Reprinted from AGRONOMY JOURNAL
Vol. 66, Jan.-Feb. 1974, p. 79-82

Magnesium Concentration in *Agropyron desertorum* Fertilized with Mg and N[1]

H. F. Mayland and D. L. Grunes[2]

ABSTRACT

Grass tetany, a Mg deficiency in ruminants, is responsible for large economic losses throughout temperate regions. Significant livestock losses occur in the semiarid western United States primarily when livestock are grazing the spring growth of *Agropyron desertorum*, an introduced grass species which provides much needed early spring forage.

The objective of this study was to increase forage Mg to about 0.2% by Mg and N fertilization and thus meet animal needs and reduce losses from death. The field study was located on *A. desertorum* grassland which had previously produced grass tetany. Two calcareous aridisols were each fertilized with 0, 90, 200, and 600 kg Mg/ha as $MgSO_4 \cdot 7H_2O$, having split plots with 0 and 150 kg N/ha applied as NH_4NO_3. Forage was harvested at regular periods intended to bracket the spring occurrence of tetany for three seasons following fertilization.

Fertilization with 600 kg Mg/ha was necessary to increase forage Mg to the recommended level (0.2%). Applying 150 kg N/ha increased forage Mg concentration as much as did 200 kg Mg/ha. The N and Mg fertilizers were additive in increasing forage Mg concentrations. Forage Mg concentrations decreased with increasing age of vegetatively growing grass, and the benefits from fertilization were less with each successive season following fertilization. Little residual effect of 600 kg Mg/ha or 150 kg N/ha fertilization on plant Mg concentration would be expected after 5 years. Rapid decreases in water-soluble soil Mg with the resulting formation of some unknown insoluble phase, as well as high investment costs, preclude Mg fertilization of these ranges to meet Mg requirements of grazing animals.

Additional index words: Crested wheatgrass, Grass tetany, Hypomagnesemia, Aridisols, Range forage.

FORAGE containing 0.2% Mg normally provides sufficient Mg to protect ruminants against grass tetany (3, 4). This is not a fixed dietary level, but it reflects the Mg concentration above which tetany seldom occurs unless the forage is unusually high in N or K. The apparent Mg availability to ruminants is about 28% for cured legume hay, but values as low as 12% have been reported for fresh grass (9). It follows, then, that most cases of tetany are reported for all grass or predominantly grass pastures.

Magnesium deficiency in ruminants is reported most frequently for humid and subhumid grass pastures growing on coarse-textured soils low in available Mg. Under these conditions, soil fertilization or forage dusting with Mg minerals is commonly used to minimize the tetany problem (3, 4). However, fertilization of humid pastures with N and K often increases the incidence of tetany (3, 4).

Grass tetany also occurs in cattle grazing the semiarid rangelands of the western United States. Livestock losses in Idaho and Nevada alone were estimated to average 4,000 head annually during the period 1965 through 1971 (H. F. Mayland, unpublished data). The magnitude of these losses varied from very few in some years to 3% of grazing animals in other years. Production losses caused by chronic Mg deficiencies in ruminant animals would further increase the economic loss attributed to grass tetany.

The objectives of this study were: 1) to determine the Mg fertilizer level required on these calcareous soils to produce grass forage containing at least 0.2% Mg, and 2) to determine the effect of N fertilization on forage Mg concentrations.

MATERIALS AND METHODS

Field Procedures

The study was located on the San Jacinto seedings in northeastern Elko County, Nevada, where grass tetany had previously occurred. The elevation was about 1,650 m and the mean annual precipitation was 280 mm. The range forage consisted of a monoculture of crested wheatgrass (*Agropyron desertorum* (Fisch.) Schult), which matures by early July. The animal stocking rate is about 0.8 to 1.2 ha (2 to 3 acres) per animal unit month.

Two sites, 5 km apart, were selected for intensive study. The soil at one site was a coarse, loamy, Durixerollic camborthid similar to the Orovada series, whereas the soil at the other site was a loamy, skeletal Haploxerollic durorthid.[3]

Magnesium as $MgSO_4 \cdot 7H_2O$ was broadcast on the soil surface of both sites in February 1969 at rates of 0, 90, 200, and 600 kg Mg/ha. Nitrogen rates of 0 and 150 kg N/ha were applied as subplots using NH_4NO_3. There was no tillage to incorporate fertilizers.

