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GRASS TETANY: A REVIEW OF MG IN THE SOIL-PLANT-ANIMAL CONTINUUM[1]

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INTRODUCTION

Grass tetany is a metabolic disorder of ruminant animals that results from a deficiency of available Mg in the diet. The etiology of tetany is complicated by the many soil, plant, and animal factors that influence Mg availability to plants and in turn to animals. This review will highlight some of these factors and provide management information which will minimize the impact of this disorder. Only the most recent and pertinent literature citations are included. A more detailed bibliographic list is available from the authors.

SOILS AND PLANTS

Magnesium occurs as a component of minerals (non-exchangeable), as ions sorbed to clay surfaces (exchangeable), as a soluble component of the soil solution (soluble), and as a structural component of soil organic matter. A dynamic relationship exists between these forms or pools and the amount and rate of movement between each pool. Thus the amount of plant-available Mg is affected by soil type, soil age, parent material, soil acidity, liming, past cropping and fertilization management, and rainfall. The net result is that Mg concentrations in the soil solution range from about 0.4 to 30 mM.

Absorption of Mg into plant roots occurs by both passive and active uptake mechanisms and is influenced by both environmental and metabolic conditions (Rengel and Robinson, 1989b). Passive uptake occurs most readily at high soil Mg levels as Mg moves into plants through the transpiration stream. Active uptake of Mg, which is more important at low soil Mg levels and probably occurs to a lesser extent at high soil Mg levels, is dependent on energy from respiration in the roots. Respiration is especially dependent on an available oxygen supply in the soil; that is, on good drainage and air exchange with the above-ground atmosphere.

Temperature and moisture have a large influence on soil-plant-animal relationships involved in the development of grass tetany. Grass tetany is anticipated about 5 days after a sudden change in temperature and moisture conditions that promotes rapid forage growth. Cool-season grasses generally contain lower Mg concentrations when grown at lower temperatures, higher soil moisture levels and lower oxygen levels (Karlen et al., 1980; Kemp, 1983; Mayland and Grunes, 1979).

The critical Mg concentration for cool season grasses is 0.1% Mg or less, while the amount to prevent grass tetany is generally accepted to be 0.2% Mg. Magnesium deficiencies, which reduce

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plant growth, rarely occur as a result of a primary deficiency of Mg in the soil, but more often involve competing cations in the soil solution such as K, Ca, NH_4, H, and Al (Mayland and Grunes, 1979; Grunes and Welch, 1989; and Wilkinson et al., 1990). Unfortunately, the mechanisms of K, Ca and Mg uptake and translocation are not fully understood (Welch, 1986).

It is well established that Mg uptake is severely depressed by high NH_4 and K concentrations in soil and solution cultures. Magnesium uptake is also depressed by Al, H, and Mn in acid soils (pH < 5.5) and by high Ca concentrations in calcareous soils (Marschner, 1986; Mengel and Kirkby, 1987; Rengel and Robinson, 1989a). In contrast to cations that depress Mg uptake, NO_3 in soil solution stimulates Mg uptake. After Mg enters the plant roots, it must be translocated to plant shoots to be effective. Both K and Ca appear to restrict Mg translocation to plant shoots (Ohno and Grunes, 1985).

Potassium fertilization of cool season pastures enhances occurrence and incidence of hypomagnesemic grass tetany (Wilkinson et al., 1987b). The antagonistic effects of K on Mg concentrations in plant shoots occurs, not at the root, but at the root-shoot interface (Grunes and Welch, 1989 and Ohno and Grunes, 1985). Increasing K also tends to decrease Ca concentration in shoots. Excess Ca usually reduces Mg concentration, but much less than does K. The mechanism for Ca reducing Mg uptake is attributed to competition via mass action rather than to specific competitive effects (Rossi et al., 1988).

