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Cation composition of tall fescue as affected by potassium and magnesium fertilization, temperature, and soil moisture

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To the Graduate Council:

I am submitting herewith a thesis written by Joe W. West entitled "Cation composition of tall fescue as affected by potassium and magnesium fertilization, temperature, and soil moisture." 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.

John H. Reynolds, Major Professor

We have read this thesis and recommend its acceptance:

Jeff Wolt, M. C. Bell

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 Joe W. West entitled "Cation Composition of Tall Fescue as Affected by Potassium and Magnesium Fertilization, Temperature, and Soil Moisture." I have examined the final 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 and Soil Science.

John H Reynolds
John H. Reynolds, Major Professor

We have read this thesis
and recommend its acceptance:

J Wolt

M. C. Bell

Accepted for the Council:

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Vice Chancellor
Graduate Studies and Research

CATION COMPOSITION OF TALL FESCUE AS AFFECTED BY POTASSIUM AND MAGNESIUM FERTILIZATION, TEMPERATURE, AND SOIL MOISTURE

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

Joe W. West
December 1982

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ABSTRACT

Field experiments were initiated on established stands of tall fescue (Festuca arundinacea Schreb.) located on soils subject to flooding at Knoxville and Chapel Hill, Tennessee. Treatments were imposed to determine effects on K, Mg, Ca, and Al concentrations in tall fescue forage. Fertilizer treatments consisted of 112 kg Mg/ha, 181 kg K/ha, or a combination of both applied as Epsom salts, potassium sulfate, Sul-Po-Mag, or Epsom salts + potassium sulfate. Concentrations of K, Mg, Ca, and Al in tall fescue forage were related to fertilizer treatments and variations in mean monthly air temperature at each location.

Potassium fertilization often resulted in higher K concentrations in the forage, while Mg fertilization had little effect on plant Mg concentration. At Chapel Hill fertilization with Mg or K had little effect on plant Ca concentration, while at Knoxville, Ca results were somewhat inconsistent. Aluminum concentration of plants was usually unaffected by fertilizer treatments. Equivalent ratios of K/(Ca + Mg) were sometimes increased by K fertilization.

Plant K concentrations were associated with increasing mean air temperature up to 12 or 13° C, when K concentrations declined. Magnesium concentrations in tall fescue declined through late fall and early winter, and then either declined or remained at low levels through spring. Calcium concentrations in the forage were somewhat erratic in relation to mean air temperature. Aluminum concentration of the forage dropped considerably when temperatures rose above 10° C. Equivalent ratios of K/(Ca + Mg) closely followed trends of K in plant tissue as associated with temperature.

Squares of sod were removed from a soil fertility field experiment for a greenhouse study in Knoxville. Epsom salts had been applied in the field at the rate of 0, 84, and 168 kg Mg/ha/year for 5 years. Half of the squares of sod were placed in trays that allowed drainage of water. The other half were placed in trays lined with polyethylene to prevent drainage and to approximate flooded field conditions. Equal numbers of sod trays were placed inside and outside the greenhouse to vary the temperature regime.

In only one instance was K concentration in tall fescue affected by soil moisture, and in no instance was it affected by level of Mg fertilization. Magnesium concentration in forage was sometimes affected by soil moisture and was often increased by the highest level of Mg fertilization. Calcium concentration was not affected by soil moisture, but was often highest at 0 kg Mg/ha, indicating possible Mg-Ca competition. Aluminum was unaffected and equivalent ratios of K/(Ca + Mg) were not consistently affected by either soil moisture or Mg fertilization. Potassium, Mg, and Ca concentrations in tall fescue were usually higher at warmer temperatures while Al concentrations were higher at cooler temperatures. Ratios of K/(Ca + Mg) were mostly unchanged between temperature regimes.

In general, fertilization with Mg fertilizers had little consistent effect on increasing tall fescue Mg concentrations, while K fertilizers increased plant K content and the potential for tetany. Fertilization had no effect on decreasing plant Al. Mean air temperatures appeared to have a considerable influence on cation composition of tall fescue, and along with K fertilization may cause the greatest changes in potential for tetany.

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CHAPTER I

INTRODUCTION

Tall fescue (Festuca arundinacea Schreb.) is a popular and widely utilized forage crop. Part of tall fescue's popularity comes from its adaptability to a wide range of climatic and soil conditions. Tall fescue will grow on marginal land with poor or flooded soils. For these reasons, among others, it is widely used as a forage crop, primarily for beef cattle.

Although tall fescue is widely used, its growth and utilization is not without problems. The chemical composition of tall fescue varies widely as a result of many factors, such as soil differences, use of fertilizers, and changes in climatic conditions, such as rainfall and temperature. It is because of these changes in chemical composition that some problems in growth and utilization may arise.

"Grass tetany," or hypomagnesemia, may arise from these chemical fluctuations. Grass tetany has been associated with low serum Mg levels in cattle and sheep. These low serum levels have been associated with the following plant factors: low Mg and Ca contents, high levels of K, high K/Mg ratios, and ratios of K/(Ca + Mg) above 2.2. In recent times, plant Al levels have been under suspicion as being responsible for low serum Mg levels, either by competing with Mg for uptake by the plant, or by making Mg unavailable for absorption in the animal.

It is suspected that under water-saturated soil conditions, Al concentration in the plant increases appreciably when air temperatures increase to 12 to 14° C. These field conditions are often found during the early spring, when grass tetany cases occur most often.

The objectives of this project were to find if cation levels in tall fescue could be affected by fertilization, and if levels of plant Al are affected by saturated and nonsaturated soil conditions under different Mg levels. Cation concentrations also were studied in relation to changes in air temperature.

CHAPTER II

LITERATURE REVIEW

I. TALL FESCUE ADAPTATION

By 1973 tall fescue had become the predominant cool season perennial grass in the United States, occupying approximately 12 to 14 million hectares (10). One reason for its wide utilization is its adaptation to a wide range of climatic conditions. In the United States it is grown from Florida to Canada. It will thrive on thin, droughty slopes, and will conserve soil as a result of its dense sods. It also survives well on poorly drained soils where other cool season grasses may not be well adapted (9, 10, 16).

In the southeast, tall fescue is a valuable grass for spring, fall, and winter grazing. Forage quality of the grass is equal or superior to most other cool season grasses during these seasons if it is properly fertilized and managed (9). According to Woodhouse and Griffith (74) tall fescue removes from the soil yearly approximately 133 kg N/ha, 30 kg P/ha, 170 kg K/ha, and 15 kg Mg/ha in producing 6,854 kg/ha dry matter yield. These nutrients must be replaced or plant deficiencies may develop. In the southeast, because of its ability to grow in the cool, moist conditions of winter, tall fescue has become an important grass for winter grazing. Tall fescue has thrived on soils varying in pH from 4.5 to 9.5. This wide soil adaptation has resulted in wider utilization than for most other grasses (16). Although tall fescue is widely utilized and accepted, it is not without problems. Due to its wide seasonal variations in chemical composition, tall fescue can cause mineral imbalances in cattle, one of which is grass tetany (4, 47).

II. GRASS TETANY

Grass tetany is a metabolic disease which mainly attacks female ruminants in early lactation. Grass tetany, also known as hypomagnesemia, hypomagnesemic tetany, grass staggers, and wheat pasture poisoning, is characterized by a low serum Mg level. Grass tetany appears to affect less than 1% of adult ruminant females, but the incidence may be much higher in individual herds (24). According to Voisin (70), grass tetany causes the loss of 1 to 2% of grazing livestock in the United States, which may be worth over $70 million annually.

Voisin (70) states that although the name hypomagnesemia implies a deficiency of Mg, the conclusion that grass tetany is due to a Mg deficiency is incorrect. Since there is often a sufficient amount of Mg present in the ration, the problem of decreased Mg availability must be considered. Symptoms of the disease are irregular heart activity, inability to rise, pedaling of the forelegs, moving of jaws and grinding of teeth, and violent convulsions (60, 70).

Potential for grass tetany has increased with more intensive pasture use. Wilkinson and Stuedemann (72) state that in the United States the gradual trend toward more intensive cow-calf pasture production systems will likely continue. Therefore as the production levels intensify, the potential for grass tetany will likely increase. Further, there is a trend toward an increase in beef cattle production in the southeast, where the potential for grass tetany is probably greater than in other regions of the United States.

III. THE ROLE OF MAGNESIUM IN GRASS TETANY IN RUMINANTS

According to Rook and Storry (60), the animal body contains only about 0.05% Mg by weight. Nearly 60% of this is in the skeleton, 40% is in cells and 1% is in extracellular fluids. As the animal matures, the blood supply to the skeleton is progressively diminished, and the mobility of skeletal Mg is restricted. This helps to explain why grass tetany occurs in older ruminants, especially females nursing calves.

Magnesium is important to the cow because it is involved in many enzymatic reactions in metabolism. It is required for cellular oxidation, especially in those reactions leading to ATP formation. It activates the enzymatic reactions which require thiamine pyrosphosphate. Magnesium is also involved in many reactions in protein and lipid metabolism (11).

Voisin (70) states that if the Mg concentration of the blood serum is lower than 1.20 mg/100 ml before convulsions, hypomagnesemia is the probable cause, and if it is lower than 0.90 mg/100 ml, it is the definite cause of convulsions. According to Grunes (31) and Kemp (39), a Mg level in the blood serum of 1.0 mg/100 ml is indicative of severe hypomagnesemia.

Low serum Mg levels result not only from low levels of Mg in the diet, but from factors that make it less available for absorption by the animal. Nitrogen fertilization increases the concentration of higher fatty acids in plants, and can depress the availability of Ca and Mg to ruminants by forming insoluble Ca and Mg soaps (31, 35, 40). Low concentrations of carbohydrates, or a negative energy balance have been found to affect Mg absorption (31, 45). In situations typical of grass tetany outbreaks, dietary protein exceeds requirements, while energy sources are deficient. Ammonia is formed in the rumen fluid due to deamination of dietary protein. This raises the pH in the rumen and can interfere with Mg as well as Ca absorption (32, 40). However, Fontenot et al. (25) state that a high nitrogen diet does not appear to affect Mg absorption, but does increase urinary Mg excretion by an unknown mechanism.

Interference by other ions has been shown to be a factor influencing Mg availability in ruminants (12, 25). Sodium has been shown to increase membrane permeability and Mg absorption, while K has been shown to decrease membrane permeability and reduce Mg absorption. Newton et al. (55), in an experiment utilizing sheep, fed a diet containing 4.9% K and 0.1% Mg, and found that the high K intake resulted in an average decrease in Mg absorption of 46%.

Magnesium is poorly available to ruminants. One reason for poor availability is that Mg in chlorophyll is an indigestible constituent of the plant. Butler (12) summarized reports showing Mg to be 28 to 30% available in alfalfa hay and meadow hay.

Kemp et al. (40) found 17% of herbage Mg was available to cows with the range of availability from 7 to 33%. Increased Mg availability was noted as the herbage matured. Young growing plants need much chlorophyll to produce the needed growth constituents, while a more mature plant is growing more slowly, needs less chlorophyll, and less Mg is involved with chlorophyll molecules. As a result, more Mg should be available to the animal.

Aluminum has become suspect in recent years of being involved with grass tetany. Allen and Robinson (2) in an in vitro experiment found that on addition of 8000 ppm Al, Ca and Mg solubility was decreased by 74 and 56%, respectively. At 4000 ppm Al, Mg solubility was reduced 47%. Using fistulated steers, the researchers added 4000 ppm Al to the diets of the animals. Serum Mg levels dropped within 24 hours, and dropped 32% within 4 days. After the treatments were discontinued, serum Mg levels returned to normal.

IV. FACTORS AFFECTING MAGNESIUM IN PLANTS

A generally accepted level of Mg considered necessary in the plant to prevent grass tetany is 0.2% (39). Hill and Guss (35) quote the Netherlands Committee on Mineral Nutrition as recommending that young grass rich in N and K should contain 0.3% Mg and more mature grass with less than 20% crude protein and less than 3.0% K should contain 0.2% Mg. According to Hill and Guss, the maximum recommended value of K of 3.0% is often exceeded in forages.

