RESEARCH BULLETIN 1037 NOVEMBER, 1980

UNIVERSITY OF MISSOURI-COLUMBIA
COLLEGE OF AGRICULTURE
AGRICULTURAL EXPERIMENT STATION
A. MAX LENNON, DIRECTOR

Alteration of Magnesium in Tall Fescue With Soil Treatments

J. R. BROWN, WM. RICE, A. L. HOGGARD,
I. B. STRONG AND CALVIN HOENSHELL

(Publication authorized November 28, 1976)

COLUMBIA, MISSOURI

ACKNOWLEDGMENTS

A study of this size and duration must involve many people and be based upon good financial support. The junior authors were Research Specialists who spent many hours on this study. William Rice is now Agronomist with Alumni Seed Foundation, Romney, Ind., A. L. Hoggard is a Graduate Research Assistant, Agronomy Dept., UMC and I. B. Strong is employed by the Farm and Home Administration. Numerous other persons were involved. Robert Light was instrumental in the establishment of the study. Richard Mattas assisted where needed. The Superintendent of the Southwest Center, Dr. Norman Justus, must be thanked for his support and encouragement.

The study was financed under Missouri Agricultural Experiment Station Project 356 (Micro- and Secondary Nutrients). However, significant support was supplied by the Missouri Cattlemen's Association. Duval Corporation aided in the final chemical analysis with a gift to the AES Project for research on soil magnesium.

Finally, the laboratory workers must be acknowledged. These were Maura Farley, John Kerr, Alan Dreves, Wallace Peterson, and Russell Vahle. The UMC Research Council provided funds for the purchase of laboratory equipment which speeded up the analytical work.

CONTENTS

Alteration of Magnesium in Tall Fescue With Soil Treatments

J. R. Brown, Wm. Rice, A. L. Hoggard,
I. B. Strong and Calvin Hoenshell

In the winter of 1967-68 it came to the author's attention that several farmers in southwest Missouri suffered large economic losses due to grass tetany. On a visit to the area in the spring of 1968 circumstances suggested that the problem was in part related to soil properties and fertilizer management. This prompted a review of published information, which in turn suggested this study.

LITERATURE REVIEW

The term "grass tetany" seems to be used in the literature to describe visible symptoms of disease associated with magnesium deficiencies in ruminants. There are other terms which are used to describe this condition which may be, in fact, synonymous. These other terms are: hypomagnesaemia tetany, lactation tetany, grass staggers, bovine hypomagnesemic tetany, and wheat pasture poisoning (Metson et al., 1966, Anon., 1968; Kingsbury, 1964). Some authors make a distinction between these terms and there may be some clinical justification for such distinctions.

In addition to the terms used to describe the disease, once visual symptoms occur there are two terms used to describe the blood serum status of animals. Hypomagnesaemia and hypocalcemia are terms applied to subnormal levels of Mg and Ca, respectively, in the blood serum, or blood plasma, as preferred by some authors.

In this report "grass tetany" will refer to situations where the symptoms are visible and "hypomagnesaemia," to conditions where the blood serum Mg is subnormal with or without visual effects on the animal. The study of the incidence of grass tetany results in the conclusion that the disease is a malady of cows in late pregnancy and the first two months of lactation. Grass tetany should not be confused with milk fever which occurs within three days of parturition.

Kingsbury (1964) reviewed the work on grass tetany in cattle and listed the following symptoms. The initial symptoms include excitement, incoordination and anorexia with twitching and grinding of teeth often observed. Frequent urination may be observed. These symptoms progress to increased staggering, followed by prostration. The afflicted animal goes into convulsions and generally slips into a coma. Death usually occurs within 6 to 10 hours after first appearance of symptoms. The literature seems to agree that the symptoms are caused or accompanied by the decline of blood serum magnesium below 1.0 mg per 100 ml (normal is 2 to 3 mg per 100 ml) and by a drop in urinary excretion of Mg down to practically nothing (Anon., 1968; Metson *et al.*, 1966; Kingsbury, 1964; Rook *et al.*, 1958; Kemp *et al.*, 1961). An animal may be hypomagnesemic without showing symptoms of grass staggers (Storry, 1961). In addition, cattle do not store Mg for later use (Parr and Allcroft, 1957; Mc Donald and Jackson, 1955).

It is very difficult to specifically define a course of either grass tetany or hypomagnesemia. Grunes et al. (1970) published a very comprehensive review of grass tetany. The reader is advised to refer to that review for considerable detail. The summary of that review indicated that grass tetany occurs in grazing, pregnant, or lactating ruminants. A primary cause is low magnesium in the forage but high concentrations of N and K in the forage contribute to grass tetany. In addition, cool temperature and forage high in certain organic acids are also implicated in outbreaks of grass tetany.

Some elaboration of this summary is needed to give the appropriate background to the study reported here.

Grass tetany has most frequently been observed in the spring or autumn. Grass has almost always been the forage involved, possibly because forage legumes sometimes fail to initiate growth as fast as grass after a dormant period or because they contain a higher concentration of Mg and Ca than the grasses.

Initiation of growth either in the spring or fall occurs after a stress period. In the case of spring the stress is due to cold weather and in the autumn it is due to hot, dry weather. In both instances K levels in the soil are higher than during the growing seasons due to accumulation of the K resulting from a combination of effects. First, K is not removed from the soil by a dormant plant. Second, alternate freezing and thawing or wetting and drying tends to accelerate release of K from clay minerals. Leaching of K from forage over winter may be a third factor. These processes result in a relatively abundant supply of K in the soil when new plant growth is initiated. Abundant K in the soil (particularly as accentuated by fertilizer) may compete with Mg in the ion absorption processes carried out by the plant resulting in less Mg absorption relative to K absorption (Omar and El Kobbia, 1960; Bear and Prince, 1948; Walsh and O' Donahoe, 1945; Hemingway, 1961; Felbeck, 1959).

There are indications that the concentration of K, Ca, and Mg in forages is less at 45°F (Williams and Parks, 1972). McLean and Corbonell (1972) indicate that 12 to 15% of the soil cation exchange capacity must be saturated with Mg to alleviate low Mg levels in forage plants. Doll and Hossner (1964) speculated that some of the effect of K on reduced Mg uptake by plants could be attributed to blocking the release of nonexchangeable Mg. If the concept of cation-anion balance in the plant is accepted, the accentuated uptake of K might stimulate the plant to produce organic acids (Hendricks, 1966).

Many workers have documented the effect of heavy K fertilization upon the incidence of (1) lower Mg percentages in forages, (2) hypomagnesaemia and (3) grass tetany. Some reports show that the use of Mg soil treatments reduce the incidence of one or more of the three conditions listed above (Parr and Allcroft, 1957; Smyth *et al.*, 1958; Butler *et al.*, 1967; Knoblauch and Odland, 1934; Dilz and Arnond, 1970). There are a few references that tend to negate the effects of Mg soil treatment (Bosch and Harmsen, 1958). Nitrogen soil treatments with K fertilizer accentuate the problems and the form of nitrogen may have some effect (Henderson, 1960; Kemp, 1958, 1960; Hemingway, 1961; MacLeod and Carson, 1966).

There are mixed reports on the correlation between the percentage of Mg in the forage and the incidence of hypomagnesaemia and/or grass staggers (Storry, 1961; Butler *et al.*, 1967). In general, hypomagnesaemia occurs most frequently when the Mg percentage in the forage drops below 0.20% as often happens in the spring (Kemp, 1958; Metson *et al.*, 1966). Magnesium percentage in forage tends to increase with stage of maturity (Fonder, 1929).

At this point the literature is not clear concerning cause-effect relationships. As a result the following paragraphs will include some undocumented speculations.

The relative status of K and Mg in growing plants is affected by environmental factors. Changes in the relative status of K and Mg have implications on both plant and animal metabolism. Magnesium is required for the synthesis of chlorophyll and for the proper functioning of many enzymes which control the pathways by which the initial photosynthate is formed into other plant compounds. Upon growth initiation following a stress period, the limited Mg level in the plant must be tapped for additional chlorophyll formation and for increased enzymatic activity. This limited Mg level may be induced by competition at the root uptake sites by K.

During this growth, photosynthate is being produced and the cool weather limits structural growth. Eventually the excess photosynthate might be shunted to organic acids. Hence, additional cations would be required to maintain a desirable pH level in the plant cell fluid. Since Mg, and perhaps to some extent Ca, are limited at the uptake sites by K and since K is relatively abundant, K would be the logical cation used for this physiological role of neutralization. The effect in turn could accentuate the low Mg level of the plant further stimulating organic acid production which could further limit the activity of Mg in plant cells (Mengel and Kirkby, 1978). Another complication is that cool weather, which often is prevalent at the initiation of both spring and fall growth, seems to cause the plant to take up K in preference to Mg (and Ca) (Grunes, 1967).

Circumstantial evidence that the accumulation of organic acids may occur is that young plant growth is higher in organic acids than is older growth. From the speculative standpoint, could high plant K stimulate organic acid production or at least accumulation thereof by interfering in some way with the normal synthesis of polysaccharides? This question arises because early grass growth has a low TDN/ crude protein relationship compared to older growth. It should be noted that there are reports that N fertilizer increases the K level of the plant relative to Ca and Mg (Kemp and t'Hart, 1957).

Another factor involved is that available N in the soil would tend to be high at the end of the stress periods. Reports of grass tetany studies indicate that crude protein (as calculated from total N) is high in tetany inducing forage. Ronson's 1965 review suggests that protein catabolism might lead to increased levels of α-ketoglutaric acid or oxaloacetate which then might become available for transformation to other organic acids.

