8-1979

Mineral composition and yield of tall fescue as affected by ammonium and nitrate nitrogen fertilization

Charles M. Finley

To the Graduate Council:

I am submitting herewith a thesis written by Charles M. Finley entitled "Mineral composition and yield of tall fescue as affected by ammonium and nitrate nitrogen fertilization." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant, Soil and Environmental Sciences.

Gary M. Lessman, Major Professor

We have read this thesis and recommend its acceptance:

John H. Reynolds, R. J. Lewis

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

To the Graduate Council:

I am submitting herewith a thesis written by Charles M. Finley entitled "Mineral Composition and Yield of Tall Fescue as Affected by Ammonium and Nitrate Nitrogen Fertilization." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant and Soil Science.

Gary M. Lessman

Gary M. Lessman, Major Professor

We have read this thesis and recommend its acceptance:

John H Reynolds

Russell J. Lewis

Accepted for the Council:

L Evans Roth

Vice Chancellor
Graduate Studies and Research

MINERAL COMPOSITION AND YIELD OF TALL FESCUE AS AFFECTED BY AMMONIUM AND NITRATE NITROGEN FERTILIZATION

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Charles M. Finley

August 1979

ACKNOWLEDGEMENTS

I wish to express my sincere gratitude and appreciation to the following persons:

Dr. G. M. Lessman, my major professor, for his patience, continued interest, and capable advice during various phases of this study.

Dr. John H. Reynolds and Dr. R. J. Lewis for serving on my graduate committee.

Dr. Vernon H. Reich for his advice and guidance on the statistical portion of the study.

Dr. Maxwell E. Springer, Dr. W. L. Parks, and Dr. R. J. Lewis for advice and use of laboratory equipment during the course of the study.

Dr. David L. Coffey for his assistance with the greenhouse portion of the study. Appreciation is also extended to the Plant and Soil Science Department faculty as a whole, since every person in the department assisted in the study in some fashion.

Special appreciation is extended to Dr. F. F. Bell for his encouragement, interest, and advice during the author's course of study. Appreciation is also extended to Dr. Lloyd Seatz, Department Head, for his guidance in the early portion of the author's course of study.

Paul Denton, John Holowid, and John Zinn, with whom I shared my office, for their friendship, advice, and assistance. Special thanks to Paul Denton for his assistance in the collection of the soil for the experiment and in the harvesting of the forage.

My parents and other members of my family, friends, and roommates for their concern and assistance.

ABSTRACT

A greenhouse experiment was conducted with tall fescue (*Festuca arunidacea* Schreb.) to evaluate the effects of NO_3 and NH_4 fertilization on mineral composition, yield and components related to grass tetany potential. A nitrification inhibitor [2-chloro-6-(trichloromethyl)-pyridine] was used to slow the conversion of NH_4 ions to the NO_3 form.

In the experiment a factorial combination of three levels of N; 34, 67, and 134 kg N/ha; three levels of K; 56, 112, 224 kg K/ha; two levels of Mg; 0 and 112 kg Mg/ha; at two soil pH levels; pH 5.2 and 6.2; was evaluated with and without a nitrification inhibitor. Two cuttings of plant material were analyzed for Mg, Ca, K, total N, and NO_3-N.

The use of a nitrification inhibitor such that primary N fertilization was from the NH_4 form was found to lower Mg, Ca, and NO_3-N concentration of first cutting forage. However, N in the NH_4 form increased Ca and K in the second cutting. The ratio of K/(Ca + Mg) was not affected at the chosen probability level by the NH_4 form of N fertilization. Total Mg uptake by forage was reduced when the NH_4 ion was the primary form of available N. Yield was not affected by NH_4 fertilization in either of the two cuttings, but was lowered when combined yield data were statistically analyzed.

First cutting forage grown at the 224 kg rate of added K/ha, at the 0 kg/ha rate of added Mg, with NH_4 as the primary form of N, contained Mg concentrations below 0.20%. Also in the first cutting, forage

contained less than 0.20% Mg when grown at pH 5.2, at the 0 kg/ha rate of Mg, and with the 67 and 134 kg/ha rates of N fertilization.

Addition of the higher levels of K used in the experiment increased K concentration and the K/(Ca + Mg) ratio of forage while lowering Mg concentrations in both cuttings. However, K concentrations were not high enough to limit Mg availability to animals as some authors have suggested. The ratio of K/(Ca + Mg) did not approach or exceed 2.2 in any cutting.

The addition of Mg at the 112 kg Mg/ha rate was found to increase Mg concentration but did not significantly affect K/(Ca + Mg) ratios.

Fertilization with the higher levels of N increased total N concentration of both cuttings, with total N being higher in the first cutting than the second. In neither cutting was total N concentration great enough to decrease Mg availability to animals consuming the forage.

First cutting results revealed higher NO_3-N levels in forage from pots receiving No_3-N as the primary form of N fertilization when compared to the NH_4 form. Levels of NO_3-N did approach or exceed the 0.35% level some have suggested as toxic to animals consuming forages in a few treatments.

An increase in soil pH from 5.2 to 6.2 significantly lowered the K/(Ca + Mg) ratio in the first cutting and increased forage Mg concentration in both cuttings.

TABLE OF CONTENTS

LIST OF TABLES

TABLE PAGE

TABLE PAGE

CHAPTER I

INTRODUCTION

Tall fescue (*Festuca arundinacea* Schreb.) is a widely grown forage grass in Tennessee and the Southeast. Of the estimated five million acres of pasture grown in Tennessee, three million acres are believed to be composed mainly of tall fescue.

Investigations have shown that additions of fertilizer are needed if quality forage and high yields are to be obtained from tall fescue pastures. Investigators have also found that the chemical composition of tall fescue may vary widely under different climatic and fertilization regimes. The chemical composition may be important not only in the growth of the forage itself, but may also affect the health of animals consuming the forage.

Hypomagnesaemia, or grass tetany, is a metabolic disorder which may result when ruminants consume forage with low magnesium (Mg) content or availability. Grass tetany has been identified as an animal health problem in the Southeast, as well as other areas of the United States of America, and in other nations. The disorder has most commonly been associated with ruminants consuming forage from pure grass pastures in the spring under conditions of rapid growth and cool temperatures. Given that Tennessee has approximately three-fifths of its total pasture acreage in tall fescue, the opportunities for grass tetany occurring in Tennessee are numerous.

The objectives of this study were: (1) to investigate the possibility that ammonium-nitrogen (NH_4-N) nutrition of tall fescue may have a depressing effect on Mg content of forage as compared to Mg content under conditions of nitrate-nitrogen (NO_3-N) nutrition, and (2) to investigate the possibility that certain interactions between cations may have an antagonistic effect upon Mg content of tall fescue. The possibility that NH_4 as the major source of nitrogen for plant growth may decrease Mg content of tall fescue was of greatest concern.

Five factors and their interactions were evaluated as they affected dry matter yield, grass tetany hazard as indicated by the equivalent ratio K/(Ca + Mg), amount of Mg contained in harvested forage, concentrations of Mg, calcium (Ca), potassium (K), NO_3-N, and total N. The factors evaluated were N form (NO_3 versus NH_4), K rate, pH, Mg rate, and N rate.

CHAPTER II

LITERATURE REVIEW

I. INTRODUCTION

Magnesium is an essential constituent of chlorophyll and as such is essential for all green plants. Salmon (1963) pointed out that the functions of nonchlorophyll Mg are not clearly established, but it is believed to be involved in cell turgor and enzymatic reactions. Included among the enzymatic functions are some of the reactions involving decarboxylation, carboxylation, and hydroxylation, but primarily those of group transfer involving phosphate participants are believed involved.

The Mg content of different plants and plant parts have been shown to differ considerably. Beeson (1941) reported the Mg content of the vegetative parts of field crops may range from 0.04 to 0.54% for cereals and grasses, 0.13 to 0.75% for clovers, 0.26 to 1.07% for sugar beet (*Beta saccharifera*), and 0.44 to 2.74% for cigar tobacco. Seeds usually contain more and roots less Mg than the leaves and stalks.

Magnesium deficiency in plants may occur, especially on the sandy, low cation exchange capacity soils of the Coastal Plain area of the Southeast. Jones (1974) suggested that Mg deficiency may occur in many plants when the leaf level is less than 0.15%. The primary exception Jones cited was small grains, where the Mg level may be as low as 0.10% without being deficient. Magnesium deficiency in corn (*Zea mays* L.) may occur when the level in the leaf is less than 0.13%, while legumes and peanuts (Arachis hypogaea L.) should contain 0.25 to 0.30% Mg to avoid deficiencies. Cotton (Gossypium sp.) and vegetable crops may need as much as 0.50% Mg, since these crops have high Mg requirements. Magnesium is a fairly mobile element in the plant and therefore deficiency symptoms usually occur first in older tissues.

Magnesium concentrations above the level considered as essential for plant growth may at times cause health problems in animals consuming the forage from low Mg containing plants.

II. GRASS TETANY

Grass tetany, hereafter referred to as tetany, is a metabolic disorder of ruminants which has been known for over 100 years. Cases have been reported in cattle, sheep, and goats. Females are mainly affected, especially when pregnant or when lactating. Sjollema (1932) related the problem to low serum Mg in 1928, but the problem had been identified in lactating dairy cattle in the Netherlands and Belgium prior to his work. The disorder is often referred to as hypomagnesaemia or hypomagnesmic tetany. In New Zealand the disorder is called grass staggers.

The symptoms of tetany, according to Murdock et al. (1975), may at first resemble milk fever. The animal may walk stiffly or stagger, the animal's appetite may decrease, and it may develop a dull appearance. It is not uncommon for the animal to isolate itself from the herd, and as the disorder progresses, the animal may become nervous and exhibit muscle tremors and rapid breathing. The animal may also develop a tendency to fight. As the disorder becomes advanced, the animal will collapse, go into convulsions, and die. These disorders may progress quickly, and, unless treated, death can occur less than an hour after the onset of visible symptoms.

Grunes (1967a) cited statistics which show that over 10,000 cattle have been lost in California and Nevada due to tetany in recent years. Tetany is more commonly found in animals grazing grass during the spring, or to a lesser degree, fall. Losses have been reported in Georgia, Mississippi, South Carolina, Tennessee, Kentucky, Maryland, Utah, Wyoming, Idaho, Oklahoma, and Texas.

In the southern United States, tetany may occur when wheat (Triticum aestivum) (wheat pasture poisoning), rye (Secale cereale), and oats (Avena sativa) are used as green pastures. Tetany has also been a problem in northern Georgia when tall fescue pastures have been heavily fertilized with broiler litter as Wilkinson et al. (1971) reported.

Murdock et al. (1975) reported that a survey conducted by the University of Kentucky Extension personnel during the winter and spring of 1971, 1972, and 1973 indicated that tetany is a serious problem for beef producers in some areas of Kentucky. Economic losses due to death of cattle were estimated in excess of 1.5 million dollars during the study period. In 1973, 1.1% of the beef cow population was estimated to be affected.

Hansard et al. (1975) expressed the opinion that reduced vigor due to impaired metabolism, decreased milk output, and subsequent reduced calf growth and vigor may be more serious than economic losses due to clinical cases of tetany.

III. SPECIES VARIATION IN MAGNESIUM CONTENT

Lessman (1972) summarized work done by Embleton (1966), Jacob (1958), and Todd (1961) which indicated that the Mg levels of various crops are quite different. Of the forage species, the grasses were found to be lower in Mg than the clovers and other legumes.

Mayland et al. (1976) reported tetany hazard for small grains pasture could be expected to follow the order wheat > oats = barley > rye. Wheat was found to have lower Ca and Mg levels but higher K, N, ash alkalinity, and higher fatty acids than other small grains when grown in the greenhouse.

Clark (1975) reported that Mg uptake of corn inbreds varied greatly. Elkins et al. (1978) found that cultivars of tall fescue varied greatly in Mg content when grown under controlled environmental conditions in the greenhouse. Species and cultivar variation in Mg content suggests that selection for Mg accumulators may prove successful in the future.

IV. SEASONAL INFLUENCE

Kemp and 't Hart (1957) reported a definite "grass tetany period" in the spring and autumn in a summary of a long term study carried out in the Netherlands. They related the seasonal fluctuations to periods in the spring and autumn when the daily mean temperature fell below 14° C. They also reported short term fluctuations. Five days after the mean daily temperature rose above 14° C, the number of cases of tetany were reported to increase, with the converse also being true.

Tetany cases were reported during the entire summer, according to 't Hart (1960), during cold, wet years. 't Hart (1960) concluded that when temperatures are low and other conditions are favorable for grass growth, tetany is more likely to occur. Tetany hazard was also reported to be greater in years with sudden, quick growth of grass in the spring than in those years with poor growth. He also suggested that tetany occurs more frequently under conditions of ample moisture and is less likely in very dry or very wet pastures. Frequently, however, cases of tetany in the autumn are associated with wet seasons.

Reith (1963) reported work which indicates the Mg content of various plant species does vary with season. There was little seasonal effect on the Mg content of clovers; however, grasses increased in Mg content as the season progressed from spring to summer. The variation in Mg content of various plant species may greatly affect pasture Mg content at a particular season of growth. Growth of cool season grasses usually surpasses that of clovers and legumes in late winter and early spring. He found the lowest Mg content of grasses occurred in early spring, which would indicate that even mixed grass and clover pastures may be prone to tetany in early spring.

Miller (1965) reported that recently tetany has been a major problem of the beef cattle industry in Georgia. The typical case occurs during the months of December to March, and involves a five to seven year old cow nursing a calf while consuming small grains pasture.

Singer et al. (1958) have worked on tetany in the state of Kentucky. Animals were reportedly hypomagnesmic, hypocalcemic, and hypocupremic, and in addition had high levels of K, P, nonprotein N, and urea N in the blood serum.

Cairney (1964) reported between 0.2 and 3.9% average incidence of presumed tetany in 477 herds studied. Animal losses were associated with wet, cold weather.

Cases of tetany have been reported in beef cattle grazing crested wheatgrass (Agropyron desertorum) pastures during the spring in Nevada, Idaho, and Utah according to Grunes et al. (1973).

Hannaway and Reynolds (1976) noted a seasonal change in Mg content of tall fescue under different levels of N fertilization. The field grown forage was higher in Mg during the summer months than in the cooler months under the same N fertilization levels.

Reynolds et al. (1971) reported higher NO_3- N and protein N concentrations in April harvested orchardgrass (Dactylis glomerata L.) forage when compared to later harvested forage grown in the field. Higher concentrations of K were also reported in April forage than in the forage from late spring and summer. They speculated that high levels of protein N and NO_3-N were a response by the plants to cooler weather during April.

V. BLOOD SERUM LEVELS IN ANIMALS

As stated by Grunes et al. (1970), "the work of several investigators indicates that cattle are generally severely hypomagnesmic when the Mg in the blood serum is about 10 ppm or less."

Burns and Allcroft (1967) indicated that the level of Mg in the blood serum commonly falls within a few days after cows are turned out to pasture on rapidly growing young grass in the spring. They concluded that two-thirds to three-fourths of the animals showing symptoms of tetany have both low serum Ca and Mg.

Suttle and Field (1969) reported tetany symptoms when they fed animals a diet low in Mg and high in K. They found that Mg concentration in the blood plasma was lowered not only by reduced Mg in the forage, but also by increasing K intake.

Stress may also play an important role in expression of tetany symptoms. Hjerpe and Brownwell (1966) reported that animals which were shipped had lower blood serum Mg levels after shipping than when measured before shipping.

Smyth et al. (1958) found that treatment of ryegrass (*Lolium multiflorum* Lam.) pastures with N only or K only did not render the forage more tetany prone. A combined dressing of N plus K, however, resulted in a highly significant decline in serum Mg values followed by the onset of tetany.

VI. SOILS

As outlined by Salmon (1963), the Mg in soils is mainly contained in silicate minerals, with smaller amounts occurring in exchangeable and water soluble forms. Also, some Mg may be present as Mg carbonates. Salmon diagrammed the relationship between the various forms in soils as follows.

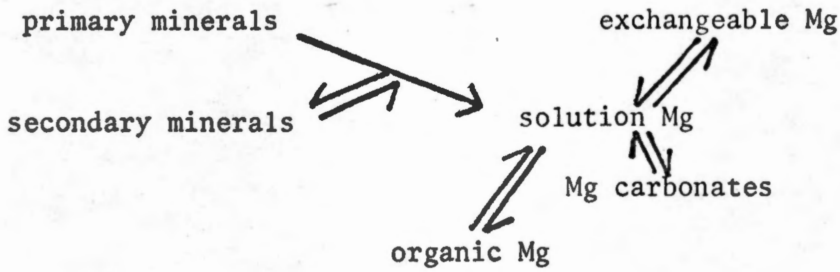

Figure 1

Plants obtain their Mg from the exchangeable and solution phases, but release of Mg from silicate minerals is important in replenishing losses from the exchangeable and solution phases due to leaching and crop removal.