It has been found that the monovalent cation K is absorbed and accumulated by plants much more rapidly and to a much greater degree than divalent ions such as Ca or Mg (70). The presence of K has an antagonistic effect on Mg. Magnesium deficiencies in the plant may not necessarily be due to soil deficiencies, but may be due to competitive effects of other ions.

For electrical neutrality, plants remove equivalent amounts of cations and anions from solution, so for a given uptake of anions or exchange with root cations, half-moles of a divalent cation are as effective as moles of a monovalent cation (63). Increasing the amount of one cation in a plant usually decreases the contents of other cations, and total cations are not greatly affected.

Levels of cations in the soil may have an influence on cations in the plant. By increasing Mg saturation of the CEC above 13%, Ca levels were decreased, showing competition between the two for uptake. When Ca saturation of the CEC was increased from 57 to 74%, percent Ca in herbage was increased for most grasses an average of 40% (30). Also, since monovalent ions are absorbed more rapidly than divalent ions of similar radii, the uptake of K would be favored at the expense of Mg and Ca.

Another factor involved in the uptake of ions is the fact that ions of smaller hydrated radii are more rapidly and strongly absorbed than those of larger radii with equivalent charge (33). Since Mg has a larger hydrated radius than some other cations, particularly K and Ca, its uptake may occur at a slower rate.

Metson (52) found that a Mg deficiency could occur at relatively high levels of available soil Mg where plant uptake of this element was impeded by an excess of some other cation. As a result, uptake of Mg depends on exchangeable K, Ca, NH_4, and on soil pH, as well as on exchangeable Mg.

Altering the amount of Mg available in the soil has been one method attempted to solve Mg deficiencies in the plant. According to Hannaway et al. (33) and Grunes (31), the soil Mg available to the plant can be increased on low CEC, sandy soils by application of Mg compounds, However, on medium to fine-textured soils these treatments were found to have little significant effect.

Researchers working with N and K fertilization have found that fertilization with N alone tended to increase Mg concentration in the plant where soil Mg was not limiting. Potassium fertilization increased herbage K levels, but depressed Mg and Ca concentration. Where N and K were used together, the incidence of grass tetany increased, due to increased N and K levels. The highest serum Mg levels resulted from low K and N levels in the herbage, after a moderate rate of fertilization with N and K (39, 56).

V. INFLUENCE OF TEMPERATURE, SOIL MOISTURE AND SOIL OXYGEN ON CATIONS

The chemical composition of forages, including tall fescue, varies seasonally. Several researchers have noted a definite relationship between temperature and cation content of forages (18, 42).

Kemp and t'Hart (42) discovered that there is little or no further occurrence of grass tetany when the mean 24-hour temperature has risen to above 14° C. The longer it takes to rise above this temperature, the longer is the duration of the tetany period. After a rise in temperature from a level of less than 14° C, an increase in the number of tetany cases was found to occur. A time lag of 5.1 days was observed. A transition from warm temperatures to cool temperatures (below 14° C) in the fall can also lead to grass tetany (18, 42). Forage from pastures with tetany cases contained a higher K content and a lower proportion of Na, Ca, and Mg than forage from non-tetany producing pastures (42). Dijkshoorn and t'Hart's (18) research agree with Kemp and t'Hart's (42), in that they found an increase in K in the forage following a temperature increase. They also found that following an increase from cold to warm temperatures, if a subsequent cold period occurred, it cancelled the effects of the warming trend.

The equivalent ratio K/(Ca + Mg) has been found to be significantly correlated to the incidence of grass tetany (42). When the value was less than 2.2, there were few cases of tetany (0.77% of 4658 cattle). When the value was greater than 2.2 there were several cases (6.66% of 1908 cattle). Several researchers (18, 41, 42) found that K was the element primarily responsible for the change in the K/(Ca + Mg) ratio. Magnesium and Ca were found to change very little. Conversely, other researchers found Mg levels to be significantly affected by temperature (32, 66, 67).

McNaught et al. (50) found that seasonal variations in Mg were much greater than any changes induced by fertilizer treatments. Values were at a maximum level in summer and at a minimum in late winter to early spring. Stuart et al. (67) found the Mg and Ca concentrations to fall during temperature rises in crested wheatgrass, but in winter wheat the Mg and Ca concentrations remained fairly constant.

Leggett et al. (44) investigated the influence of root temperatures on growth and cation composition of tall fescue. Comparing plants whose root temperature was kept at 12° C with plants whose root temperature was kept at 25° C, they found that while the lower root temperature resulted in lower dry matter accumulation, no effects were seen on the concentration of K, Ca and Mg in the plant. From these results it was concluded that cation composition as it is affected by temperature is not controlled solely at the root level, but the physiological processes in the shoot are heavily involved.

Soil moisture content, along with its attendant effect, soil O_2 content, has also been suspected of affecting plant cation composition. Karlen et al. (38) found evidence to support the theory of soil moisture influence on cation composition in the plant. Potassium probably plays a major role in the influence of moisture levels on the uptake of Mg by plants (72). Potassium is the dominant monovalent cation in soils of the temperate zone. When soil moisture is increased, the proportion of divalent cations in solution is decreased, while the quantity of dissolved K usually increases (58). When this occurs, the changes that occur due to moisture conditions are reflected in the equivalent ratio of K/(Ca + Mg) in plant material.

Elkins and Hoveland (20) found that under increasing soil oxygen conditions, ryegrass contained higher K, Ca, and Mg contents. While Mg levels at 2 to 16% soil oxygen were below the critical level of 0.2% Mg, the level of K was above 2.5% when soil oxygen was at 4 to 8%. The indication is that low soil oxygen would be conducive to grass tetany.

Karlen et al. (37), using two soil moisture levels, found that Ca and Mg were generally depressed by high soil moisture, while K concentrations remained unchanged or increased slightly. Elkins et al. (19) also found that under flooded soil conditions with low soil oxygen, magnesium content of the plant was reduced significantly.

When comparisons of nutrient concentrations in different plant parts were made in experiments using two moisture levels, differences were found in the Mg concentrations of roots and upper plant parts. The differences were evident at both moisture levels, indicating that even when sufficient Mg is absorbed by the plant roots, an impaired translocation mechanism may result in lowered levels of Mg in the forage (31).

VI. FACTORS AFFECTING ALUMINUM CONTENT IN THE PLANT

Since almost 8% of the earth's crust is made up of Al, it is a very important constituent of the soil. Along with Si, it is the major element making up the lattices of primary and secondary clay minerals (51). Even with this abundance of Al, in most cases little is found in plants. Its availability is low at pH 5.5 to 7.0.

According to Foy et al. (28), Al toxicity is of consequence at a pH below 5.0, but can occur as high as pH 5.5. Accordingly, Al should not be a problem, or even available, at near-neutral pH.

The radius of Al in ionic crystals falls between that of the doubly charged Mg and the quadruply charged Si ion (7.8, 5.7, and 3.9 nm for Mg, Al, and Si, respectively). According to Hutchinson (36), in the lattice structure of the aluminosilicate clay minerals, limited substitution of Al^{3+} for Si^{4+}, or of Mg^{++} for Al^{3+} is possible. Elements having a low ratio of charge to radius tend to form soluble cations. Elements having a high ratio form anions with oxygen. In the middle sector, in which Al lies, the elements tend to form oxides insoluble in neutral water solutions.

According to Smith (64), scientists are in agreement as to the nature of the Al species existing in aqueous environments above neutrality, and existing below a pH of 4.0. Between pH 4 and 7, there is little agreement as to what species are present. Foy (26) states that it is assumed that Al^{3+} is hydrolyzed in water according to the reaction $Al^{3+} + H_2O \longrightarrow AlOH^{2+} + H^+$. It may also hydrolyze to polymers, such as $Al_6(OH)_{15}^{3+}$, and may exist as $AlSO_4^+$. Aluminum and H ions are more strongly absorbed than other ions. When rainfall is high, other cations may be leached out of the soil, and H^+ and $AlOH^{2+}$ can become more abundant on the mineral surfaces (36).

Soils under conditions of heavy rainfall can become acidic, because rain water contains dissolved CO_2, which combines with water to form carbonic acid ($CO_2 + H_2O \rightleftharpoons H_2CO_3$). The carbonic acid can then ionize to form H^+ plus bicarbonate and a small amount of carbonate ($H_2CO_3 \rightleftarrows H^+ + HCO_3^- \rightleftarrows H^+ + CO_3^=$). As ions, except for $AlOH^{+2}$, are replaced by H^+ and are leached to the water table, the increased acidity can promote solutions of hydroxides such as Fe and Al. Since cations can exchange reversibly with other cations in the soil, this makes the possibility of Al availability much greater under these conditions (62).

Along with acid conditions produced by high soil moisture, the possibility of root-produced acids lowering the pH of the soil in the root zone may account for a low enough pH to bring Al into solution. With cool weather and lower Mg utilization, the plant could balance its ionic needs with K and the Al ion (17).

Foy et al. (27), using wheat varieties which were sensitive and non-sensitive to Al, found that the Al sensitive variety lowered its root zone pH more than the non-sensitive variety. This would indicate that its Al sensitivity is due to the lower root zone pH, since this would aid in mobilization of greater amounts of Al.

According to Chenery (14) many plants have the capacity to accumulate large amounts of Al. Miller (53) and Chenery (13, 14) have found that *Hydrangea macrophylla* accumulates up to 13,000 ug/g Al when grown on acid soils, while on neutral soils it may accumulate only 60 ug/g. Using Al chelates in nutrient solutions, Muchovej et al. (54) found evidence of increased Al in ryegrass (*Lolium* species). All Al chelate treatments showed increased Al uptake, while Mg levels did not change and Ca levels were depressed. Clark (15), using corn (Zea mays L.), found when Al was added to nutrient solutions that root Mg was decreased more than leaf Mg, but decreases in top Mg and Ca were significant.

Aluminum levels have been found to occur in high levels in forages under field conditions. Allen et al. (3) found that Al concentrations ranged from 100-8000 ug/g in ryegrass hay fed cattle in a grass tetany outbreak. Water soluble Mg averaged 32% less in high Al hay samples. Total Al was found to be negatively correlated with water soluble Mg.

High Al concentrations and low water soluble Mg have been found to be closely related to flooded soil conditions by Allen (1). High Al samples (>1000 ug/g) were lower in water soluble Ca and Mg, and higher in HCl soluble Mg. The increases were found to occur during periods of high soil moisture and low temperatures. Highest Al accumulation occurred following exposure to low temperatures (0 to 3° C). A linear increase in forage Al concentration began two days after the rise in temperature. Forage Al concentrations in a tetany-prone pasture exceeded 1000 ug/g 7 days after the soil temperature rose from 3° C to above 14° C. Forages with high Al concentrations grew on many different soil types which ranged in pH from 5.1 to 7.3. Exchangeable Al was not detected in soil surface horizons.

VII. SUMMARY

Tall fescue is a popular forage species which is widely utilized in the United States. It is utilized heavily because it is so adaptable to quite variable, sometimes adverse, soil and climatic conditions.

The effects of climate and fertilization cause wide fluctuations in the chemical composition of fescue. Heavy N and K fertilization in the late winter and early spring may lead to luxury consumption of K at the expense of Mg and Ca. Climatic conditions, such as warming trends in early spring, when temperatures climb to 12-14° C after an extended cold period, and flooded soil conditions, with low oxygen contents, can also affect chemical composition. Uptake of excess K and Al have been found to occur under these conditions. Concentrations of Mg and Ca have been shown to decline under the same conditions. It is possible, through genetic selection, to select for plants that can accumulate more Mg and less K.