There is convincing evidence that soluble or exchangeable soil Al and Mn interfere with Ca and Mg uptake in many plant species (Wilkinson et al., 1990). The toxicity of both metals can be alleviated by adding Mg to the rooting media. An Al x Mg interaction at the animal level was suggested as a cause of grass tetany (Allen et al., 1986). Post-mortem analyses of rumen contents of cattle who died from grass tetany revealed very high Al contents. Others have shown that much of the ingested Al was associated with soil contamination of the herbage and that this Al was not available to the animal (Allen et al., 1986 and Robinson et al., 1984).

Nitrogen fertilization is generally associated with increased incidence of grass tetany. Nitrogen generally increases concentrations of crude protein, higher fatty acids, and organic acids and decreases water-soluble carbohydrate concentrations in forages, all factors that have been associated with lower Mg availability to animals (Mayland and Grunes, 1979; Wilkinson and Stuedemann, 1979; Kemp, 1983). Nitrogen fertilizers change both the botanical and chemical composition of forage swards, usually favoring grasses over legumes and forbs. This botanical shift results in forage with lower Ca and Mg and higher K concentrations.

Ammonium (NH_4) can be antagonistic to Mg uptake by plants, while NO_3 fertilization often enhances Mg uptake (Mayland and Grunes, 1979). An interaction can occur with NO_3 fertilization which may result in NO_3 stimulating K uptake which in turn reduces net Mg translocation to plant tops. Crop fertilization with acid-forming N fertilizers increases soil acidity, and enhances differential K, Ca, and Mg loss from the soil. Nitrogen fertilizer is required by pasture grasses in large amounts to stimulate growth and increase available spring grazing. Under conditions of high K availability in the soil, N fertilization can increase K absorption and shoot concentration, while under conditions of low K availability, N fertilization can decrease K absorption and shoot concentration, presumably by growth dilution. Concentrations of K and N are often correlated with each other, and the combination results in the higher negative correlations with cattle blood Mg levels than either alone (Wilkinson et al., 1987b). Nitrogen fertilization sometimes enhances uptake of other nutrients by increasing root growth, and root absorption in response to nutrient demand from the N stimulated growth.

Interpretive Summary

Hypomagnesemia, known as grass tetany in ruminants, is a commonly occurring mineral deficiency that occurs in temperate regions of the world. Reduction in weight gain and milk production are chronic symptoms while tremors, tetanic convulsions, coma and death are signs of acute deficiency. The economic impact is difficult to define, but 10% of grazing cows may experience chronic deficiencies and 1 to 3 % may die. Grass tetany is simply a deficiency of available magnesium to the animal, but in reality it is a very complex problem. Grass tetany involves factors that affect the solubility of soil magnesium, absorption and transport to plant shoots, absorption and loss by the animal, and most importantly, other factors that reduce the availability of magnesium to the plant and ultimately to the animal. This review of grass tetany identifies some of the interactions that reduce magnesium availability and provides management practices which will reduce losses. These include: splitting applications of nitrogen and potassium fertilizers, liming acid soils, draining and aerating wet soils, planting grass:legume mixtures where feasible, using grass varieties selected for low tetany-potential and supplementing animals with magnesium in salt mixes, molasses licks, in the drinking water, or by spraying on the forage, and by avoiding the grazing of lush, monoculture grass pastures by lactating cows during high risk periods.

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the forage. The required frequency of Mg application will depends on grazing intensity and rate of forage growth. Depending on other alternatives available, foliar application may be recommended for short term control in cases of severe grass tetany outbreaks.

CONCLUSIONS

It appears that grass tetany can be effectively overcome in humid regions by using agronomic management practices that are supported by good animal management. In drier, alkaline soil regions, which are less amenable to agronomic management practices, animal management remains the major means of controlling grass tetany.

Much is to be learned about the absorption and translocation mechanisms of Mg, Ca, and K in plants and animals. Expanded research is needed on ion antagonisms in soil, plant, and animal systems. Best management practices should be developed to economically produce quality forage to meet mineral requirements of ruminant animals. Information on genetic variability in ion uptake by both plants and animals needs to be assessed in a systems manner.