Beeson (1959) reported that Mg deficiency in plants occurs quite often on the sandy soils of the Atlantic and Gulf Coast Plans of the United States, but also occur on the finer textured soils of the Midwest. He speculated that continuous cropping and heavy fertilization with materials containing no Mg may be partially responsible.

Salmon (1964) reported high correlations (r = 0.99) between the concentration of Mg in ryegrass grown in a greenhouse and a ratio involving ion activites of Mg, Ca, and K in equilibrium solutions. Salmon and Arnold (1963) also cited a high correlation (r = 0.99) between initial exchangeable Mg, and Mg uptake in a greenhouse study in which soils were exhaustively cropped.

Rice and Kamprath (1968) reporting results from research with corn on sandy Coastal Plain soils, found that Mg uptake was closely related to initial exchangeable Mg. However, a major portion of the Mg absorbed by the plants came from nonexchangeable forms. They speculated that hydrogen (H) ions exchanged from the roots may have been active in releasing nonexchangeable Mg.

Felbeck (1959) suggested 10% of the total cation exchange capacity as an ideal amount of exchangeable Mg for soils to contain. When the exchangeable Mg falls below 10% of total exchange capacity or less than 112 kg/ha, Felbeck suggested that Mg fertilization was needed. Horvarth and Todd (1968) suggested 10 to 15% of the exchange capacity, or not less than twice the exchangeable K percentage, as the level of Mg saturation for good plant growth. A Ca/Mg ratio of five to one was also recommended by Horvarth and Todd as the highest ratio of Ca to Mg that would not be expected to cause Mg deficiency in plants.

Adams et al. (1967) reported that exchangeable soil Mg in all soil depths down to 91 cm was reduced when coastal bermudagrass [Cynodon dactylon (l) Pers.] growing on Cecil loam received annual applications of NH_4NO_3 fertilizer. The same investigators referred to research by Abruna et al. (1958) and Pearson and Abruna (1961) which indicated that exchangeable bases are leached from the soil surface when high rates of acid forming N fertilizers are applied.

Grunes et al. (1970) cited work by Hooper (1967) who found that Mg concentration in field grown forage decreased as soil pH increased. Hooper also suggested that herbage Mg concentration was more highly correlated with the exchangeable Mg/K ratio in the soil than with the Mg/Ca ratio, Mg as a percentage of the cation exchange capacity, Mg as a percent of the total exchangeable cations, or with total Mg extracted.

Graham et al. (1956) stated that yields were increased when Mg fertilization was used on 11 of 15 soils in a greenhouse study. Soybean (Glycine max L.), Ladino clover (Trifolium repens L.), and wheat were used as test crops. Yield increases due to Mg additions were found on soils with less than 10% Mg saturation of the cation exchange capacity.

Lombin and Fayemi (1975) found deficiency symptoms in corn when the two week old plants contained 0.11 to 0.15% Mg. Persistent deficiency symptoms were associated with 0.10% Mg in the plants, 21 to 22 ppm exchangeable Mg in the soil, or less than 5% Mg saturation of the cation exchange capacity.

VII. MINERAL LEVEL IN THE FORAGE

Although the incidence of tetany can be related to low Mg concentration in the forage, symptoms are sometimes not observed, even though Mg concentration in the forage is low. Kemp (1960) found that no cases of clinical tetany occurred at blood serum Mg levels above 9 ppm or when the herbage contained Mg levels above 0.19%. Thus, 0.20% Mg in the oven dry forage was established as the "safe" level for Mg content of forages.

Kemp (1960) also found that at each level of Mg in the forage, an increase in the K or crude protein in the forage decreased the blood serum Mg level, and increased the likelihood of tetany. He also reported that low concentrations of Mg in the blood serum, along with cases of tetany, were observed when the forage contained between 0.17 and 0.20% Mg, but K and total N averaged 3.88 and 3.79%, respectively.

Metson et al. (1966) found that on New Zealand pastures where tetany cases had been reported, K concentrations in the forage averaged 3.29%, while N concentrations averaged 5.28%. In these same pastures, the Mg concentration in the forage averaged 0.19%. Metson and his associates suggested that when K concentrations in the forage are high, Mg levels may have to be well above 0.20% to prevent tetany. Metson reviewed work by Todd and Morrison (1964) which suggests that a "safe" level in forage may be as high as 0.25% or higher.

Cummins and Perkins (1974) stated that Mg content of field grown millet (Pennisetum glaucum) and sorghum-sudan crosses [Sorghum bicolor (L.) Moench] was inversely related to the K content of the plant.

Kemp and 't Hart (1957) reported that when the ratio of K/(Ca + Mg) in forage was less than 2.2, there were very few tetany cases. However, when K/(Ca + Mg) ratios had a value greater than 2.2, the incidence of tetany increased. Burns and Allcroft (1967) quoted Seekles (1964), who stated that, although statistical data supported the hypothesis that there exists a relationship between tetany occurrence and the ratio of K/(Ca + Mg), data obtained from many years of research in the Netherlands does not substantiate this theory.

de Groot (1970) stated that on experimental farms in the Netherlands which use high rates of N fertilizer, 0.45% Ca and 0.35% P are considered the lower limits for forages. Furthermore, he suggested that the Ca/P ratio should be close to 1.5.

VIII. SOIL TEMPERATURE AND OXYGEN LEVEL

Reith (1963) observed that Mg concentration in grasses was higher in the summer. McNaught et al. (1968) found the same effect and also stated that K concentrations did not differ to any great extent in cool or warm weather. Grunes (1967b) found that crested wheatgrass grown in the growth chamber at 10° C was much lower in Ca and Mg concentrations than those plants grown at 20° C. Grunes also reported an effect of temperature on K concentration, such that the ratio of K/(Ca + Mg) was higher at the lower temperature. Grunes (1967b) and Grunes et al. (1968) stated that similar effects of temperature, lower Ca and Mg with high K, when perennial ryegrass (Lolium perenne) was grown in sand culture.

Dijkshoorn and 't Hart (1957) conducted experiments on the effect of temperatures of 10° C versus 20° C as it affected regrowth of perennial ryegrass, after 24 hours in the greenhouse. Plant Mg, Ca, and K concentrations were lower at 10° C than at 20° C. Plants grown for a 16 day period at 10° C and then transferred to a 20° C environment, had higher ratios of K/(Ca + Mg) than plants grown at 20° C continuously. In another experiment, Dijkshoorn and 't Hart grew perennial ryegrass at 10° C and then transferred the plants to a 20° C compartment. Plants were sampled at intervals following the transfer. The K concentration increased rapidly during a 10 day period and then decreased slightly. The K/(Ca + Mg) ratio increased and later decreased, which may explain why tetany occurs when a period of cool weather is followed by higher temperatures.

Elkins and Hoveland (1977) reported on their investigations into the effects of soil oxygen and temperature on the tetany potential of three annual forage species. In their experiments increasing soil oxygen had little effect on Ca or Mg content of rye forage. Increasing soil oxygen did, however, increase K content from 2% to 5%, and increased the K/(Ca + Mg) ratio to over 4. Rye also responded to temperature, with forage grown at 10° C containing less K, Ca, and Mg than that grown at 16° C. Italian ryegrass forage, however, responded to higher soil oxygen with greater concentrations of Ca, Mg, and K. The content of K, Mg, and Ca in Italian ryegrass forage was lower at 12° C than at 16° C. Italian ryegrass contained Mg concentrations below the critical 0.2% when grown at 16% or less soil oxygen, and at 12° C temperatures. Soil oxygen had little effect on the composition of arrowleaf clover (_Trifolium vesiculosum_ Savi), except for a small increase in K content. These results suggest that Italian ryegrass forage, grown on poorly drained soils, would be more likely to induce tetany than forage grown on well-drained soils.

Elkins et al. (1978) reported results from a field experiment in which tall fescue was grown under different soil drainage regimes. The cultivar Kentucky 31 contained Mg levels from 0.18 to 0.25% when grown on poorly drained areas, whereas nearby well-drained areas produced forage with 0.27 to 0.40% Mg. They concluded that poor drainage may contribute to some soils being more tetany prone and may be a contributing factor in the production of tetanogenic tall fescue forages.

Gross and Jung (1978), in a greenhouse study, observed that legumes responded to Mg fertilization over a wider range in temperature than grasses. They also reported greater accumulation of Mg when temperate origin forage species were grown under cool autumn conditions rather than cool spring conditions. Lower K/(Ca + Mg) ratios were reported when grasses were grown under cool autumn conditions than when the same grasses were grown under similar conditions in the spring.

IX. NITROGEN

Kemp (1960) reported that high concentrations of N or crude protein in the forage decreased the level of Mg in the blood serum, which increased the likelihood of tetany. Metson et al. (1966) in his review of the literature dealing with this matter, pointed to high protein and low energy in animal diets as a possible cause of low blood serum Mg. Metson speculated that another possible cause of low blood serum Mg, when forage high in N is fed, could be that a buildup of rumen ammonia occurs which interferes with Mg absorption due to an increase in rumen pH.

Metson et al. (1966) reported higher levels of nonprotein N in "grass tetany" pastures. Metson quoted Lavor and Guegén (1963), who reported a negative correlation between nonprotein N in the forage and Mg levels in the blood serum. Lowrey and Grunes (1968) reported N content of forages from 4.1 to 5.0% from N fertilized rye forage grown at Tifton, Georgia, in January and February. Such high values would lead to expectations of low Mg availability in the forage.

Kemp et al. (1966) speculated that N fertilization of grasslands may produce increases in the higher fatty acids in the forage, and may result in the formation of insoluble Mg soaps which render Mg unavailable to the animal.

Wilcox and Hoff (1974) speculated that NH_4 nutrition of spring grasses may lead to tetany in ruminants. Not only were NH_4 sources of N suggested as a possible cause for reduced Mg content by plants, but in addition, the NH_4 ion was suggested as a possible agent in reduced availability of Mg in the rumen.

Nielsen and Cunningham (1964) cited a decrease in Ca and Mg concentration and uptake in grasses given NH_4 as the N form instead of the No_3 form. Gasser et al. (1967) found that when NH_4 is the only form of N, growth of grass is adversely affected. Mulder (1956) reported decreased Mg content of wheat and oats grown on acid soils in the greenhouse which received $(NH_4)_2SO_4$ as their N form. Sodium or Ca $(NO_3)_2$ when used as the N form did not produce Mg deficiency. Ammonium nitrate was intermediate in its effect on Mg deficiency of the plants. Wheat grown in field experiments produced similar Mg levels as was observed in greenhouse experiments. Mulder associated NO_3 nutrition of the plant species studied with greater Mg content. Mulder suggested that the NH_4 ion and the H ion may compete with the Mg ion in such a way that an antagonism toward Mg uptake and forage content may result.

Wolton (1960) expressed the opinion that when there is no deficiency of Mg, N applied to pure grass swards or predominantly grass swards increases the Mg content of the herbage. Wolton also reported that well nodulated clover pastures did not respond in yield or Mg content when fertilized with N fertilizers. The use of N fertilizers on mixed pastures was suggested as a possible cause of lower total Mg in the mixed herbage, due to the depressing effect of N on the clover population.

Wolton (1960) also reported that the effect of N may vary with the N source used. Ammonium sulfate was found to lower Mg levels in the forage when compared to NH_4NO_3. The effect due to $(NH_4)_2SO_4$ was attributed to the antagonistic effect of the NH_4 ion, and to a lowering of soil pH over a period of time.

X. FERTILIZATION

Researchers have found that Mg deficiency symptoms of plants may occur when Mg in plant tissues falls below 0.10% of the oven dry weight. This is considerably lower than the minimum 0.20% Mg discussed earlier with relation to tetany in ruminants.

Lowrey and Grunes (1968) investigated the effect of fertilization on the Mg content of rye grown on coarse textured soil in the greenhouse. They reported that K fertilization decreased the content of Mg in the plants. Additions of Mg and K increased Mg in the forage. Potassium fertilization decreased Ca content of the plants, as did additions of both Mg and K together. Potassium fertilization increased the K content of harvested forage, but K content was not affected appreciably or predictably by additions of Mg. The ratio of K/(Ca + Mg) was increased by K additions, but Mg additions did not affect the ratio due to decreases in Ca concentrations.

Schwartz Kafkafi (1978) reported that the Mg content of corn was not affected by K applications at low fertility levels. However, Mg concentrations were reduced by K additions at high levels of N and P fertilization.

Seatz et al. (1958) observed a depressing effect on the Mg content of snap beans (Phaseolus vulgaris L.) at higher levels of K fertilization. Magnesium content was increased by Mg fertilization, but no yield increase was reported due to Mg fertilization.

Foy and Barber (1958) reported low Mg levels in corn when grown on an acid, sandy soil with additions of K. Yield was not reduced by the low levels of Mg, however. Addition of Mg prevented deficiency symptoms, increased the concentration of Mg in the leaves, and reduced the K concentration in the leaves, but did not affect yield.

Hannaway and Reynolds (1976) stated that K fertilization significantly decreased the Mg concentration of tall fescue forage harvested in winter and early spring.

Boswell and Parks (1957) reported that corn grown in the field showed increased K content with increased rates of K fertilization. Maximum K content was observed during the early stages of growth. Calcium and Mg decreased at a given stage of growth as the rate of K fertilization increased. Potassium, Ca, and Mg increased with age of the plant at the lower K levels, but remained essentially constant throughout the life of the plant at the highest K level.

Investigations by Follett et al. (1975) indicated that N fertilization of bromegrass (Bromus inermis L. cr. 'Lincoln') increased the yield of forage but also increased the tetany potential. Fertilization with NH_4NO_3 increased the total N and K content of the forage, and the ratio of K/total cations in the forage. As the ratio of K/total cations in the forage increased, the Mg/total cations and Ca/total cations ratios decreased. Also, the ratio of K/(Ca + Mg) was reported to increase.

Mayland and Grunes (1974) found that Mg fertilization and N fertilization were additive in increasing forage Mg concentrations of crested wheatgrass. Mayland et al. (1975) also reported that N fertilization increased the concentration of forage Mg and Ca more than it increased K concentrations of crested wheatgrass. The increased Mg content relative to the increased K slightly reduced the K/(Ca + Mg) ratio when compared to unfertilized forage. Dietary benefits of higher Mg concentration in the forage may have been offset by increased concentration of K, N, and higher fatty acids, since these parameters are often associated with decreased availability of Mg to animals consuming the forage.

Follett et al. (1977) used bromegrass to study tetany potential as affected by N, K, and P fertilization, as well as N source and clipping frequency. Forage yields were increased two or three fold by N fertilization. The NO_3 form of N generally outyielded the NH_4 form. Forage Mg content was decreased slightly by K or NH_4 N form. Total K, ratio of K/(Ca + Mg), and total N were increased by N fertilization. Increased hazard of tetany was indicated due to N fertilization.

McClean and Carbonell (1972) found evidence that increased Mg saturation of the cation exchange capacity increased the Mg content of plant tissues. At the same time, however, soil K levels were found to have a depressing effect on plant Mg as the soil K level was raised.

The effect of higher soil K levels was found to be more important in lowering Mg than was the effect of increased Mg saturation in raising plant Mg levels. They suggested 12 to 15% Mg saturation of the cation exchange capacity as a sufficient level for soils used to grow grass for ruminants.

Welte and Werner (1963) investigated K-Mg antagonisms using pot experiments in sand cultures. They reported that the H ion in high concentrations depressed Mg uptake most seriously. On strongly acid substrates it was not possible to completely correct Mg deficiency unless lime was applied. Welte and Werner also found that raising pH by liming was more effective in improving Mg uptake and plant growth than were additions of Mg without correcting pH. In addition, it was found that the depressing effects of different cations on the Mg uptake and content of the forage are additive, such that the K-Mg antagonism is more pronounced at lower pH levels. This effect was demonstrated in an experiment using oats grown on an acid, sandy soil deficient in Mg.

Usherwood and Miller (1967) grew corn in a greenhouse experiment in which a fine sandy loam was used as the growth medium. They reported an increase in soil pH from 5.3 to 6.7 significantly decreased the uptake of Mg by corn from soil treated with coarse and finely ground dolomitic limestone. However, the pH level had no effect on Mg uptake from soil treated with magnesium sulfate.

Todd (1967) reported that fertilization with Mg at the rate of 340 kg/ha gave control of tetany by raising forage Mg levels for three to four years on coarse textured soils. However, Todd also stated that on fine textured soils, much larger applications would be needed to raise forage levels appreciably. He also speculated that unless Mg cost per unit is low, the addition of Mg would only be practical on coarse textured soils.

Adams (1975) reported a yield response with cotton to added Mg but not with corn or peanuts when grown on sandy soils with low available Mg. Adams also suggested that 25 pounds per acre or more exchangeable Mg is sufficient on sandy Coastal Plain soils for plant growth.

Dantzman (1976) reported higher Mg content of pangola digitgras (Digitaria decumbens Stent.) when grown on plots limed with a mixture of calcitic and dolomitic limestone than that grown on unlimed plots. Total Mg removed by the forage was also greater for lime treated plots.