These variations in composition have been shown to be directly related to hypomagnesemia, or grass tetany, a metabolic disorder which is very costly to the beef producers of our country. Low levels of serum Mg are characteristic of grass tetany and may be caused by several factors. Low levels of Mg in the plant may be a cause, while high plant K levels may cause low serum Mg due to reduced absorption in the animal. High plant N may lead to reduced Mg and Ca absorption due to increased pH in the rumen, while excess Al is thought to remove Mg from solution in the rumen, and to compete with Al in the plant. All these factors, and others, are involved in the etiology of grass tetany.

The purpose of this experiment was to find if levels of certain cations related to grass tetany could be affected by the addition of fertilizers containing K and/or Mg salts. The intent was to determine the effect, if any, on the uptake of K, Mg, Ca, and Al in fescue forage. The effects due to high soil moisture were considered as well as the relation of cation concentrations to changes in air temperatures.

CHAPTER III

MATERIALS AND METHODS

I. FIELD EXPERIMENTS

Field studies were conducted at The University of Tennessee Plant Science Field Laboratory, Knoxville, Tennessee, and at the James West farm near Chapel Hill, Tennessee. At Chapel Hill the soil is Roellen silty clay loam, with a 0-2% slope (fine mixed thermic family of Vertic Haplaquolls) (65). Before treatments were applied the soil pH was 7.0 and it contained the following levels of soil test (Mehlich I) extractable nutrients: 77 ug/g Mg (high), 3792 ug/g Ca (very high), 48 ug/g K (medium) and 5 ug/g P (very low). The site chosen was a tall fescue pasture, which had been seeded two years before the experiment. The soil is poorly drained and subject to flooding in the winter and spring months. At Knoxville the soil is Lindside loam with a 0-2% slope (fine-silty, mixed, mesic family of Fluvaquentic Eutrocrepts) (65). These soils are often saturated with water during some periods of the year. This soil, before treatments were applied, had a pH of 7.2 and contained 603 ug/g Mg (very high), 2678 ug/g Ca (very high), 51 ug/g K (medium), and 6 ug/g P (low) of soil test extractable nutrients. The site was a tall fescue sod established several years earlier.

Forage samples were harvested by taking grab samples above a 2 cm stubble height at random from each plot. These samples were placed in paper bags and dried in a forced-air oven at 70° C for approximately 24 hours. Dried samples were ground in a stainless steel Wiley mill to pass a 1 mm screen. Samples were stored in glass jars until analysis. Sampling dates for field experiments are in Appendix A. Soil samples were taken using a 2.4 cm diameter core sampler at two depths, 0-7.6 cm and 7.6-15.2 cm. They were taken following the last harvest. Soil samples were air dried and ground with mortar and pestle and stored until analyzed.

Five treatments were imposed in the field experiments in a randomized complete block design with four replications. Treatments were: control, Sul-Po-Mag, Epsom salts, potassium sulfate, and Epsom salts plus potassium sulfate. Description and rates of treatments are found in Table 1. At the time treatments were applied, all plots received an additional 672 kg/ha of 10-10-10 fertilizer (67-29-56 kg/ha of N-P-K). Fertilizers were applied with a Gandy spreader to the Knoxville experiment October 29, 1981 and to the Chapel Hill experiment December 9, 1981. Daily temperatures and precipitation were recorded 325 m from the experimental site at Knoxville and 27 km from the Chapel Hill site. The 30 days preceding each harvest were used for calculating the mean monthly temperature for a harvest.

TABLE 1. Fertilizers Used in Field Experiment Treatments with their Chemical Formulas and Rates of Application

				Rate Applied		
Fertilizer	Chemical Formula	Mg	K	Fertilizer	Mg	K
		--- % ---		--------- kg/ha --------		
Epsom salts	$MgSO_4 \cdot 7H_2O$	9.8	----	1143	112	---
Potassium sulfate	K_2SO_4	----	41.5	437	---	181
Sul-Po-Mag	$2\ MgSO_4 \cdot K_2SO_4$	11.6	18.8	965	112	181
Epsom salts + potassium sulfate	$MgSO_4 \cdot 7H_2O + K_2SO_4$	9.8	41.5	1143+437	112	181

II. GREENHOUSE EXPERIMENT

Sod for the greenhouse experiment was obtained from an existing experiment near Knoxville on an Etowah silt loam with a 2-5% slope (fine-loamy, siliceous, thermic family of Typic Paleudults) (65). The site was a tall fescue sod, which had been utilized in a fertility experiment for five years (59).

Squares of sod 29 x 29 x 7 cm deep were removed from the existing experiment on February 19, 1982. All sod was removed from the same replication. Squares of sod were removed from treatments which had been fertilized annually with 201 kg N/ha, 58 kg P/ha, and 112 kg K/ha, and had received three different levels of Mg annually from Epsom salts: 0, 84, and 168 kg Mg/ha. These squares were placed in plastic trays, half of which had been lined with a double layer of polyethylene to prevent drainage of water from the soil, while the other trays were left unlined to allow drainage. Half of each group was placed inside and half outside a greenhouse in Knoxville. The experiment was in a randomized complete block design with a factorial arrangement of treatments replicated three times. There were two environments: One inside and one outside the greenhouse. There were three levels of Mg mentioned previously: 0, 84, 168 kg/ha, and two moisture treatments: drained or wet.

Mean temperatures inside the greenhouse were usually maintained below 28° C by fans but twice exceeded 29° C. No attempt was made to control temperature of outside trays. Trays were watered daily, and sometimes twice daily during periods of high moisture loss. Trays lined with plastic were maintained at saturated soil moisture to approximate flooded field conditions. Unlined trays were kept moist, but were allowed to drain. Weekly mean air temperatures beside the indoor and outdoor trays are listed in Appendix B.

Greenhouse samples were harvested by removing forage at a height of approximately 2 cm with scissors. Samples were dried as in the field experiments. Samples were ground in a Wiley mill to pass a 20 mesh screen and were stored in plastic bags until analysis. Harvest dates for greenhouse plots are found in Appendix A.

III. CHEMICAL ANALYSIS

Plant tissue samples were digested for mineral determinations by the wet ashing procedure described by Blanchar et al. (7). The digestates were analyzed for Mg, Ca, K, and Al on a Perkin Elmer 5000 atomic absorption spectrophotometer. Atomic absorption was used to analyze Mg, Ca, and Al, while flame emission was used for K. The digestate was analyzed for P with a Technicon Autoanalyzer. Results for Ca, Mg, K, and P are reported as percent on a dry weight basis, and Al is reported as ug/g on a dry weight basis.

Soil samples were extracted with 0.05 $\underline{N}$ HCl in 0.025 $\underline{N}$ H_2SO_4 (Mehlich I) (61) and analyzed for Mg, Ca, K, and P as described for the plant tissue samples. Aluminum was determined on soil sample extracts from 1 $\underline{N}$ KCl (59) in a Perkin Elmer 5000 atomic absorption spectrophotometer.

IV. STATISTICAL ANALYSIS

An analysis of variance was calculated on each sampling date for both field experiments. The ANOVA procedure was used as outlined by Barr et al. (6) for SAS 79. Means were separated using Duncan's Multiple Range Test. The ANOVA procedure was used to partition sums of squares associated with main effects, interactions, and error in the greenhouse experiment. Using Hartley's test (73), error variances were tested for homogeneity. When non-homogeneity was detected, appropriate pooling was done and was used to test main and interaction effects. Means were separated in the same manner as the field experiments. Tests made to detect differences due to environment used replications confounded with environment as the error term. All tests were at the level of significance of $\alpha = 0.05$.

CHAPTER IV

RESULTS AND DISCUSSION

I. CHAPEL HILL FIELD EXPERIMENT

Harvest 1 on January 2, 1982 occurred when tall fescue is normally dormant. Fescue forage receiving K_2SO_4 contained less plant K than forage from the control (Table 2). This is not consistent with expected results, and may be explained by the fact that treatments had been applied less than one month prior to harvest (December 9, 1981). By first harvest the mean air temperature had dropped below 4.4° C and little uptake of nutrients should have occurred as evidenced by low plant K concentration. Some leaf deterioration had occurred, as leaf tissue was somewhat brown. At harvest 2, significant differences were found with K_2SO_4-treated forage having the highest K concentration. The Epsom salts + K_2SO_4 fertilizer produced a higher tissue K concentration, but was not significantly greater than other fertilizers. Harvests 3 and 4 were more clear-cut, in that both harvests showed K-fertilized plots had higher plant tissue K concentrations than non-K-fertilized and control plots. Harvests 2, 3, and 4 were taken in March, April, and May, respectively, when mean temperatures were above 4.4° C, allowing for growth and nutrient uptake by tall fescue.

Means of K consistently increased for forages from all treatments from harvests 1 through 3, and then dropped at harvest 4

TABLE 2. Potassium Concentration in Tall Fescue at Chapel Hill as Affected by Fertilizer Treatment

Treatment	2 Jan 82 Harvest 1	15 Mar 82 Harvest 2	3 Apr 82 Harvest 3	1 May 82 Harvest 4
	--------------------	-------------------- %	--------------------	--------------------
Control	.93 a[1]	1.59 c	2.20 b	1.96 b
Sul-Po-Mag	.82 ab	1.67 bc	2.39 a	2.14 a
Epsom salts + K_2SO_4	.81 ab	1.78 ab	2.40 a	2.10 a
Epsom salts	.75 ab	1.69 bc	2.22 b	1.99 b
K_2SO_4	.73 b	1.90 a	2.52 a	2.19 a

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

(Figure 1), indicating that a climatic factor or advancing maturity was responsible. t'Hart (68) has stated that 95% of the tetany cases in the Netherlands occurred when the temperature was between 8 and 14° C when soil moisture was high. Conditions at these harvests met these temperature criteria, and soil was saturated with water when harvests were taken. Several other researchers have reported similar trends in seasonal K accumulation as reported here (18, 37, 66, 70, 72).

Seasonal and maturity effects corresponding to the changes in plant K have been reported by researchers. Reid et al. (57) noted a dramatic increase in K concentration in tall fescue from March until May, which approximated the period of vegetative growth. Baker and Reid (4), also using tall fescue, reported an increase in K concentrations throughout the vegetative growth of tall fescue until a decline at jointing or early boot stage.

The Sul-Po-Mag fertilizer caused significantly higher plant tissue Mg than the K_2SO_4 fertilizer in harvest 1 (Table 3). The possibility exists that ion uptake occurred since the mean temperature was well above that required for complete dormancy (43). At harvest 2 the $MgSO_4$ + K_2SO_4 resulted in highest plant tissue Mg, while the control was lowest. Magnesium fertilization tended to cause higher plant tissue Mg than fertilizers without Mg. At harvest 3 differences between means were quite small, and their biological validity is questionable. Harvest 4 results revealed no differences between treatments.