The soil at each site was initially sampled at depths of 0 to 15, 15 to 30, and 30 to 45 cm for general chemical characterization. The soil under each Mg treatment was sampled in 5-cm depth increments down to 25 cm after each of four successive growing seasons. Soil bulk densities were determined from 2.0-cm thick cores taken at approximately 3, 8, 13, 18, and 23-cm soil depths (1, Chapter 30.2). Soil samples, except those for bulk density determinations, were air-dried, passed through a 2-mm sieve and stored in waxed cartons at room temperature.

Grass was harvested several times throughout the vegetative growth of the plants in each of 3 years following fertilization. Forage was clipped at a 2-cm height above the stem base. The sampling period was selected to bracket the occurrence of grass tetany. Harvested material was immediately frozen with solid CO_2, then freeze-dried, ground to pass through a 20-mesh sieve, and stored in glass bottles at room temperature. Root masses were determined at the end of the 1970 growing season by washing away the mineral matter from soil monoliths 15 × 30 × 60 cm deep. The roots were air-dried and weighed.

Laboratory Procedure

The "reserve" soil Mg was extracted after boiling 5 g of soil in 100 ml 3*N* HCl for 1 hour (2). The 20-hour water-soluble Mg was determined on a 1:1 soil water paste that was manually mixed at 0, 6, and 20 hours before vacuum extraction of the soluble phase. Soil Mg was determined by atomic absorption. Other soil analyses were conducted using methods outlined in Table 1.

[1] Contribution from the Western Region, Agricultural Research Service, USDA, Idaho Agricultural Experiment Station cooperating. Received Jan. 22, 1973.

[2] Soil Scientists, Snake River Conservation Research Center, Kimberly, ID 83341, and U.S. Plant, Soil and Nutrition Laboratory, Ithaca, NY 14850, respectively. The authors wish to thank Mrs. Arlene Florence, Harold Waggoner, D. A. Hewes, and P. K. Joo for their assistance during the study.

[3] Morphological and classification details were provided by Mr. Warren W. Rasmussen, Agricultural Research Service, Kimberly, Idaho, and the Nevada State Office, Soil Conservation Service, Reno, respectively.

Table 1. Soil methodology.

Parameter	Procedure	Reference*
Particle size	Hydrometer	1-43.5
Mineralogical	Petrographic	1-46.2
Mineralogical	X-ray	1-49
Organic matter	Walkley-Black	1-90.3
pH	Glass electrode	1-60.3
Electrical conductivity	Saturated paste extract	1-62.2
$CaCO_3$ equivalent	Acid neutralization	1-91.4
Cation exchange capacity	NH_4-saturation	1-57.2
Extractable cations	1*N* NH_4OAc, pH 7.0	1-57.2
Water soluble cations	Saturated paste extract	1-62.3
Saturation water content	Gravimetric	1-62.3

* Citation includes chapter and section.

Table 2. Soil characterization of two northeastern Nevada study sites.

Soil Characteristic	Durixerollic camborthid			Haploxerollic durorthid		
Depth, cm	0-15	15-30	30-45	0-15	15-30	30-45
Textural class	L	L	L	L	L	SL
Organic matter, %	0.98	0.77	0.59	0.88	0.66	0.62
pH - sat. paste	8.0	8.2	8.2	7.0	7.2	7.7
pH - 1:5	7.6	7.5	8.2	7.0	7.0	7.2
EC × 10^3, mmhos cm^{-1}	0.7	0.4	0.5	1.3	0.6	0.8
$CaCO_3$ equiv., %	1.7	1.7	2.0	0.1	0.2	0.5
CEC, meq/100 g	17	17	22	16	24	27
Mg "reserves" - soluble in boiling 3*N* HCl						
Mg, meq/100 g	19	21	26	15	22	24
Extractable cations - 1*N* ammonium acetate pH 7.0						
Na, meq/100 g	0.2	0.3	0.4	0.8	1.4	1.8
K, meq/100 g	1.8	1.3	1.3	1.3	0.5	0.5
Mg, meq/100 g	1.4	1.5	2.6	2.9	5.0	5.2
Ca, meq/100 g	20.5	20.0	44.8	10.5	16.7	20.3
Ca/Mg	15	13	17	3.6	3.3	3.9
Mg/K, meq basis	0.8	1.2	2.0	2.2	10.0	10.4
Mg/CEC, meq basis, %	8	9	12	18	21	19
Water-soluble cations from sat.-extract						
Na, meq/liter	0.4	0.5	0.8	6.1	2.9	3.6
K, meq/liter	1.0	0.7	0.5	1.3	0.9	0.7
Mg, meq/liter	0.8	0.4	0.5	0.5	0.6	0.7
Ca, meq/liter	2.9	3.0	3.1	1.3	2.0	2.1
Moisture at saturation, %	36	33	38	28	35	37