Chambers and Gardner (1951) found that additions of lime increased plant size, decreased the concentration of manganese (Mn) in the plant, and increased concentration and total Mg in the plant. Calcium and K concentration were almost unaffected, although the total content was greater due to more total plant material.

Brown et al. (1976) suggested that forage Mg concentration can be maintained at high levels without loss of yield by delaying topdressed fertilizer, including N, until May.

Allcroft and Burns (1968) reported that $MgSO_4$ was less effective than calcined magnesite for top dressing pastures. The ease with which $MgSO_4$ is leached and storage problems were cited as main deterrents to its use.

Burns and Allcroft (1967) reviewed literature on additions of Mg to soils and concluded that Mg additions are most effective on coarse textured, acid soils. They also speculated that although dolomitic limestone is less effective than calcined magnesite, it has one redeeming feature, that of lower price.

Some researchers have been successful in increasing the Mg concentration of forages through use of dusts and solutions containing Mg. These dusts and solutions raise the level of Mg consumed by animals when applied to the plant leaves and stems. Such applications do not increase plant content of Mg, but do increase total Mg in animal diets. Allcroft and Burns (1968) reported that weather conditions are a major deterrent to the use of solutions and dusts, since heavy rains may wash solutions or dusts off. They also reported that dry, windy weather made applications difficult and may also remove the powder.

Todd and Morrison (1964) showed good results when as little as 19 kg/ha of Mg as calcined magnesite was used on pastures low in Mg. Treated pastures contained 0.31% Mg while grass harvested from untreated pastures contained an average of 0.16% Mg.

Horvarth and Todd (1968) advised dusting of small grains pastures in Texas, Oklahoma, Georgia, and Mississippi when low Mg levels were suspected and suggested that silage and hay could be fortified with Mg by adding MgO.

XI. NITRIFICATION

For the purposes of this study, nitrification will be considered in a somewhat limited scope, as the oxidation of NH_4 to NO_3 with NO_2 as an intermediate in the conversion. The two dominant genera associated with soil nitrification are Nitrosomonas and Nitrobacter, both being classified in the family Nitrobacteriaceae, of the order Psuedomonadales, according to Alexander (1965).

Nitrosomonas and Nitrobacter, the nitrifying autotrophs, have often been used as examples of beneficial soil bacteria. More recently, some detrimental effects of nitrification have been identified. Perhaps lack of nitrification should be cited as detrimental, since plant nutrition may be affected by the differences with which the NH_4 and NO_3 ions are assimilated. McCants et al. (1959) reported beneficial aspects of NO_3 sources of N as compared to the NH_4 source in cases where nitrification had been inhibited by fumigation.

Nitrification may result in greater losses due to leaching, since the anionic form is more readily leached than the cationic form. If nitrates generated during nitrification are not incorporated into plant tissues or assimilated by microorganisms, the nitrogen present in the NO_3 form may be leached below the rooting zone of plants.

Nitrification is important in other ways, not the least of which is the acidification of the soil environment. From ammonium sources the net reaction is as follows:

$$NH_4^+ \dashrightarrow NO_3^- + H_2O + 2H^+$$

The use of ammonium fertilizers leads to an increase in the H ion concentration, which eventually retards the activities of the nitrifying bacteria unless additions of lime are made. Alexander (1965) pointed out that the nitrifying bacteria stand out in their sensitivity to pH. However, nitrifying bacteria have been recovered from soils with a pH of 4.0, according to Alexander (1965).

Aeration is of great importance in the nitrification process since the nitrogen autotrophs are obligate aerobes. Alexander (1965) pointed out that the reduction of NO_3 and NH_4 is favored by a deficiency of oxygen. Amer and Bartholomew (1951) and Grechin and Ch'eng (1960) found that the optimum oxygen level for the soil air with respect to nitrate production is similar to that found in the atmosphere. Alexander (1965) reported that very high or very low oxygen levels suppress the nitrifying organisms.

Alexander (1965) stated that many researchers have documented the sensitivity of nitrifying organisms to temperature, with increasing temperature favoring the oxidation of NH_4 to NO_3. The optimum temperature for nitrification appears to be in the range of 30 to 35° C. Alexander (1965) stated that nitrates do not often appear above 40° C. Slow but significant oxidation of NH_4 to NO_3 does occur at 2° C. according to Frederick (1956). It appears, therefore, that some nitrates are formed until the soil temperature falls below the freezing point. Tyler et al. (1959) pointed out that the oxidation of NH_4 is more sensitive to low temperature than the mineralization sequence which produces NH_4. This would lead to speculation that NH_4 levels may be highest in the soil when temperatures are low enough to suppress nitrification, but do not retard mineralization to the same degree.

Alexander (1965) reported that although nitrates are not readily formed at low moisture levels, the mineralization of N may proceed under the above mentioned conditions, giving rise to high NH_4 concentrations. Robinson (1957) found that lack of oxidation under conditions of excess moisture may also increase NH_4 concentration since nitrification is retarded to a greater extent than mineralization. Alexander (1965) stated that, in general, the nitrifying population is most active when the soil moisture holding capacity is at half to two-thirds of its maximum.

The season of the year has often been related to the activity of the nitrifying bacteria. Alexander (1965) suggested that the season effect is a combination of several factors, including nutrient availability, temperature, moisture status, and soil aeration.

As a matter of speculation, conditions for optimum nitrification would most likely occur in late spring to fall in the Southeast. Conversely, low temperatures and waterlogged soils which are typical of winter and early spring in the Southeast would be expected to reduce the activity of the nitrifying bacteria. High rainfall levels tend to occur in the winter and early spring in the Southeast, and considerable leaching occurs during this period. Under the above conditions, NH_4 ion concentrations would tend to be high, especially if early applications of ammonium fertilizers are made before soil temperature, oxygen levels, and high rainfall are optimum for nitrification. These same conditions of low soil temperature, low soil oxygen, and high rainfall are most often associated with greatest incidence of tetany.

XII. NITRIFICATION INHIBITORS

Many investigations have been made to determine the effects of inhibitory substances on the autotrophic nitrifying bacteria. Goring

(1962a) and others have advocated the use of 2-chloro-6-(trichloromethyl)-pyridine known by the trade name "N-Serve" as a nitrification inhibitor. The chemical is selective in its action and does not exhibit phytotoxicity. This compound suppresses the N autotrophs, but not sulfur, iron, or photoautotrophs as reported by Shattuck and Alexander (1963). The concentration of the chemical which is effective in controlling the autotrophic nitrifying bacteria varies from 0.05 to 20 ppm, depending on the method of application, soil pH, and soil organic matter content, according to Goring (1962b).

CHAPTER III

MATERIALS AND METHODS

I. GENERAL INFORMATION

This greenhouse study was conducted at the University of Tennessee Agricultural Campus at Knoxville. A randomized incomplete block design with two blocks per replication was selected as the experimental design. A factorial arrangement of treatments was selected with three replications of the 72 treatments used in the experiment. Complete confounding of all fourth order interactions with block effects was used in each replication.

The site chosen as a source of soil for the experiment consisted of Dickson Silt Loam, uneroded, with a slope of 2 to 5%. The Dickson Series is a member of the fine-silty, siliceous, thermic family of Ochreptic Fragiudults. The area chosen was wooded and had a mixed vegetation of deciduous hardwoods. No recent history of cropping was known. Some chemical and physical properties of the material removed from the site are reported in Appendix A. With the permission of the Highland Rim Experiment Station Superintendent, Mr. Lawson Safley, a quantity of soil was removed from the site, bagged, and transported by truck to Knoxville in late August of 1977.

II. PREPARATION OF GREENHOUSE POTS

The mixed topsoil and subsoil removed, hereafter referred to as soil, was screened through a plastic screen which had one opening per linear centimeter to remove roots, stones, and extraneous material. The soil was thoroughly mixed several times and stored in a wooden bin. Samples from the bin were taken at various points and depths. These samples were extracted for Ca, Mg, K, and P by the dilute double acid or "North Carolina" method as described by Page (1965). The pH of these samples was determined using a 1:1 soil to water ratio and utilizing a pH electrode as described by Jackson (1958). Analyses indicated that the material was thoroughly mixed and sufficiently homogenous for the purposes of the experiment. Results are reported in Appendix A.

Reagent grade $(NH_4)_2SO_4$, $MgSO_4$, K_2SO_4, $Ca(H_2PO_4)_2$, and $CaCO_3$ were used to adjust pH and nutrient levels. Levels used are outlined in Appendix B. Nitrification was inhibited by 2-chloro-6-(trichloromethyl)-pyridine, also known by the trade name "N-Serve." For each pot 3,600 g of air dry soil was weighed and placed in a twin shell soil mixer. Calcium carbonate and $Ca(H_2PO_4)_2$ which had been previously weighed on an analytical balance were added, and the soil plus reagents were allowed to mix for five minutes. The amended soil was then placed in a number 10 metal can, which had been previously lined with a polyethylene liner of appropriate size. Each can was struck sharply to settle the soil in the liner and pot, and given an identification number. At the completion of a replication, each pot received 500 ml of deionized distilled water to speed reaction of the reagents and equilibrium of pH.

Stock solutions of $MgSO_4$, KCl, $(NH_4)_2SO_4$, and 2-chloro-6-(trichloromethyl)-pyridine were prepared. The solutions were pipetted into cups in the appropriate amounts and the contents were added to each pot. Approximately 250 ml of deionized distilled water was added to aid in distribution of the solution through the soil. When the soil had dried sufficiently, the contents of each pot was removed, thoroughly mixed by hand, and returned to the container. During the mixing operation five ppm in addition to the original treatment of 2-chloro-6-(trichloromethyl)-pyridine were added to insure control of nitrification in those pots receiving NH_4 as the primary source of N.

On February 3, 1978, each pot was planted with 50 seeds of "Kentucky 31" tall fescue. A filter paper was placed on the soil surface to reduce crusting and each pot received approximately 125 ml of deionized distilled water. Pots were thinned to 30 plants per pot on February 13.

Since 2-chloro-6-(trichloromethyl)-pyridine has been shown to decrease in effectiveness with respect to nitirfication control after thirty to forty days, additions of the chemical were made to insure proper inhibition of nitrification. An additional five ppm were added on March 8, with an additional 10 ppm being added on April 14 to those pots receiving NH_4 as the primary N form.

III. ENVIRONMENTAL CONTROL

After thinning, each pot was brought to weight with distilled water. All watering prior to the first cutting on April 12 was accomplished by weighing pots and bringing each pot to weight with distilled water. A moisture release curve, the values of which are outlined in Appendix A, was used to determine the proper weight based on moisture tension. Pots were checked daily by observation, and some pots were weighed to determine the appropriate time for watering. On one occasion after the first cutting the plants did receive some tap water in small amounts due to moisture stress, but were brought to weight the following day and thereafter with distilled water.

Temperature control was accomplished through use of a water drip evaporation exhaust fan system during periods of high temperature. Air temperature data are presented in Appendix C. No attempt was made to reduce air temperature other than when air temperatures exceeded 27° C. Supplemental heating was used such that in most cases night air temperatures did not dip below 16° C.

IV. HARVEST PROCEDURE

On April 12 and May 17 the first and second cuttings of the tall fescue plants were taken. Each pot was clipped uniformly at four centimeters from the soil surface. Harvest was begun after 9:30 a.m. and concluded by 5:00 p.m. to insure typical NO_3-N content of the plant tissues. One replication was harvested before beginning another. Clippings were collected and funneled into previously weighed and numbered paper bags. At the completion of the harvest of one replication, the bags containing the clippings were placed in a mechanical convection oven and dried at 70° C for 24 hours, cooled, and weighed on an analytical balance. Harvest was begun and completed on the same day.

The dried samples were ground in a Wiley mill, using a 30 mesh screen and then stored in sealed plastic bags until analyzed.

V. LABORATORY ANALYSIS OF PLANT TISSUES

Tissue samples were analyzed for N concentration by a modification of the procedure of Thomas et al. (1967) and a portion of the digestate was analyzed on the Technicon Autoanalyzer. Results are presented as percent N on a dry weight basis.

Nitrate nitrogen concentration in the harvested plant tissue was determined using a modification of the NO_3 electrode method as described by Paul and Carlson (1968) and modified by Raveh (1973). Results are reported as percent NO_3-N on a dry weight basis.

Tissue samples were digested by a modification of the wet digestion procedure outlined by Steckel and Flannery (1971). The digestates were analyzed for Ca, Mg, and K by use of a Perkin Elmer 372 atomic absorption spectrophotometer. Atomic absorption was used for the determination of Ca and Mg, while K was determined by flame emission. Results are reported as percent Mg, Ca, and K on a dry weight basis.

VI. LABORATORY ANALYSIS OF SOIL SAMPLES

Extractable Ca, Mg, K, and P were extracted by the "North Carolina" method (0.05 N HCl in 0.025 N H_2SO_4) as described by Page (1965). Calcium, Mg, and K were analyzed by atomic absorption on a Perkin Elmer 372 atomic absorption spectrophotometer. Phosphorus was determined colorimetricly by the NH_4VO_3 reaction described by Steckel and Flannery (1971) for use on a Technicon Autoanalyzer.

Soil pH values were determined on one to one soil to water suspensions with a glass electrode in conjunction with a potentiometer, as outlined by Jackson (1958).

Cation exchange capacity was determined for six soil samples taken from the bulk soil bin, as sorted prior to amendment. The procedure used was described by Busenburg and Clemency (1973) and utilizes an NH_4 electrode in conjunction with a digital pH meter in millivolt mode. The results are presented in Appendix A.

The percent moisture by weight held at one third bar tension and one bar tension was determined by a modification of the porous plate method as described by Richards (1949). Results are presented in Appendix A.

Particle size distribution was determined by a modification of the pipette method as described in Soil Survey Investigations Report No. 1 (1967). Results are presented in Appendix A.

VII. STATISTICAL METHODS

Plant tissue analysis data and treatment levels were recorded on computer cards. Analysis of variance was conducted on an individual cutting basis, with the exception of yield data which were analyzed for each cutting as well as combined. The ANOVA procedure outlined by Barr et al. (1976) for use with SAS 76 was used to partition the sum of squares associated with main effects, interactions, and error times.

Nonhomogeneity of error variances was detected by Hartley's test, and therefore individual error variances were used to test main and interaction effects. In cases which revealed a significant F test, means were separated using Duncan's Multiple Range Test. Unless otherwise noted, all tests of significance were conducted at $\alpha \leq .05$.

Mean values of all treatments for both cuttings are presented in Appendix D. It should be remembered that all fourth order interactions were completely confounded with block effects.

CHAPTER IV

RESULTS AND DISCUSSION

Each component, constituent, or comparison of plant composition will be presented and discussed on an individual basis. Each cutting will be discussed individually, if differences between cuttings exist.

I. MAGNESIUM

The Mg concentration of the first cutting forage was reduced as a result of supplying fescue with the NH_4 form of N (Table 1). This agrees with the work and theories of Mulder (1956), Wolton (1960), and Nielsen and Cunningham (1964). The NH_4 and K ions have very similar hydrated radii; therefore, it is possible that the depression in tissue Mg content often associated with the K ion would also be observed under conditions of NH_4 nutrition.

Second cutting forage did not exhibit significantly reduced Mg concentration due to NH_4 nutrition when tested at the 0.05 level of probability, but it was reduced significantly at the 0.10 level. The reduced Mg concentration due to NH_4 nutrition will prove of interest in later discussions.

Several investigators including Seatz et al. (1958), Foy and Barber (1958), Lowrey and Grunes (1968) and Mayland and Grunes (1974) have reported increased Mg content of forage due to Mg fertilization. Results of both cuttings of the forage agree with the findings of these researchers.

Table 1. Magnesium concentration of first and second cuttings as affected by N form, rates of Mg, K, N and ph level.

Treatment	Rate (kg/ha)	Level	Mean Mg Content[1] 1st Cut (%)	2nd Cut (%)
NO_3	-		0.27 a[2]	0.34 a
NH_4	-		0.23 b	0.31 a
Mg	0		0.22 b	0.28 b
	112		0.28 a	0.37 a
K	56		0.27 a	0.39 a
	112		0.25 b	0.33 b
	224		0.24 c	0.26 c
N	34		0.26 a	0.31 c
	67		0.25 a	0.33 b
	134		0.25 a	0.34 a
ph Level		5.2	0.22 b	0.29 b
		6.2	0.28 a	0.36 a

[1]Dry matter basis.

[2]Values within a column in the same section of the table that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

Both first cutting and second cuttings also contained lower Mg due to increased levels of K fertilization. Reith (1965) reviewed the work of several authors and reported similar results. It is interesting to note that Mg content of the forage was reduced by a larger amount due to increased K in the second cutting than in the first cutting.

The second cutting contained a higher Mg concentration due to N fertilization. Investigations by Wolton (1960), Mayland and Grunes (1974), and Mayland et al. (1975) support such results. Since plants were grown in metal pots with plastic liners, both plant roots and added N were confined to the pots. Examination of soil cores taken during sampling of pots for soil determinations revealed roots had penetrated to the bottom of the pots. Differences in total root weight or volume cannot be ruled out, but great differences seem unlikely.