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that cows must have a frequent, preferably daily, intake of dietary Mg to meet tissue needs.

It is important that cows consume adequate quantities of dietary Mg to meet requirements for specific productive processes or functions. Blood Mg levels in cows normally range from 1.8 to 2.0 mg/dl and values near or slightly higher than 1.0 mg/dl reflect Mg deficiency. O'Kelley and Fontenot (1969 and 1973) determined that the Mg requirement of gestating beef cows ranged from 7 to 9 g/d (.10 to .13% of dry matter) and that lactating beef cows required from 18 to 22 g/d (.16 to .18% of dry matter intake). The primary loss of Mg via milk is reflected in increased dietary requirements of lactating cows.

Magnesium Supplements. Most Mg compounds included in dietary supplements are rather unpalatable to cattle and vary in percentage and bioavailability of Mg. Some compounds available for use in supplement formulation include Mg0, $Mg(OH)_2$, magnesium carbonate, magnesium chloride, magnesium sulfate, dolomite, and magnesium chelates.

The most commonly used Mg supplement is Mg0. Since Mg0 is unpalatable, it is commonly mixed with trace mineralized salt and such ingredients as cottonseed meal, dry molasses, steamed bone meal, dehydrated alfalfa meal, corn distillers dried grains, or ground corn (1:1:1) to increase intake. Effective, although not complete prevention of grass tetany can be achieved by free-choice feeding of these palatable supplements containing Mg. There are indications that the energy provided in these mixtures may increase Mg absorption. Providing the Mg source in a palatable, high energy supplement may, therefore, enhance the effectiveness of the supplied Mg by increasing its absorption as well as by increasing Mg intake.

The onset of clinical signs of grass tetany usually occurs when the animal is both hypomagnesemic and hypocalcemic (Kappel et al., 1983; Ritter et al., 1984). Animals that are only hypomagnesemic are less likely to exhibit clinical signs. The close relationships between Mg and Ca metabolism in ruminants suggest that maintenance of serum Ca is an important factor in the prevention of clinical grass tetany and that Ca in mineral mixtures may help prevent grass tetany.

Use of Magnesium Boluses. Magnesium alloy boluses designed to provide a slow release of Mg in the rumen have shown varying degrees of success in maintaining adequate serum Mg in cattle and sheep. The indications are that Mg boluses may provide protection to some animals that have marginally depressed serum Mg. However, due to slow and variable rates of bolus decomposition, they are less effective than palatable feed supplements, and usually provide a lower and less consistent degree of protection.

Supplying Supplemental Magnesium in Drinking Water. Magnesium added to drinking water as Mg chloride, sulfate, and acetate has effectively increased apparent absorption and retention of Mg, increased serum Mg levels, and prevented grass tetany. However, access to natural water sources must be eliminated. Also, a proportioner must be used or the Mg source mixed with a fixed volume of water at regular intervals. Tetany-producing forages such as wheat and ryegrass are high in water content during the winter and spring months. Thus, fluid water intake may be low when animals are grazing these forages. In cases of severe tetany outbreaks, altering management procedures to supply Mg in drinking water may be justified.

Foliar Applications of Magnesium. Application of a mixture of Mg0-bentonite-water to foliage has been effective in preventing hypomagnesemia and grass tetany for about 4 weeks (Wilkinson and Stuedemann 1979). However, rainfall greater than 4 cm removed the material from first grazing during the tetany season. In general, grasses tend to be most tetany-prone at immature stages of growth, even though forage Mg concentrations generally decrease with plant age (Cherney and Robinson, 1985).

Potassium fertilization at moderate levels, adequate for plant growth, generally have little effect on incidence of tetany (Kemp, 1983). Addition of N with K increases forage K concentration more than with applications of only N or K. Intensive management frequently includes both N and K fertilization. Spring K application usually decreases forage Mg concentration more than does fall applications (Lidgate, 1976). Large K applications should be avoided; instead, K should be divided into multiple, small applications, with most K being added after the grass tetany season. Rates of K application should be based on locally calibrated soil tests and forage K analysis, but kept at the lower end of the recommended ranges if grass tetany has been a problem. Keep in mind that very little K is removed from grazed pastures but large quantities of K are removed in hay and silage crops. Potassium fertilization practices should compensate K removal rates.