The speculation given in the preceding paragraphs might be elaborated upon as follows: Climatic conditions immediately following initiation of growth due to a break in a stress period is most often accompanied by rainy conditions. This leads to limited solar radiation. Lack of sunlight might limit energy needed for full operation of the polysaccharide synthesis mechanisms in the plant. Reasonably, organic acids could then accumulate in the plant involved. Hence, two possible causes of organic acid accumulation may be operative, i.e. K-related and weather-related.

Why the interest in organic acids? Information has indicated that grass tetany can be induced artificially by feeding K and trans-aconitic acid to sheep (Camp *et al.*, 1968; Bohman *et al.*, 1969). It was suggested in these papers that if in some way the trans-isomer of aconitic acid was formed in the plant it might interfere in the normal formation of isocitrate from citrate in the citric acid cycle since the cis isomer of aconitate is an intermediate in this citrate conversion. As pointed out above, early growth of plants is high in acidic components.

Other observations have shown that the "availability" of Mg in forage entering the rumen is lower in forage that is high in K, crude protein, and organic acids than in forage with a relatively higher carbohydrate-crude protein ration (Kemp *et al.*, 1961; Kemp, 1958; Sjollema, 1950; Henderson, 1960; Fontenot *et al.*, 1960). This lowered availability of Mg has been attributed (1) to higher pH in the rumen due to release of NH_3 from crude protein degradation, (2) to formation of insoluble Mg "soaps" upon reaction in the rumen between plant Mg and organic acids, and (3) to reduction in the ability of Mg to move through the walls of the animal gut due to reduced Na levels caused by the high K conditions under which the plants grew (Na seems to be involved in the permeability of intestinal walls to other cations) (Naumann *et al.*, 1959; Rook and Wood, 1960; Wind *et al.*, 1966; Metson *et al.*, 1966; Kemp, 1960). This effect of Na may be questioned since Dishington (1965) could find no other influence of Na fed as various salts. The effect of pH on magnesium absorption from the gastro-intestinal tract has been refuted by Marshak (1959).

An examination of the fatty acid synthesis and utilization pathways presented by Bull *et al.* (1967) would suggest that acid metabolism within the rumen could possibly by involved in lower Mg availability if organic acids were synthesized by rumen bacteria. Rook *et al.* (1958) stated that about 20% of the magnesium in forage is available; work cited above shows that this availability decreases as crude protein, lipid, and K content increase. Dietary Mg absorption declines rapidly as calves mature to the level of 20 to 27% in mature animals (Thomas, 1959).

There are reports that the incidence of grass tetany depends upon changes in atmospheric temperature (Dijkshoorn and t'Hart, 1967). Whether this effect of temperature results from effects on plant composition, from temperature induced animal stresses, or from both remains to be answered. It has been observed that blood serum Mg levels can be altered by sudden changes in both diet (quantity and quality) and environmental conditions (Swan and Jamieson, 1956; Dijkshoorn and t'Hart, 1957; Kemp and t'Hart, 1957) or other disturbances (Dozsa, 1959).

Much of the work done on relating forage composition to hypomagnesaemia and/or grass tetany has presented the ratio $\frac{K}{Ca+Mg}$ in meq. per kg or alkali alkalinity to alkaline earth alkalinity as predictors of grass tetany (Brouwer, 1952; Naumann and Barth, 1959; Harada and Shinohara, 1970). In general, workers express the opinion that incidence of grass tetany increases when the $\frac{K}{Ca+Mg}$ ratio exceeds 2.2 (Henricksen, 1960; Azevedo and Rendig, 1972). There has been mixed response to the use of such ratios. Werner (1959) and others find no particular relationship between $\frac{K}{Ca+Mg}$ and grass tetany or hypomagnesaemia (Hvidsten *et al.*, 1959). Redlech (1960) stated that grass tetany was controlled by correcting the $\frac{K}{Mg}$ ratio of soil from 2 to 3 down to 0.8 to 1.3.

Another factor which is involved is the relative amounts of crude protein and carbohydrates in the diet (Metson *et al.*, 1966; Hickey, 1960; Hvidsten *et al.*, 1959). It has been suggested that grass tetany may result from an energy deficiency in the diet because more energy is used in the ruminant to degrade crude protein than carbohydrates. The higher rumen bacterial energy requirement resulting from a high protein diet would rob the animal of available energy producing material. It has been noted that the crude protein level in grasses decreases with increasing maturity and rises in fall growth (Kirchgissner, 1957; Johns, 1955).

Numerous field surveys have been conducted over the years which have shown other factors might be involved. Kentucky workers (Grainger *et al.*, 1959) surveyed animals which caused the workers to describe "a complicated grass tetany syndrome." The blood analysis of these animals showed high NPN, low Ca, and high P; afflicted animals seldom responded to grass tetany therapy (calcium gluconate).

A limited survey in southern Missouri following the spring 1973 grass tetany outbreak showed that liquid feed which contained urea was being fed in many cases. Allison (1970) reported that ruminal urease activity was stimulated by Mg, Mn, Ca, Sr, or Ba ions and inhibited by Na, K, or Co ions and that ruminal urease hydrolysis usually proceeded faster than ammonia assimilation. Allison stated that feeding of readily available carbohydrates should be encouraged when urea is fed.

Grass tetany in Missouri in recent years has been most often observed in beef cow herds which have received no grain supplement to pasture (or hay). On the other hand, grass tetany observed in New Zealand, the Netherlands, England, and Scandinavia has been in dairy herds on pasture. Reports citing occurrences from these countries have implied that little grain was fed to the afflicted animals in both cases, whereas the dairy herds in the Missouri grass tetany region receive liberal quantities of grain.

Grace (1972) indicated that pregnancy and lactation had no significant effect on the level of plasma Mg in sheep and young dairy cattle. However, in mature cattle, plasma Mg increased during pregnancy until 3 to 4 weeks prior to parturition. Lactation seemed to cause a significant decline in serum Mg 3 to 4 weeks after parturition.

In summary, evidence shows that grass tetany is highest in spring and fall on forage low in Mg, high in K, high in crude protein, high in organic acids and relatively low in available energy.

Where does the agronomist fit into the picture? This question will be answered only for Missouri conditions because of differences in soil, plant, and animal conditions between observed instances of grass tetany in this state and those in other areas. With the exception of a few isolated cases, the main area of grass tetany problems is in southwestern Missouri, principally in the following counties: Barry, Stone, Christian, Lawrence, Greene, Dade, Cedar and Polk (Figure 1). The actual problem areas seem to be those areas in these counties where the soils were derived from either calcitic Mississippian limestone or the basal Pennsylvanian sandy strata. Magnesium is found in only trace or near trace amounts in these types of residual material. The soils formed from these strata are consequently naturally low in exchangeable (available) magnesium throughout the soil profile.

The low available magnesium levels in these soils can be (and have been) accentuated by the use of calcitic limestone and/or the use of macronutrient fertilizer (N, P, and K). An understanding of cation exchange reactions is necessary to understand the effects of soil treatments on plant-available Mg. At low levels of any exchangeable cation the addition of a second cation will suppress the ionization of the cation present in low relative amounts. Thus if Ca (from calcitic limestone), or NH_4 and K (from fertilizer) are added to the low Mg soil, the availability of Mg to plants will be suppressed.

Continued use of K and N fertilizers has lowered soil Mg levels and K fertilizer use over time has decreased the percentage base saturation (Gajek, 1971). Harrod (1971) reported that the level of exchangeable Mg tends toward an equilibrium level, dependent upon release of Mg from non-exchangeable sources. He reports the main loss of Mg from the root zone is likely to be due to leaching.

In addition, competition at the root uptake sites will result in depression of Mg uptake if K is present in relatively large quantities (Ca might have the same effect as K). Observation that grass tetany most often occurs on fertilized pastures emphasizes that the above effects or some similar phenomena are obtained.

From the discussion above it is evident that the following questions must be answered by the agronomist in solving the grass tetany problem. There have been instances of grass tetany in animals consuming many different species of grasses, thus these questions will apply to forage grasses in general.

1. As the grasses grow from spring growth initiation through the boot stage, what are the patterns of accumulation of N, K, Na, Mg, crude protein, free amino acids, carboxylic and fatty acids, fat and TDN?
2. Will the application to the soil of calcitic limestone, dolomitic limestone, K, N, and soluble Mg compounds singly or in combination alter the accumulation patterns of

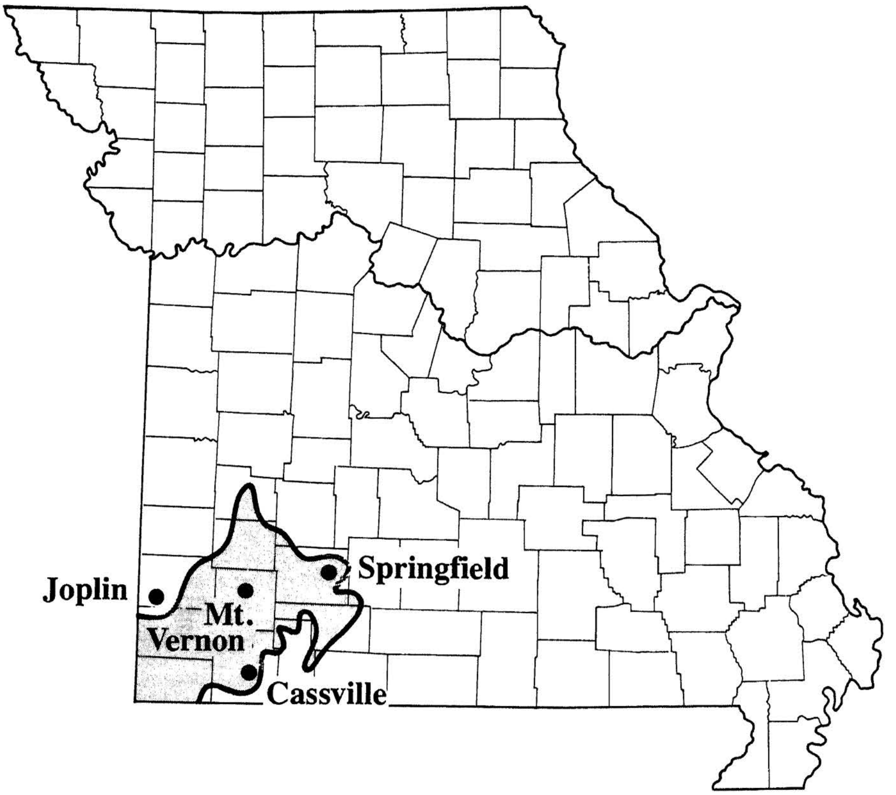

Figure 1. The soil area in Missouri covered by the study. It is predominantly underlain by calcitic limestone. The major upland soil series includes Baxter, Newtonia, Gerald, Creldon (Craig), and Keeno (Eldon).

the components listed in 1? If so, how?