The soil pH level effect detected in the first and second cutting is supported by the investigations of Welte and Werner (1963) and Dantzman (1976). Competition by H and Al ions may explain the reduced Mg concentration by plants grown in low pH soil. It is also of interest that the second cutting contained higher Mg levels than did the first cutting at comparable pH levels.

Reduced Mg content of the first cutting due to the first order interaction involving N form and K rate was detected (Table 2). Obviously NH_4 nutrition reduced Mg content of forage at each level of K rate when compared to the NO_3 form of N. The rate of K fertilization reduced Mg content of forage over a wider range when NO_3 was the dominant form of N rather than the NH_4 form. It would seem that the effects of

Table 2. Magnesium concentration of first cutting as affected by the interaction of N form and K rate.

N Form	K Rate (kg/ha)	Mean Mg Content[1] (%)
NO_3	56	0.29 a[2]
	112	0.26 b
	224	0.25 c
NH_4	56	0.25 c
	112	0.23 d
	224	0.23 d

[1]Dry matter basis.

[2]Values within a column that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

the K ion and the NH_4 ion were at least additive. The Mg content of forage grown at the lowest K level with NH_4 nutrition was not significantly different than that of forage grown at the highest K level under NO_3 nutrition. The effect of monovalent cations has been shown to be antagonistic, with high levels of monovalent ions tending to depress plant uptake and content of divalent cations. Thus, under NH_4 nutrition the level of monovalent cations in the soil solution is increased and the level of divalent cations such as Mg in the plant tissues may be depressed.

In the second cutting, a significant first order interaction involving K rate and pH level was detected. Forage grown at pH 5.2 was lower in Mg content than forage grown at pH 6.2 (Table 3). It is likely that the combination of higher H ion concentration plus the K ion reduced Mg content due to competition and antagonism of the divalent Mg cation. Forage Mg content was also lower at each level of K fertilization at either pH level. This effect might be due to simple antagonism and competition by the monovalent K cation on uptake of the divalent Mg cation.

In the first cutting, a second order interaction involving N form, Mg rate, and K rate revealed an interesting effect (Table 4). Under NH_4 nutrition a greater decline in Mg content was observed at the 112 kg/ha level of K fertilization, when Mg was added at the rate of 112 kg/ha than when Mg was not added. Further increases in K level slightly increased Mg concentration of the forage when the 112 kg/ha rate of Mg was added, but Mg content declined when Mg was not added.

Table 3. Magnesium concentration of second cutting as affected by the interaction of K rate and pH level.

K Rate (kg/ha)	pH Level Approximate	Mean Mg Content[1] (%)
56	5.2	0.35 c[2]
56	6.2	0.43 a
112	5.2	0.30 d
112	6.2	0.37 b
224	5.2	0.24 f
224	6.2	0.28 e

[1]Dry matter basis.

[2]Values within a column that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

Table 4. Magnesium concentration of first cutting as affected by the interaction of N form, Mg rate and K rate.

N Form	kg/ha Mg	kg/ha K	Mean Mg Content[1] (%)
NO_3	0	56	0.26 ed[2]
	0	112	0.23 f
	0	224	0.22 fg
	112	56	0.33 a
	112	112	0.30 b
	112	224	0.28 c
NH_4	0	56	0.21 g
	0	112	0.21 g
	0	224	0.19 h
	112	56	0.29 bc
	112	112	0.25 e
	112	224	0.26 d

[1]Dry matter basis.

[2]Values within a column that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

This effect was observed only when the NH_4 form of N was supplied. Also of interest is the lower Mg concentration of forage grown at the 224 kg/ha rate of K with the NH_4 form of N, without Mg fertilization. This caused the tissue to fall below the 0.20% level suggested by Kemp (1960) as being critical with respect to tetany hazard.

In the first cutting, a second order interaction involving Mg rate, N rate and pH level was identified as significant (Table 5). Nitrogen at the rate of 134 kg/ha decreased Mg concentration when forage was grown in pots at pH 6.2 with Mg fertilization at the rate of 112 kg/ha. Without added Mg, the same increase in N rate from 34 to 134 kg/ha had no significant effect on the Mg content of forage grown in pots at pH 6.2. The lowest Mg concentration with Mg fertilization is also higher than the highest Mg concentration without added Mg. Forage grown at pH 5.2 with Mg at the rate of 112 kg/ha showed no decrease in Mg concentration due to N rate. However, forage grown at pH 5.2 without added Mg decreased in Mg concentration as the level of N increased from the 34 to 67 kg/ha level. It is also of interest that Mg concentration of forage grown at the zero level of Mg rate, at the lower pH level, and at the two highest levels of N rate fell below the 0.20% level. The high Mg rate apparently offset the effects of low pH and added N as these factors affected Mg concentration at the lower pH level. Without added Mg, the effects of low pH and N rate diluted the Mg concentration of the forage. Examination of yield data from the first cutting reveals higher dry matter yield due to N rate increases at the lower pH level.

Table 5. Magnesium concentration of first cutting as affected by the interaction of rates of Mg, N and pH level.

Added Mg (kg/ha)	Added N (kg/ha)	pH Level	Mean Mg Content[1] (%)
0	34	5.2	0.20 d[2]
0	34	6.2	0.26 c
0	67	5.2	0.18 e
0	67	6.2	0.26 c
0	134	5.2	0.17 e
0	134	6.2	0.26 c
112	34	5.2	0.25 c
112	34	6.2	0.32 ab
112	67	5.2	0.26 c
112	67	6.2	0.32 ab
112	134	5.2	0.26 c
112	134	6.2	0.29 b

[1]Dry matter basis.

[2]Values within a column that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

II. CALCIUM

The effect of N form was not consistent in affecting Ca concentration from cutting one to cutting two (Table 6). The NH_4 form of N depressed Ca concentration of harvested forage in the first cutting but increased Ca concentration of the forage harvested in the second cutting. The depression of Ca concentration due to NH_4 fertilization in the first cutting agrees with the work of Nielsen and Cunningham (1964) and Kershaw and Banton (1965). Increased Ca content of the second cutting harvested forage due to NH_4 fertilization might lead to speculation as to the efficacy of the nitrification inhibitor. The author has no clear explanation for this inconsistency. The Mg concentration of second cutting harvested forage although not depressed significantly by NH_4 fertilization at the chosen level of probability was significantly depressed at the 0.10 level. Also the Ca concentration of first cutting was higher than that of second cutting.

The reduced Ca concentration of the first cutting due to the lower soil pH may be attributed to lower Ca concentration in the soil solution as well as competition by H ions.

The results of the second cutting revealed a significant interaction between N form and pH (Table 7). The NH_4 form of N promoted higher Ca concentration than the NO_3 form of N at pH 5.2. Since no differences in Ca concentration due to N form were detected at pH 6.2, the higher Ca concentration of NH_4 grown forage was due primarily to the pH level X N form interaction at pH 5.2.

Table 6. Calcium concentration of first and second cuttings as affected by N form and pH level.

Treatment	Mean Ca Content[1] 1st Cut (%)	2nd Cut (%)
N Form (NO_3)	0.64 a[2]	0.46 b
(NH_4)	0.58 b	0.50 a
pH level 5.2	0.52 b	0.45 b
6.2	0.70 a	0.51 a

[1]Dry matter basis.

[2]Values within a column in the same section of the table that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

Table 7. Calcium concentration of second cutting as affected by the interaction of N form and pH level.

N Form	pH Level	Mean Ca Content[1] (%)
NO_3	5.2	0.41 c[2]
	6.2	0.51 a
NH_4	5.2	0.48 b
	6.2	0.52 a

[1]Dry matter basis.

[2]Values within a column that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

Differences in Ca concentration were also detected due to the interaction of N form, Mg rate, and K rate in the second cutting (Table 8). Lower Ca concentration in forage was observed in pots receiving the NH_4 form of N, 112 kg/ha of Mg, and 112 kg/ha of K when compared to equivalent pots receiving the NO_3 form of N. The effect of N form can also be observed when Mg at the rate of 112 kg/ha was applied, and K was increased from the 112 kg/ha to the 224 kg/ha rate. Under the influence of the NO_3 form of N, the Ca concentration decreased while under the above mentioned conditions and the NH_4 form of N, Ca concentration increased. It would appear that the NO_3 form of N encourages greater Ca uptake under some circumstances than does the NH_4 form due to a possible competition with the divalent Ca cation. However, at the highest rate of added K, the N form effect becomes masked by Ca concentration depression due to higher K levels.

The second cutting interaction of N form, Mg rate and N rate produced significant differences in Ca concentration of the forage (Table 9). Magnesium at the rate of 112 kg/ha depressed Ca concentration under NO_3 nutrition when added N was applied at the 67 and 134 kg/ha rates. Under NH_4 nutrition, no differences in Ca concentration were detected due to added Mg at any rate of N. Increased Ca concentration of NH_4 treated plants was greater than Ca concentration of NO_3 treated plants at most rates of N and Mg. One exception was that of NO_3 versus NH_4 nutrition when Mg was not added and the highest rate of N was applied. This result might be due to the depression of Ca by the monovalent NH_4 cation which would be present in highest concentrations at the highest N rate. Possibly under NO_3 nutrition, Mg depresses Ca

Table 8. Calcium concentration of second cutting as affected by the interaction of N form, Mg and K rate.

N Source	Mg (kg/ha)	K (kg/ha)	Mean Ca Content[1] (%)
NO_3	0	56	0.64 ab[2]
	0	112	0.62 abc
	0	224	0.64 ab
	112	56	0.63 abc
	112	112	0.67 a
	112	224	0.60 bc
NH_4	0	56	0.59 cd
	0	56	0.62 abc
	0	224	0.60 bc
	112	56	0.57 cd
	112	112	0.51 d
	112	224	0.61 abc

[1]Dry matter basis.

[2]Values within a column that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

Table 9. Calcium concentration of second cutting as affected by the interaction of N form, Mg and N rates.

N Form	kg/ha Mg	N	Mean Ca Content[1] (%)
NO_3	0	34	0.49 bcd[2]
	0	67	0.47 d
	0	134	0.51 abc
	112	34	0.48 cd
	112	67	0.41 ef
	112	134	0.40 f
NH_4	0	34	0.54 a
	0	67	0.54 a
	0	134	0.42 ef
	112	34	0.53 a
	112	67	0.52 ab
	112	134	0.44 e

[1]Dry matter basis.

[2]Values within a column that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

concentration due to an increase in Mg concentration of the forage. The NH_4 form of N may depress Ca less than Mg, such that under NH_4 nutrition Ca content tends to be greater. Environmental conditions such as temperature of the soil and the light intensity may be critical in this interaction when less controlled conditions exist.

III. POTASSIUM

A significant effect involving N form was detected in the second cutting (Table 10). However, increased K concentration of harvested forage due to NH_4 nutrition was not expected. It is possible that under the conditions of this experiment, N fertilization in the NH_4 form tended to displace K from the soil colloids. This would increase the soil solution K levels and in turn increase potential K uptake by plant roots. This effect might also be expected to vary with pH, since at the low pH, Al and H cations would occupy an appreciably larger percentage of the exchange capacity. No interaction, involving N form and pH, affecting K concentration of the forage was detected.

The higher rates of K significantly increased K concentration in both the first and second cuttings (Tables 10 and 11). First cutting results revealed a higher K concentration of forage grown at the highest rate of fertilization when compared to the lowest rate. Second cutting forage contained significantly higher K concentrations at both the 112 and 224 kg/ha rates of K. Greater K concentrations in the forage would be expected due to higher levels of exchangeable and soil solution K at the higher rates of K. Although no test of significance was made, higher K concentration values were observed in the first cutting than

Table 10. Potassium concentration of second cutting as affected by N form and K rate.

Treatment	Rate (kg/ha)	Mean K Content[1] (%)
N Form (NO_3)		1.84 a[2]
(NH_4)		1.93 b
K	56	1.55 a
	112	1.83 b
	224	2.26 c

[1]Dry matter basis.

[2]Values within a column in the same section of the table that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

Table 11. Potassium concentration of first cutting as affected by K rate and pH level.

Treatment	Rate or Level (kg/ha)	Mean K Content[1] (%)
K	56	2.23 a[2]
	112	2.57 a
	224	2.81 b
pH Level	5.2	2.45 a
	6.2	2.63 b

[1]Dry matter basis.

[2]Values within a column in the same section of the table that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

that of the second cutting. Reynolds et al. (1971) reported decreased K concentration of orchardgrass forage when late spring and summer cuttings were compared to April cuttings.

Soil pH proved significant in its effect on K concentration of the first cutting (Table 11). Higher K concentration of forage at pH 6.2 may be due to reduced competition by H ions in part. However, the Ca-K antagonism would be expected to affect K levels also. Mean Ca concentration was also higher at the higher pH in the first cutting, as was Mg concentration. Greater plant vigor and metabolic efficiency as evidenced by higher yields at pH 6.2 may have contributed to the higher K levels. Also, Ca and Mg concentrations on an equivalent basis were increased more than the K concentration due to the effects of higher pH.

The interaction of N form and N rate significantly affected K concentration of first cutting fescue forage (Table 12). Potassium concentration of the forage when the NH_4 form of N was used as the N source, was lower than the K concentration of NO_3 treated forage when grown at the 134 kg/ha rate of N. Competitive effects of the NH_4 ion on the K concentration of the forage were only detected at the highest rate of N. This competitive effect would be expected due to the similar hydrated radii of the NH_4 and K ions as it affected cation exchange by the roots. As was discussed earlier, however, the effect of N form in the second cutting was such that the NH_4 form of N increased K concentration of forage over the mean K concentration of the NO_3 form.

Table 12. Potassium concentration of first cutting as affected by the interaction of N form and N rate.

N Form	N (kg/ha)	Mean K Content[1] (%)
NO_3	33.6	2.64 a[2]
	67.2	2.48 ab
	134.4	2.68 a
NH_4	33.6	2.50 ab
	67.2	2.65 a
	134.4	2.26 b

[1]Dry matter basis.

[2]Values within a column that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

IV. YIELD

The significantly lower yield of fescue harvested from pots treated with NH_4 as the dominant N form was found only in combined yield data (Table 13). This effect has been reported in other research. Gasser et al. (1967) reported that NH_4 nutrition of grass severely affected growth. Reduced growth may be attributed to a lowering of pH level due to the acidifying effects of NH_4 sources of N nutrition. In this experiment the use of a nitrification inhibitor held a major portion of the added N in the NH_4 form in treated pots. Thus the pH effect was reduced in NH_4 treated pots. Speculating, it would seem reasonable that the uptake of the NH_4 form of N would, through the exudation of H ions needed to balance cellular charges, reduce the rhizosphere pH over time without substantially reducing the soil pH. Also, the possible use of carbohydrate reserves in the detoxification of large amounts of NH_4 may enter into the reduced growth of forages from pots receiving NH_4 as the predominate N form.

The second cutting produced increased yields with the higher rates of K (Table 14). Potassium at the highest rate produced significantly greater forage yields than did K at the lowest rate. Long et al. (1964) reported increased growth of corn and wheat when fertilized with high rates of K.

The addition of N was found to be significant in its effect on yield of both the second cutting and combined yield. The response of both field and greenhouse grown forages to N has been well documented

Table 13. Combined yield of cuttings as affected by N form, N rate and pH level.

Treatment	Rate (kg/ha)	Level	Mean Yield[1] (g)
N Form (NO_3)			5.79 a[2]
N Form (NH_4)			5.45 b
N	34		4.75 c
	67		5.56 b
	134		6.69 a
pH Level		5.2	5.14 b
		6.2	5.93 a

[1]Dry matter basis.

[2]Values within a column in the same section of the table that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

Table 14. Yield of second cutting as affected by rates of K, N and pH level.

Treatment	Rate (kg/ha)	Level	Mean Yield[1] (g)
K	56		3.05 b[2]
	112		3.13 ab
	224		3.25 a
N	34		2.41 c
	67		3.10 b
	134		4.12 a
pH Level		5.2	2.88 b
		6.2	3.43 a

[1]Dry matter basis.

[2]Values within a column in the same section of the table that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

and it is widely accepted that additions of fertilizer N in many cases increases forage dry matter yields.

Higher yields were detected in all cuttings due to pH level, with pH 6.2 grown forage yielding more than forage grown at pH 5.2 (Table 14 and Table 15). Competition and antagonistic effects by H ions may account for decreased yields at the lower pH level.

Examination of the combined yield of cutting one and two revealed a significant interaction involving N form and Mg rate (Table 16). Yield was reduced by the NH_4 form of N nutrition when compared to NO_3 nutrition, but only when Mg was added at the rate of 112 kg/ha. However, under conditions of NO_3 nutrition the addition of Mg at the rate of 112 kg/ha significantly increased yields.