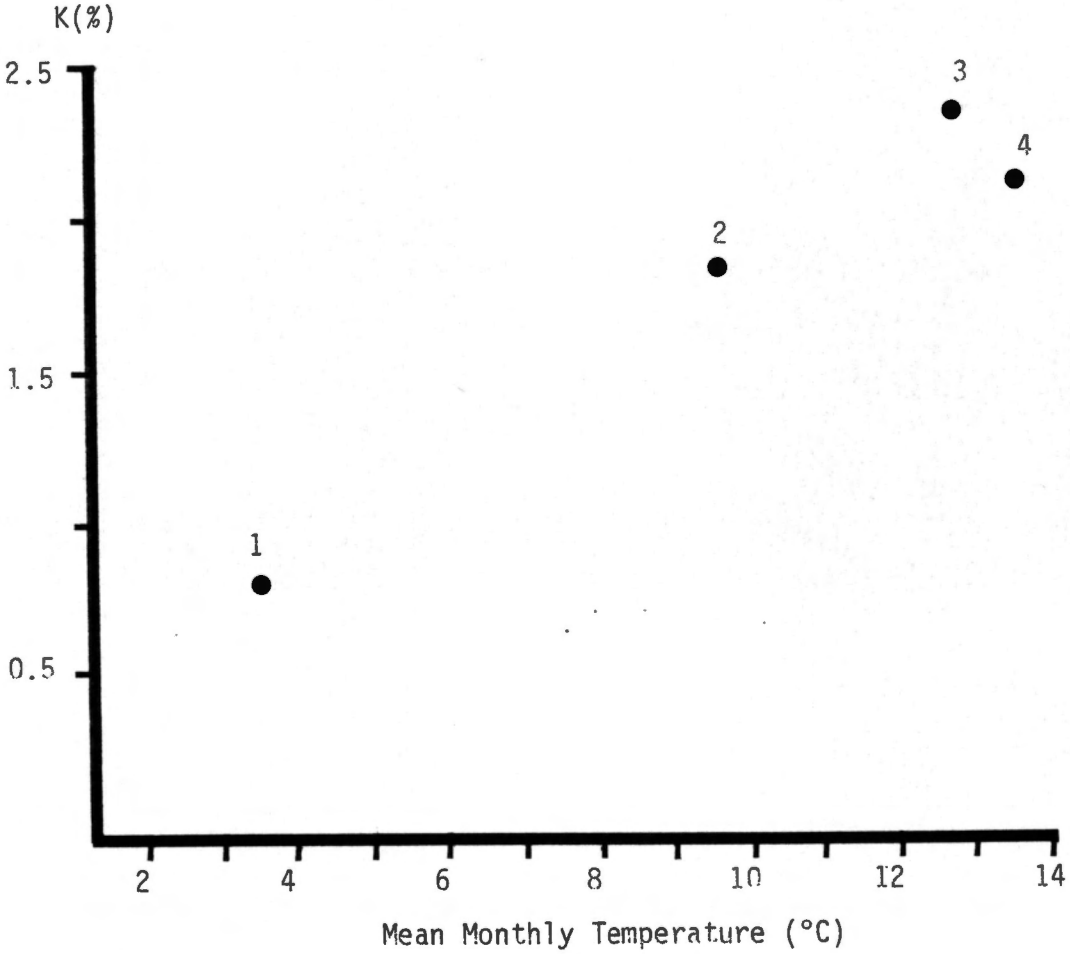

FIGURE 1. Potassium Concentration in Four Harvests of Tall Fescue at Chapel Hill in Relation to Air Temperature

TABLE 3. Magnesium Concentration in Tall Fescue at Chapel Hill as Affected by Fertilizer Treatment

Treatment	2 Jan 82 Harvest 1	15 Mar 82 Harvest 2	3 Apr 82 Harvest 3	1 May 82 Harvest 4
	%			
Control	.154 ab[1]	.096 b	.102 ab	.101 a
Sul-Po-Mag	.170 a	.108 ab	.102 ab	.091 a
Epsom salts + K_2SO_4	.151 ab	.115 a	.095 b	.094 a
Epsom salts	.155 ab	.106 ab	.105 a	.103 a
K_2SO_4	.132 b	.101 ab	.094 b	.098 a

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

No fertilizer emerged as consistently raising plant tissue Mg concentrations. Mayland and Grunes (46) found that it was necessary to apply 600 kg Mg/ha to raise Mg levels to 0.2% in Agropyron desertorum Fisch. They concluded that high costs precluded Mg fertilization to meet Mg requirements of grazing animals. McNaught et al. (50) also found it took large amounts of Mg fertilizers to produce small increases in herbage Mg levels. Metson (52) stated that for practical purposes, the degree of control that can be exercised over plant Mg concentrations through the use of Mg fertilizer is limited, since plant Mg is increased only in proportion to the square root of the exchangeable soil Mg.

It should be noted that in no treatment or harvest was the mean plant concentration of Mg above the 0.2% level suggested as a safe level to prevent grass tetany. This makes the safety of beef cows grazing these pastures without providing supplemental Mg questionable.

Magnesium concentrations in plant tissue consistently declined in almost all treatments as temperature increased (Figure 2). Stewart et al. (66) found that Mg concentration in forages changed very little until spring growth, when they gradually decreased. Reid et al. (57) found levels of Mg in forage to be low in the early spring, and found them to increase through summer and fall. Baker and Reid (4) reported that Mg concentration in tall fescue declined throughout the vegetative stage, and did not start to increase until the forage reached full bloom.

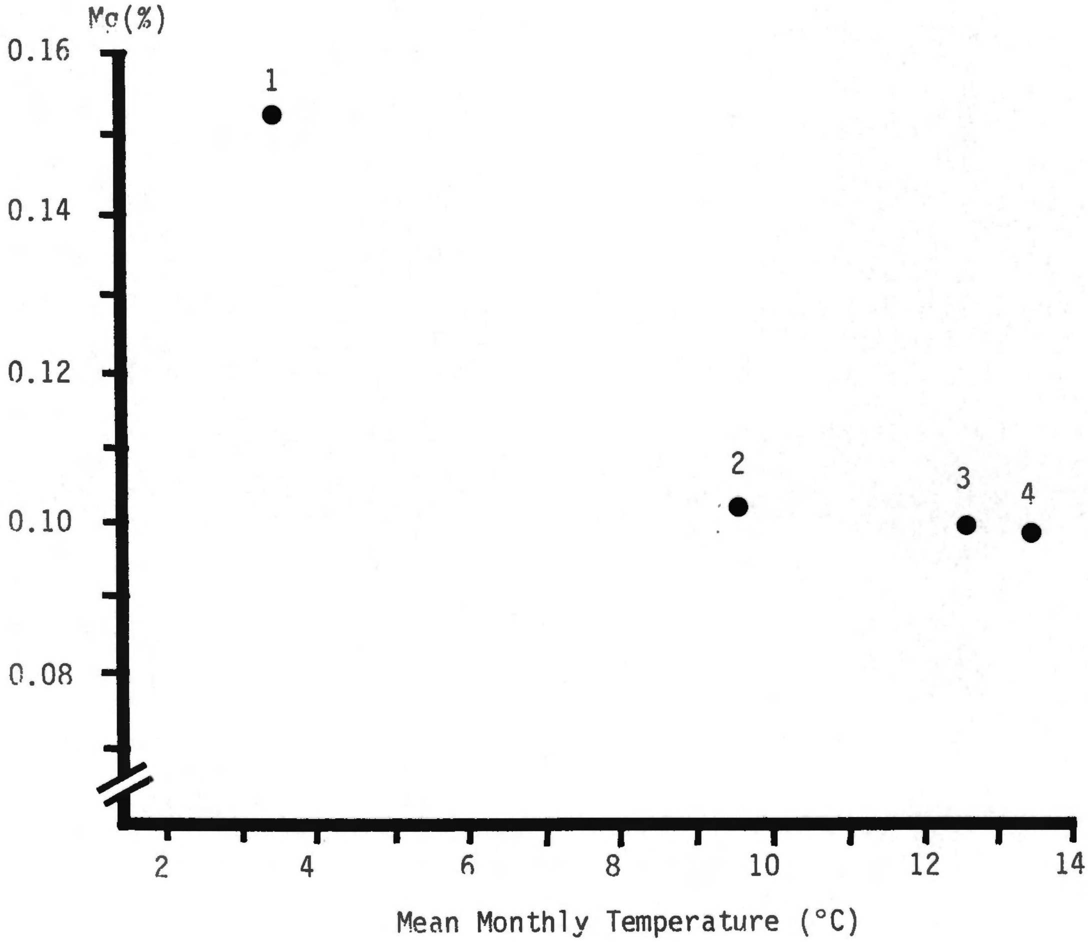

FIGURE 2. Magnesium Concentration in Four Harvests of Tall Fescue at Chapel Hill in Relation to Air Temperature.

No differences in Ca concentration due to fertilizer were found in harvests 1, 2, or 4 (Table 4) while in harvest 3 highest plant tissue Ca levels were found in the control and $MgSO_4$ treatments. The trend in plant Ca content indicates a possible competition for uptake between Ca and K. Hannaway et al. (33) stated that monovalent ions are absorbed more rapidly than divalent ions by the plant, and Wilkinson and Stuedemann (72) stated that when soil moisture is increased, the proportion of divalent cations in solution is decreased in relation to the monovalent cations. This would lead to increased competition by K, and reduced Ca and Mg levels in the plant. Kemp (39) and Balasko (5) reported that applications of K fertilizers reduced Mg and Ca concentrations in forage, lending support to these statements.

Calcium concentrations in plant tissue increased from first harvest to second harvest, but declined from harvests 2 through 4 (Figure 3). The increase of Ca from harvest 1 to harvest 2 corresponds with the mean temperature where dormancy of tall fescue is broken (43). When growth was initiated, Ca would be taken up as a result of that increased growth. Subsequent decline in Ca concentration could be attributed to a dilution effect due to rapid growth during the vegetative stage. Hannaway and Reynolds (34) reported similar trends, while Stewart et al. (66), found that Ca concentration in winter wheat fluctuated but showed no consistent trend except for a decrease during rapid growth in the spring.

TABLE 4. Calcium Concentration in Tall Fescue at Chapel Hill as Affected by Fertilizer Treatment

Treatment	2 Jan 82 Harvest 1	15 Mar 82 Harvest 2	3 Apr 82 Harvest 3	1 May 82 Harvest 4
	%			
Control	.557 a[1]	.717 a	.594 a	.568 a
Sul-Po-Mag	.618 a	.699 a	.551 bc	.522 a
Epsom salts + K_2SO_4	.603 a	.709 a	.546 bc	.507 a
Epsom salts	.620 a	.744 a	.579 ab	.530 a
K_2SO_4	.641 a	.656 a	.533 c	.525 a

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

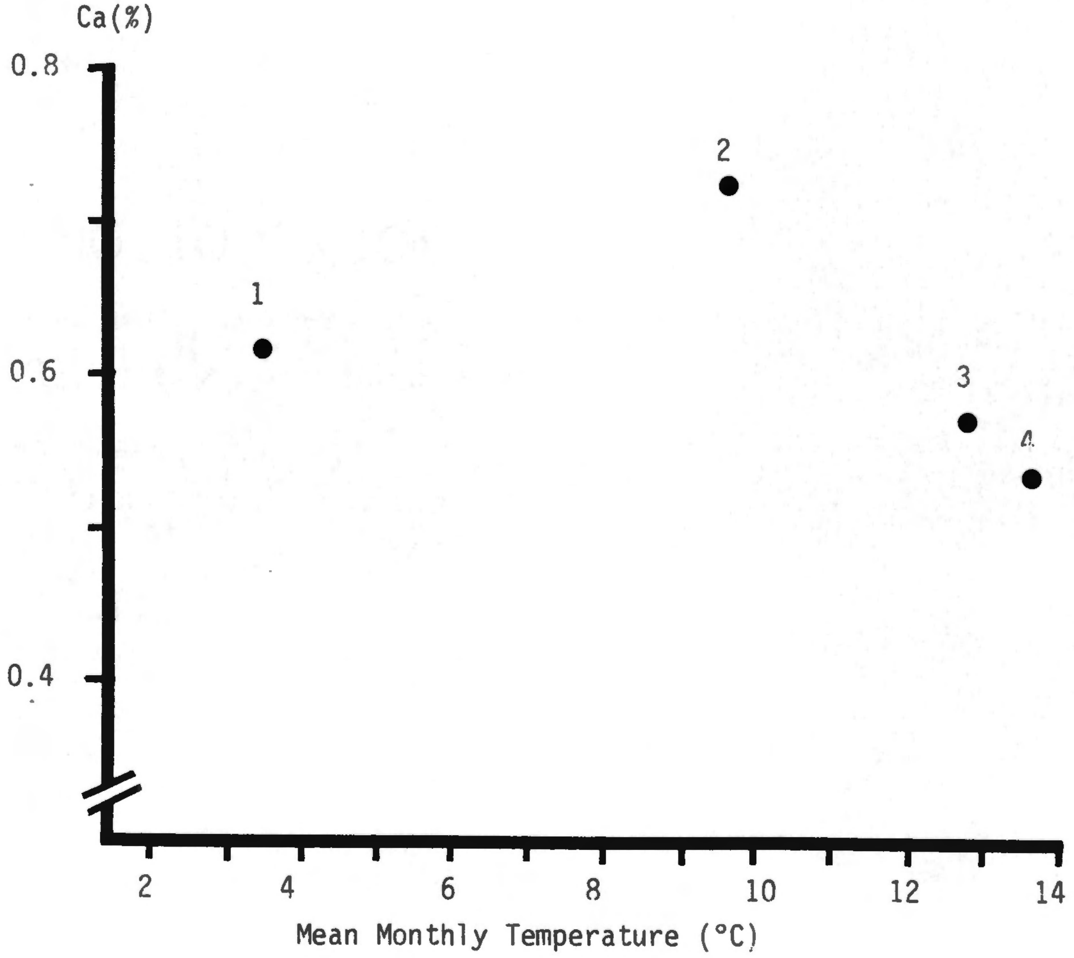

FIGURE 3. Calcium Concentration in Four Harvests of Tall Fescue at Chapel Hill in Relation to Air Temperature

Since these soils were saturated at all harvests during the sampling period, it is possible that flooding could have lead to a decline in plant Ca concentrations, since soils were flooded during the entire experiment.