3. Can the time of N and/or K fertilizer applications be adjusted to prevent the grasses from achieving the toxic conditions, i.e. high K, high crude protein, high fat, low Mg, and low TDN?

These questions are answerable. However, the literature search has pointed out that no one has really studied specific species of grass as the questions listed above indicate they should be. Workers have studied organic acids, for example, but few if any have related their results to soil factors. There are instances of such studies with grass composition, but few if any really completely specify the soil and atmospheric environment under which grass was grown. Limited work has shown that results obtained from plants grown in pots in the greenhouse cannot be applied directly to the field.

The study reported on following pages was undertaken after this review and evaluation of literature. The specific objectives were to determine if the magnesium level in spring growth of tall fescue could be kept at relatively high levels by soil treatments.

MATERIALS AND METHODS

The study was conducted on a site in the southwest corner of the University of Missouri's Southwest Center, located in Lawrence County. The site had been mapped in 1960 as Gerald silt loam (fine, mixed, mesic umbric fragiaqualf).

The site was divided into twelve 30.5 x 10.7 meter (100 x 35 ft.) blocks separated by 6.1 meter (20 foot) alleys. Four different lime treatments were applied to these blocks making three replications of each basic or whole block treatment. At the initiation of the treatments the soil tests indicated a lime requirement of 2200 lbs of effective neutralizing material per acre (2460 kg/ha). The initial assumption was that for economic reasons a farmer would apply about half of the recommended limestone (1100 lbs ENM/A or 1230 kg/ha). Table 1 gives the lime treatments. Local limestones, MgO and Agrisul were used.[1]

Table 1 Whole plot treatments, tall fescue study, Southwest Center.

Treatment	Material	Rate+
Dolomitic	Dolomic Limestone	1100 lbs ENM/A
Calcitic	Calcitic Limestone	1100 lbs ENM/A
MgO	MgO	240 lbs Mg/A
Dolomitic + Sulfur	Dolomitic Limestone Agrisul	1100 lbs ENM/A 72 lbs S/A

+ENM = Effective Neutralizing Material; based upon the calcium carbonate equivalent and screen size of the limestone.

---

[1] The MgO was furnished by Basic Chemicals, Cleveland, Ohio. Agrisul is an elemental sulfur carrier granulated with bentonite clay.

The whole-plot treatments were worked into the plow layer of the blocks. Each block was then divided into ten 3.1 x 10.7 meter (10 x 35 ft.) plots. Within each block five plots selected at random were treated with 269 kg Mg/ha (240 lbs Mg/A) as MgO, which was worked into the surface of the plowed soil.

The initial soil tests (Table 2) made using the standard Missouri procedures showed the need for added phosphorus (Brown *et al.*, 1977). Therefore, 117 kg P/ha and 28 kg K/ha were worked into the plowed soil.[2] Kentucky 31 tall fescue (*Festuca arundinacae*) was seeded in the spring of 1972.

No growth removal or sampling of plant material was made in 1972. In the fall of 1972 the ten plots within each block received a topdressing of NPK according to a treatment plan. The treatment plan was designed to apply the recommended quantities of N + P + K annually but divided up so that the fertilizer was applied at different calendar dates (Table 3). In 1974 and subsequent years the plan given in Table 4 was followed. Each treatment was applied to one plot which had received supplemental Mg and to one plot in each block which had not received supplemental Mg.

The sampling and harvest plan selected was a compromise to simulate grazing where grazing would be impractical due to plot numbers and size. The fall growth was allowed to accumulate and go dormant. In January, after being leached by November and December precipitation, the fall growth was removed, dry matter yields were determined, and the material was analyzed for K, Ca, and Mg. The "late winter" treatment was applied after removal of the stockpiled material. When the new spring growth reached a 5-inch leaf length, grab samples were taken periodically from each plot by hand and analyzed for K, Ca, and Mg. The entire growth was harvested for yield measurement and analysis at initiation of seed head emergence. Soil samples from each plot were taken immediately after this harvest and the appropriate top dress treatments were made. The late spring-summer growth was harvested for yield check and analysis in early July and the "August" treatment was applied in August. After the first frost, periodic grab samples were taken until growth ceased. (The January harvests are considered as yield of the previous calendar year.)

The plant samples were dried and ground. One-half gram samples were digested in a mixture of nitric and perchloric acids (3:2; v:v). The digest was diluted, the concentration of K was determined by flame photometry, and the concentrations of Ca and Mg were determined by atomic absorption spectroscopy. The data were analyzed by sampling date by the UMC Computer Center with the SAS data analysis system.

Total sulfur was determined on the samples of the first 1974 harvest from the dolomite and dolomite plus sulfur plots. The UMC Experiment Station Chemical Laboratory determined the total S as well as the concentration of total N, methionine, and cysteine in the material.

---

[2] 240 lbs. P_2O_5 and 30 lbs. K_2O per acre.

Table 2 Initial soil test results, tall fescue study, Southwest Center, 1972.

	%	lbs/A	pH	Me/100g
OM	2.7	---	---	---
Bray II P	---	5.3	---	---
K	---	250	---	0.3
Ca	---	3300	---	8.2
Mg	---	169	---	0.7
pHs	---	---	5.1	---
N.A.	---	---	---	7.0
CEC	---	---	---	16.2

Table 3. Variable fertility treatments applied to the tall fescue study, Southwest Center 1972, 1973.

	Dates		
Treatment Number	Fall 1972 N + P + K	May 1973 N + P + K	August 1973 N + P + K
	--------------------lbs/A--------------------		
1	80 + 0 + 33	80 + 18 + 33	80 + 0 + 0
2	80 + 18 + 33	80 + 18 + 33	80 + 0 + 33
3	80 + 18 + 33	80 + 0 + 33	80 + 0 + 33
4	80 + 18 + 0	80 + 0 + 66	80 + 0 + 0
5	80 + 18 + 0	80 + 0 + 66	40 + 0 + 0

Table 4. Variable topdress fertility treatments applied to the tall fescue, Southwest Center, 1974 through 1978[+]

	Date of Treatment		
Treatment Number	Late Winter	After First Harvest	Early August
	lbs/A		
1	80 + 18 + 66	0 + 0 + 0	80 + 0 + 0
2	80 + 18 + 33	0 + 0 + 0	80 + 0 + 33
3	0 + 0 + 0	80 + 18 + 33	80 + 0 + 33
4	0 + 0 + 0	80 + 18 + 66	80 + 0 + 0
5	80 + 18 + 33	40 + 0 + 33	40 + 0 + 0

[+] In 1976, 1977 and 1978 the K treatments were 42 and 84 lbs K/A instead of 33 and 66, respectively. No P was applied in 1977 and 18 lbs P/A was applied to all plots in 1978 in late winter.

RESULTS AND DISCUSSION

Dry Matter Production

The cation composition of forage grass can be greatly changed by the quantity of available nitrogen and potassium in the soil. Available phosphorus (P) tends to have much less effect on entry of cations into the plant than does nitrogen (N) or potassium (K). All three, nitrogen, phosphorus, and potassium, are often applied annually to pastures and hay fields.

Frequently N, P and K are applied in late winter or very early spring. This practice, especially if in quantities in excess of 60 lbs/A each of N and K, may lower the concentration of magnesium (Mg) in the forage once growth starts. This lowered Mg has been suspected as contributing to grass tetany.

One of the reasons for the early application of N, P, and K has been to have the nutrients present when moisture is adequate so maximum dry matter could be produced. In this study we evaluated this practice in comparison with putting the N, P, and K on at times other than late winter. As pointed out earlier, one of our objectives was to reduce the fertilizer effect of lowering Mg in the early spring forage without sacrificing dry matter production during the year.

Table 5 indicates that over the six year period the more common treatments (1 and 2) averaged slightly higher in total dry matter yield but the greatest average difference between yields (2 and 3) was only 200 lbs dry matter per year. This difference could hardly be considered significant especially if the tetany potential of the forage from treatment 3 was less than that from treatments 1 or 2.

The proneness toward tetany will be discussed later as there are two other aspects of dry matter production which require discussion. First, the total dry matter production in a given year varied between years as did the ranking of dry matter production from the five treatments (Table 5).