The interaction of N rate and pH level was significant in the first cutting, second cutting, and combined yield results (Table 17). Lowest yields were detected at the 34 kg/ha rate of N and at pH 5.2 in all cuttings. In the first cutting, yields were higher at pH 6.2 when compared to yields at pH 5.2 with the exception of the highest rate of N. The lack of significant differences at the highest rate of N, despite differences in pH level, would seem to indicate that the pH effect may be overcome by additions of N fertilizers. Differences were detected due to pH level at the highest rate of N in the second cutting. It may be that light intensity was not optimum for utilization of the highest rate of N in the first cutting but was higher in the second cutting growth period. In the second cutting differences due to pH were detected at all N rates. Within each pH level, N at the 67 and 134 kg/ha rates increased yields when compared to the lowest rate of N. One might note

Table 15. Yield of first cutting as affected by pH level.

pH Level	Mean Yield[1] (g)
5.2	2.33 b[2]
6.2	2.52 a

[1]Dry matter basis.

[2]Values within a column that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

Table 16. Combined yield of cuttings as affected by N form and Mg rate.

N Form	Mg (kg/ha)	Mean Yield[1] (g)
NO_3	0	5.63 b[2]
	112	5.95 a
NH_4	0	5.53 bc
	112	5.37 c

[1]Dry matter basis.

[2]Values within a column that are followed by the same letter are not significantly different at $\alpha \leq$ according to Duncan's Multiple Range Test.

Table 17. Yield of cuttings one, two and combined as affected by the interaction of N rate and pH level.

N (kg/ha)	pH Level	Mean Yield[1] 1st Cut (g)	2nd Cut (g)	Total (g)
34	5.2	2.13 c[2]	2.09 e	4.27 d
34	6.2	2.48 ab	2.76 d	5.27 c
67	5.2	2.32 b	2.78 d	5.14 c
67	6.2	2.54 a	3.44 c	6.02 b
134	5.2	2.55 a	4.02 b	6.60 a
134	6.2	2.53 a	4.23 a	6.78 a

[1]Dry matter basis.

[2]Values within a column that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

that the second cutting produced greater yields of dry matter than did the first cutting, which included the seedling growth period.

In the second cutting the interaction of N form, Mg rate, and pH level significantly affected yields (Table 18). Neither N form nor Mg rate influenced dry matter yield at pH 5.2. At pH 6.2 without added Mg, the NO_3 form of N was not significantly higher in dry matter yield than the NH_4 form of N. The addition of Mg at the 112 kg/ha rate increased yield at pH 6.2 when compared to forage grown without Mg. Magnesium at the 112 kg/ha rate decreased dry matter yield of forage grown with NH_4 as the predominate N form at pH 6.2 when compared to forage grown without Mg. Increased yield of forage grown under NO_3 nutrition at pH 6.2 when Mg was added is conceivably a response to increased Mg and NO_3 uptake. The negatively charged NO_3 anion could conceivably serve as a counter ion to encourage assimilation of Mg and vice versa. Conversely, the NH_4 ion would be expected to compete with the Mg ion since root cells must balance their ionic charge through organic acid synthesis, exudation of positive ions, or balanced ion uptake. Possibly, the uptake of high levels of NH_4 and Mg ions may increase exudation of H ions to the rhizosphere and lower rhizosphere pH levels as a result. Such a lowering of the plant root environment could conceivably decrease yields.

The interaction of N form, K rate, and pH level proved significant on second cutting dry matter yield (Table 19). The NO_3 form produced higher yields than the NH_4 form of N at pH 6.2 within each level of K. The NH_4 form of N could be expected to antagonize the uptake of K ions due to competition, and therefore reduce yields. At the lower pH level,

Table 18. Yield of second cutting as affected by N form, Mg rate and pH level.

N Form	Mg Rate (kg/ha)	pH Level	Mean Yield[1] (g)
NO_3	0	5.2	2.88 d[2]
	0	6.2	3.32 bc
	112	5.2	2.96 d
	112	6.2	3.81 a
NH_4	0	5.2	2.84 d
	0	6.2	3.40 b
	112	5.2	2.83 d
	112	6.2	3.22 c

[1]Dry matter basis.

[2]Values within a column in the same section of the table that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

Table 19. Yield of second cutting as affected by N form, K rate and pH level.

N Form	K Rate (kg/ha)	pH Level	Mean Yield[1] (g)
NO_3	56	5.2	2.84 h[2]
	56	6.2	3.45 c
	112	5.2	2.89 g
	112	6.2	3.50 b
	224	5.2	3.03 f
	224	6.2	3.73 a
NH_4	56	5.2	2.74 i
	56	6.2	3.24 e
	112	5.2	2.90 g
	112	6.2	3.28 d
	224	5.2	2.88 g
	224	6.2	3.42 c

[1]Dry matter basis.

[2]Values within a column that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

H and Al ions may be present in such high concentrations that the effect of the NH_4 ion is of lesser importance. Potassium fertilization increased yield at every level regardless of pH or N form with only one exception. This exception was between the two higher rates of K with NH_4 as the N form at pH 5.2. No difference was detected between the 112 and 224 kg/ha rate of K under these conditions. Possibly the exception may be due to competition and antagonisms between the NH_4, K, and H ions as they affected yield. The pH 6.2 level was higher in yield when compared to the lower pH level in every case.

The interaction of N form, Mg rate, K rate and N rate was significant in its effect on yield in the second cutting (Table 20). This data will be presented but due to the complexity of this type of interaction no attempt will be made to discuss or explain it.

V. TOTAL NITROGEN

The addition of N increased the total N concentration of both cuttings significantly (Tables 21 and 22). Higher levels of N were available for plant uptake at the higher levels of N fertilization, and at both of the higher rates of N fertilization higher concentrations of total N were detected. These results agree with the findings of Follett et al. (1977).

The second cutting was found to be lower in total N concentration at all levels of N fertilization when compared to the first cutting. Presumably, lower levels of soil nitrogen and the higher yield of cutting two influenced the total N concentration of the forage through a dilution effect.

Table 20. Yield of second cutting as affected by the interaction of N form, rates of Mg, K and N.

N Form	Mg (kg/ha)	K (kg/ha)	N (kg/ha)	Mean Yield[1] (g)
NO_3	0	56	34	2.26 q[2]
	0	56	67	2.99 kl
	0	56	134	4.15 cde
	0	112	34	2.11 r
	0	112	67	3.05 ijkl
	0	112	134	4.37 bc
	0	224	34	2.28 q
	0	224	67	3.27 h
	0	224	134	4.19 cde
	112	56	34	2.46 nop
	112	56	67	3.10 hijkl
	112	56	134	4.28 bcd
	112	112	34	2.53 mno
	112	112	67	3.16 hijk
	112	112	134	4.51 ab
	112	224	34	2.60 mn
	112	224	67	3.70 g
	112	224	134	4.67 a
NH_4	0	56	34	2.46 nop
	0	56	67	2.93 l
	0	56	134	4.07 de
	0	112	34	2.58 mn
	0	112	67	3.03 jkl
	0	112	134	3.82 fg
	0	224	34	2.39 opq
	0	224	67	3.23 hi
	0	224	134	3.96 ef

Table 20 (continued)

N Form	Mg (kg/ha)	K (kg/ha)	N (kg/ha)	Mean Yield[1] (g)
NH_4	112	56	34	2.36 pq
	112	56	67	2.68 m
	112	56	134	3.70 g
	112	112	34	2.38 opq
	112	112	67	2.95 l
	112	112	134	4.04 def
	112	224	34	2.52 mno
	112	224	67	3.19 hij
	112	224	134	3.81 fg

[1]Dry matter basis.

[2]Values within a column that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

Table 21. Total N concentration of first cutting as affected by N rate and pH level.

Treatment	Rate (kg/ha)	Level	Mean N Content[1] (%)
Added N	34		2.18 c[2]
	67		2.43 b
	134		2.89 a
pH Level		5.2	2.43 b
		6.2	2.57 a

[1]Dry matter basis.

[2]Values within a column in the same section of the table that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

Table 22. Total N concentration of second cutting as affected by N.

N (kg/ha)	Mean N Content[1] (%)
34	1.37 c[2]
67	1.45 b
134	1.69 a

[1]Dry matter basis.

[2]Values within a column that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

In the first cutting, pH level significantly influenced total N concentration of forage (Table 21). Total N concentration was higher at the pH 6.2 level. Plants grown at pH 6.2 generally were more vigorous, yielded more, and accumulated more cations. Possibly this greater accumulation of cations and possibly a more rapid metabolic rate encouraged greater total N concentration.

The interaction of Mg rate and N rate significantly influenced total N concentration of the first cutting (Table 23). When N was added at the 67 kg/ha rate, Mg at the rate of 112 kg/ha significantly reduced total N concentration as compared to forage grown without Mg. The author has no explanation for this effect, but would note that the differences were significant but small. Nitrogen at the higher rates increased total N concentration at either level of Mg fertilization.

VI. NITRATE NITROGEN

Significantly higher levels of NO_3-N concentration due to NO_3 nutrition as compared to NH_4 nutrition were detected in the first cutting (Table 24). Lower NO_3 concentration of forage grown under NH_4 nutrition would be expected due to low levels of NO_3 in NH_4 treated pots. It is interesting to note that no differences in NO_3-N concentration of forage harvested from the second cutting were detected. Since NO_3 levels in the second cutting forage were lower, conceivably the more rapid growth of forage in the second growth period may have diluted the NO_3 levels of the forage due to greater yield or better light conditions for NO_3 reduction.

Table 23. Total N concentration of first cutting as affected by the interaction of Mg rate and N rate.

Mg (kg/ha)	N (kg/ha)	Mean N Content[1] (%)
0	34	2.14 d[2]
0	67	2.47 b
0	134	2.85 a
112	34	2.21 d
112	67	2.38 c
112	134	2.93 a

[1]Dry matter basis.

[2]Values within a column that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

Table 24. Nitrate N concentration of first cutting as affected by N form and pH level.

Treatment	Level	Mean NO_3 N Content[1] (%)
N Form (NO_3)		0.21 a[2]
(NH_4)		0.04 b
pH Level	5.2	0.07 b
	6.2	0.17 a

[1]Dry matter basis.

[2]Values within a column in the same section of the table that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

Significantly higher levels of NO_3-N due to added K were observed in the second cutting (Table 25). Small but significantly higher NO_3 levels due to additions of K above the lowest level may be a response by the plant to K uptake. Possibly, the plant root cells respond to greater K uptake through absorption of NO_3 anions rather than exudation of H ions or synthesis of organic anions. It is generally accepted that plant cells attempt to balance their cellular charge through absorption of anions and synthesis of organic anions when excess cations are absorbed. Hiatt (1978) advanced the theory that NH_4 effects on K absorption operate through the availability and transport of mobile counter ions, principally NO_3 and HCO_3 ions.

First cutting fescue grown at pH 6.2 was significantly higher in NO_3 concentration than forage grown at the pH 5.2 (Table 24). This effect is due to the interaction of the NO_3 form of N and pH level. This interaction will be discussed in later presentations of data.

The interaction of N form and pH level was significant in the first cutting (Table 26). Forage grown at pH 5.2 or 6.2 with NH_4 nutrition contained lower NO_3-N than forage grown at pH 6.2 with NO_3 as the dominant N form. The NH_4 form of N produced no differences due to pH level as it affected NO_3-N concentration. Possibly at the lower pH level, competition by Al and H ions reduced basic cation concentration of the forage. At pH 6.2 with NH_4 as the dominant form of N, basic cations may have been reduced by antagonism or competition by the monovalent NH_4 ion. Higher levels of NO_3-N at pH 6.2 may have been a response to greater basic cation composition at the higher pH

Table 25. Nitrate N concentration of second cutting as affected by K rate.

K (kg/ha)	Mean NO_3 N Content[1] (%)
56	0.02 c[2]
112	0.03 b
224	0.04 a

[1]Dry matter basis.

[2]Values within a column that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

Table 26. Nitrate N concentration of first cutting as affected by the interaction of N form and pH level.

N Form	pH Level	Mean NO_3 N Content[1] (%)
NO_3	5.2	0.10 b[2]
	6.2	0.30 a
NH_4	5.2	0.03 b
	6.2	0.04 b

[1]Dry matter basis.

[2]Values within a column that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

level under NO_3 nutrition. The counter ion effect has been proposed as a possible explanation for increased anion composition of plants under conditions of high cation concentration of plant tissues. Whether greater basic cation content induced NO_3 uptake or vice versa is, of course, a point of speculation.

The interaction of Mg rate and K rate in the first cutting significantly affected NO_3-N concentration of harvested forage (Table 27). The lowest NO_3-N concentration was observed at the 56 kg/ha rate of K without addition of Mg. Increasing the level of K to the 112 or 224 kg/ha rate increased NO_3-N concentration of the forage when Mg was not added. This suggests a counter ion effect in which increased K uptake at high rates of K fertilization encourages absorption and translocation of NO_3-N to plant tops as a counter ion. No significant differences in NO_3 concentration were observed as the K level was increased at the 112 kg/ha rate of Mg fertilization.

Significant differences in NO_3-N concentration in the first cutting were detected due to the interaction of N form, Mg rate, and K rate (Table 28). No differences were detected due to the NH_4 form of N at any level of Mg or K fertilization. Differences involving Mg rate and K rate were detected under the NO_3 form of N. These differences are the same as those discussed in the Mg rate × K rate interaction and are presented there.

The interaction of N form, Mg rate, K rate, and pH level was significant in its effect on NO_3-N concentration of first cutting forage (Table 29). Due to the complexity of this interaction, no attempt will be made to discuss this relationship.

Table 27. Nitrate N concentration of first cutting as affected by the interaction of rates of Mg and K.

Mg (kg/ha)	K (kg/ha)	Mean NO_3 N Content[1] (%)
0	56	0.10 c[2]
0	112	0.12 b
0	224	0.13 a
112	56	0.13 ab
112	112	0.12 ab
112	224	0.12 b

[1]Dry matter basis.

[2]Values within a column that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

Table 28. Nitrate N concentration of first cutting as affected by the interaction of N form, Mg rate and K rate.

N Form	Mg (kg/ha)	K (kg/ha)	Mean NO_3 N Content[1] (%)
NO_3	0	56	0.18 c[2]
	0	112	0.20 b
	0	224	0.22 a
	112	56	0.22 a
	112	112	0.21 ab
	112	224	0.20 b
NH_4	0	56	0.03 d
	0	112	0.04 d
	0	224	0.04 d
	112	56	0.03 d
	112	112	0.04 d
	112	224	0.04 d

[1]Dry matter basis.

[2]Values within a column that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

Table 29. Nitrate N concentration of first cutting as affected by the interaction of N form, Mg rate, K rate and pH level.

N Form	Mg (kg/ha)	K (kg/ha)	pH Level	Mean NO_3 N Content[1] (%)
NO_3	0	56	5.2	0.12 d[2]
	0	56	6.2	0.24 c
	0	112	5.2	0.10 d
	0	112	6.2	0.29 bc
	0	224	5.2	0.08 de
	0	224	6.2	0.40 a
	112	56	5.2	0.10 d
	112	56	6.2	0.35 ab
	112	112	5.2	0.13 d
	112	112	6.2	0.29 d
	112	224	5.2	0.10 d
	112	224	6.2	0.30 bc
NH_4	0	56	5.2	0.03 e
	0	56	6.2	0.03 e
	0	112	5.2	0.04 e
	0	112	6.2	0.04 e
	0	224	5.2	0.04 e
	0	224	6.2	0.04 e
	112	56	5.2	0.03 e
	112	56	6.2	0.03 e
	112	112	5.2	0.04 e
	112	112	6.2	0.04 e
	112	224	5.2	0.04 e
	112	224	6.2	0.04 e

[1]Dry matter basis.

[2]Values within a column that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

VII. K/(Ca + Mg) RATIO

The ratio of K/(Ca + Mg) in first cutting fescue was found to be higher than that of second cutting fescue. Although no test of significance was made, this result agrees with the work of 't Hart (1960) who reported increased tetany hazard when air temperatures were low as compared to higher temperatures in late spring.

The ratio of K/(Ca + Mg) did not exceed 2.2 in any cutting. Ratios of K/(Ca + Mg) above 2.2, which have been associated with greater incidence of grass tetany, were not approached.

Increased hazard of tetany as determined by K/(Ca + Mg) ratio was detected in both the cuttings due to the influence of K fertilization (Tables 30 and 31). High levels of K fertilization have been reported to increase the ratio of K/(Ca + Mg) by several investigators including Lowrey and Grunes (1968). The influence of higher levels of K may be due to higher K concentration of the forage on an equivalent basis, while Ca and Mg are depressed on an equivalent basis. The monovalent K cation has often been cited as an antagonistic factor in that it reduces Ca and Mg uptake of the forage. Also, at each level of K rate, the first cutting proved higher in the K/(Ca + Mg) ratio than did the second cutting.

First cutting K/(Ca + Mg) ratios were reduced by an increase in pH level from the 5.2 to 6.2 (Table 30). Possibly reduced Ca and Mg concentration of forage at the lower pH level resulted from the antagonism of the divalent Ca and Mg cations by Al and H ions. Potassium concentration of forage was also reduced at the lower pH, but not to

Table 30. Ratio of K/(Ca + Mg) in first cutting as affected by K rate and pH level.