The freeze-dried plant samples were dry-ashed at 500 C, dissolved with 5 ml 1*N* HCl, and brought to volume with water. The 1971 samples were wet-ashed in a mixture of nitric and perchloric (1:1) acids and then brought to volume with water. All plant samples were then filtered to remove silica, spiked with 1,500 ppm Sr to minimize interferences, and analyzed for Mg by atomic absorption.

The paired T-test ($P = 0.05$) was used to test the significance of seasonal differences in forage parameters resulting between treatments and control (8).

RESULTS AND DISCUSSION

Soil Description

The camborthid soil has a higher pH, higher soluble and extractable Ca and $CaCO_3$ concentrations, and lower ammonium-acetate-extractable Mg concentrations than does the durorthid (Table 2). Both soils have similar cation exchange capacity, K, and total soluble salt concentrations. The exchangeable Mg/K values range from 0.8 to 2.0 for the camborthid and from 2.2 to 10.4 for the durorthid (Table 2). An herbage Mg concentration of 0.2% may be attained with a soil Mg/K ratio of 1.2, but a higher ratio may be necessary in some instances (5). The Mg reserves (Table 2) are much greater than 5 meq/100 g soil suggested for plant requirements, especially in acid soils (2). Others (4) have suggested that the Mg/K ratio in soil should not be less than 2.0, that Ca/Mg be about 5 or less, and that the Mg should equal 10 to 15% of the exchange capacity. The camborthid soil, based on these values, would be expected to produce forage having less than 0.2% Mg, but forage grown on the durorthid soil should have adequate Mg to meet animal requirements.

The durorthid soil, when examined with the aid of a petrographic microscope, showed a high percentage of glass (80 to 90%), and smaller amounts of hornblende, feldspar, and quartz in the 50 to 250-μ fraction. Mineralogical X-ray traces showed that the 2 to 20-μ silt contained easily collapsible vermiculite (14 Å collapse to 10 Å with K saturation), some illite or mica, and a large amount of quartz. The < 2-μ clay fraction was predominantly montmorillonite, with small amounts of illite, kaolinite, and quartz. The camborthid soil is mineralogically similar to the durorthid soil.[4]

Forage Mg

Each additional increment of Mg fertilizer significantly (paired T-test, $P = 0.05$) increased vegetative forage Mg concentrations compared to unfertilized grass. However, only the 600 kg/ha rate increased the concentration to the 0.2% level recommended for ruminants (4), and then only for part of the first season (Fig. 1). Because grass tetany in crested wheatgrass generally occurs early in the growing season, it would not appear to be of major importance that Mg concentrations in the plants were somewhat lower than 0.2% later in the season. The temporary increase in Mg concentration on some treatments during May 1969 was related to regrowth of forage resulting from increased soil water content. When no N fertilizer was added, the seasonal means for 1969 (when averaged for both sites) were 0.11, 0.12, 0.13, and 0.17% Mg in the forage harvested from areas fertilized with 0, 90, 200, and 600 kg Mg/ha, respectively. The forage Mg data were pooled for the two sites because of the small, even though significant, difference between the Mg data.

The residual effect of the Mg fertilizer on forage Mg concentrations, compared to Mg in controls, decreased each year following fertilization (Fig. 1). The forage Mg concentration for the 600 kg/ha treatment probably would not be significantly different (paired

[4] Mineralogical data were provided by Dr. S. W. Buol, Department of Soil Science, North Carolina State University, Raleigh.