Table 5. The effect of top dressing treatments on the annual dry matter yield of tall fescue - Southwest Center

Treatment	1973	1974	1975	Year 1976	1977	1978	Avg
				lbs/A			
1	8930	5840	4780	4310	7400	6020	6210
2	9060	6220	4760	4060	7470	5960	6260
3	8940	5980	4500	3880	7580	5480	6060
4	8660	5660	4540	4260	7710	5880	6120
5	8050	5760	4760	4740	7120	6640	6180

More important was the distribution of production within the year. Treatments 3 and 4 received no early spring top dressed fertilizer whereas the other three treatments did. This had a significant effect on the seasonal distribution of dry matter production (Table 6). On the average, there were about 1000 lbs per acre more dry matter production in May and June from treatments 3 and 4 than from treatments 1 and 2. This effect was due mainly to nitrogen, as the results from treatment 5 would indicate.

One must conclude, therefore, that application of fertilizer in early to mid-May will give a better distribution of dry matter production over the year than will the common practice of applying top dressing in mid-winter in southwest Missouri.

Dry matter production was not significantly affected by either the lime treatments or the extra magnesium applied at establishment.

Cation Ratio

The ratio of K to the sum of Ca and Mg on the chemically equivalent basis in forage has been used as an indicator of the tendency of the forage to contribute to the onset of grass tetany. If the cation ratio in a forage is greater than 2.2 the forage is quite likely to contribute to grass tetany if consumed by a ruminant. The ratio obviously is dominated by K since plants contain much more K than Ca and Mg. Also, the rate of uptake of K by the plant can be affected by environmental and availability factors more quickly than the rate of uptake of Ca and Mg.

In this study the sampling program was designed to follow the trend of the cation concentration and ratio through the growth period of the fescue. The ratios in the sampled forage are presented in Table 7. Treatments 3 and 4 were included to observe

Table 6. Effect of top dressing treatments on dry matter production of tall fescue by harvest and year.

Treatment	Year	Harvest 1	Harvest 2	Harvest 3
		--------lbs/A--------		
1	1973	4030	2860	2040
	1974	2880	800	2160
	1975	2920	460	1400
	1976	2930	1380	--
	1977	3240	1270	2890
	1978	3920	1320	780
	Avg	3320	1350	1540
2	1973	3920	2960	2180
	1974	2820	880	2520
	1975	2740	460	1560
	1976	2720	1340	--
	1977	3160	1240	3070
	1978	3820	1360	750
	Avg	3200	1370	1680
3	1973	4080	2760	2100
	1974	1280	2100	2600
	1975	1440	1340	1720
	1976	1440	2480	--
	1977	2300	2260	3020
	1978	2280	2300	900
	Avg	2130	2210	1720
4	1973	3890	2830	1940
	1974	1260	2040	2360
	1975	1360	1540	1640
	1976	1480	2780	--
	1977	2290	2510	2910
	1978	2240	2660	970
	Avg	2090	2390	1640
5	1973	3860	2810	1380
	1974	2760	1500	1500
	1975	2780	960	1020
	1976	2540	2200	--
	1977	2980	1880	2260
	1978	3840	2100	700
	Avg	3130	1910	1140
$lsd_{.05}$	1973	NS	NS	160
	1974	106	332	172
	1975	100	72	154
	1976	280	130	--
	1977	138	95	130
	1978	150	160	70

Table 7. The effect of top dressing upon the cation ratio (K/Ca+Mg) in tall fescue.+

		Spring Sampling				Harvest		Fall Sampling			Harvest
		1	2	3	4	1	2	1	2	3	3
1	1973	1.99	1.87	1.88	.82	1.39	.99	.93	1.01	--	.72
	1974	1.77	1.71	1.35	--	1.31	1.11	.61	.64	--	.62
	1975	1.48	1.46	1.50	1.41	1.59	.83	.61	.58	--	.57
	1976	1.31	1.25	1.25	--	1.30	.99	.78	.69	.77	--
	1977	1.04	1.09	1.14	--	1.60	1.01	.74	.87	--	.72
	1978	1.42	1.45	1.12	--	1.22	.72	.31	--	--	.38
2	1973	2.00	ND	ND	ND	1.42	1.08	ND	ND	--	ND
	1974	1.72	1.63	1.38	ND	1.30	1.08	.79	.86	--	.81
	1975	1.51	1.45	1.50	1.40	1.50	.79	.79	.77	--	.74
	1976	1.21	1.15	1.21	--	1.23	.91	.97	.85	1.01	--
	1977	1.06	1.02	1.14	--	1.51	.95	1.01	1.08	--	.87
	1978	1.54	1.37	1.13	--	1.22	.73	.49	--	--	.48
3	1973	ND	ND	ND	ND	1.36	1.02	ND	ND	--	ND
	1974	1.51	1.48	1.22	--	1.27	1.19	.76	.89	--	.84
	1975	1.42	1.35	1.41	1.40	1.45	.96	.79	.70	--	.75
	1976	.95	1.03	1.19	--	1.10	1.16	.96	.85	1.03	--
	1977	.90	1.01	1.07	--	1.38	1.18	1.02	1.14	--	.89
	1978	1.64	1.51	1.16	--	1.23	.87	.52	--	--	.54

4	1973	1.86	1.65	1.76	.84	1.26	1.02	1.09	1.07	--	.73
	1974	1.41	1.27	1.12	--	1.16	1.30	.64	.72	--	.69
	1975	1.32	1.24	1.29	1.29	1.35	1.10	.71	.69	--	.71
	1976	.93	1.03	1.12	--	1.04	1.26	.81	.73	.82	--
	1977	.81	.91	.94	--	1.20	1.33	.84	1.00	--	.81
	1978	1.53	1.33	.98	--	1.06	1.00	.39	--	--	.49
5	1973	ND	ND	ND	.99	1.24	1.10	1.08	1.14	--	.71
	1974	1.65	1.57	1.33	--	1.23	1.21	.60	.66	--	.57
	1975	1.40	1.36	1.33	1.29	1.38	.98	.66	.62	--	.57
	1976	1.12	1.07	1.09	--	1.16	1.20	.81	.77	.85	--
	1977	1.00	.98	1.04	--	1.39	1.18	.81	.91	--	.68
	1978	1.47	1.31	1.01	--	1.13	.83	.33	--	--	.35
lsd$_{.05}$[‡]	1973	NS	.18	NS	NS	.12	NS	NS	NS	--	NS
	1974	.07	.097	.08	--	.07	.06	.065	.082	--	.06
	1975	.068	.05	.078	.076	.116	.044	.073	.060	--	.065
	1976	.081	.08	.07	--	.075	.092	.051	.068	.076	--
	1977	.069	.069	.059	--	.10	.072	.067	.067	--	.056
	1978	.09	.08	.05	--	.09	.06	.04	--	--	.04

[+] In 1973 chemical analysis of many of the samples was not done; these entries are designated "ND" i.e. not determined. Cells in this table which contain a dash (-) indicate samplings or harvests which were not made.

[‡] The lsd values apply only to treatment means within a given year and sampling or harvest.

the effect of no late winter fertilization on yields and cation composition. It is obvious that the cation ratios of spring forage in a given year from treatments 3 and 4 were significantly lower than the ratios from 1 and 2. Treatment 5 resulted in ratios which usually fell between the two other sets of treatments. It should be noted that only in 1973 did any cation ratios approach the cardinal value of 2.2. In spite of that failure, the fact remains that delaying the top dressing of N, P, and K until May did significantly lower the cation ratio and, as pointed out above, gave better growth distribution over the season.

The wide variability between years was due to rainfall and temperature differences. Therefore, no overall statistical analysis of the experiment was made. A statistical evaluation of means over years would not be valid due to variability in sampling dates, stages of growth at sampling and weather between years. For example, sampling dates differed (Table 8), which would make the stage of maturity for a given sample differ between years.

The May fertilizer application caused the cation ratio of forage from the second harvest to be greater than where no May top dressing was made. The cation ratios of fall samplings from treatments 2 and 3 were somewhat higher than the ratios in fescue from the other treatments. However, the August application of K did not affect the cation ratio in the magnitude that the late winter application did.

In the fall, the K concentration in the forage tended to decline except in 1977 when it increased slightly. The temperature regime during the fall months would naturally influence the results. The first sample in the fall was to be taken a few days after a killing frost. In some years the date of a killing frost for fescue on a site with some air drainage was difficult to determine. Only one sample was taken in 1978 because of the mild nature of the fall. However, the concentration of K in that forage (Table 9) indicated leaching of K which could occur if the vegetative material was inactive.

In all cases there was a higher K concentration in the forage from the second harvest than from the first. This could result from the limited growth due to the inherent nature of fescue, limited moisture and, perhaps, limited nitrogen. The third harvest consisted of material grown in the fall and subjected to winter weather and was designed to study the cation content of stockpiled forage.

Calcium concentration differences between treatments within a year were relatively small (Table 10). In general, the calcium concentration was somewhat lower at a given sampling or harvest on forage grown on treatments which received top dressing closest to the harvest or sampling date. For example, the calcium concentration in the stockpiled material (Harvest 3) was lowest on treatments 2 and 3. These were treatments in which K was applied in August. This would indicate that soil K interfered with calcium uptake or stimulated growth which diluted plant calcium.

The magnesium concentration in the samples and harvests over the course of the experiment showed small but statistically significant differences between treatments (Table 11). In some cases these differences did not follow work published by others. For example, the spring sampling in 1974, 1977, and 1978 showed that the Mg concentration in forage from treatments 1, 2, and 5 was higher than in forage from treatments 3 and 4. That is, treatments fertilized in January resulted in higher Mg concentration than forage not fertilized in January. This effect held true for the first harvest. Under the conditions of this experiment the dilution effect on Mg due to increased growth did not hold. The fescue, in fact, was able to take up more Mg when fertilized. Delaying top dressing until late spring, therefore, did not increase Mg concentration in the fescue as was hypothesized at the start of the study.