Treatment	Rate (kg/ha)	Level	Mean K/(Ca + Mg) Ratio[1]
K	56		1.13 c[2]
	112		1.34 b
	224		1.46 a
pH Level		5.2	1.45 a
		6.2	1.17 b

[1]Dry matter basis.

[2]Values within a column in the same section of the table that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

Table 31. Ratio of K/(Ca + Mg) in second cutting as affected by K rate.

K (kg/ha)	Mean K/(Ca + Mg) Ratio[1]
56	0.71 c[2]
112	0.94 b
224	1.32 a

[1]Dry matter basis.

[2]Values within a column that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

the extent that Ca and Mg was depressed on an equivalent basis. Thus, pH level may influence K/(Ca + Mg) ratios in harvested forage due to possible antagonism of basic cations by H ions. Percent base saturation and cation exchange capacity may also enter into this effect but were not studied in this experiment.

The interaction of N form and Mg rate significantly influenced the ratio of K/(Ca + Mg) in the first cutting (Table 32). Magnesium fertilization at the rate of 112 kg/ha reduced the K/(Ca + Mg) ratio under both the NO_3 and NH_4 forms of N nutrition. Grunes et al. (1968) also reported that Mg fertilization reduced the K/(Ca + Mg) ratio. The influence of Mg fertilization may be accounted for by increased levels of plant tissue Mg in relation to plant tissue K. It would appear that under NO_3 nutrition, Mg additions have a greater influence on K/(Ca + Mg) ratios than under the NH_4 source of N since both the lowest and highest K/(Ca + Mg) ratios were observed under the NO_3 form of N.

The first cutting interaction of N form and K rate was significant in its effect on K/(Ca + Mg) ratios of the harvested forage (Table 33). Potassium fertilization increased the K/(Ca + Mg) ratio at all levels above the lowest rate under the NO_3 form of N. When NH_4 was the predominant source of N nutrition, K fertilization at the 112 kg/ha and the 224 kg/ha rate increased the K/(Ca + Mg) ratio when compared to the lowest rate. The NH_4 form of N significantly increased the K/(Ca + Mg) ratio of forage grown at the 112 kg/ha rate of K when compared to the same rate under NO_3 N nutrition. This data suggests

Table 32. Ratio of K/(Ca + Mg) in first cutting as affected by the interaction of N form and Mg rate.

N Form	Mg (kg/ha)	Mean K/(Ca + Mg) Ratio[1]
NO_3	0	1.38 a[2]
	112	1.19 d
NH_4	0	1.35 b
	112	1.32 c

[1]Dry matter basis.

[2]Values within a column that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

Table 33. Ratio of K/(Ca + Mg) in first cutting as affected by the interaction of N form and K rate.

N Form	K (kg/ha)	Mean K/(Ca + Mg) Ratio[1]
NO_3	56	1.10 d[2]
	112	1.28 c
	224	1.49 a
NH_4	56	1.16 d
	112	1.40 b
	224	1.44 ab

[1]Dry matter basis.

[2]Values within a column that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

that tetany hazard, as determined by K/(Ca + Mg) ratio, is not greater when N is applied as NH_4 at the low or high rates than when NO_3 was the form of N nutrition. However, at moderate rates of K, NH_4 significantly increased the K/(Ca + Mg) ratio over that of the NO_3 form. Possibly at low rates of K fertilization, the NH_4 ion antagonizes the uptake of K appreciably, as well as Mg and Ca uptake. At moderate rates of K, possibly K and NH_4 antagonism or competition with Ca and Mg uptake becomes of a greater magnitude than the suppression of K concentration by the NH_4 form of N. At the highest K rate, apparently the antagonism or competition with Mg and Ca concentration by the K ion overshadows the N form effect.

In the second cutting, the interaction of N form and N rate proved significant in its effect on the K/(Ca + Mg) ratio of harvested forage (Table 34). N fertilization at the rates above 34 kg/ha showed no increase in tetany hazard as indicated by K/(Ca + Mg) and in some cases reduced the indicated hazard. It would appear that addition of N fertilizers does not increase tetany hazard as measured by the ratio of K/(Ca + Mg) in this experiment.

The interaction of N form, Mg rate, K rate, and N rate was found to be significant in its effect on the K/(Ca + Mg) ratio of first cutting harvested forage as was the interaction of N form, Mg rate, K rate and pH level. No attempt to explain this interaction and its relationships will be made due to the complexity of the interaction.

Table 34. Ratio of K/(Ca + Mg) in second cutting as affected by the interaction of N form and N rate.

N Form	N (kg/ha)	Mean K/(Ca + Mg) Ratio[1]
NO_3	34	1.02 ab[2]
	67	1.02 ab
	134	0.86 c
NH_4	34	1.04 a
	67	0.95 b
	134	1.06 a

[1]Dry matter basis.

[2]Values within a column that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

VIII. MAGNESIUM UPTAKE

Magnesium uptake was significantly greater when fertilized with NO_3 than when fertilized with the NH_4 form of N (Table 35). This effect was observed in both cuttings. Both increased Mg concentration of the forage as well as increased yield of NO_3 treated plants contributed to the greater Mg uptake.

The second cutting contained greater total Mg uptake then did the first cutting (Tables 35 and 36). This result is due to greater yield and Mg concentration of second cutting forage. No test of significance was made between cuttings.

Magnesium fertilization at the rate of 112 kg/ha increased the total Mg uptake of both cuttings significantly. Since Mg fertilization did not increase yield, the response would be due to increased Mg concentration. The addition of Mg at the rate of 112 kg/ha would be expected to increase exchangeable and soil solution Mg. Plant uptake and forage levels of Mg would be expected to increase due to higher soil solution and exchangeable Mg.

Total Mg uptake was significantly decreased by the higher rates of K fertilization in both cuttings. Examination of yield data revealed that yield was increased by K fertilization. However, any effect of K rate which increased the Mg contained in the forage due to increased yield was offset by decreased Mg concentration of the forage. Potassium fertilization decreased Mg concentration of the forage in both cuttings. The reduction in Mg uptake of the forage due to K rate appears to be due to antagonism by the K ion toward Mg.

Table 35. Total Mg uptake in first cutting as affected by N form, Mg rate and pH level.

Treatment	Rate (kg/ha)	Level	Mean Mg Uptake[1] (mg.)
N Form (NO_3)			7.01 a[2]
(NH_4)			5.66 b
Mg	0		5.55 b
	112		7.11 a
K	56		6.85 a
	112		6.17 b
	224		5.98 c
pH Level		5.2	5.36 b
		6.2	7.30 a

[1]Total uptake.

[2]Values within a column in the same section of the table that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

Table 36. Total Mg uptake in second cutting as affected by N form, Mg rate, K rate, N rate and pH level.

Treatment	Rate (kg/ha)	Level	Mean Mg Uptake[1] (mg.)
N Form (NO_3)			11.67 a[2]
(NH_4)			9.86 b
Added Mg	0		9.09 b
	112		12.44 a
Added K	56		12.45 a
	112		10.94 b
	224		8.91 c
Added N	34		7.71 c
	67		10.35 b
	134		14.24 a
pH Level		5.2	8.82 b
		6.2	12.72 a

[1]Dry matter basis

[2]Values within a column in the same section of the table that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

Second cutting forage contained significantly greater amounts of Mg expressed as total Mg uptake due to additions of N fertilizers. This increase was due to both increased yield of plants receiving higher N applications as well as increased Mg concentration of the forage.

Total Mg uptake was also significantly affected by pH level in both cuttings. Forage contained more total Mg when grown at pH 6.2 than at pH 5.2. Increased yield and Mg concentration of the pH 6.2 grown forage contributed to this result.

The interaction of N form and N rate significantly affected total Mg uptake of second cutting forage (Table 37). Additions of N fertilizer increased total Mg uptake of the forage regardless of N form. The NO_3 form of N encouraged greater total Mg uptake of the forage at all but the lowest level of N fertilization when compared to the NH_4 form of N. Additions of N fertilizer increased both the dry matter yield and Mg concentration of the forage. Increased total Mg uptake would therefore be expected due to N fertilization. The lower total Mg uptake of NH_4 fertilized forage may be due to statistically nonsignificant decreases in Mg concentration.

The interaction of N form, Mg rate, and pH level significantly affected total Mg uptake of second cutting harvested forage (Table 38). The total Mg uptake of forage grown at pH 6.2 at all levels of added Mg and under either N form was greater than plants grown at pH 5.2. The NO_3 and NH_4 form of N did not differ in their effect on total Mg uptake at the zero level of Mg fertilization at either pH level. When Mg was added at the 112 kg/ha rate, the NO_3 form of N promoted greater

Table 37. Total Mg uptake in second cutting as affected by N form and N rate.

N Form	N (kg/ha)	Mean Mg Uptake[1] (mg.)
NO_3	34	7.98 e[2]
	67	11.05 c
	134	15.98 a
NH_4	34	7.44 e
	67	9.65 d
	134	12.50 b

[1]Total uptake.

[2]Values within a column that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

Table 38. Total Mg uptake in second cutting as affected by the interaction of N form, Mg rate and pH level.

N Form	Mg (kg/ha)	pH Level	Mean Mg Uptake[1]
NO_3	0	5.2	7.62 e[2]
	0	6.2	10.92 c
	112	5.2	11.27 bc
	112	6.2	16.89 a
NH_4	0	5.2	7.02 e
	0	6.2	10.81 c
	112	5.2	9.36 d
	112	6.2	12.26 b

[1]Total uptake.

[2]Values within a column that are followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Duncan's Multiple Range Test.

total Mg uptake at either pH level. This effect is possibly due to decreased yield due to NH_4 nutrition as detected in yield data, as well as decreased Mg concentration under the NH_4 form of N.

CHAPTER V

GENERAL DISCUSSION AND CONCLUSIONS

The effect of the NH_4 ion on the tetany potential of tall fescue has been discussed on a component basis. In general, the NH_4 ion tended to lower the Mg concentration of the harvested forage. It also significantly affected Mg concentration through its interaction with the K cation. The results of this investigation suggest that NH_4-N does lower the Mg concentration and total uptake of tall fescue forage. It has been demonstrated that the Mg concentration of forage was below the 0.20% "safe" level suggested by Kemp (1960) under NH_4 fertilization in one particular instance. However, the NH_4 ion did not increase the tetany potential of tall fescue as estimated by the ratio of K/(Ca + Mg).

High K concentrations in forage grasses have been suggested as a possible factor in the tetany potential of forage grasses. The NH_4 ion was found to be inconsistent in its effect on the K concentration of the harvested forage. In the first cutting, K concentration was reduced as NH_4 fertilization levels increased. In the second cutting, NH_4 fertilization increased the K concentration of the forage.

The total N concentration of forage has also been suggested as an important factor in the tetany potential of the forage. Concentrations of total N in the harvested forage were not found to be higher than would be normally expected due to any treatment or interaction. It is important to note that the second cutting was much lower in total N concentration than was the first cutting. The level of total N observed in the second cutting fell below the level suggested by Jones (1974) as the critical level below which N deficiencies occur. Therefore, results of the second cutting must be evaluated with this fact in mind. The NH_4 ion was not found to significantly affect the total N concentration of forage in either cutting.

It is the author's opinion, based on the results of this experiment, that the NH_4 ion can play an important role in determining the tetany potential of tall fescue forage. Field experiments are needed to further define this effect.

Although the effect of the NH_4 ion on the tetany potential of tall fescue forage was the main concern of this study, other factors were also evaluated.

The addition of Mg at the rate of 112 kg/ha was found to significantly increase Mg concentration but did not affect K/(Ca + Mg) ratios significantly. The addition of Mg at the 112 kg/ha level also increased total Mg uptake by the forage.

The higher levels of K fertilization used in the study decreased the Mg concentration of the forage as well as increasing the K/(Ca + Mg) ratio significantly. The addition of high levels of K was found to increase the K concentration of the forage. The use of K fertilizers was also found to decrease the total uptake of Mg by the forage.

The addition of N was found to be variable in the effect it had on Mg concentration of the forage. In the first cutting, additions of N at the higher levels to plants growing at the lower pH level without Mg additions, were found to decrease Mg concentrations below 0.20%. In the second cutting, increased levels of N fertilizer were found to increase Mg concentration of the forage. However, caution must be used in the application of second cutting results, since the level of total N concentration found in the forage was below the deficiency threshold. This could account for the apparent discrepancy. The addition of N at the higher levels was not found to increase the K/(Ca + Mg) ratio in either cutting. The addition of N fertilizers at the higher levels was also found to increase the total N concentration and total Mg uptake of forage.

The pH level at which the forage was grown significantly affected the Mg concentration. Fescue grown at the higher pH level contained higher Mg concentrations than forage grown at the pH 5.2 level. The pH 6.2 level also produced forage with lower K/(Ca + Mg) ratios than pH 5.2 grown forage. Total Mg uptake by fescue grown at pH 6.2 was also higher than that of plants grown at the lower pH level.

The author would also caution that field experiments are needed to test the results of this experiment. It is well known that experimental results from greenhouse investigations are often difficult to verify in the field.

Further investigations into the effects of air temperature, soil temperature, light, and other environmental factors are also needed, since these factors may interact with the fertility treatments applied to grasslands. The response of ruminants consuming the treated forage must also be further defined since tetany hazard has been shown to differ with age, sex, and physical condition of the animal.

It is no surprise to the author that the understanding and prevention of conditions which lead to tetany have baffled both agronomists and animal scientists for years. The complex interaction of soils, plants, environment, and animals which is involved in grass tetany contains a host of variables which baffle the investigator's efforts to separate individual effects and sources of variation.

LITERATURE CITED

LITERATURE CITED

1. Abruna, F., R. W. Pearson, and C. B. Elkins. 1958. Quantitative evaluation of soil reaction and base status changes resulting from field application of residually acid forming nitrogen fertilizers. Soil Sci. Soc. Am. Proc. 22:539-542.

2. Adams, F. 1975. Field experiments with magnesium in Alabama—cotton, corn, soybeans, peanuts. Auburn Univ. Exp. Sta. Bull. 472.

3. Adams, W. E., A. W. White, Jr., and R. N. Dawson. 1967. Influence of lime source and rate on "Coastal" bermudagrass production, soil profile reaction, exchangeable Ca and Mg. Agron. J. 59:147-149.

4. Alexander, M. 1965. Nitrification. In W. V. Bartholomew and F. E. Clark (Eds.), Soil Nitrogen. Agronomy 10:307-343. Amer. Soc. of Agron., Madison, Wis.

5. Allcroft, R., and K. N. Burns. 1968. Hypomagnesaemia in cattle. New Zeal. Vet. Jour. 16:109-128.

6. Amer, F. M., and W. V. Bartholomew. 1951. Influence of oxygen concentration in soil air on nitrification. Soil Sci. 71:215-219.

7. Barr, A. J., H. Goodnight, P. Sall, and J. T. Helwig. 1976. A user's guide to SAS 76. SAS Institute Inc., Raleigh, N. C.

8. Beeson, K. C. 1941. The mineral composition of crops with particular reference to the soils in which they were grown. USDA Misc. Pub. 369.

9. Beeson, K. C. 1959. Magnesium in soils-sources, availability, and zonal distribution. pp. 1-11. In G. C. Anderson, E. M. Jencks, and D. J. Horvarth (Eds.), Magnesium and Agriculture. West Virginia Univ., Morgantown.

10. Boswell, F. C., and W. L. Parks. 1957. The effect of soil potassium levels on yield, lodging, and mineral composition of corn. Soil Sci. Soc. Am. Proc. 21:301-305.

11. Brown, J. R., W. M. Rice, M. Farley, and B. Strong. 1976. Altering forage magnesium with soil treatments. 1976 Res. Reports. Univ. of Missouri, Southwest Center.

12. Burns, K. N., and R. Allcroft. 1967. Hypomagnesaemic tetany in cattle II. Prevention measures. Brit. Vet. J. 123:383-389.

13. Busenburg, E., and C. V. Clemency. 1973. Determination of the cation exchange capacity of clay and soils using an ammonia electrode. Clays Clay Miner. 21:213-217.

14. Cairney, I. M. 1964. Grass staggers in beef cattle, results of survey of disease in Hawkes Bay. N.Z.J. Agric. 109:47-49.

15. Chambers, W. E., and H. W. Gardner. 1951. The effect of soil calcium on the mineral content of wheat. J. of Soil Sci. 2:246-253.

16. Clark, R. B. 1975. Differential magnesium efficiency in corn inbreds: I. Dry-matter yields and mineral element composition. Soil Sci. Soc. Am. Proc. 39:488-491.

17. Cummins, D. G., and H. F. Perkins. 1974. Response of millet and sorghum X sudangrass crosses to magnesium fertilization. Agron. J. 66:809-812.

18. Dantzman, C. L. 1976. Effects of lime levels on calcium and magnesium recovery and yield of Pangola Digitgrass. Soil Crop Sci. Soc. of Florida, Proc. 35:143-144.

19. Dijkshoorn, W., and M. L. 't Hart. 1957. The effect of alteration of temperature upon the cation composition in perennial ryegrass. Neth. J. Agric. Sci. 5:18-36.