At harvests 1 and 2 no differences were found in plant Al concentrations due to treatments (Table 5). At harvests 3 and 4 the control produced one of the highest plant Al concentrations. Epsom salts + K_2SO_4 and Sul-Po-Mag produced the lowest plant Al concentration in harvests 3 and 4, respectively. No fertilizer treatment was consistently effective in lowering plant tissue Al concentrations, however. In fact, treatment effects appeared to be erratic.

Aluminum concentrations in plant tissue increased from harvest 1 to harvest 2 then declined through the next two harvests (Figure 4), much the same as was observed for Ca. When temperatures rose above the minimum 4.4° C suggested for tall fescue growth (43), Al concentration in the forage increased, then declined possibly from a dilution effect. Reid et al. (57) reported that Al concentrations in both orchardgrass (Dactylis glomerata L.) and tall fescue declined as the season progressed from early March to early May.

Aluminum concentrations found in harvests 1 and 2 were high enough to be in the 2,000 to 8,000 ug/g range suggested by Allen and Robinson (2). As mentioned previously these Al levels declined from harvests 2 through 4, and in most cases Al concentrations dropped below 2,000 ug/g for harvests 3 and 4. Allen (1) found in many cases high Al concentrations in wet field conditions, quite similar to

TABLE 5. Aluminum Concentration in Tall Fescue at Chapel Hill as Affected by Fertilizer Treatment

Treatment	Al Concentration 2 Jan 82 Harvest 1	 15 Mar 82 Harvest 2	 3 Apr 82 Harvest 3	 1 May 82 Harvest 4
	ug/g			
Control	3063 a[1]	4148 a	2144 a	1364 a
Sul-Po-Mag	4075 a	4144 a	1901 a	680 b
Epsom salts + K_2SO_4	3600 a	4458 a	1178 b	1033 ab
Epsom salts	3691 a	4818 a	1719 ab	1107 ab
K_2SO_4	3432 a	4091 a	1913 a	1116 ab

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

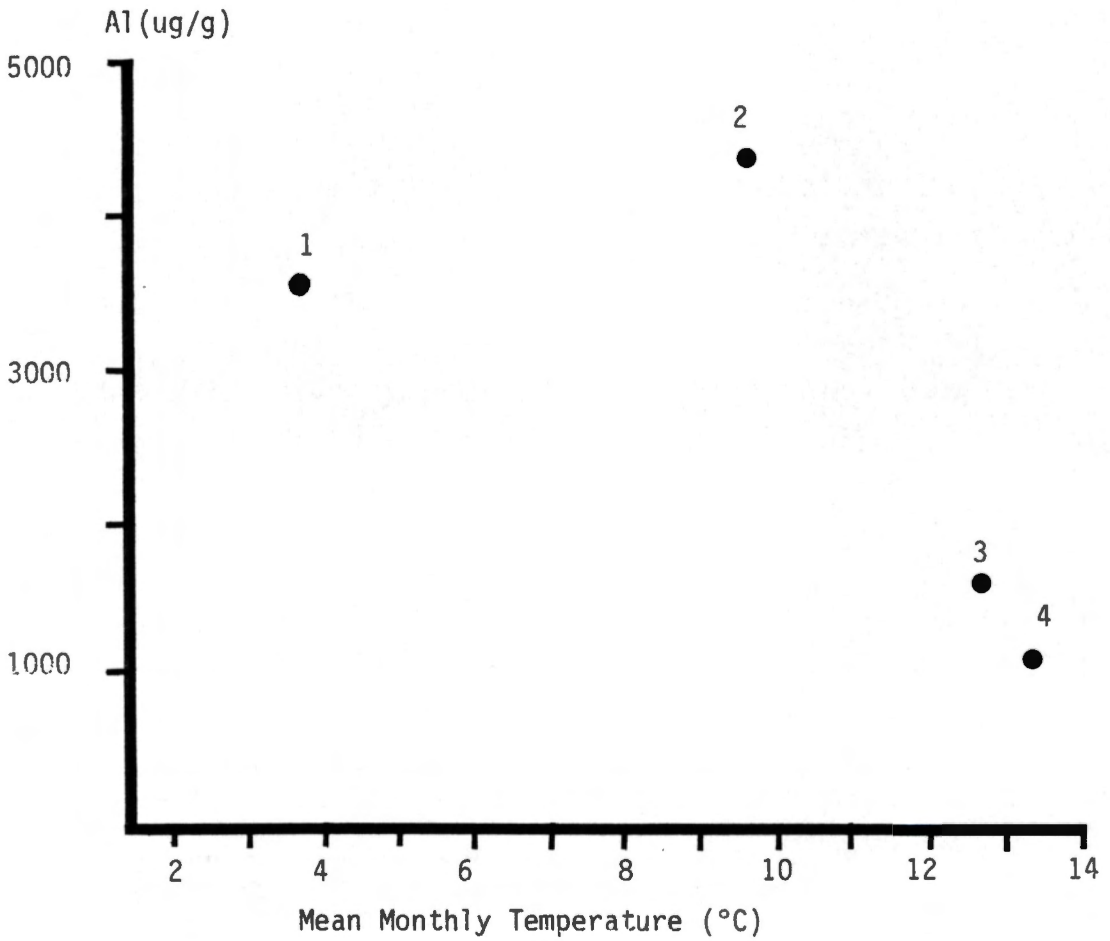

FIGURE 4. Aluminum Concentration in Four Harvests of Tall Fescue at Chapel Hill in Relation to Air Temperature

moisture conditions in this study. It seems plausible that high soil moisture conditions are related to increased Al levels in, or on, the plant. Another possibility is that there was contamination by soil on the exterior portion of the tall fescue. Tall fescue was very short during early harvests, and water was standing on the experimental site increasing the potential for contamination by soil and water and leading to increased Al levels.

Equivalent ratios of K/(Ca + Mg) were not significantly different due to treatments at harvest 1 (Table 6). Additionally, ratios were very low, well below the 2.2 level suggested by Kemp (39), above which the hazard of grass tetany increases substantially. At harvest 1, K concentrations were at their lowest point during the experimental period, while Mg was at its highest point, and Ca was at its second highest point to contribute to very low K/(Ca + Mg) ratios. At harvest 2, treatments receiving K_2SO_4 and Epsom salts + K_2SO_4 were not significantly different from other treatments. Fertilizers containing K tended to increase K/(Ca + Mg) ratios, by contributing K for plant uptake. Magnesium fertilizer would not be as effective in lowering this ratio since Mg is not taken up as readily as K. At harvest 3, significant differences were again apparent, with treatments receiving K fertilizer had K/(Ca + Mg) forage ratios significantly higher than those not receiving K fertilizer. Ratios reached their highest point at harvest 3, even though they were still well below the 2.2 point. At harvest 3, K concentrations were at their highest point, while Mg and Ca

TABLE 6. Equivalent Ratio of K/(Ca + Mg) in Tall Fescue at Chapel Hill as Affected by Fertilizer Treatment

Treatment	2 Jan 82 Harvest 1	15 Mar 82 Harvest 2	3 Apr 82 Harvest 3	1 May 82 Harvest 4
Control	.59 a[1]	.98 b	1.48 c	1.37 a
Sul-Po-Mag	.48 a	.98 b	1.70 b	1.66 a
Epsom salts + K_2SO_4	.48 a	1.03 ab	1.75 ab	1.66 a
Epsom salts	.44 a	.95 b	1.51 c	1.46 a
K_2SO_4	.44 a	1.22 a	1.89 a	1.64 a

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

concentrations in the forage were declining, so there were higher ratios. Within harvest 4, no significant differences among treatment means were found. Although differences were not significant, treatments receiving K fertilizers tended to be higher. Overall, the indication is that K fertilizers can appreciably affect the K/(Ca + Mg) ratio, while fertilizers containing Mg had little effect in lowering the ratio.

As time progressed through the harvest period, K/ (Ca + Mg) ratios increased from harvest 1 through 3. This trend followed the same pattern as K concentrations in plant tissue. Also, through the four harvests Mg concentrations were declining, while Ca concentrations declined from harvests two through four. It seems K/ (Ca + Mg) ratio was directly related to effects of temperature and maturity on Ca, Mg, and K uptake. As temperature increased, so did the K/ (Ca + Mg) ratio, before declining at about 13.5° C (Figure 5). Investigations with crested wheatgrass and smooth bromegrass (_Bromus inermis_ Leyss.) have indicated that as air temperature increased K concentration increased, while Mg concentration remained unchanged and Ca concentration dropped. Conversely, Reid et al. (57), using orchardgrass, found that as the forage approached maturity, levels of K dropped off while Mg and Ca were increasing slightly and resulted in decreasing K/(Ca + Mg) ratios as forage approached maturity.

At Chapel Hill, fertilization with a K-containing fertilizer resulted in higher soil K in two of three cases at a depth of 0-7.6 cm

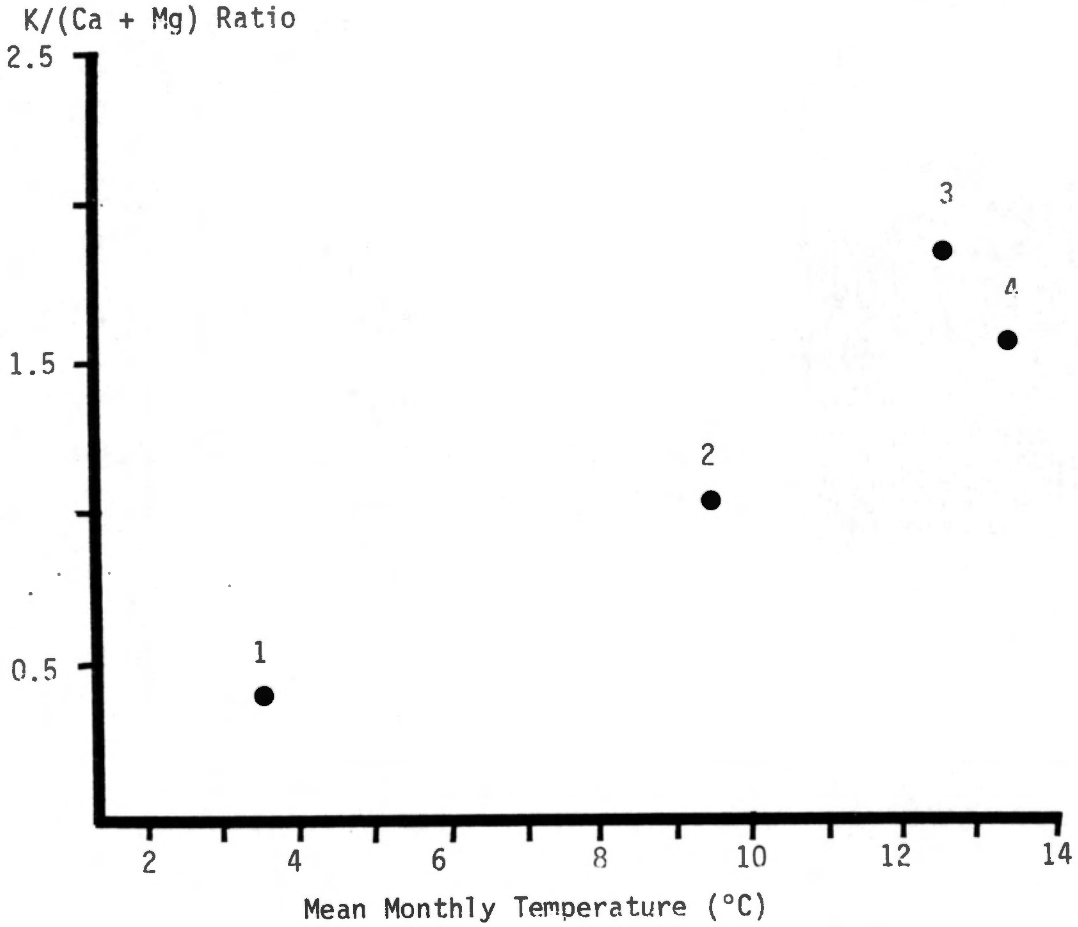

FIGURE 5. Equivalent Ratio of K/(Ca + Mg) in Four Harvests of Tall Fescue at Chapel Hill in Relation to Air Temperature