In the fall, those treatments which received only N in August (1, 4, 5) tended to yield fescue with higher Mg concentration than those treatments with both N and K (2,3). The K effect on Mg in vegetative tissue is well documented and supported by this study.

Table 8. Sequence of activities 1973-1978.

Activity	1973	1974	1975	1976	1977	1978
Fertilization	--	12 Feb	9 Jan	14 Jan[+]	9 Feb	22 Mar
Sp Sampling 1	3 Apr	16 Mar	27 Mar	26 Mar	1 Apr	5 Apr
Sp Sampling 2	13 Apr	28 Mar	7 Apr	7 Apr	15 Apr	17 Apr
Sp Sampling 3	24 Apr	10 Apr	18 Apr	23 Apr	27 Apr	28 Apr
Sp Sampling 4	4 May	--	30 Apr	--	--	--
Harvest 1	15 May	7 May	12 May	4 May	5 May	16 May
Soil Samples	--	8 May	15 May	12 May	9 May	24 May
Fertilization	16 May	10 May	16 May	14 May	10 May	25 May
Harvest 2	2 July	10 June	27 June	25 June	13 July	6 July
Fertilization	Aug	5 Aug	4 Aug	3 Aug	2 Aug	2 Aug
Fall Sampling	3 Oct	11 Nov	13 Nov	20 Oct	14 Nov	19 Dec
Fall Sampling	18 Oct	9 Dec	4 Dec	12 Nov	28 Nov	--
Fall Sampling	1 Nov	--	--	1 Dec	--	--
Fall Sampling	12 Dec	--	--	--	--	--
Harvest 3[‡]	5 Feb	6 Jan	6 Jan	--	4 Jan	27 Feb

[+] Limestone (2.7 T/A) applied 24 Feb 1976

[‡] The dates for the third harvest are the year following that of the column heading.

Table 9. The effect of top dressing upon the potassium concentration in tall fescue.+

Treatment		Spring Sampling				Harvest		Fall Sampling			Harvest
		1	2	3	4	1	2	1	2	3	3
		%K									
1	1973	3.22	2.44	2.57	1.87	2.07	2.67	1.69	ND	1.42	.99
	1974	3.53	3.17	2.37	--	1.93	2.10	1.23	1.14	--	.94
	1975	2.46	2.57	2.83	2.37	1.86	1.90	1.50	1.29	--	.96
	1976	2.36	2.26	2.34	--	2.10	2.11	1.66	1.34	1.14	--
	1977	1.82	2.69	2.27	--	2.22	2.22	1.54	1.69	--	1.17
	1978	2.77	2.97	2.22	--	1.96	1.92	.67	--	--	.57
2	1973	3.23	ND	ND	ND	2.02	2.66	ND	ND	ND	ND
	1974	3.42	3.04	2.43	--	1.90	2.01	1.47	1.42	--	1.14
	1975	2.49	2.56	2.82	2.30	1.77	1.85	1.83	1.56	--	1.15
	1976	2.24	2.09	2.27	--	1.98	2.00	1.99	1.53	1.34	--
	1977	1.85	2.53	2.21	--	2.12	2.14	1.93	1.99	--	1.33
	1978	3.01	2.77	2.22	--	1.87	1.95	.97	--	--	.64
3	1973	ND	ND	ND	ND	2.00	2.60	ND	ND	ND	ND
	1974	2.70	2.50	1.94	--	1.72	2.21	1.45	1.49	--	1.17
	1975	2.32	2.46	2.71	2.26	1.67	2.15	1.82	1.50	--	1.19
	1976	1.87	1.93	2.13	--	1.82	2.34	1.96	1.58	1.35	--
	1977	1.45	2.31	2.01	--	1.87	2.39	1.97	2.04	--	1.32
	1978	2.86	2.77	2.08	--	1.77	2.14	1.01	--	--	.72

4	1973	3.04	2.29	2.42	1.81	1.91	2.77	1.97	ND	1.55	.93
	1974	2.55	2.27	1.84	--	1.63	2.47	1.32	1.25	--	1.02
	1975	2.24	3.32	2.60	2.13	1.56	2.43	1.70	1.44	--	1.17
	1976	1.86	1.92	2.05	--	1.77	2.48	1.72	1.40	1.19	--
	1977	1.34	2.11	1.87	--	1.77	2.62	1.73	1.89	--	1.26
	1978	2.71	2.53	1.92	--	1.64	2.37	.86	--	--	.71
5	1973	ND	ND	ND	1.84	1.97	2.83	2.06	ND	1.57	.88
	1974	3.41	2.93	2.37	--	1.85	2.27	1.23	1.17	--	.85
	1975	2.34	2.45	2.61	2.24	1.71	2.22	1.61	1.31	--	.89
	1976	2.14	2.00	2.18	--	1.93	2.46	1.68	1.41	1.16	--
	1977	1.73	2.47	2.12	--	2.02	2.39	1.67	1.76	--	1.09
	1978	2.92	2.65	2.03	--	1.75	2.09	.68	--	--	.49
lsd$_{.05}$[+]	1973	NS	NS	NS	NS	NS	0.12	0.17	--	NS	NS
	1974	.114	.13	.13	--	.069	.08	.115	.121	--	.074
	1975	.111	.076	.10	.088	.085	.076	.105	.107	--	.083
	1976	.120	.110	.087	--	.082	.131	.076	.097	.087	--
	1977	.11	.14	.09	--	.10	.12	.12	.10	--	.09
	1978	.16	.15	.11	--	.10	.11	.07	--	--	.05

[+] See footnotes for Table 7.

Table 10. The effect of top dressing upon the calcium concentration in tall fescue.+

Treatment		Spring Sampling				Harvest		Fall Sampling			Harvest
		1	2	3	4	1	2	1	2	3	3
		%Ca									
1	1973	.42	.31	.33	.38	.41	.66	.35	ND	.25	.24
	1974	.45	.40	.43	--	.37	.49	.48	.39	--	.37
	1975	.38	.42	.47	.43	.27	.57	.62	.52	--	.43
	1976	.50	.51	.54	--	.44	.58	.54	.50	.31	--
	1977	.50	.76	.59	--	.34	.53	.54	.50	--	.42
	1978	.44	.51	.56	--	.42	.70	.67	--	--	.57
2	1973	.42	ND	ND	ND	.39	.60	ND	ND	ND	ND
	1974	.44	.40	.44	--	.37	.48	.44	.36	--	.34
	1975	.37	.42	.46	.41	.25	.58	.58	.49	--	.39
	1976	.53	.50	.53	--	.44	.59	.53	.46	.28	--
	1977	.50	.76	.57	--	.35	.54	.49	.47	--	.40
	1978	.44	.50	.55	--	.44	.70	.56	--	--	.40
3	1973	ND	ND	ND	ND	.41	.61	ND	ND	ND	ND
	1974	.43	.40	.41	--	.35	.44	.45	.36	--	.34
	1975	.41	.47	.48	.42	.27	.52	.58	.50	--	.38
	1976	.60	.54	.52	--	.49	.51	.52	.47	.27	--
	1977	.50	.72	.56	--	.35	.48	.50	.45	--	.39
	1978	.44	.49	.53	--	.40	.61	.54	--	--	.40

4	1973	.42	.35	.32	.35	.42	.64	.34	ND	.26	.24
	1974	.44	.42	.42	--	.36	.45	.48	.38	--	.36
	1975	.42	.48	.51	.42	.26	.51	.60	.50	--	.40
	1976	.61	.55	.53	--	.49	.50	.53	.49	.30	--
	1977	.50	.72	.60	--	.38	.45	.54	.48	--	.41
	1978	.44	.51	.57	--	.44	.59	.59	--	--	.42
5	1973	ND	ND	ND	.30	.44	.62	.36	ND	.23	.24
	1974	.44	.39	.42	--	.37	.46	.49	.39	--	.38
	1975	.38	.43	.48	.44	.26	.54	.61	.51	--	.43
	1976	.55	.53	.57	--	.45	.53	.52	.46	.29	--
	1977	.49	.77	.60	--	.36	.48	.53	.49	--	.43
	1978	.43	.50	.56	--	.40	.64	.58	--	--	.43
lsd$^{+}_{.05}$	1973	NS	.037	NS	.04	.03	.04	NS	--	NS	NS
	1974	NS	NS	NS	--	.017	.02	.022	.021	--	.014
	1975	.016	.012	.020	.018	NS	.023	NS	NS	--	.018
	1976	.029	.022	.022	--	.029	.028	NS	.033	.018	--
	1977	NS	.033	.021	--	.026	.028	.022	.018	--	.016
	1978	NS	NS	.02	--	.03	.03	.03	--	--	.02

[+] See the footnotes for Table 7.