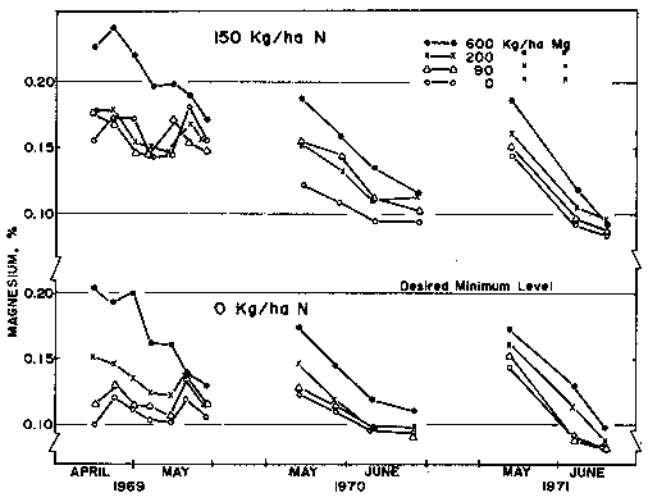

Fig. 1. Magnesium concentration in *Agropyron desertorum* forage during three successive seasons as affected by $MgSO_4 \cdot 7H_2O$ and NH_4NO_3 applied to the soil surface in February 1969. Data are treatment means for forage grown on the durorthid and camborthid soils.

T-test, P = 0.05) from that for the check after the fourth or fifth year. The decrease in forage Mg concentrations during each season contrasts with European reports, but may be related to physiological aging of the crested wheatgrass in this study or to the presence of legumes in European pastures (4). Year-to-year differences in Mg concentrations of the control are not known, but may relate to soil-water relations and to seasonal growing conditions.

Fertilization with 150 kg N/ha increased forage Mg concentrations more in the first year than did fertilization with 200 kg Mg/ha (Fig. 1). In the presence of 150 kg/ha applied N, the seasonal means for the first year were 0.16, 0.16, 0.16, and 0.20% Mg in the forage fertilized with 0, 90, 200, and 600 kg/ha of Mg, respectively. Nitrogen and Mg fertilizer effects were additive in increasing plant Mg, but the combined effects of 150 kg N/ha and 600 kg Mg/ha were not expected to produce forage having Mg concentrations significantly greater than the control treatment after 5 years.

The increased Mg uptake following NH_4NO_3 fertilization could have resulted from increased root growth and proliferation. However, rooting depths and root mass:soil volume ratios were similar whether or not N fertilizer was added. Rooting depths were easily identified and there was no significant difference in rooting depth of N fertilized areas compared to that of the control. The relatively large sampling error in root mass may have precluded detection of significant differences in root proliferation of this bunchgrass. Nitrogen may physiologically increase the ability of plant roots to absorb Mg or increase the rate of Mg translocation from roots to the aboveground portions of the plants (6, 7).

Forage grown on the durorthid soil contained a 3-year seasonal average of 0.025% more Mg and when fertilized with 150 kg N/ha, contained an average of 0.028% more Mg than forage grown on the camborthid soil (data not shown). This difference between sites, although quite small, was statistically significant (paired T-test, P = 0.05) and corroborates previous observations (5) that forage Mg concentrations are inversely proportional to soil pH in the neutral to alkaline range and that Ca^{++} and K^{+} ions (Table 2) are antagonistic to Mg uptake. However, the difference in Mg concentrations of forage grown on the two sites was not as great as might have been predicted from the soil data (Table 2). The statistical difference in forage Mg concentrations from the two sites may have limited practical significance in the incidence of grass tetany because Mg concentrations were normally quite low at both sites.

The progressively reduced uptake of Mg each year after fertilization was not a result of Mg removal in forage. Dry matter yields were measured only in 1971, which was the best production year in at least 10 consecutive seasons. It was also the only year when a visual increase in plant growth resulted from N fertilization. Yields from the durorthid and camborthid soils were 280 and 540 kg/ha with no N applied, and 590 and 1,100 kg/ha, respectively, where 150 kg N/ha had been applied in early 1969. It was calculated that less than 2 kg/ha Mg was removed from even the high N-high Mg treated plots over the 3 years. Therefore, the decrease must be related to reduced availability of Mg from the soil.