(Appendix C). These samples were taken after plant sampling in May. All values remained within the medium range (36-72 ug/g). No differences were seen at 7.6-15.2 cm. Fertilization with Mg amendments resulted in higher Mg levels in the soil than with non-Mg fertilizers at 0-7.6 cm. Addition of Mg with K had no effect on concentration. As with K however, all Mg levels remained within the high range (60-120 ug/g), and addition of Mg may have had little effect on available Mg. No differences were seen at 7.6-15.2 cm. Not surprisingly, no differences were seen at either depth for both Ca (very high) and P (low). Extractable Al was very low (1-6 ug/g).

II. KNOXVILLE FIELD EXPERIMENT

Plant K was below the 2.5% critical level for all eight harvests, but interesting trends were apparent. Of the first five harvests, only harvest 3 showed significant differences between treatments with respect to plant K content (Table 7). Within harvest 3, treatments containing K resulted in highest tissue K concentration, but only tall fescue receiving K_2SO_4 vs. $MgSO_4$ respectively, were significantly different. It should be noted that the first four harvests were taken after the growing season, when temperatures were low and daylength was short. During this period tall fescue activity was declining toward dormancy, until early spring when the forage emerged from dormancy. At harvest 4, when K concentrations were lowest, fescue was dormant, and some

TABLE 7. Potassium Concentration in Tall Fescue at Knoxville as Affected by Fertilizer Treatment

Treatment	1 Dec 82 Harvest 1	16 Dec 82 Harvest 2	5 Jan 82 Harvest 3	5 Feb 82 Harvest 4	5 Mar 82 Harvest 5	18 Mar 82 Harvest 6	19 Apr 82 Harvest 7	3 May 82 Harvest 8
				%				
Control	1.41 a[1]	1.40 a	1.25 ab	.82 a	1.49 a	1.97 c	2.08 b	1.85 b
Sul-Po-Mag	1.57 a	1.25 a	1.29 ab	.79 a	1.53 a	2.24 ab	2.35 a	2.11 a
Epsom salts + K_2SO_4	1.53 a	1.22 a	1.29 ab	.81 a	1.53 a	2.33 a	2.33 a	2.07 a
Epsom salts	1.43 a	1.26 a	1.19 b	.87 a	1.45 a	2.06 bc	2.08 b	1.83 b
K_2SO_4	1.41 a	1.26 a	1.34 a	.87 a	1.61 a	2.20 ab	2.35 a	2.10 a

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

leaf deterioration had probably occurred with lowered concentrations. Harvest 5 (March 5, 1982) was made when mean temperature for the month preceding harvest had risen to 6.6° C (Figure 6). Tall fescue was actively growing at this point. At harvest 6 differences between treatments were found, with K-containing fertilizers resulting in highest plant tissue K concentrations, although treatments receiving Sul-Po-Mag and K_2SO_4 were not significantly different from the treatment receiving Epsom salts. Harvest 7 and 8 were more clear-cut, with treatments receiving K fertilization having higher plant tissue K concentrations than those not receiving K fertilizer. It appears that all K-containing fertilizers raised K concentrations equally in plant tissue, with Mg having no noticeable antagonistic effect when applied with the K fertilizer. These results are quite similar to those found at Chapel Hill.

Concentration of K in plant tissue fell from harvests 1 through 4, then rose through harvest 7, before declining again at harvest 8 (Figure 6). Reid et al. (57), using orchardgrass, reported similar findings, with K concentrations falling from November through early March, increasing from early March until about May 1, and then declining again. Hannaway and Reynolds (34) found a decrease in K in N-fertilized tall fescue from December to February, an increase in K until April, and then another decline. The sharp increase in K concentrations here paralleled a sharp increase in temperature. From harvests 4 to 5 mean monthly temperatures increased from -0.7° C for the month preceding harvest

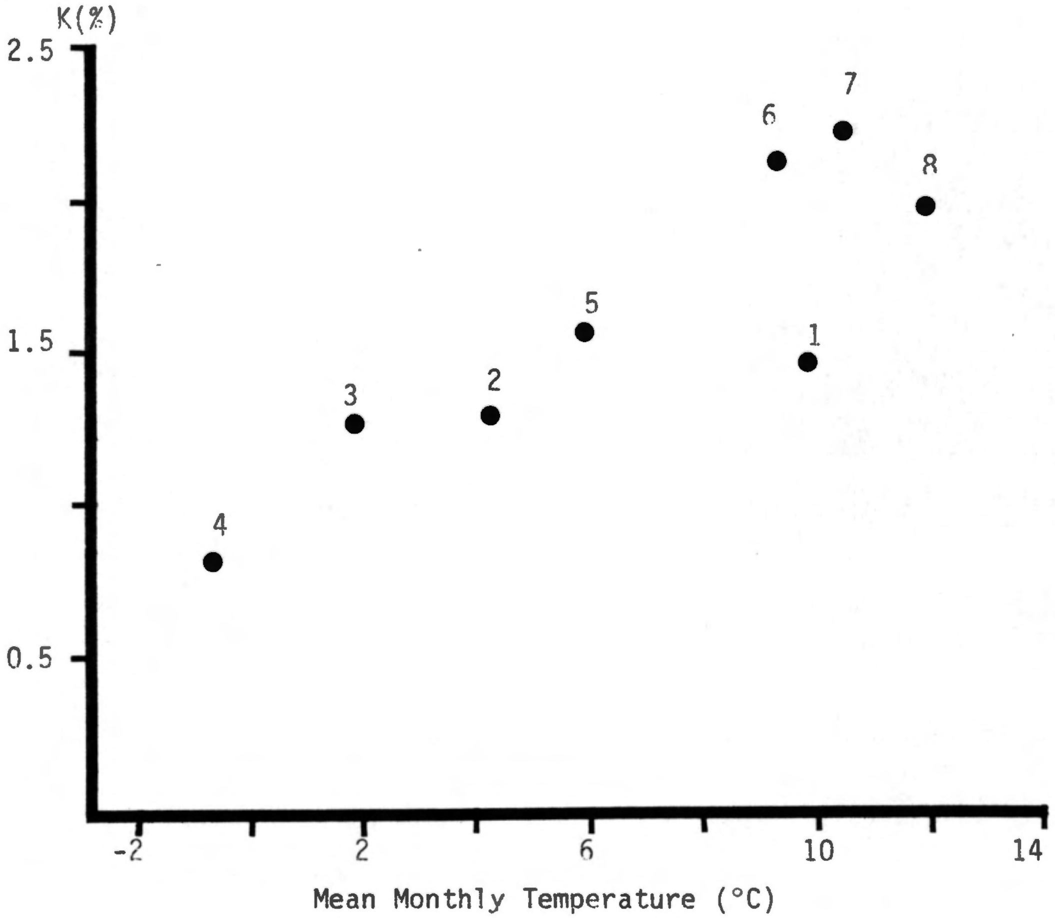

FIGURE 6. Potassium Concentration in Eight Harvests of Tall Fescue at Knoxville in Relation to Air Temperature

to 6.2° C. Potassium concentrations climbed rapidly as temperatures increased, until harvest 8, when K declined. At this point, mean temperature for the month preceding harvest was 12.2° C, close to the 14° C weekly temperature above which few cases of grass tetany occurred (42). The decline in K at harvest 8 also follows closely the results reported by Baker and Reid (4), who found that as tall fescue approached maturity, the concentration of K in the forage started to decline. Herbage at Knoxville was in the jointing to early boot stage when harvest 8 was taken.

Plant tissue Mg concentrations were above 0.2% during the early portion of the experiment, but as the season progressed Mg levels declined to below 0.2% Mg, making the forage a potential hazard for grass tetany. At harvest 1 differences in plant tissue Mg were found, with treatments receiving Mg fertilizer being higher in plant Mg than treatments without Mg (Table 8) but there was no difference among the Mg fertilizer effects. In harvest 2, treatments with highest plant Mg concentrations all received Mg containing fertilizer, but few significant differences were found. Harvests 3 and 4 produced similar results, with treatments receiving Mg fertilizers having higher plant Mg levels. In addition, at harvest 4, forage receiving Epsom salts was significantly higher in plant Mg than treatments receiving both Mg and K, but differences were quite small. Differences were not significant in harvests 5 through 8. During the latter harvests plant Mg levels were lower than the late fall harvests which might offer a possible reason

TABLE 8. Magnesium Concentration in Tall Fescue at Knoxville as Affected by Fertilizer Treatment

Treatment	1 Dec 82 Harvest 1	16 Dec 82 Harvest 2	5 Jan 82 Harvest 3	5 Feb 82 Harvest 4	5 Mar 82 Harvest 5	18 Mar 82 Harvest 6	19 Apr 82 Harvest 7	3 May 82 Harvest 8
	%							
Control	.260 b[1]	.245 ab	.194 b	.137 c	.138 a	.149 a	.169 a	.159 a
Sul-Po-Mag	.303 a	.252 ab	.215 a	.154 b	.148 a	.150 a	.154 a	.167 a
Epsom salts + K_2SO_4	.295 a	.271 a	.215 a	.153 b	.145 a	.152 a	.150 a	.147 a
Epsom salts	.308 a	.258 ab	.213 a	.166 a	.146 a	.151 a	.163 a	.161 a
K_2SO_4	.263 b	.235 b	.191 b	.142 c	.146 a	.142 a	.155 a	.163 a

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

for no significant differences. It appears that Mg treatments increased plant Mg levels in some harvests, contrary to reports by some other researchers (50, 42) and different from results found at the Chapel Hill location. However when soil tests were done to test differences due to fertilization, no differences were found in soil Mg due to fertilization (Appendix C). It is not clear how significant differences in the plant could occur.

Magnesium concentration of tall fescue decreased from harvests 1 through 4, and held nearly stable from harvests 4 through 8 (Figure 7). The temperature dropped steadily from harvest 1 through 4, from December to February. As temperatures dropped, Mg content in the forage also decreased. This seasonal effect has been observed by Reid et al. (57) in orchardgrass. Hannaway and Reynolds (34) found Mg concentrations in tall fescue to decline slightly from November until a slight increase in March. Harvests 5 through 8 showed only slight gains in Mg concentration in the forage. This occurred in spite of the fact that temperatures were increasing steadily through these harvests. This is consistent with findings by Hannaway and Reynolds (34), and Fleming and Murphy (22) who found no increases in Mg concentration in tall fescue until May. This increase is probably related to effects due to maturity of the forage. Baker and Reid (4) found levels of Mg in tall fescue decreased until full bloom stage, at which time tall fescue increased in Mg. It should be noted that plant Mg concentration was below the 0.2% "safety" level at harvests 4 through 8, during the period (February, March, and April) when most grass tetany cases occur in Tennessee.