20. Elkins, C. B., and C. S. Hoveland. 1977. Soil oxygen and temperature effects on tetany potential of three annual forage species. Agron. J. 69:626-628.

21. Elkins, C. B., L. Haaland, S. Hoveland, and W. Griffey. 1978. Grass tetany potential of tall fescue as affected by soil O_2. Agron. J. 70:309-311.

22. Embleton, T. W. 1966. Magnesium. pp. 225-263. In H. D. Chapman (Ed.), Diagnostic Criteria for Plants and Soils. Univ. of California, Riverside.

23. Felbeck, G. T. 1959. Problems of magnesium assay in soils. pp. 96-105. In G. C. Anderson, E. M. Jencks, and D. J. Horvarth (Eds.), Magnesium and Agriculture. West Virginia Univ., Morgantown.

24. Flannery, R. L., and D. K. Markus. 1971. Determination of phosphorus, potassium, calcium and magnesium simultaneously in North Carolina, ammonium acetate, and Bray P. soil extracts by autoanalyzer. In L. M. Walsh, ed. Instrumental methods for analysis of soils and plant tissue. Soil Sci. Soc. Am. Madison Wisc.

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

26. Follett, R. F., J. F. Power, D. L. Grunes, and C. A. Klein. 1977. Effect of N, K, and P fertilization, N source, and clipping on potential tetany hazard of bromegrass. Plant Soil. 48:485-508.

27. Foy, C. D., and S. A. Barber. 1958. Magnesium deficiency and corn yields on two acid Indiana soils. Soil Sci. Soc. Am. Proc. 22:145-148.

28. Frederick, L. R. 1956. The formation of nitrate from ammonium nitrogen in soils. I. Effect of temperature. Soil Sci. Soc. Am. Proc. 20:496:500.

29. Gasser, J. K. R., D. J. Greenland, and R. A. Rawson. Measurement of losses from fertilizer nitrogen during incubation in acid sandy soils and during subsequent growth of ryegrass, using ^{15}N-labelled fertilizers. J. Soil Sci. 18:289-300.

30. Goring, C. A. I. 1962a. Control of nitrification by 2-chloro-6-(trichloromethyl)-pyridine. Soil Sci. 93:211-218.

31. Goring, C. A. I. 1962b. Control of nitrification of ammonium fertilizers and urea by 2-chlor-6-(trichloromethyl)-pyridine. Soil Sci. 93:431-439.

32. Graham, E. R., S. Powell, and M. Carter. 1956. Soil magnesium and the growth and chemical composition of plants. Missouri Agr. Exp. Sta. Res. Bull. 607.

33. Grechin, I. P., and H. S. Ch'eng. 1960. Influence of various concentrations of gaseous oxygen in the air of the soil on oxidation-reduction conditions. Soviet Soil Sci. 1960:775-778.

34. de Groot, T. 1970. Some experiences with the use of high levels of nitrogen on grassland in the Netherlands, with special reference to animal health. Int. Grassland Congr., Proc. 11th. (Surfer's Paradise, Queensland, Australia). pp. A107-A112.

35. Gross, C. F., and G. A. Jung. 1978. Magnesium, Ca, and K concentration in temperate-origin forage species as affected by temperature and Mg fertilization. Agron. J. 70:397-403.

36. Grunes, D. L. 1967a. Grass tetany. pp. 191-193. In D. L. Eggenburger et al. (Ed.) McGraw-Hill Yearbook of Sci. and Technology. New York, N. Y.

37. Grunes, D. L. 1967b. Grass tetany of cattle as affected by plant composition and organic acids. pp. 105-110. Cornell Nutr. Conf. Feed Mfr. Proc. Buffalo, N. Y.

38. Grunes, D. L. 1973. Grass tetany of cattle and sheep. pp. 113-140. Spec. Publ. No. 4. Crop Sci. Soc. Am. Madison, Wisc.

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

40. Grunes, D. L., J. F. Thompson, J. Kubota, and V. A. Lazar. 1968. Effects of Mg, K, and temperature on growth and composition of Lolium perrene. Int. Congr. Soil Sci. Trans. 9th (Adelaide, Australia) II:597-603.

41. Hannaway, D. B., and J. H. Reynolds. 1976. Seasonal changes in minerals, protein, and yield of tall fescue forages as influenced by nitrogen and potassium fertilization. Tenn. Farm and Home Sci. Prog. Rep. No. 98:14.

42. Hansard, S. L., F. C. Madsen, G. M. Merriman, and J. B. McLaren. 1975. Tennessee grass-fed cattle need supplementary magnesium. Tenn. Farm and Home Sci. Prog. Rep. No. 93:36.

43. 't Hart, M. L. 1960. The influence of meteorlogical conditions and fertilizer treatment on pasture in relation to hypomagnesaemia. pp. 88-95. British Vet. Assoc., London.

44. Hiatt, A. J. 1978. Critique of "Absorption and utilization of ammonium nitrogen by plants." pp. 191-197. In Donald Nielsen and J. G. McDonald (Eds.) Nitrogen in the Environment, Vol. 2. Academic Press Inc., New York.

45. Hjerpe, C. A., and J. R. Brownwell. 1966. Bovine hypomagnesaemic tetany: Two cases related to transportation. Vet. Record. 79: 396-397.

46. Jooper, L. J. 1967. The uptake of magnesium by herbage and its relationship with soil analysis data. pp. 160-173. In W. Dermott and D. J. Eagle (Eds.) Soil Potassium and Magnesium. Min. Agr. Food Tech. Bull. 14. H. M. Stationery Office, London.

47. Horvarth, D. J., and J. R. Todd. 1968. Magnesium supplements for cattle. Proc. 23rd Annu. Texas Nutr. Conf. pp. 96-104.

48. Jackson, M. L. 1958. Soil Chemical Analysis. Prentice-Hall, Inc., Englewood Cliffs, N. J.

49. Jacob, A. 1958. Magnesium—the fifth major plant nutrient. Staples Press Ltd., London.

50. Jones, J. B., Jr. Plant analysis handbook for Georgia. Cooperative Ext. Serv., Univ. of Georgia Col. of Agr. Bull. 735.

51. Kemp, A. 1960. Hypomagnesaemia in milking cows: The response of serum magnesium to alterations in herbage composition resulting from potash and nitrogen dressing on pasture. Neth. J. Agr. Sci. 14:290-295.

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

53. Kershaw, E. S., and C. L. Banton. 1965. The mineral content of S.22 ryegrass on calcareous loam soil in response to fertilizer treatment. J. Sci. Fd. Agric. 16:698-701.

54. Lavor, P., and L. Guegen. 1963. Grass composition and grass tetany. Ann. Zootech. 12:39-52. (Reprinted in Potash Review 19, 1964).

55. Lessman, G. M. 1972. Differential response of plant genotypes to magnesium fertilization. pp. 177-192. In J. B. Jones, Jr., M. C. Blount, and S. R. Wilkinson (Symposium committee) Magnesium in the Environment: Soils, Crops, Animals, and Man. The Taylor Publishing Co. Reynolds, Georgia.

56. Lombin, Ganyir and A. Fayemi. 1975. Release of exchangeable and nonexchangeable magnesium from Nigerian soils on cropping with maize or chemical extraction. J. Sci. Fd. Agric. 27:101-108.

57. Long, O. H., J. A. Odom, and L. M. Safley. 1964. Phosphorus and potassium fertilization in crop rotations. Univ. of Tenn. Agr. Exp. Sta. Bull. 376.

58. Lowrey, R. S., and D. L. Grunes. 1968. Magnesium metabolism in cattle as related to potassium and magnesium fertilization of rye forage. Aroc. Georgia Nutr. Conf. Feed Mfr. Atlanta pp. 51-56.

59. Mayland, J. F., and D. L. Grunes. 1974. Magnesium concentration in Agropyron desertorum fertilized with Mg and N. Agron. J. 66:79-82.

60. Mayland, J. F., D. L. Grunes, and V. A. Lazar. 1976. Grass tetany hazard of cereal forages based upon chemical composition. Agron. J. 68:665-667.

61. Mayland, H. F., D. L. Grunes, and D. M. Stuart. 1974. Chemical composition of Agropyron desertorum as related to grass tetany. Agron. J. 66:441-446.

62. Mayland, H. F., D. L. Grunes, J. Waggoner, A. Florence, D. A. Hawes, and P. K. Joo. 1975. Nitrogen effects on crested wheatgrass as related to forage quality indices of grass tetany. Agron. J. 67:410-414.

63. McCants, C. B., E. O. Skogley, and W. G. Woltz. 1959. Influence of certain soil fumigation treatments on the response of tobacco to ammonium and nitrate forms of nitrogen. Soil Sci. Soc. Am. Proc. 23:466-469.

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

65. McNaught, K. J., F. D. Dorofaeff, and J. Karlovsky. 1968. Effect of magnesium fertilizers and season on levels of inorganic nutrients in a pasture on Hamilton Clay Loam. N.Z.J. Agric. Res. 11:533-550.

66. Metson, A. J., W. M. H. Saunders, 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.

67. Miller, J. G. 1965. The grass tetany problem in Georgia. Proc. Georgia Nutr. Conf. Feed Mfr. Atlanta, 1965. pp. 1-3.

68. Mulder, E. G. 1956. Nitrogen-magnesium relationships in crop plants. Plant Soil VII:341-374.

69. Murdock, L. W., C. W. Abner, N. Gay, and J. A. Boling. 1975. Beef: Grass tetany in beef cattle. Coop. Ext. Ser., Univ. of Kentucky, ASC. 16.

70. Nielsen, K. F., and R. F. Cunningham. 1964. The effect of soil temperature and form and level of nitrogen on growth and chemical composition of Italian ryegrass. Soil Sci. Soc. Am. Proc. 28:213-218.

71. Page, N. R. 1965. Procedures used by state soil testing laboratories in the southern region of the United States. Southern Coop. Series Bull. 102.

72. Paul, J. L., and R. M. Carlson. 1968. Nitrate determination in plant extracts by the nitrate electrode. J. Agric. Food Chem. 16:766-768.

73. Pearson, R. W., and F. Abruna. 1961. Nitrogen speeds lime movement in subsoil. Crops Soils 13:23.

74. Raveh, Ariella. 1973. The adaptation of the nitrate-specific electrode for soil and plant analysis. Soil Sci. 116:388-389.

75. Reith, J. W. S. 1963. The magnesium contents of soils and crops. J. Sci. Fd. Agric. 14:417-426.

76. Reith, J. W. S. 1965. Mineral composition of crops. NAAS Quart. Review. 68:150-156.

77. Reynolds, I. H., C. R. Lewis, and K. F. Laaker. 1971. Chemical composition and yield of orchardgrass forage grown under high rates of nitrogen fertilization and several cutting managements. Univ. of Tenn. Agr. Exp. Sta. Bull. 479.

78. Rice, H. B., and E. J. Kamprath. 1968. Availability of exchangeable and nonexchangeable Mg in sandy coastal plain soils. Soil. Sci. Soc. Amer., Proc. 32, 386-388.

79. Richards, L. A. 1941. A pressure-membrane extraction apparatus for soil solution. Soil Sci. 51:377-386.

80. Richards, L. A. 1949. Methods of measuring soil moisture tension. Soil Sci. 68:95-112.

81. Robinson, J. B. D. 1957. The critical relationship between soil moisture content in the region of wilting point and mineralization of soil nitrogen. J. Agric. Sci. 49:100-105.

82. Salmon, R. C. 1963. Magnesium relationships in soil and plants. J. Sci. Fd. Agric. 14:605-610.

83. Salmon, R. C. 1964. Cation-activity ratios in equilibrium soil solutions and availability of magnesium. Soil Sci. 98:213-221.

84. Salmon, R. C., and P. W. Arnold. 1963. The uptake of magnesium under exhaustive cropping. J. Agric. Sci. 61:421-425.

85. Schwartz, S., and U. Kafkafi. 1978. Mg, Ca, and K status of silage corn and wheat at periodic stages of growth in the field. Agron. J. 70:227-231.

86. SCS-USDA. 1967. Soil survey laboratories methods and procedures for collecting soil samples. Soil Survey Investigations Report No. 1. U. S. Gov't. Printing Office, Washington.

87. Seatz, L. F., T. R. Gilmore, and A. J. Sterges. 1958. Effect of potassium, magnesium, and micronutrient fertilization on snap bean yields and plant composition. Soil Sci. Soc. Am. Proc. 22:137-140.

88. Seekles, L. 1964. Hypomagnesaemia and nutrition tetany in adult cattle. Nord. Verterinaermed. Rep. III Int. Ntr. Dis. Cattle, 16, (Suppl. 1) Copenhagen. pp. 119-142.

89. Shattuck, G. E., Jr., and M. Alexander. 1963. A differential inhibitor of nitrifying microorganisms. Soil Sci. Soc. Am. Proc. 27:600-601.

90. Singer, R. H., R. B. Grainger, and F. H. Baker. 1958. Investigations on a complicated grass tetany syndrome in ruminants in Kentucky. Kentucky Agric. Exp. Sta. Bull. 658.

91. Sjollema, B. 1932. Nutritional and metabolic disorders in cattle. Nutr. Abstr. Rev. 1:621-632.

92. Smythe, P. J., A. Conway, and M. J. Walsh. 1958. The influence of different fertilizer treatments on the hypomagnesaemic proneness of a rye grass sward. Vet. Record. 70:846-848.

93. Steckel, J. E., and R. L. Flannery. 1971. Simultaneous determination of phosphorus, potassium, calcium, and magnesium in wet digestion solutions of plant tissue by Autoanalyzer. In L. M. Walsh (Ed.) Instrumental Methods for Analysis of Soils and Plant Tissue. Soil Sci. Soc. Am., Madison, Wisc.

94. Suttle, N. F., and A. C. Field. 1969. Studies on magnesium in ruminant nutrition. 9. Effects of potassium and magnesium intake on development of hypomagnesaemia in sheep. Brit. J. Nutr. 23:81-90.

95. Thomas, R. L., R. W. Sheard, and J. R. Moyer. 1967. Comparison of conventional and automated procedures for nitrogen, phosphorus, and potassium analysis of plant material using a single digestion. Agron. J. 59:240-243.

96. Todd, J. R. 1961. Magnesium in forage plants. I. Magnesium content of different species and strains as affected by season and soil treatment. J. Agric. Sci. 56:411-415.

97. Todd, J. R. 1967. Grass tetany. Vet Record. 81 (clin. supp. 12):VI-VII.

98. Todd, J. R., and N. E. Morrison. 1964. Control of hypomagnesaemia in cows: A comparison of foliar dusting with free access to calcined magnesite-molasses mix. Irish Vet. J. 25:197-202.

99. Tyler, K. B., F. E. Broadbent, and G. N. Hill. 1959. Low-temperature effects on nitrification in four California soils. Soil Sci. 87:123-129.

100. Usherwood, N. R., and J. R. Miller. 1967. Effects of soil pH on the availability of magnesium to corn (*Zea mays* L.) from magnesium sulfate and high magnesium liming materials. Soil Sci. Soc. Am. Proc. 31:390-393.

101. Welte, E., and W. Werner. 1963. Potassium-magnesium antagonisms in soils and crops. J. Sci. Fd. Agric. 14:180-186.

102. Wilcox, G. E., and J. E. Hoff. 1974. Grass tetany: an hypothesis concerning the relationship with ammonium nutrition of spring grasses. J. Dairy Sci. 57 1085-1089.

103. Wilkinson, S. R., D. J. Williams, J. B. Jones, Jr., R. N. Dawson, and W. A. Jackson. 1971. Recycling broilerhouse litter on tall fescue pastures at high rates and evidence of beef cow health problems. In Livestock Waste Management and Pollution Abatement. pp. 321-324, 328. Int. Sym. Livestock Waste Proc. (Columbus, Ohio) Am. Soc. Agric. Eng., St. Joseph, Michigan.

104. Wolton, K. M. 1960. Some factors affecting herbage magnesium levels. Int. Grassland Congr., Proc. 8th (Reading, England) pp. 544-548.

APPENDICES

APPENDIX A

APPENDIX A

Some physical and chemical properties of Dickson Silt Loam as used in a greenhouse experiment.

A. Particle size analysis (mixed A and B Horizons)

Sand - 8.1%

Silt - 73.9%

Clay - 18.0%

Textural class - Silt Loam

B. Moisture release characteristics expressed as percent by weight

	Tension in Bars					
	1/3	1	2	5	9	15
Dickson Silt Loam (mixed A and B)	26.1	14.1	8.7	7.0	5.5	4.5

C. Dilute double acid extractable ions

		pp 2 m			
	pH	Ca	Mg	K	P
Dickson Silt Loam (mixed A and B)	4.4	254	40	60	9
Relative category		L	L	L	VL

D. Cation exchange capacity

CEC 7.9 meq/100 g

E. Base saturation

Cation	meq/100 g dry soil
Ca	0.64
Mg	0.17
K	0.15
total bases	0.96 meq/100 g dry soil

base saturation = 12%

APPENDIX B

APPENDIX B

Levels, form, and weights of nutrients used in adjusting the fertility of greenhouse pots.

