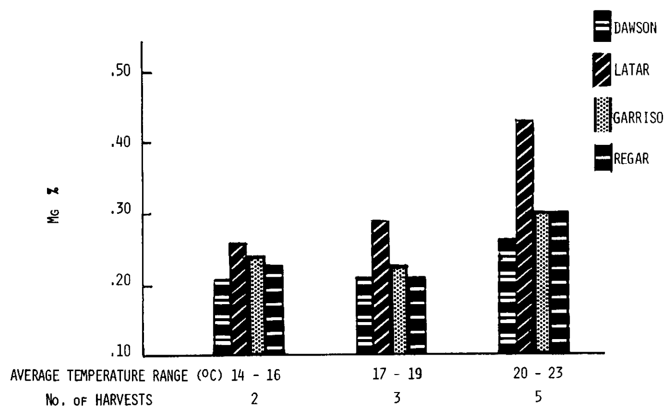

Fig. 1. *Average forage Mg concentration in ten consecutive harvests of Dawson alfalfa, Latar orchardgrass, Garrison creeping foxtail, and Regar bromegrass with average temperatures (C) for growing periods and number of harvests per temperature range.*

10° C rise in temperature. However, the Mg concentration in Latar orchardgrass tissues is apparently due to an inherent mechanism of the species for element uptake (Sutcliffe 1962).

Forage from 13 consecutive harvests were observed and analyzed after the $MgSO_4$ fertilization, and the composition or growth of the forage species was not affected.

Soil analysis data showed an area of the research plots where the total exchangeable cations between the 0 and 30-cm depth were relatively low as compared with most of the Archerson soil (Table 1). The low exchangeable cation content was due mainly to lower Ca. This difference suggested that possibly forage Mg is affected by the low total exchangeable cation level in the soil. Thus, we designed the second greenhouse experiment to test forage grown on both high and low CEC soils. The forage Mg concentrations were generally 0.2% or more for all orchardgrass and alfalfa harvests. There was no significant difference between forages grown on high or low CEC soils (Table 2). However, the Mg concentration response of Latar orchardgrass as compared with Dawson alfalfa indicated an inherent species mechanism for Mg uptake similar to that shown in the first greenhouse study.

Table 2. Forage Mg of Dawson alfalfa and Latar orchardgrass grown on soils with high (28 meq/100 g) and low (17 meq/100 g) CEC in 1976.

	Dawson alfalfa		Latar orchardgrass	
Harvest date	High	Low %	High	Low %
April 26	.24bc[1]	.22cd	.26b	.23c
May 24	.21d	.18de	.25b	.26b
June 21	.22cd	.20d	.32a	.30a

[1]Values followed by the same letter are not significantly different at the 5% level.

The field forages responded to temperatures of 20° C or above much the same as the greenhouse forages (Table 3). These responses were not only for Mg but also for Ca concentrations, which indicated ion movement in the soil solution increased as soil temperature increased. Fawn tall fescue and Latar orchardgrass both had a consistently high Mg concentration as compared with the other forages. These species appeared to have a relatively active inherent species mechanism for Mg.

A comparison of the legumes with the grasses of this study indicates the legumes have an inherent species mechanism for Ca uptake. Our legumes have concentrations of Ca that are twice as great as Ca levels in similar material as reported by Smith (1972), but only one-half as much Mg. This result may be due to the high level of exchangeable Ca in the Archerson soil.

The inherent species mechanism for nutrient uptake did not seem apparent in the wheatgrasses. They apparently have a nutrient uptake system that is very sensitive to temperature. In our field study the Greenar intermediate wheatgrass had radical differences in Mg concentrations from one harvest to the next. This was probably a Q_{10} response, since Ca and K concentrations were also increased as average soil temperatures were increased to 20–25° C.

The wheatgrasses seemed to absorb low levels of Mg (0.10–0.15%) in the spring and early summer. Luna pubescent and Greenar intermediate of our study had the low Mg level in common with Western (*Agropyron smithii*) studied by Rauzi et al. (1969) and Crested *(Agropyron desertorum)* studied by Mayland and Grunes (1974). Since the Agropyrons are widely distributed throughout the High Plains, some of the grass tetany problems in this region could be caused by the spring and early summer grazing of high percentages of these grasses (Samuel and Howard 1978). Many cattle herds will also have wintered on mature wheatgrass forage, which is often very low in Mg content (Fairbourn 1978).

In contrast to the low Mg levels in wheatgrass, Latar orchardgrass and Fawn tall fescue consistently had 0.2% Mg or more. These two species seem to have ability to absorb relatively high levels of Mg in their tissues. While neither of these introduced species is adapted to the semiarid environment of the High Plains rangelands, both grasses produced high forage yields under irrigation (M.L. Fairbourn, unpublished data). Our data showed that Latar orchardgrass and Fawn tall fescue hay or pasture could supply enough Mg in animal diets to prevent grass tetany.

The tetany hazard of forage depends not only on Mg but also on Ca, K, and N concentrations. An interaction of these elements will sometimes interfere with Mg utilization by livestock. A K/Ca + Mg ratio of 2.2 or above in grasses increases the incidence of tetany (Grunes 1972). In our study the K/Ca + Mg ratio was acceptable in all grass forages

Table 3. Magnesium, calcium, potassium, and nitrogen concentrations (%) in 1975 harvests of legume and grass field forages with average soil temperatures.