Table 11. The effect of top dressing upon the magnesium concentration in tall fescue.+

Treatment		Spring Sampling				Harvest		Fall Sampling			Harvest
		1	2	3	4	1	2	1	2	3	3
		%Mg									
1	1973	.26	.21	.23	.48	.22	.46	.39	ND	.31	.28
	1974	.35	.33	.28	--	.23	.29	.34	.32	--	.25
	1975	.29	.29	.30	.26	.21	.37	.40	.37	--	.26
	1976	.25	.26	.26	--	.24	.31	.33	.31	.27	--
	1977	.24	.31	.26	--	.24	.36	.33	.30	--	.25
	1978	.34	.33	.27	--	.24	.41	.31	--	--	.19
2	1973	.25	NS	NS	ND	.21	.42	ND	ND	ND	ND
	1974	.35	.33	.28	--	.23	.29	.31	.29	--	.23
	1975	.28	.29	.31	.26	.21	.38	.37	.34	--	.25
	1976	.26	.26	.26	--	.24	.33	.31	.28	.24	--
	1977	.24	.31	.26	--	.23	.38	.30	.29	--	.23
	1978	.34	.32	.28	--	.24	.41	.28	--	--	.17
3	1973	ND	ND	ND	ND	.22	.44	ND	ND	ND	ND
	1974	.29	.29	.25	--	.21	.31	.31	.30	--	.23
	1975	.26	.28	.30	.25	.20	.38	.37	.35	--	.26
	1976	.25	.25	.24	--	.22	.32	.31	.31	.24	--
	1977	.20	.27	.24	--	.21	.34	.29	.28	--	.22
	1978	.28	.27	.23	--	.20	.39	.28	--	--	.18

4	1973	.24	.22	.23	.45	.23	.46	.35	ND	.30	.26
	1974	.30	.30	.26	--	.22	.32	.35	.31	--	.25
	1975	.27	.29	.32	.26	.21	.38	.39	.35	--	.27
	1976	.26	.25	.25	--	.23	.31	.34	.30	.27	--
	1977	.21	.28	.26	--	.23	.34	.31	.30	--	.23
	1978	.28	.29	.26	--	.22	.38	.32	--	--	.20
5	1973	ND	ND	ND	.39	.24	.44	.38	ND	.30	.26
	1974	.37	.34	.30	--	.24	.30	.33	.32	--	.23
	1975	.29	.30	.32	.28	.23	.37	.39	.35	--	.24
	1976	.26	.26	.28	--	.25	.32	.32	.29	.25	--
	1977	.24	.32	.27	--	.24	.34	.32	.30	--	.24
	1978	.35	.33	.28	--	.24	.40	.30	--	--	.18
$\text{lsd}_{.05}$	1973	NS	NS	NS	.03	.014	NS	.02	--	NS	.01
1	1974	.013	.013	.009	--	.01	.011	.019	.017	--	.009
	1975	.008	NS	.015	.011	.013	NS	NS	.018	--	.016
	1976	NS	NS	.011	--	.012	NS	.012	NS	.011	--
	1977	.013	.016	.008	--	.013	.017	.012	.009	--	.009
	1978	.01	.01	.04	--	.01	.01	--	.03	--	.01

[+] See the footnotes for Table 7.

Unfortunately, there were no "N only" treatments in January so the K effect could not be isolated in the spring grown forage. One must speculate that the increased growth due to the January top dressing was indicative of a more vigorous root system. The nutrient causing this could not be isolated in this study.

The only fescue which dropped below 0.2% Mg was the stockpiled material from 1978. In many cases the Mg concentration in the material taken in the first harvest approached 0.2% Mg (Table 11). However, mid-May is considered to be past the "tetany season."

In summary, the concentrations of the individual cations showed that Mg in spring forage was above the critical level (0.2% Mg) in all years in all treatments. January fertilized forage contained more Mg than forage not fertilized in January. However, the individual effects of N, P, and K could not be isolated.

Quite often the K concentration in the spring samples exceeded 3%. This is in the range (2 to 4% K) that is supposed to accentuate the potential of a forage to trigger grass tetany (Metson *et al.*, 1966). However, as Follet *et al.* (1975) point out, K concentration alone is not adequate to describe the cation ratio even though K is the dominant cation.

The forage collected in this study would not pose a tetany hazard based upon the usual criteria of a cation ration >2.2 with a magnesium concentration <0.2% on the dry matter basis.

Individual Cations

The cation ratio reflects the combined effects of the three cations K, Ca, and Mg. The concentration of these cations, especially K and Mg, have been implicated in the onset of grass tetany. Therefore, a detailed examination of these cations seems necessary.

Potassium was applied every year at various times and was present in vegetative material in much larger quantities than either Ca or Mg. If one looks at the results from the individual years, the pattern of K accumulation is not consistent (Table 9).

The samplings carried out in the spring and the fall were included to follow the pattern of cation accumulation. However, there was no set pattern of K concentration changes, especially in the spring. In 1974 and 1978 the general tendency was for the K concentration to decline with time. This would be the expected pattern due to dilution resulting from rapid dry matter accumulation characteristic of the spring months.

This declining pattern did not hold across all spring samplings in 1975, 1976, and 1977. In both 1975 and 1977, K concentrations increased early in the sampling period, then declined. In 1976, the K concentration pattern with time was treatment dependent. Treatments 3 and 4 (no January top dressing) resulted in increased K concentration in the samples with time. This indicated increased availability of K with time or restricted growth due to lack of N. The other three treatments showed a decline in K concentration from the first to the second sampling with an increase in the third sampling.

Unfortunately, the size of the plots did not permit a dry matter determination at each sampling. Therefore, dilution could not be separated from the other effects on the K concentration. There are reports in the literature that hours of sunlight, day and night temperature, and soil moisture supply all contribute to the relative uptake of cations (Wilkerson et al., 1972).

Soil Tests

The study site was selected to be low in magnesium, as illustrated in Table 2. The initial limestone treatments (Table 1) were purposely selected to set up a variable Mg level in the soil. The quantity of limestone was less than would have been recommended to raise the soil pH to the most desired level for tall fescue. The assumption was that most pastures in the grass tetany region of southwestern Missouri would not be at the desired level of acidity.

In 1975, after the study had gone through two full cycles, soil tests were run on the 0-3 inch soil samples from each plot. An additional uniform calcitic lime treatment of 2.7 tons per acre was top dressed in February, 1976 (Table 8). The potassium treatments were increased starting in 1976. The alterations in treatment were made because the soil pH had dropped from an initial 5.1 to 4.8. Also the soil test K had dropped from 250 lbs/A to 101 lbs/A.

Tables 12 through 16 show the changes which occurred in the soil tests made on the 0 to 3 inch layer of soil over the course of the experiment. The soil samples were taken in May following the first harvest but before the designated treatments were applied (Table 8). While soil samples were taken every year only the results from 1975 and 1979 are given.

Ammonium nitrate is an acidifying source of nitrogen (Tisdale and Nelson, 1975). This acidification resulting from nitrification of the ammonium ion in the ammonium nitrate would decrease soil pH and could accelerate leaching of basic cations. The fact that the top dressing treatments were surface applied means that the immediate soil surface became quite acid. This acidification was reflected in the decline in pH noted above prior to 1975. The lime treatment made early in 1976 raised the pHs significantly and without any interaction with the previous lime treatments. Little or no magnesium was added with this uniform lime treatment.

The data indicate that the lime treatments had several effects on the soil as reflected in data from samples taken in 1975 and 1979 (Table 12). The significant effects of the

Table 12. The effect of lime treatment on soil test results in 1975 and 1979 (0-3 inch samples)

Lime Treatment	Bray PI	Bray PII	K	Ca	Mg	pHs	NA
	lbs P_2O_5/A		------------	lbs/A	------------		me/100g
				1975			
Dolomitic	158	194	94	1508	271	4.8	6.4
Calcitic	131	170	92	1699	186	4.8	5.7
MgO	148	202	114	1439	314	4.7	6.7
Dolomitic + S	166	204	104	1714	286	4.9	5.8
$lsd_{.05}$	24.9	NS	15.9	NS	16.5	NS	NS
				1979			
Dolomitic	98†	133†	83	2678	226	6.1	2.0
Calcitic	101	140	87	2848	186	6.2	1.6
MgO	110	148	106	2594	242	5.9	2.2
Dolomitic + S	121	161	98	2697	248	6.1	2.0
$lsd_{.05}$	12.8	12.8	9.8	NS	30.5	NS	NS

†interaction with top dressing treatment was significant (see Table 15)

lime treatments on the phosphorus soil test results cannot be explained since there was no variable P treatment included in the study. Phosphorus undergoes a complex series of reactions in soil which are pH dependent (Tisdale and Nelson, 1975). It is clear that the amount of P applied in this study as top dressing was insufficient to maintain the level of soil P present in 1975.

The significant effects of the lime treatments on K appeared to be a carryover from initial plot differences. The soil treated with calcitic limestone persisted in being significantly lower in Mg than the soils receiving MgO or dolomitic limestone. The quantity of soil Mg declined from 1975 to 1979.

The top dressing treatments were expected to have no net effect on relative soil test levels between treatments because the same quantities of N, P, and K were applied each year (Table 13). However, the timing would result in some soil differences because some plots were treated in late winter and some were not (Tables 3 and 4). Soil samples were taken in May.

Early in the experiment, treatment 2 received 18 lbs P/A more than the other four treatments. It seems improbable, but this treatment difference was still evident in 1979.

Table 13. The effect of top dressing upon soil test results in 1975 and 1979 (0-3 inch samples)

	Bray						
	PI	PII	K	Ca	Mg	pHs	NA
	lbs P_2O_5/A		------------lbs/A------------				me/100 g
Treatment				1975			
1	154	198	115	1555	248	4.8	6.2
2	169	219	109	1515	247	4.7	6.2
3	145	181	100	1570	271	4.8	6.2
4	135	176	86	1671	288	4.9	5.9
5	149	189	95	1639	265	4.8	6.1
lsd$_{.05}$	15.6	17.0	8.9	NS	26.1	0.12	NS
				1979			
1	109†	145†	90	2634	225	6.0	2.1
2	120	156	100	2666	216	6.0	2.0
3	105	148	94	2707	223	6.1	1.8
4	102	140	91	2782	220	6.1	1.8
5	102	138	92	2732	243	6.1	1.9
lsd$_{.05}$	9.5	11.5	NS	NS	14.2	NS	NS

†interactions with lime were significant.

There was some evidence of the late winter 1975 treatment of K in the 1975 soil samples (Table 3). Overall it is encouraging that the treatment differences in soil test P and K can be explained. The significant treatment effects on Mg, however, are not explainable. The decline in soil Mg from 1975 to 1979 and the treatment rankings in the two years all contribute to the inability to explain the treatment effects. Keep in mind, however, that the Mg data in Table 13 are averages of plots which got initial supplemental Mg and those that did not.