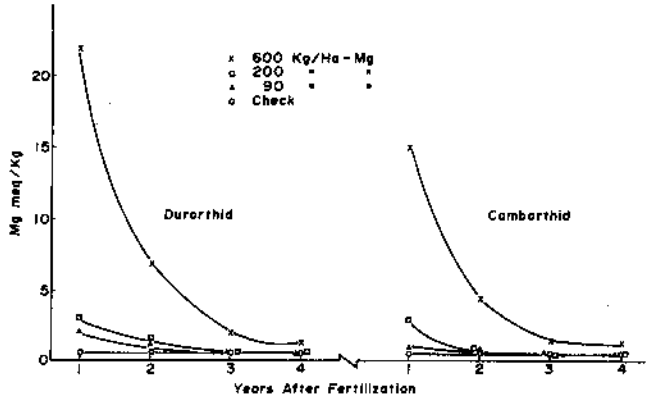

Fig. 2. Twenty-hour Mg solubility (1:1, soil:water) for the 0 to 25-cm depth samples taken in each of four successive seasons following surface application of 0, 90, 200, and 600 kg Mg/ha as $MgSO_4 \cdot 7H_2O$.

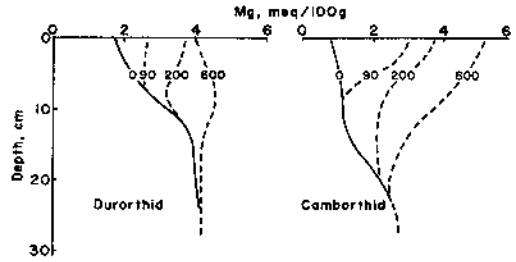

Fig. 3. Ammonium acetate (1.0*N*, pH 7.0) extractable soil Mg in durorthid and camborthid soil profiles fertilized with 0, 90, 200, or 600 kg Mg/ha as $MgSO_4 \cdot 7H_2O$ surface applied in February 1969 and sampled in June 1971.

Soil Mg

The rapid decrease in water-soluble Mg in the soil following fertilization may explain the reduced availability of soil Mg to plants (Fig. 2). The reduced water extractability might suggest that fertilizer Mg was converted to an exchangeable form. However, the NH_4OAc-extractable Na, K, and Ca values were not changed following Mg fertilization (data not shown). Such changes would have been expected if the fertilizer Mg simply exchanged for other soil cations at the exchange sites. Another possible explanation for the reduced water extractability is that the fertilizer Mg was leached below the soil sampling zone. The NH_4OAc-extractable Mg concentration profiles, however, do not support the leaching hypotheses. Integration of areas under each curve (Fig. 3), when corrected for bulk density, showed that the NH_4OAc-extractable Mg quantitatively accounted for the added fertilizer Mg. The rapid decrease in water-soluble soil Mg was verified by preliminary laboratory experimentation. These results suggested the formation of magnesite ($MgCO_3$) or some similar mineral which is only slightly soluble in water but is more soluble in NH_4OAc.

LITERATURE CITED

1. Black, C. A., ed. 1965. Methods of soil analysis. Agronomy No. 9. Amer. Soc. of Agron., Madison, Wis. 1572 p.
2. Broek, J. M. M. van den, and H. W. van der Marel. 1959. Magnesium in soils of Limburg. Part 1. Soil types and Mg-contents. Z. PflErnahr. Dung. Bodenk. 84:237-244. Herb. Abstr. 22:1533.
3. Grunes, D. L. 1973. Grass tetany of cattle and sheep. *In* A. G. Matches (ed.) Anti-quality components of forages. Crop Sci. Soc. of Amer., Madison, Wis. (In press).

4. ———, P. R. Stout, and J. R. Brownell. 1970. Grass tetany of ruminants. Advan. Agron. 22:331-374.
5. Hooper, L. J. 1967. The uptake of magnesium by herbage and its relationship with soil analysis data. p. 160-173. *In* Soil potassium and magnesium, Tech. Bull. 14. Her Majesty's Stationery Office, London.
6. Kershaw, E. S., and C. L. Banton. 1965. The mineral content of S.22 ryegrass on calcareous loam soil in response to fertilizer treatments. J. Sci. Food Agr. 16:698-701.
7. Kirkby, E. A. 1969. Ion uptake and ionic balance in plants in relation to the form of nitrogen nutrition. p. 215-235. *In* I. H. Rorison (ed.) Ecological aspects of the mineral nutrition of plants. Blackwell Scientific Publications, Oxford, England.
8. Snedecor, G. W., and W. G. Cox. 1967. Statistical methods, 6th ed. Iowa State University Press, Ames.
9. Stillings, R. B., J. W. Bratzler, L. F. Marriott, and R. C. Miller. 1964. Utilization of magnesium and other minerals by ruminants consuming low and high nitrogen-containing forages and vitamin D. J. Anim. Sci. 23:1148-1154.