Nitrogen fertilization stimulates plant growth and nutrient uptake. Nitrogen will accentuate the grass tetany problem at high soil K levels and (or) low soil Mg levels. Yet, N fertilizers can help alleviate the problem if Mg is added to the soil. Various reports have shown that N fertilization increased forage Mg concentrations (Robinson et al., 1987). Mayland and Wilkinson (1989) reported that N and Mg fertilization effects were additive in increasing forage Mg concentrations.

The impact of N-fertilizer source on the incidence of grass tetany relates to the amount of NH_4- and NO_3-N in the fertilizer or to the rate of mineralization in the soil. Nitrate-N stimulates uptake of Mg more than does NH_4-N (Robinson et al., 1987). Urea is hydrolyzed to produce NH_4 in the soil. These sources generally increase forage concentrations of crude protein, Ca, and Mg. Ammonium nitrate increased herbage Mg concentration somewhat more than did urea. Soil acidification is a natural process that is increased by the use of NH_4-containing N fertilizers and by production of N_2-fixing legumes. Soil acidification lowers soil exchangeable Ca and Mg and increases exchangeable Al. These relationships underscore the need for a judicious liming program for acid soils as a part of the forage-livestock system. Smaller, more frequent N applications cause less variation in these forage components than do similar N rates applied infrequently. Applications should be made well before or following the tetany season.

Dolomitic lime is the primary material used to supply Mg to acid soils. The major Mg fertilizers used where lime is not required are Mg0 and Mg sulfate. In general, forage Mg concentrations have been increased at relatively low levels of Mg application on acid, sandy soils. In contrast, fine-textured or calcareous soils, require very high rates of Mg application to increase forage Mg concentrations, often making Mg fertilization impractical (Mayland and Wilkinson, 1989). Based on research with fine-textured soils in the Netherlands, Kemp (1983) concluded that Mg fertilization did not ensure adequate Mg for animals.

ANIMAL MANAGEMENT PRACTICES

Magnesium Requirements of Cows. Approximately 70% of the Mg in animals is found in the skeleton and the remaining 30% is associated with body fluids and soft tissues. Roughly one-third of skeletal Mg can be mobilized to meet soft tissue and body fluid needs when dietary intake does not meet requirements. However, it is believed that the quantity of skeletal Mg that can be mobilized under such conditions decreases with age of the cow. The non-labile nature of Mg reserves indicates

Mg. Shiga et al. (1980) reported that serum Mg was lower in lactating than non-lactating ewes. Bray et al. (1987) reported that ewes not supplemented with Mg were hypomagnesemic, but low serum Mg concentrations did not limit lamb growth suggesting that Mg level in the milk was maintained at the expense of body Mg. Milk production places a high demand upon physiological Ca and Mg. Xin et al. (1989) reported that milk fat percentage was increased in Holstein cows supplemented with MgO.

Stuedemann et al. (1983) found that supplementing cows with Mg increased 205-d calf weights and conception rates of angus cows grazing N-fertilized tall fescue. In order to maintain maximum production during times of peak production stress, adequate Mg must be supplied to prevent subclinical or clinical deficiencies of this mineral.

Diagnosis of Grass Tetany. Unfortunately, hypomagnesemia cannot be detected in cattle by visual appraisal. Serum Mg concentrations can become extremely low without any physical signs of a deficiency, and then, any acute excitement may trigger nervous tissue dysfunction to bring about the onset of tetanic contractions. Cows can appear apparently normal and then seriously ill or dead within a few hours (Whitaker, 1983). Some scenarios exist where hypomagnesemic cows may display symptoms in developing stages. At first, cows may appear anxious, and more attentive to an intruder's actions followed by more developed symptoms of aggression, staggering, listlessness and eventually exhibit a series of uncontrollable tetanic contractions. These symptoms may last for a few hours or days. Some cows may appear to improve in their condition, but once the cow is stressed enough to initiate the tetanic contractions it is unlikely that she will recover unless treated with an intravenous administration of Ca-Mg-P gluconate. Bacon and others (1990) concluded that rectal infusion with $MgCl_2.6H_2O$ was more effective for immediate response on plasma Mg, but oral dosing produced a more extended repletion of body Mg supplies.