The initial MgO treatment made in 1972 continued to be detected by soil tests in 1979 (Table 14). The soil test level of Mg declined 10 lbs/A from 1975 to 1979 on the untreated plots but declined 67 lbs/A on the treated plots. This later decline is approximately the amount of Mg that was removed during the interval between tests in the harvested forage (Table 15). The small decline in soil test Mg on the untreated plots reflects the ability of the soil to supply Mg from "storehouse" forms undetectable by usual soil tests.

When the treatment effects on soil Mg are divided into those resulting with and without supplemental Mg the picture is clarified somewhat (Figure 2). In 1975, extractable Mg was highest on samples from treatments 3, 4, and 5, whether or not supplemental Mg had been applied. Treatments 1 and 2 received top dressing treatments in late winter but so had treatment 5. In spite of this differential, it still might have been possible for the timing of the top dressing to influence soil Mg in the 0 to 3 inch layer. In 1979, when there were no late winter treatments, there were no significant differences due to treatment.

There is one obvious effect of time on the results of extractable Mg. There was a small decline in the magnesium soil test on plots where no supplemental Mg has been applied at seeding but this decline in extractable Mg was quite large on plots which had received the supplemental Mg (Figure 2, Table 15). In either case the greatest decline in extractable Mg occurred with treatments which received no top dressing in late winter. This effect could not be attributed to greater removal of Mg (Table 15). One must, therefore, speculate that application of K fertilizer during the warmer months may have an effect on extractable Mg. Alternatively, application of K in the cooler

Table 14. The effect of supplemental Mg upon soil tests in 1975 and 1979 (0-3 inch sample).

Mg lbs/A	Bray PI lbs P_2O_5/A	Bray PII lbs P_2O_5/A	K ------------	Ca ------lbs/A	Mg ------	pHs ------------	NA me/100 g
				1975			
0	152	191	104	1607	204	4.7	6.5
240	149	194	98	1573	324	4.9	5.7
$lsd_{.05}$	NS	NS	5.6	NS	16.5	.07	.31
				1979			
0	109	146	93	2649	194	6.0	2.1
240	107	145	94	2759	257	6.2	1.8
$lsd_{.05}$	NS	NS	NS	95	9	0.1	0.2

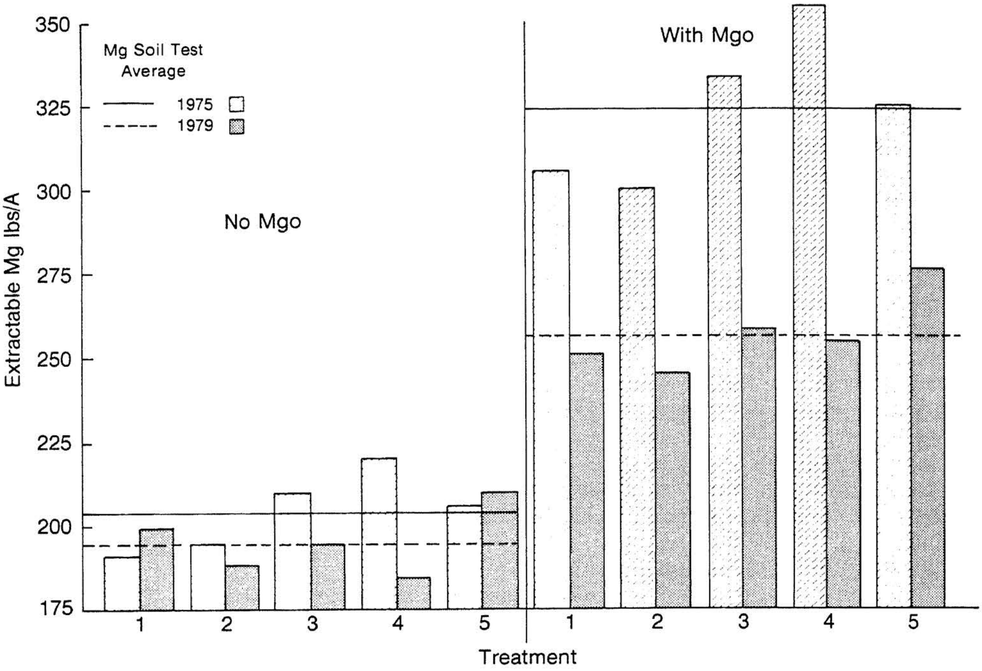

Figure 2. The effect of soil treatments on extractable soil magnesium in 1975 and 1979.

Table 15. Magnesium balance sheet from 1975 through 1979.

Treatment	Plant Removal[+]	Soil Test Changes[‡] -Mg	+Mg	mean
		lbs/A		
1	52.3	8	-51	-22
2	51.1	-7	-55	-31
3	55.2	-21	-75	-48
4	60.6	-36	-101	-68
5	59.3	4	-48	-22

[+] Includes the last two harvests of 1975 through the harvest of the stockpiled 1978 material.

[‡] 1979 soil test - 1975 soil test = soil test change.

months (late winter) may enhance retention of extractable Mg by the soil. The specific mechanisms involved remain to be clarified.

The potassium balance sheet shows two things (Table 16). First, the existing K recommendations did not replace crop removals but tended to restrict the decline in extractable K in the 0 to 3 inch layer. Secondly, the large excess removal of K in the harvested material over additions must have come from the subsoil. Subsoil samples were not routinely taken but work by Kroth (unpublished data) on an adjacent, concurrent study confirmed these observations.

Table 16. Potassium balance sheet from 1975 through 1979.

	Potassium			
Treatment	Plant Removal[+]	Added K	Net	ΔST[‡]
	lbs/A			
1	353.2	252	-101.2	-25
2	343.8	252	- 81.8	- 9
3	366.3	318	- 48.3	- 6
4	405.9	318	- 87.9	5
5	387.1	285	-102.1	- 3

[+] Includes the last two harvests of 1975 through the harvest of the stockpiled 1978 material in 1979.

[‡] 1979 soil test - 1975 soil test = ΔST

SUMMARY

This study has shown that top dressings of nitrogen and potassium when delayed from late winter to May in southwest Missouri did not significantly lower annual dry matter production. On the other hand, this delay in top dressing did keep the cation ratio in forage lower than in forage fertilized in late winter. This lowered cation ratio was due principally to lowered potassium concentration in the forage. It is suggested that the lowered cation ratio would make the May fertilized forage less likely to increase incidence of grass tetany than forage fertilized in late winter.

LITERATURE CITED

Allison, M. J. 1970. Nitrogen metabolism of ruminal micro-organisms *in* Physiology of digestion and metabolism in the ruminant. A. T. Phillipson, ed. chm., Oriel Press. New Castle upon Tyne, England.

Anonymous. 1968. Hypomagnesemic tetany and magnesium homestasis in the adult bovine. ASCAPI#5403, University of Missouri Extension Division, Columbia, MO.

Azevedo, J. and V. V. Rendig. 1972. Chemical composition and fertilizer response of two range plants in relation to grass tetany. J. Rg. Mgt. 25:24-27.

Bear, F. E. and A. B. Prince. 1948. Magnesium needs of N. J. soils. N. J. Agr. Ext. Sta. Bulletin 739 (20 p).

Bohman, V. R., A. L. Lesperance, G. D. Harding, and D. L. Grunes. 1969. Induction of experimental tetany in cattle. J. An. Sci. 29:99-102.

Bosch, S. and H. E. Harmsen. 1958. Influence of fertilizer magnesium on the mineral composition of pasture grass. Mededel. Proefsta. Akker-en Weidebouw No. 10 9pp. CA54:21585i (1960).

Brouwer, E. 1952. On the base excess, the alkali alkalinity and the mineral ratios in grass and hay with reference to grass tetany and other disorders in cattle. Brit. Vet. J. 108:123-131.

Brown, J. R., J. Garrett, and T. R. Fisher. 1977. Soil Testing in Missouri, University of MO Extension Circular 923.

Bull, L. S., P. E. Johnson, and J. T. Reid. 1967. The utilization of volatile fatty acids by ruminants. Proc. 1967 Cornell Nutrition Conference for Feed Manufactures. Cornell University. p. 83-96.

Butler, E. J., and Vet. Invest. and Agric. Advisory Officers of the East and West of Scotland Agric. Colleges. 1967. The mineral element content of spring pasture in relation to the occurrence of grass tetany and hypomognesaemia in dairy cows. J. Agric. Sci. 60:329-340.

Camp, J., J. W. Dollahite and W. L. Schwartz. 1968. Biochemical changes in sheep given trans-aconitic acid. Jour. of Vet. Res. 29:2009-2015.

Dilz, K., and G. H. Arnold. 1970. Increasing the magnesium content of grass by applying magnesium (nitrogen-magnesium fertilizer) with regard to the danger of grass tetany. Landwirt. Forsch. Sonderh. 25:6-13 (CA 74:110988p).

Dijkshoorn, W. and M. L. t'Hart. 1957. The effect of alteration of temperature upon the cationic composition of perennial ryegrass. Neth. J. of Agriculture Science 5:18-36.

Dishington, I. W. 1965. Changes in serum magnesium levels of ruminents as influenced by abrupt changes in the composition of the diet. Acta Vet. Scand. 6:150-177.

Doll, E. C. and L. R. Hossner. 1964. Magnesium deficiency as related to liming and potassium levels in acid sandy podzols. 8th Int. Congr. Soil Sci. Trans. Bucharest, Vol. IV 907-911.