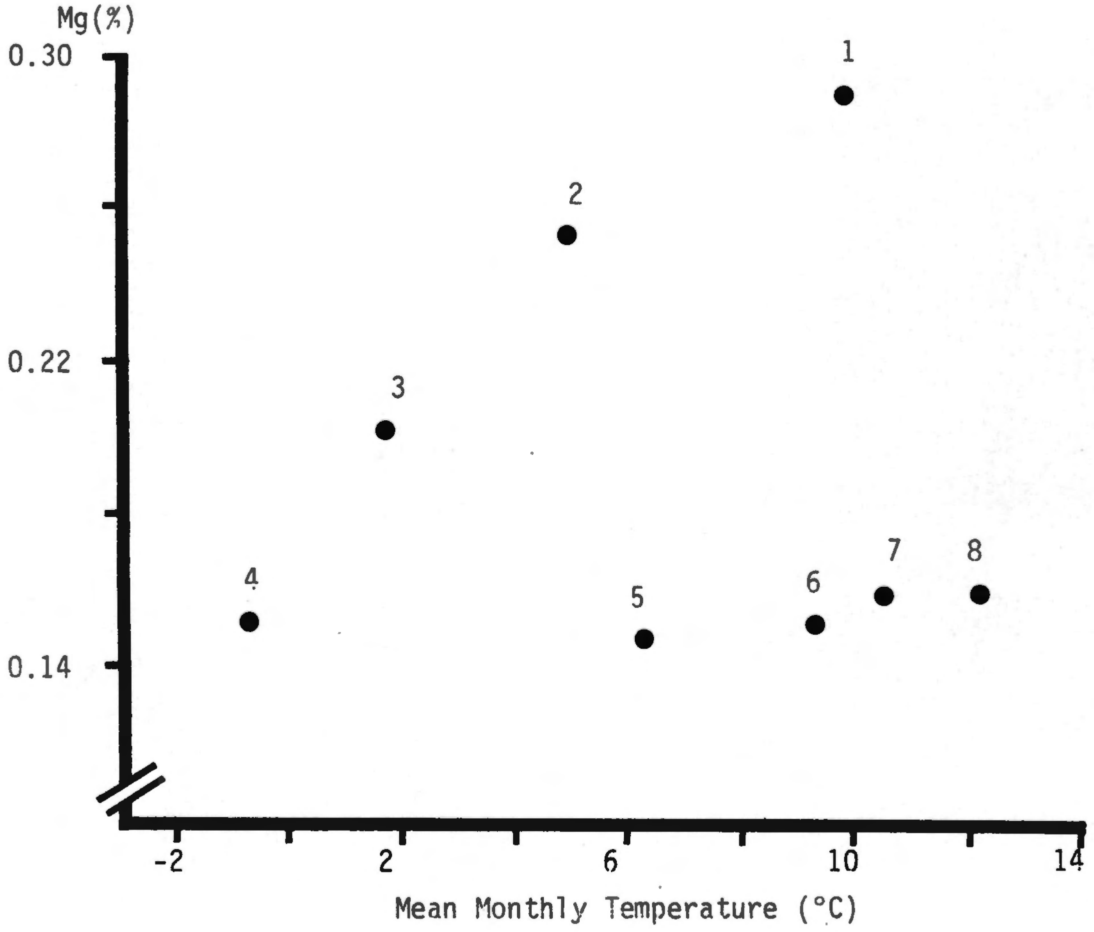

FIGURE 7. Magnesium Concentration in Eight Harvests of Tall Fescue at Knoxville in Relation to Air Temperature

Mean Ca concentration of tall fescue varied from 0.35 to 0.56%, in the same range reported by others (4, 57). There were differences in plant Ca concentration among treatments at harvests 1, 2, 6, and 7 (Table 9). However, few treatments were consistent. No significant differences were found at harvests 3, 4, 5, and 8. The control had highest plant Ca in four of eight harvests. These results show a possible competition between Ca, Mg, and K for uptake by tall fescue. No Mg or K fertilizers were added to control plots, and Ca was often highest on those plots. These results are consistent with those of Gross and Jung (30) who found that increased saturation of the CEC with Mg resulted in decreased Ca concentration in grasses. Brown et al. (8) indicated that soil K interfered with Ca uptake, or stimulated growth which diluted plant Ca. Other than the control however, treatment effects were inconsistent.

Examination of Ca concentrations in the forage revealed no consistent effects due to temperature (Figure 8). Results here showed that Ca increased from harvests 4 to 5 as temperature increased, while from harvests 5 to 6 Ca concentration dropped before climbing again at harvest 7 and remaining stable through harvest 8. This follows trends observed by other researchers, with a gradual increase in Ca concentration through the vegetative stage, and declining as the forage approaches maturity (4, 34, 66).

Plant Al concentrations at Knoxville were sometimes over 1,000 ug/g and approached 2,000 ug/g in a few cases. Aluminum concentrations are typically much less than 1,000 ug/g (4, 57), but

TABLE 9. Calcium Concentration in Tall Fescue at Knoxville as Affected by Fertilizer Treatment

Treatment	1 Dec 82 Harvest 1	16 Dec 82 Harvest 2	5 Jan 82 Harvest 3	5 Feb 82 Harvest 4	5 Mar 82 Harvest 5	18 Mar 82 Harvest 6	19 Apr 82 Harvest 7	3 May 82 Harvest 8
	%							
Control	.468 ab[1]	.497 ab	.449 a	.428 a	.525 a	.508 a	.553 a	.501 a
Sul-Po-Mag	.478 ab	.375 ab	.432 a	.407 a	.472 a	.517 a	.447 b	.488 a
Epsom salts + K_2SO_4	.404 b	.354 b	.419 a	.396 a	.478 a	.376 b	.452 b	.399 a
Epsom salts	.526 a	.378 ab	.426 a	.426 a	.475 a	.392 b	.488 ab	.444 a
K_2SO_4	.375 b	.528 a	.430 a	.403 a	.563 a	.392 b	.466 ab	.491 a

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

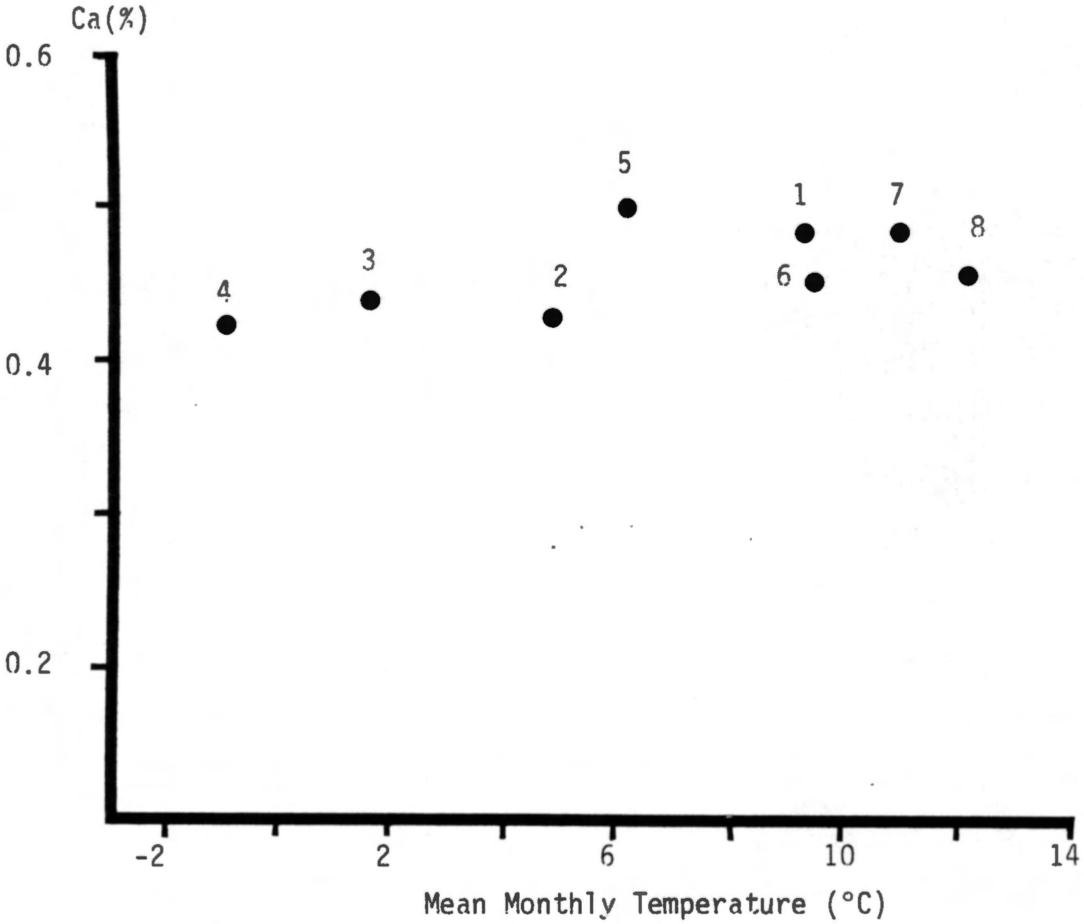

FIGURE 8. Calcium Concentration in Eight Harvests of Tall Fescue at Knoxville in Relation to Air Temperature

Allen (1) reported tissue Al of 2,000-3,000 ug/g in grass tetany-prone ryegrass pastures. Within the first four harvests, differences among treatments were found only in harvests 2 and 3 (Table 10), where the Epsom salts + K_2SO_4 treatments produced highest plant Al concentrations (although in harvest 3 this was not significantly different from the Epsom salts and the K_2SO_4 treatments). This high concentration is puzzling, since it would seem an increased level of Mg and K in the soil would result in increased competition for uptake, and a reduced level of Al in the plant. No differences were found in harvests 5 through 8.

Concentration of Al in tall fescue was below 1,000 ug/g for harvests 1 through 3, then increased at harvest 4 and stayed constant through harvest 6 (Figure 9). These levels are similar to those found by Allen (1), and occurred in the months of February and March, during the grass tetany season in Tennessee. When temperatures went above 10° C, concentration of Al in the forage dropped drastically, from an average of 1,350 ug/g at harvest 6 to about 250 ug/g at harvest 7 through harvest 8. During this period precipitation levels for the month preceding harvest had dropped from 128 mm preceding harvest 6 to 71 mm and 73 mm preceding harvests 7 and 8. Allen (1) found that plant samples containing highest Al concentrations were usually associated with wet field conditions. Further, Al concentrations were found to be high when temperatures were cool and precipitation was high. As mentioned previously,

TABLE 10. Aluminum Concentration in Tall Fescue at Knoxville as Affected by Fertilizer Treatment

Treatment	1 Dec 82 Harvest 1	16 Dec 82 Harvest 2	5 Jan 82 Harvest 3	5 Feb 82 Harvest 4	5 Mar 82 Harvest 5	18 Mar 82 Harvest 6	19 Apr 82 Harvest 7	3 May 82 Harvest 8
	ug/g							
Control	797 a[1]	616 b	501 b	1222 a	861 a	1732 a	186 a	165 a
Sul-Po-Mag	902 a	770 b	480 b	907 a	1437 a	943 a	224 a	228 a
Epsom salts + K_2SO_4	745 a	1989 a	966 a	1557 a	1478 a	1735 a	420 a	205 a
Epsom salts	942 a	829 b	761 ab	1350 a	1332 a	1386 a	158 a	198 a
K_2SO_4	684 a	720 b	599 ab	1321 a	1129 a	1104 a	231 a	307 a