Often cows will be treated for grass tetany (or Mg deficiency) when a true Ca deficiency exists. The physical symptoms are the same and a distinction between the two is impossible to determine without a serum Ca and Mg analysis. From our experience with cows grazing oats and other cool-season annuals at the McGregor Research Center at McGregor, TX, those that were treated for grass tetany were both hypocalcemic and hypomagnesemic. However, in cattle grazing cool-season perennial forages, this does not always appear to be the case.

MANAGEMENT PRACTICES

Effective management practices that overcome the incidence of grass tetany should be based on principles that control Mg uptake by plants and Mg availability to animals. These practices should influence processes involved in movement of Mg through the soil-plant-animal continuum. The primary objective is to produce forages containing at least 2.0 g Mg/kg of diet during the tetany season, and then to provide supplemental dietary Mg as needed (Robinson et al., 1989).

AGRONOMIC MANAGEMENT FACTORS

Forage Species and Forage Maturity. Grass tetany has occurred in ruminants grazing nearly all major cool-season (C-3) grasses, both annual and perennial. Legumes generally contain higher concentrations of Ca and Mg and lower concentrations of K than do grasses. Therefore, the use of grass-legume mixtures rather than pure grass swards has been a recommended practice in some grass tetany areas. Fall-planted clover pastures can be developed, with or without grasses, and saved for

Fertilization of spring cool season annuals or perennials with N and K results in an increased organic acid concentration (Grunes et al., 1970). Trans-aconitate is the main organic moiety found in the leaves of many cool-season grasses suggesting this compound may be involved with the onset of grass tetany. This is consistent with information presented by Russell and Mayland (1987). They found that ruminants fed forages containing trans-aconitate converted the trans-aconitate to tricarballylate which appeared in the circulatory system. Tricarballylate could potentially chelate Mg preventing it from becoming biologically active.

Higher fatty acids in the ingested herbage have been shown to decrease Mg absorption in dairy cows (Kemp et al. 1966; Wilson et al., 1969). A close association exists between forages of higher fatty acids and crude protein concentrations (Mayland and Grunes, 1979).

Genetic Factors. Greene et al. (1989) showed that apparent absorption of Mg varied among cows with Jersey, Holstein, Brahman, Angus and Hereford breeding. Apparent absorption of Mg (g/d) was lowest ($P < .05$) for European breeds and highest for Brahman and Brahman crosses. The overall mean apparent availability of Mg for straightbred and crossbred cows were 29.2 and 32.3%, respectively. These data suggest that heterosis improved apparent availability of Mg by 3 percentage units. The apparent availability of Mg paralleled apparent digestibility of Mg. Studies (Chirase et al., 1988 and Hardt et al., 1989) have found either no difference, or an increased efficiency in Mg utilization by Asian or Asian crossbreds when compared with European breeds.

Greene et al. (1989) reported on the incidence of grass tetany in a five-breed diallel herd with Angus, Brahman, Hereford, Holstein and Jersey ancestry. Breed-types containing Brahman breeding had the longest productive life span, whereas breed-types composed of 100% dairy breeds had the shortest. They estimated that the incidence of grass tetany in this herd was 1.1% annually during the years February 1980 to February 1984. During this 4 year period, 112 cattle were removed from the herd because of failure to rebreed for two consecutive years or because of other health-related problems. Of those removed, 26 died with symptoms resembling those of grass tetany. Expressed as a percentage of each breed group, cattle with Angus breeding had a higher ($P < .06$) incidence of grass tetany than Brahman, Hereford, Holstein or Jersey cattle. Cattle of Brahman breeding had a lower ($P < .10$) incidence of grass tetany than the other breed groups. No cases of grass tetany were reported in straightbred Brahman cattle, but seven cases were observed in the straightbred Angus cows.