Dozsa, L. 1959. Field case descriptions of spring tetany, *in* Magnesium in Agriculture - A Symposium. W. Va. University, Morgantown, p. 165-168.

Felbeck, G. T., Jr. 1959. Problems of magnesium assay in soils, *in* Magnesium in Agriculture - A Symposium. W. Va. University, Morgantown, p. 96-105.

Follett, R. F., J. F. Power, D. L. Grunes, D. A. Hewes and H. F. Mayland. 1975. Potential tetany hazard of N-fertilized bromegrass as indicated by chemical composition. Agron. J. 67:819-824.

Fonder, J. F. 1929. A critical study of the influence of soil type on the calcium and magnesium content and other physiological characteristics of the alfalfa plant. Soil Sci. 27:205-232.

Fontenot, J. R., R. W. Miller, C. K. Whitehair and R. MacVicar. 1960. Effect of high-protein high-potassium ration on the mineral metabolism. J. Animal Science 19:127-133.

Gajek, F. 1971. Effect of mineral fertilization during many years on the yields of cultivated plots as well as on some changes in soil properties II. Chemical soil properties. Pamiet. Pulawski 42:37-53 (CA 75:109323g).

Grace, N. D. 1972. Grass tetany III. Observations on plasma magnesium levels in grazing ruminants during pregnancy and lactation. N.Z. J. Agric. Res. 15:79-82.

Grainer, R. B., R. H. Singer, R. H. Baker, and J. W. Stroud. 1959. Investigation on a complicated tetany syndrome in ruminants in Kentucky, *in* Magnesium in Agriculture - A Symposium, W. Va. University, Morgantown p. 191-196.

Grunes, D. L. 1967. Grass tetany of cattle as effected by plant composition and organic acids. Proc. Cornell Nutrition Conf. for Feed Manufactures, p. 105-110. Cornell University, Ithaca, NY.

Grunes, D. L., P. R. Stout and J. R. Brownell. 1970. Grass tetany of ruminants. Adv. Agron. 22:331-374.

Harada, I., and I. Shinohara. 1970. [Studies on the balance of inorganic elements in grassland agriculture: I. On the balance of inorganic elements in pasture plants on the variation of available elements in the soil: I. Orchard grass - Dactylis glamerata]. J. Coll. Dairy Agric. (NOPPORO) 3(2):262-280 (Biol. Abst. 54:64191).

Hemingway, R. G. 1961. Magnesium, potassium, sodium, and calcium contents of haylage as influenced by fertilizer treatments over a three year period. J. Brit. Grassland Soc. 16:106-116.

Henderson, R. 1960. The application of potassic fertilizers to pasture and the evidence of hypomagnesoemia. Int. Potash Ltd. Tech. Ser. 1(23p) (SF 24:339 [1961]).

Hendricks, S. B. 1966. Salt entry into plants. Soil Sci. Soc. Amer. Proc. 30:1-7.

Hendriksen, A. 1960. Influence of fertilizer treatment on the mineral content of pastures. Tedsskr. Planteavd 64:1-50. [Soils and Fertilizer 23:2295].

Hickey, F. 1960. Some metabolic aspects of the pasture (Animal Association) N.Z. J. Agric. Res. 3:468-484.

Hvidsten, H., M. Odelren, R. Baerug, and S. Tollersrud. 1959. The influence of fertilizer treatments of pastures on the mineral composition of the herbage and the incidence of hypomagnesemia in dairy cows. Acta. Agric. Scand. 9:261-291.

Johns, A. T. 1955. Pasture quality and ruminant digestion I. Seasonal changes in botanical and chemical component of pasture. N.Z. J. of Sci. (Technical) A37:301-311.

Kemp, A. 1960. Hypomagnesoemia in milking cows. Neth. J. Agric. Science 8:281-304.

Kemp, A. 1958. Influence of fertilizer treatment of grassland in the evidence of hypomagnesoemia and hypomagnesoemic tetany (grass tetany) in milking cows. Neth J. Agric. Science 6:281-297.

Kemp, A., W. B. Deijs, O. J. Henekes, and A. J. H. Van Es. 1961. Hypomagnesoemia in milking cows: intake and utilization of magnesium from herbage by lactating cows. Neth. J. Agric. Sci. 9:134-149.

Kemp, A., and M. L. t'Hart. 1957. Grass tetany in grazing milking cows. Neth. J. Agric. Sci. 5:4-17.

Kingsbury, J. M. 1964. Poisonous Plants of the United States and Canada. Prentice Hall. New York.

Kirchgissner, M. 1957. The influence of different growth stages on the macro- and micro-nutrient content of meadow grass. Landwirtsch Forsch 10:45-50.

Knoblauch, H. C. and T. E. Odland. 1934. A magnesium deficiency induced by previous fertilizer treatments. J. Am. Soc. Agron. 26:609-615.

MacLeod, L. B. and R. B. Carson. 1966. Influence of K on the yield and chemical composition of grasses grown in hydroponic culture with 12, 50, and 75% of the N supplied as NH_4^+, Agron. Jnl. 58:52-57.

Marshak, R. R. 1959. The role of magnesium in the tetany syndromes of cattle, *in* Magnesium in Agriculture - A Symposium. W. Va. University, Morgantown, p. 169-181.

Mc Donald, P., and Jackson, T. H. 1955. Application of magnesium sulfate to grass for silage as a means of preventing hypomagnesoemic tetany. Proc. Brit. Soc. Animal Prod. 1955:109-114.

McLean, E. O., and M. D. Carbonell. 1972. Calcium, magnesium, and potassium saturation ratios in two soils and their effects upon yields and nutrient contents of German millet and alfalfa. Soil Sci. Soc. Am. Proc. 36:927-930.

Mengel, K. and E. A. Kirkby. 1978. Principles of Plant Nutrition. International Potash Institute, Bern, Switzerland.

Metson, A. J., W. M. H. Lounders, T. W. Collie, and V. W. Graham. 1966. Chemical composition of pastures in relation to grass tetany in beef breeding cows. N.Z. J. Agric. Res. 9:410-436.

Naumann, K., and K. Barth. 1959. Chemical investigations in the grass tetany region of the lower Rhine. Landw. Forsch. 12:186-195.

Omar, M. A. and T. El Kobbia. 1966. Some observations on the inter-relationships of potassium and magnesium. Soil Sci. 101:437-440.

Parr, W. H. and R. Allcroft. 1957. The application of magnesium compounds to pasture for the central hypomagnesaemia in grazing cattle: a comparison between magnesium limestone and calcined magisite. Vet. Record 69:1041-1047.

Pratt, P. F. 1965. Potassium. Ch. 71 *in* Methods of Soil Analysis, Part 2. C. A. Black ed. in chief, Amer. Soc. Agron., Madison, WI.

Redlich, M. 1960. Contribution to the study of the effect of soil composition on grass tetany and warty swelling. C. R. Acad. Agric. Fr. 46:291-296 (SF 24:1738[1961]).

Ronson, S. L. 1965. Plant Acids in Biosynthetic Pathways in Higher Plants. J. B. Pridham and T. Swain, ed. p. 179-198. Academic Press, New York.

Rook, J. A. F., C. C. Balch, and C. Line. 1958. Magnesium metabolism in the dairy cow, I. Metabolism in stall rations. J. Agric. Science 51:189-198.

Rook, J. A. F. and M. Wood. 1960. Mineral composition of fertilizer in relation to the development of hypomagnesoemia in grazing cattle. J. Science Food Agric. 11:137-143.

Sjollema, B. 1950. On the influence of the composition of pasture herbage on the production of dairy cows, and on the benefit of supplementing the grass with protein poor foods. J. British Grassland Soc. 5:179-194.

Smyth, P. J., A. Conway and M. J. Walsh. 1958. The influence of different fertilizer treatments on the hypomagnesaemia proneness of a ryegrass sward. Vet. Record. 70:846-849.

Storry, J. E. 1961. Changes in blood constituents which occur in dairy cattle transferred to spring pastures. Res. Vet. Sci. 2:272-284.

Swan, J. B. and N. D. Jamieson. 1956. Studies on metabolic disorders in dairy cattle III. The effects of after calving, underfeeding and of thyro-protein dosing on the level of serum magnesium in dairy cows. N.Z. J. Sci. (Tech.) A38:363-382.

Thomas, J. W. 1959. Magnesium nutrition of the calf, *in* Magnesium in Agriculture - A Symposium. W. Va. University, Morgantown, p. 131-153.

Tisdale, S. L. and W. L. Nelson. 1975. Soil Fertility and Fertilizers. Third ed., Macmillan Publishing Co. Inc., New York, NY.

Walsh, T. and T. F. O'Donahoe. 1945. Magnesium deficiency in some crop plants in relation to the level of potassium nutrition. J. Agric. Sci. 35:254-263.

Werner, W. 1959. The mineral content of young pasture fodder with special reference to the $\frac{K}{CA+MG}$ ratio. Landwirtsch Forsch. 12:133-139.

Wilkinson, S. R., J. A. Stuedemann, J. B. Jones, Jr., W. A. Jackson, and J. A. Dobson. 1972. Environmental factors affecting magnesium concentrations and tetanigenicity of pastures. Ch. 6 *in* Magnesium in the Environment, J. B. Jones, Jr., M. C. Blount and S. R. Wilkinson, eds. Taylor County Printing Co., Reynolds, GA.

Williams, J. N. and C. L. Parks. 1972. Grass tetany in cattle. Clemson University Extension Service Circular 533.

Wind, J., W. B. Deits, and A. Kemp. 1966. Jaarb. Inst. Biol. Scheik. Ondearz. landb. Gewass (1966) 1966:91-100 (Herb Abst. 37:1263 [1967]).