	Harvest 1 (16.6 C)[1]				Harvest 2 (25.5 C)[1]				Harvest 3 (22.7 C)[1]			
Species	Mg	Ca	K	N	Mg	Ca	K	N	Mg	Ca	K	N
Fremont alfalfa	0.18abc[2]	1.54ab	2.64bc	3.16abc	0.24abc	1.84ab	2.73ab	2.67bc	0.23ab	2.02b	2.71ab	3.68a
Team alfalfa	0.18abc	1.63ab	2.77b	3.27ab	0.23bc	2.06a	2.86ab	3.02bc	0.25ab	2.15ab	3.34a	3.68a
Vernal alfalfa	0.18abc	1.74a	2.79b	3.44a	0.20c	1.64b	2.62 abc	2.85bc	0.22ab	1.86b	2.92ab	3.59a
Dawson alfalfa	0.18abc	1.64ab	2.24bc	3.19abc	0.18c	1.76ab	2.59bc	2.88bc	0.20b	1.96b	3.29a	3.46ab
L.C. milkvetch	0.17abc	1.29bc	2.35bc	3.16abc	0.22bc	1.79ab	3.13ab	3.26ab	0.22ab	2.37a	2.55abc	3.52ab
Remont sainfoin	0.15abc	1.08c	1.62c	2.71abcd	0.18c	1.44b	1.66c	2.40c	0.19b	1.88b	1.68c	3.45ab
Latar orchardgrass	0.22ab	0.42d	4.13a	2.82abcd	0.31ab	0.42c	3.59a	2.89bc	0.25ab	0.79d	2.57abc	2.37d
Fawn tall fescue	0.23a	0.50d	2.48bc	2.57bcd	0.31ab	0.50c	3.10ab	2.63bc	0.29a	0.68d	3.00ab	2.65cd
Manchar bromegrass	0.14bc	0.48d	2.44bc	2.67cd	0.21c	0.48c	2.68ab	3.23ab	0.23ab	1.04cd	2.68abc	3.02abcd
Regar bromegrass	0.14bc	0.44d	2.25bc	2.42cd	0.24abc	0.44c	2.32bc	2.63bc	0.19b	0.67d	2.56abc	2.23d
Luna pub. wheatgrass	0.12c	0.41d	1.84bc	2.71abcd	0.20c	0.41c	2.64abc	2.58bc	0.18b	0.89d	2.00bc	2.75bcd
Greenar int. wheatgrass	0.11c	0.39d	2.06bc	2.04d	0.32a	0.39c	3.19ab	3.85a	0.20b	0.72d	2.20bc	2.94abcd

[1]Values in parenthesis are average soil temperatures.
[2]Within columns values followed by the same letter do not differ significantly at the 1% level according to Duncan's multiple range test. Each value represents the mean of two observations.

Table 4. Predicted blood-serum Mg levels[2] (mg/liter) using the percentage values of K times crude protein ($N \times 6.25$) and Mg from Table 3.

Species	Harvests		
		2	3
Fremont alfalfa	21c[1]	28abc	23bcd
Team alfalfa	19c	25abc	22bcd
Vernal alfalfa	19c	25abc	22bcd
Dawson alfalfa	23abc	23bc	17d
L.C. milkvetch	22bc	21c	24abcd
Remont sainfoin	27ab	31a	27abc
Latar orchardgrass	18c	26abc	30a
Fawn tall fescue	28a	28ab	28ab
Manchar bromegrass	21c	23bc	26abc
Luna pub. wheatgrass	22bc	25abc	26abc
Regar bromegrass	23abc	29ab	28ab
Greenar int. wheatgrass	23abc	26abc	26abc

[1]Within columns values followed by the same letter are not significantly different at the 5% level according to Dundan's multiple range test.

except the first Latar orchardgrass field harvest which had a K/Ca + Mg ratio of 2.7

The forages can be further assessed for tetany hazard by using values of Table 3 along with a nomograph as suggested by Mayland et al. (1976) to predict blood-serum Mg levels in lactating cows. The nomograph is based on a survey of Mg, K, and N levels in animal diets and the resulting blood-serum Mg levels. Forage analyses values for K times crude protein (N + 6.25) and Mg can be fitted to the nomograph and the probable livestock response to forages can be determined. The predicted blood-serum Mg levels for the field grown forages are shown in Table 4. Values below 20 mg/liter show Mg supplement is needed. Apparently, none of the forages in this study would cause clinical tetany.

Conclusions

1. The predicted effects on forage Mg concentrations by exchangeable Mg ratios with Ca and K are neither consistent nor dependable for Archerson soil, which has a high level of alkaline earth carbonates.
2. Successive forage harvests did not reduce Mg concentration of forages grown on Archerson fine sandy loam soil.
3. Mg fertilization of Archerson soil with 1,134 kg of Mg as magnesium sulfate did not increase forage Mg concentration.
4. Low CEC soil did not reduce forage Mg concentration in this study.
5. Forage Mg uptake increased when soil temperatures were at 20° C or above.
6. Some forage species apparently have intrinsic plant mechanisms which were more important in determining Mg and Ca uptake under our experimental conditions than were extrinsic environmental factors. Included are Latar orchardgrass and fawn tall fescue for Mg and the legumes for Ca.
7. Wheatgrasses apparently have a nutrient uptake system that is very sensitive to temperature. They had relatively low Mg concentrations and are potentially tetany hazardous in cool, wet weather.
8. The K/Ca + Mg ratio in forages is occasionally increased above 2.2 by a luxury use of K.

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