Production Responses. Grass tetany is generally considered to be one of the leading causes of cow deaths in the U.S. In addition, hypomagnesemia and hypocalcemia conditions result in production losses such as decreased forage intake, decreased growth, decreased milk yield and subsequent reduction in calf weaning weights, all related to the inefficiency of energy metabolism in animals with Mg deficiencies as discussed by Fontenot et al. (1989).

Hardt et al. (1989) reported a significant positive correlation was found between serum Ca concentrations and milk yield ($r^2 = .49$; $P < .05$) in Hereford × Holstein cows. However, at weaning (7 mo post parturition) a negative correlation occurred between serum Ca concentrations and milk yield for Hereford (-.46; $P < .05$) and Hereford × Holstein (-.79; $P < .01$) cows. As milk-production potential is maximized, there is a greater demand for calcium. During late gestation Ca is secreted at the expense of circulating levels of Ca.

Serum Mg was negatively correlated with milk yield ($r = -.47$; $P < .10$) at weaning in Hereford × Holstein cows, suggesting that cows secreted Mg in the milk at the expense of serum

ANIMALS

Magnesium is important in animal metabolism where it functions to stabilize biological membranes, serves in many enzyme systems representing every major metabolic pathway, and serves in important physiological functions (Fontenot et al., 1989). A deficiency of magnesium results in various biochemical and physiological responses, few of which are clearly defined. A subclinical deficiency of this mineral is evidenced by a decline in energy metabolism (Fontenot et al., 1989; Matsunobu et al., 1990). This may occur without animals showing any specific clinical symptoms and results in hidden losses to production.

There is no apparent endocrine system regulating Mg homeostasis within the body. However, Mg absorption and excretion are closely associated with parathyroid hormone (PTH) levels and circulating 1,25-dihydroxycholecalciferol (vitamin D). Goff et al. (1986) suggested that the renal threshold for Mg excretion is under PTH control. Schneider et al. (1985) suggested that Mg absorption may be enhanced by vitamin D. Many scientists have recognized the close association between Mg and Ca in biological fluids and in many cases, hypomagnesemic animals are also hypocalcemic. Similar physical symptoms occur in both hypocalcemic and hypomagnesemic animals and a clinical distinction between the two is impossible without serum analysis.

Dietary Factors. Evidence exists to show that the primary site of Mg absorption in ruminants is the preintestinal area (Greene et al., 1983a,b; Wylie et al., 1985). Several dietary factors have been shown to affect the efficiency and extent of Mg utilization in ruminants. Nitrogen and K fertilized forage may decrease Mg absorption from the digestive tract. Stuedemann et al. (1983) used Angus cows grazing on low-, moderate- and high-N tall fescue and found that during a 7-year period, 1970 to 1977, 0, 9, and 14 cases of grass tetany occurred in cows grazing in the three pastures, respectively. Although direct feeding of non-protein nitrogen did not decrease Mg absorption in lambs (Moore et al., 1972), Martens and Rayssiguier (1980) indicated that NH_3 affects Mg absorption due to an acute rise in ruminal NH_3 concentration. Potassium has been shown to directly lower the absorption of Mg in ruminants (Greene et al., 1983a,b,c). The main effect of K on Mg absorption has been shown to occur in the preintestinal region (Greene et al, 1983b,c). Greene et al. (1983 a,c) showed that increasing dietary Mg intake from .1 to .2% increased Mg absorption by 94% in the presence of increasing dietary K concentrations.

Johnson and Powley (1990), in a recent study of Mg metabolism in lactating goats, reported that the high apparent-availability of Mg in their grass diets, was significantly depressed ($P < .05$) when the intake of K was high; but was not significantly different when a high intake of K was accompanied by a high intake of Na. The actual mechanism by which a high K intake or a Na deficiency exert their inhibitory effect on Mg are not yet well understood (Leonhard et al., 1989).