Factor	Levels	
Magnesium Rate	2	0 kg/ha 112 kg/ha
Adjusted pH	2	pH 5.2 pH 6.2
Nitrogen Rate	3	34 kg/ha 67 kg/ha 134 kg/ha
Potassium Rate	3	56 kg/ha 112 kg/ha 224 kg/ha
Nitrogen Form	2	0 ppm and 10 ppm 2-chloro-6-(trichloromethyl)-pyridine (nitrification inhibitor)

No Nitrification Inhibitor Pots - 34 kg N/ha $(NH_4)_2SO_4$

pH 5.2 3.79 g/pot $CaCO_3$

pH 6.2 7.39 g/pot $CaCO_3$

No Nitrification Inhibitor Pots - 67 kg N/ha $(NH_4)_2SO_4$

pH 5.2 3.97 g/pot $CaCO_3$

pH 6.2 7.57 g/pot $CaCO_3$

No Nitrification Inhibitor Pots - 134 kg N/ha $(NH_4)_2SO_4$

pH 5.2 4.35 g/pot $CaCO_3$

pH 6.2 7.95 g/pot $CaCO_3$

Nitrification Inhibitor Pots - All rates of $(NH_4)_2SO_4$

pH 5.2 3.60 g/pot $CaCO_3$

pH 6.2 7.20 g/pot $CaCO_3$

Phosphorus

0.439 g/pot $CaH_4(PO_4) \cdot H_2O$

APPENDIX C

APPENDIX C

Weekly Greenhouse Air Temperatures

Week of	Maximum	Minimum	Mean
Feb. 13-19	36° C	17° C	21° C
Feb. 20-26	38° C	11° C	20° C
Feb. 27-Mar. 5	35° C	17° C	21° C
Mar. 6-12	34° C	19° C	2 ° C
Mar. 13-19	36° C	19° C	23° C
Mar. 20-26	37° C	12° C	23° C
Mar. 27-Apr. 2	37° C	12° C	24° C
Apr. 3-9	31° C	19° C	24° C
Apr. 10-16	37° C	17° C	23° C
Apr. 17-23	39° C	16° C	22° C
Apr. 24-30	36° C	19° C	24° C
May 1-7	37° C	12° C	22° C
May 8-14	34° C	14° C	24° C
May 15-21	39° C	16° C	26° C

APPENDIX D

Table 39. Treatment means for concentrations of Mg, Ca, K, total N, NO_3-N and yield of the first cutting.

K Rate (kg/ha)	N Rate (kg/ha)	Mg Rate (kg/ha)	pH (kg/ha)	N Form	Mg (%)[1]	Ca (%)	K (%)	Total N (%)	NO_3-N (%)	Yield[1] (g)
56	34	0	5.2	NO_3	0.25	0.56	1.88	2.11	0.04	2.15
112	34	0	5.2		0.20	0.54	2.79	2.04	0.04	2.18
224	34	0	5.2		0.19	0.53	2.95	2.01	0.04	2.00
56	34	0	6.2		0.30	0.75	2.35	2.15	0.10	3.51
112	34	0	6.2		0.27	0.74	2.74	2.16	0.08	2.73
224	34	0	6.2		0.26	0.73	2.76	2.08	0.10	2.79
56	67	0	5.2		0.19	0.36	2.45	2.46	0.04	2.44
112	67	0	5.2		0.16	0.49	2.35	2.44	0.04	2.15
224	67	0	5.2		0.18	0.64	2.58	2.54	0.04	2.21
56	67	0	6.2		0.30	0.84	2.57	2.72	0.26	2.58
112	67	0	6.2		0.26	0.71	3.07	2.49	0.28	2.65
224	67	0	6.2		0.26	0.77	2.73	2.75	0.47	2.17
56	134	0	5.2		0.19	0.50	2.47	2.93	0.27	2.50
112	134	0	5.2		0.20	0.51	2.12	2.76	0.22	2.88
224	134	0	5.2		0.18	0.58	3.55	2.67	0.15	3.03
56	134	0	6.2		0.32	0.98	2.35	2.63	0.25	2.94
112	134	0	6.2		0.30	0.80	3.50	2.99	0.52	2.69
224	134	0	6.2		0.24	0.68	3.08	2.75	0.54	2.73
56	34	112	5.2		0.27	0.48	2.36	1.99	0.03	2.38
112	34	112	5.2		0.29	0.58	2.87	2.09	0.05	2.20
224	34	112	5.2		0.25	0.52	2.64	2.06	0.03	2.57
56	34	112	6.2		0.38	0.83	2.46	2.30	0.20	2.47
112	34	112	6.2		0.35	0.76	2.84	2.34	0.26	2.49
224	34	112	6.2		0.33	0.75	3.32	2.27	0.21	2.85
56	67	112	5.2		0.32	0.62	1.98	2.11	0.06	2.87
112	67	112	5.2		0.27	0.52	2.31	2.27	0.08	2.43
224	67	112	5.2		0.25	0.49	2.48	2.27	0.04	2.62

Table 39 (continued)

K Rate (kg/ha)	N Rate (kg/ha)	Mg Rate (kg/ha)	pH (kg/ha)	N Form	Mg (%)[1]	Ca (%)	K (%)	Total N (%)	NO_3-N (%)	Yield[1] (g)
56	67	112	6.2	NO_3	0.34	0.69	1.92	2.38	0.27	2.60
112	67	112	6.2		0.34	0.77	2.61	2.29	0.19	2.83
224	67	112	6.2		0.31	0.72	2.97	2.38	0.25	2.59
56	134	112	5.2		0.30	0.49	1.92	2.96	0.22	2.48
112	134	112	5.2		0.29	0.69	2.31	2.85	0.25	2.80
224	134	112	5.2		0.27	0.53	3.12	2.92	0.23	2.49
56	134	112	6.2		0.39	0.76	2.64	2.87	0.56	2.41
112	134	112	6.2		0.28	0.78	2.23	2.58	0.41	2.29
224	134	112	6.2		0.28	0.65	3.28	2.58	0.42	2.73
56	34	0	5.2	NH_4	0.21	0.64	1.95	2.04	0.03	2.13
112	34	0	5.2		0.20	0.65	2.39	2.01	0.03	2.10
224	34	0	5.2		0.18	0.62	2.68	2.07	0.05	2.09
56	34	0	6.2		0.25	0.74	2.60	2.31	0.03	2.44
112	34	0	6.2		0.24	0.65	2.72	2.35	0.03	2.33
224	34	0	6.2		0.23	0.70	2.43	2.37	0.03	2.16
56	67	0	5.2		0.18	0.51	1.72	2.34	0.02	2.48
112	67	0	5.2		0.19	0.67	3.05	2.32	0.05	2.05
224	67	0	5.2		0.17	0.52	2.88	2.25	0.03	2.23
56	67	0	6.2		0.26	0.65	2.39	2.50	0.02	2.70
112	67	0	6.2		0.25	0.69	3.13	2.30	0.04	2.71
224	67	0	6.2		0.21	0.64	2.84	2.55	0.03	2.68
56	134	0	5.2		0.15	0.45	1.48	2.97	0.02	2.49
112	134	0	5.2		0.15	0.52	2.33	2.66	0.04	2.72
224	134	0	5.2		0.16	0.48	2.40	2.72	0.04	2.27
56	134	0	6.2		0.24	0.61	2.40	3.05	0.04	2.82
112	134	0	6.2		0.24	0.59	2.41	3.00	0.03	2.54
224	134	0	6.2		0.21	0.67	2.58	3.09	0.06	2.72
56	34	112	5.2		0.25	0.45	2.52	2.32	0.02	1.97
112	34	112	5.2		0.22	0.48	2.77	2.03	0.04	2.06

Table 39 (continued)

K Rate (kg/ha)	N Rate (kg/ha)	Mg Rate (kg/ha)	pH (kg/ha)	N Form	Mg (%)[1]	Ca (%)	K (%)	Total N (%)	NO_3-N (%)	Yield[1] (g)
224	34	112	5.2	NH_4	0.24	0.50	2.53	2.04	0.04	2.40
56	34	112	6.2		0.33	0.60	2.36	2.44	0.03	2.44
112	34	112	6.2		0.29	0.63	2.41	2.35	0.04	2.26
224	34	112	6.2		0.28	0.71	2.90	2.24	0.05	2.45
56	67	112	5.2		0.26	0.46	2.47	2.35	0.03	2.22
112	67	112	5.2		0.24	0.50	2.77	2.38	0.03	2.32
224	67	112	5.2		0.26	0.55	2.69	2.43	0.04	2.29
56	67	112	6.2		0.34	0.76	2.64	2.47	0.04	2.45
112	67	112	6.2		0.25	0.55	2.61	2.54	0.03	2.50
224	67	112	6.2		0.31	0.84	2.92	2.68	0.04	2.36
56	134	112	5.2		0.25	0.52	2.37	2.98	0.03	2.72
112	134	112	5.2		0.25	0.39	2.06	3.01	0.04	2.27
224	134	112	5.2		0.23	0.52	3.03	2.95	0.05	2.37
56	134	112	6.2		0.31	0.57	1.89	3.11	0.03	2.20
112	134	112	6.2		0.25	0.57	1.96	3.07	0.04	2.33
224	134	112	6.2		0.27	0.58	2.75	3.26	0.02	2.28

[1]Dry matter basis.

Table 40. Treatment means for concentrations of Mg, Ca, K, total N, NO_3-N and yield of the second cutting.

K Rate (kg/ha)	N Rate (kg/ha)	Mg Rate (kg/ha)	pH (kg/ha)	N Form	Mg (%)[1]	Ca (%)	K (%)	Total N (%)	NO_3-N (%)	Yield[1] (g)
56	34	0	5.2	NO_3	0.33	0.48	1.70	1.42	0.03	1.95
112	34	0	5.2		0.22	0.45	2.08	1.28	0.03	2.01
224	34	0	5.2		0.19	0.47	2.46	1.19	0.03	2.01
56	34	0	6.2		0.39	0.53	1.56	1.21	0.02	2.67
112	34	0	6.2		0.31	0.53	1.78	1.22	0.03	2.24
224	34	0	6.2		0.25	0.48	2.20	1.23	0.04	2.58
56	67	0	5.2		0.24	0.38	1.79	1.40	0.02	2.89
112	67	0	5.2		0.23	0.42	1.95	1.52	0.03	2.82
224	67	0	5.2		0.21	0.38	1.61	1.33	0.03	2.98
56	67	0	6.2		0.36	0.67	1.46	1.37	0.03	3.11
112	67	0	6.2		0.30	0.46	1.73	1.38	0.03	3.34
224	67	0	6.2		0.27	0.52	2.63	1.40	0.04	3.69
56	134	0	5.2		0.32	0.45	1.43	1.52	0.02	4.06
112	134	0	5.2		0.29	0.39	1.37	1.49	0.03	4.36
224	134	0	5.2		0.22	0.44	2.15	1.57	0.04	3.95
56	134	0	6.2		0.36	0.84	1.28	1.65	0.02	4.30
112	134	0	6.2		0.36	0.53	1.60	1.65	0.03	4.41
224	134	0	6.2		0.27	0.42	1.98	1.69	0.05	4.45
56	34	112	5.2		0.40	0.45	1.46	1.35	0.02	2.09
112	34	112	5.2		0.36	0.50	1.84	1.34	0.03	1.87
224	34	112	5.2		0.26	0.45	2.16	1.34	0.03	2.21
56	34	112	6.2		0.44	0.55	1.50	1.26	0.03	2.89
112	34	112	6.2		0.41	0.47	1.99	1.47	0.04	3.40
224	34	112	6.2		0.32	0.48	2.68	1.19	0.04	3.11
56	67	112	5.2		0.44	0.42	1.57	1.50	0.02	2.74
112	67	112	5.2		0.37	0.37	2.00	1.39	0.03	2.83
224	67	112	5.2		0.28	0.39	2.11	1.41	0.03	3.19

Table 40 (continued)

K Rate (kg/ha)	N Rate (kg/ha)	Mg Rate (kg/ha)	pH (kg/ha)	N Form	Mg (%)[1]	Ca (%)	K (%)	Total N (%)	NO_3-N (%)	Yield[1] (g)
56	67	112	6.2	NO_3	0.53	0.44	1.49	1.45	0.02	3.53
112	67	112	6.2		0.46	0.47	2.16	1.44	0.04	3.53
224	67	112	6.2		0.36	0.41	2.29	1.21	0.04	4.31
56	134	112	5.2		0.45	0.39	1.41	1.42	0.02	3.97
112	134	112	5.2		0.39	0.34	1.45	1.51	0.03	4.40
224	134	112	5.2		0.31	0.28	1.96	1.47	0.03	4.63
56	134	112	6.2		0.57	0.47	1.20	1.72	0.03	4.65
112	134	112	6.2		0.43	0.51	1.89	1.93	0.04	4.69
224	134	112	6.2		0.38	0.38	2.19	1.40	0.04	4.75
56	34	0	5.2	NH_4	0.30	0.56	1.80	1.50	0.03	2.21
112	34	0	5.2		0.25	0.53	2.23	1.41	0.03	2.22
224	34	0	5.2		0.18	0.47	2.06	1.42	0.03	2.03
56	34	0	6.2		0.35	0.55	1.53	1.44	0.02	2.76
112	34	0	6.2		0.30	0.52	1.93	1.43	0.03	3.09
224	34	0	6.2		0.25	0.63	2.76	1.58	0.04	2.82
56	67	0	5.2		0.29	0.57	1.53	1.50	0.02	2.52
112	67	0	5.2		0.24	0.49	1.82	1.41	0.04	2.85
224	67	0	5.2		0.20	0.63	2.21	1.35	0.04	2.92
56	67	0	6.2		0.40	0.53	1.61	1.53	0.02	3.42
112	67	0	6.2		0.34	0.56	1.59	1.30	0.03	3.23
224	67	0	6.2		0.23	0.47	2.07	1.56	0.03	3.60
56	134	0	5.2		0.28	0.47	1.48	1.61	0.02	3.92
112	134	0	5.2		0.26	0.43	1.84	1.68	0.03	4.09
224	134	0	5.2		0.18	0.35	2.12	1.90	0.04	3.73
56	134	0	6.2		0.39	0.40	1.29	1.62	0.02	4.26
112	134	0	6.2		0.33	0.47	1.66	1.98	0.03	3.61
224	134	0	6.2		0.24	0.43	1.94	1.66	0.03	4.26
56	34	112	5.2		0.36	0.49	1.88	1.50	0.02	2.07
112	34	112	5.2		0.31	0.47	2.08	1.44	0.03	2.22
224	34	112	5.2		0.25	0.38	2.21	1.41	0.04	2.55

Table 40 (continued)

K Rate (kg/ha)	N Rate (kg/ha)	Mg Rate (kg/ha)	pH (kg/ha)	N Form	Mg (%)[1]	Ca (%)	K (%)	Total N (%)	NO_3-N (%)	Yield[1] (g)
56	34	112	6.2	NH_4	0.45	0.85	1.63	1.45	0.02	2.73
112	34	112	6.2		0.35	0.51	1.58	1.42	0.03	2.57
224	34	112	6.2		0.26	0.48	2.27	1.36	0.04	2.54
56	67	112	5.2		0.36	0.48	1.80	1.51	0.02	2.53
112	67	112	5.2		0.32	0.44	1.94	1.67	0.03	2.57
224	67	112	5.2		0.28	0.47	2.33	1.47	0.04	2.81
56	67	112	6.2		0.49	0.64	1.81	1.68	0.02	2.85
112	67	112	6.2		0.38	0.65	1.59	1.55	0.03	3.39
224	67	112	6.2		0.29	0.44	2.42	1.58	0.04	3.64
56	134	112	5.2		0.39	0.44	1.30	1.75	0.02	3.73
112	134	112	5.2		0.33	0.31	1.91	1.85	0.03	4.13
224	134	112	5.2		0.26	0.61	2.71	1.91	0.04	3.65
56	134	112	6.2		0.46	0.41	1.75	1.80	0.02	3.71
112	134	112	6.2		0.42	0.42	1.89	1.87	0.03	4.03
224	134	112	6.2		0.29	0.43	2.71	1.78	0.04	4.02

[1]Dry matter basis.

VITA

Charles Michael Finley was born in Lewisburg, Tennessee, on May 5, 1951. He attended elementary schools in Marshall County and Lewisburg, and was graduated from Marshall County Senior High School in June of 1969. The following September he entered The University of Tennessee at Knoxville, and in June 1973 received the Bachelor of Science degree in agronomy.

After two and one half years with The University of Tennessee Agricultural Extension Service, he entered the graduate school of The University of Tennessee, Knoxville, in September 1976. He received the Master of Science degree with a major in plant and soil science in August 1979.

The author is a member of Alpha Gamma Rho, Gamma Sigma Delta, and Phi Kappa Phi as well as the Soil Science Society of America and the American Society of Agronomy.