Aluminum has been linked to the etiology of grass tetany (Allen et al. 1986). However, any clear and precise mechanism of involvement has not been presented. Soil contamination on herbage contributes to dietary Al intake. Some soils serve as a source of available Mg (Grace and Healy, 1974). Hurley et al. (1990) recently reported that smectite, a colloidal clay, significantly increased the apparent absorption of Mg from .96 g/day to 1.96 g/day in lambs. The clay-containing diet shifted the major site of Mg absorption from the preintestinal region to the intestinal region of the digestive tract.

Liming acid soils can help overcome the incidence of grass tetany in three important ways. First, raising the soil pH, even with calcitic lime, can increase Mg uptake by plants (Rengel and Robinson 1989a), probably as a result of decreased exchangeable Al in limed soils. Secondly, liming acid soils with Mg-containing materials not only increases soil pH but also supplies additional Mg which is available to plants. Finally, decreasing soil acidity creates more favorable conditions for legumes, resulting in higher forage Ca and Mg and lower K concentrations. Recommended liming rates are highly variable among soils and crops, but soil pH should generally exceed 5.5 to minimize Al activity in the soil solution and to optimize forage yield and mineral concentrations. Lime should be applied according to soil test results 3 to 6 months prior to the grass tetany season. It should be incorporated into the soil for best results.

Many reports indicate that Mg concentrations of perennial grasses are higher in summer and fall than in spring (Wilkinson, 1983). However, this seasonal effect may be caused at least in part by variation in tissue physiological age. Seasonal increases in Mg concentration over the season are greater than changes brought about by Mg fertilization. In perennial cool season grasses, higher levels of exchangeable soil Mg or fertilizer Mg are required to increase Mg levels in early spring growth than in summer growth.

Plants grown at warmer temperatures usually have higher Mg concentrations than when grown at lower temperatures (Grunes and Welch 1989). Changing temperatures from cool to warm increased concentrations of K, Ca and Mg, with the greatest increase occurring in K, and in increasing K/(Ca+Mg) molar ratios (Mayland and Grunes 1979; Cherney and Robinson, 1985). The greatest change in nutrient concentration occurred when temperatures increased from 18/13 to 24/18C. These findings were corroborated by wheat pasture work of Bohman et al., 1983. Magnesium concentration in grasses from the Himalayan grasslands was negatively correlated with rainfall (-0.58) and temperature (-0.50) (Singh and Mishra 1987).

Differences in Mg concentration are found between plant genera, plant species, and cultivars or lines within a specie. Magnesium and Ca concentrations are higher in legumes and herbs than in grasses (Mayland and Grunes 1979, Wilkinson et al., 1990). Potassium, Ca, and Mg concentrations as well as K/(Ca+Mg) ratios are often lower in C4 forage species than C3 forage species (Blevins, 1983). Grass tetany does not occur on C4 grasses when they are actively growing (Wilkinson et al., 1987a). Genetic variation in Mg concentration in herbage has been measured in several C3 grasses, and progress toward producing genotypes with more favorable K, Ca and Mg composition has been made (Sleper et al., 1989). It should be noted that the Mg in different species, is not equally available to grazing animals (Powell et al., 1978).

Moseley and Griffiths (1984) developed a high Mg cultivar of Italian ryegrass which, when fed to sheep indoors, showed a higher Mg intake and bioavailability (Moseley et al., 1989). The ewes grazing the high Mg cultivar had an incidence of hypomagnesemia of 2.5% with recovery in all cases, while those grazing a low Mg cultivar had a hypomagnesemia incidence of 21% with 16% of those resulting in fatalities. However, the high Mg cultivar did not prevent tetany since ewes with low blood Mg, regardless of grass, received Mg intravenously and all ewes were dosed with Mg alloy bullets to prevent death losses.