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

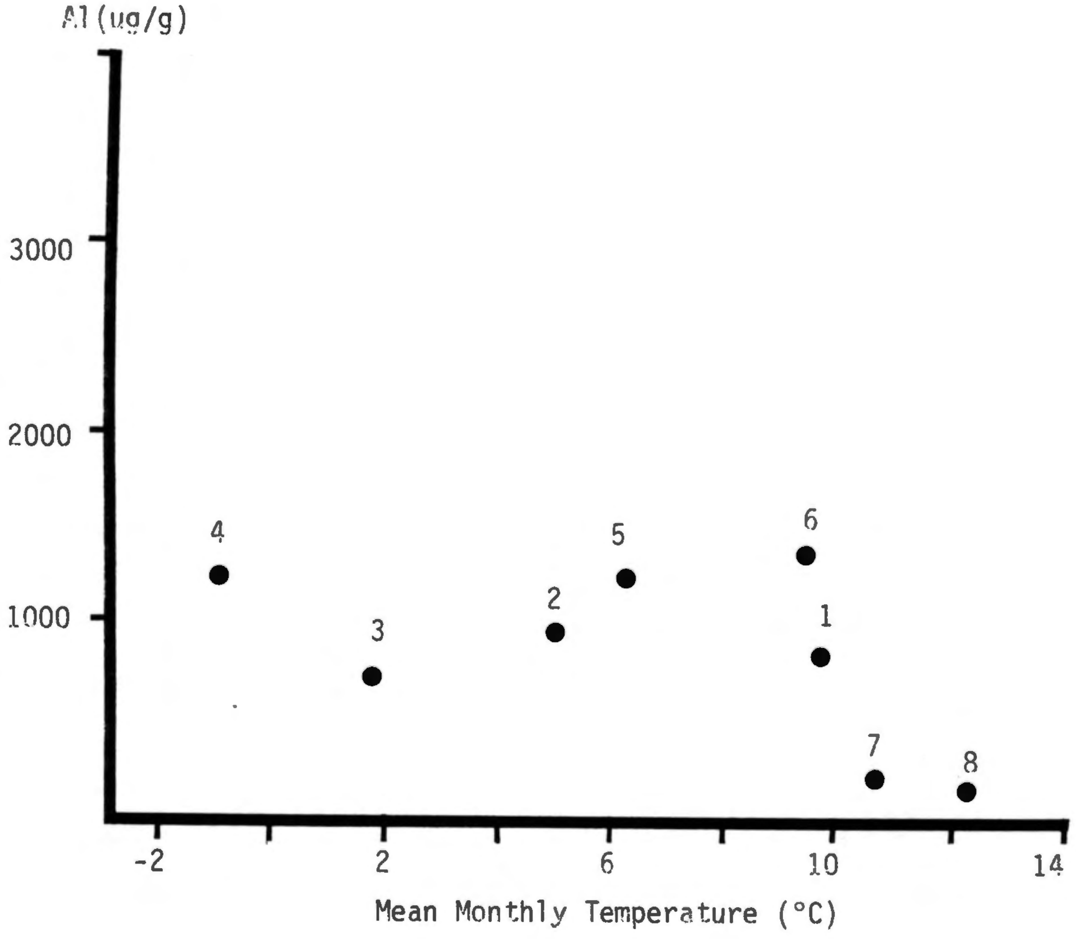

FIGURE 9. Aluminum Concentration in Eight Harvests of Tall Fescue at Knoxville in Relation to Air Temperature

the soil was usually saturated with water in the winter months at Knoxville. Highest concentrations of Al were found during cool months and during periods of high precipitation.

Although no equivalent K/(Ca + Mg) ratios exceeded the 2.2 point above which forage is considered a potential grass tetany hazard, distinct trends were apparent. Harvests 1 through 4 all had ratios below 1.0, and will not be discussed since they are so far below the 2.2 critical point (Table 11). For harvests 6 through 8, differences were found, but were not clear cut. In some cases, treatments of K-containing fertilizers usually had higher plant K/(Ca + Mg) ratios than the control. The fact that some fertilizers also contained Mg had little effect.

Ratios stayed somewhat constant from harvests 1 through 4 (Figure 10), increased greatly for harvests 5 and 6, and declined at harvests 7 and 8. The increase coincided with an increase in mean temperature for the month preceding harvest from -0.7° C at harvest 4 to 6.2° C at harvest 5. Ratios continued to increase through harvest 6 as temperature increased to 9.6° C. At harvest 7 temperature had reached 10.4° C, while harvest 8 mean temperature had reached 12.2° C. Ratios increased drastically when temperature exceeded the growth minimum of 4.4° C. At this point, K uptake started to increase, while Mg and Ca levels in the forage remained stable. Although in no instance did ratios of K/(Ca + Mg) exceed 2.2, the ratio was dependent on K, Ca, and Mg contents as affected by temperature.

TABLE 11. Equivalent Ratio of K/(Ca + Mg) in Tall Fescue at Knoxville as Affected by Fertilizer Treatment

Treatment	1 Dec 82 Harvest 1	16 Dec 82 Harvest 2	5 Jan 82 Harvest 3	5 Feb 82 Harvest 4	5 Mar 82 Harvest 5	18 Mar 82 Harvest 6	19 Apr 82 Harvest 7	3 May 82 Harvest 8
Control	.81 c[1]	.81 a	.84 ab	.64 ab	1.04 a	1.35 c	1.28 b	1.25 b
Sul-Po-Mag	.82 bc	.81 a	.84 ab	.61 b	1.10 a	1.53 bc	1.77 a	1.43 ab
Epsom salts + K_2SO_4	.88 ab	.78 a	.85 ab	.64 ab	1.11 a	1.91 a	1.77 a	1.75 a
Epsom salts	.71 d	.80 a	.79 b	.64 ab	1.04 a	1.65 ab	1.41 ab	1.32 ab
K_2SO_4	.89 a	.72 a	.92 a	.70 a	1.07 a	1.81 a	1.68 a	1.44 ab

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

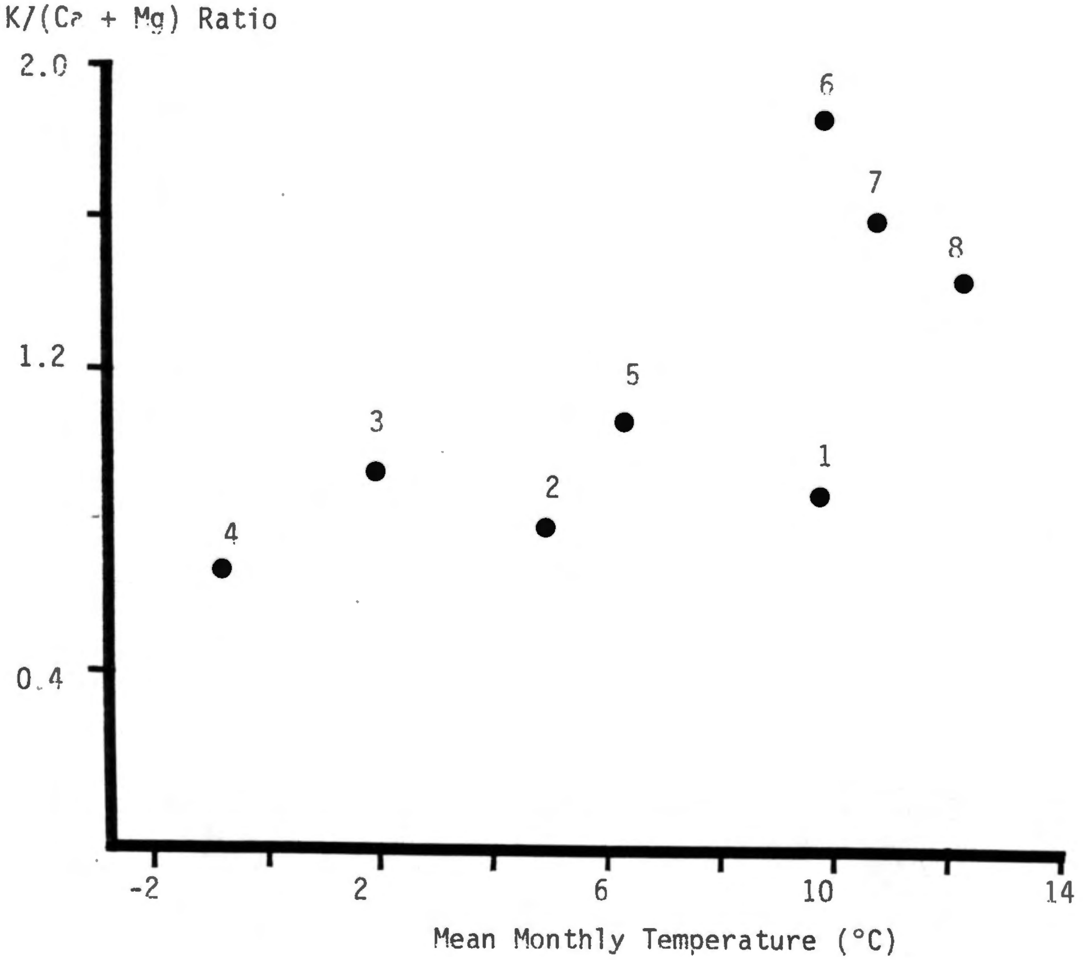

FIGURE 10. Equivalent Ratio of K/(Ca + Mg) in Eight Harvests of Tall Fescue at Knoxville in Relation to Air Temperature

Fertilization with K-containing fertilizers resulted in higher soil K levels than non-K fertilizers at 0-7.6 cm depth (Appendix C). As in the Chapel Hill experiment, all values remained within the medium range (36-72 ug/g), with little effective difference. No differences were found at 7.6-15.2 cm. Magnesium fertilization resulted in no differences at either soil depth. Soil Mg levels were already in the very high range, which was probably the reason for no effect of Mg fertilizers. Results from Ca and P were similar to the Chapel Hill results, with no differences at either depth as a result of fertilizer treatment. Extractable Al levels were quite low (1-3 ug/g).

III. GREENHOUSE EXPERIMENT

Potassium concentrations found in tall fescue outside the greenhouse were generally below the 2.5% critical level above which a forage may be a potential tetany hazard (29). This critical level was exceeded in only a few cases, but was approached several times, and could be involved in producing tetanic conditions. No differences in K in plant tissue were found regardless of moisture or Mg treatment at harvests 1 or 2 (Table 12). At harvest 3 significant differences between forage from drained and wet treatments were found, with forage from drained containing higher K concentrations. No differences were found due to level of Mg fertilization. These results agree with those reported by Elkins and Hoveland (20) and Elkins et al. (19), who found that

TABLE 12. Potassium Concentration in Tall Fescue in the Greenhouse Experiment as Affected by Mg Level and Soil Moisture

Mg level[1]	Soil moisture[2]	Outside Greenhouse 17 Mar 82 Harvest 1	Outside Greenhouse 8 Apr 82 Harvest 2	Outside Greenhouse 13 May 82 Harvest 3	Inside Greenhouse 17 Mar 82 Harvest 1[3]	Inside Greenhouse 8 Apr 82 Harvest 2	Inside Greenhouse 13 May 82 Harvest 3
kg/ha		%					
	Drained	1.55 a[4]	2.10 a	2.70 a	2.54	2.52 a	2.37 a
	Wet	1.51 a	2.07 a	2.26 b	2.52	2.61 a	2.02 a
0		1.58 a	2.03 a	2.50 a	2.55	2.58 a	2.37 a
84		1.43 a	2.16 a	2.49 a	2.53	2.67 a	2.25 a
168		1.58 a	2.07 a	2.45 a	2.51	2.44 a	1.98 a

[1] Includes both soil moisture treatments in each Mg level.

[2] Includes all Mg levels in each soil moisture treatment.

[3] Significant interaction discussed in text.

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

K concentrations in forage grasses increased as soil O_2 increased. Soil O_2 would be expected to be lower in a flooded soil than in a drained soil.

When harvest 1 inside the greenhouse was examined for differences due to moisture treatments, a significant interaction between moisture treatment and Mg level was noted. Wet treatments at 168 kg Mg/ha resulted in higher plant K concentration than drained treatments at 168 kg Mg/ha (2.72% vs. 2.29%). At harvests 2 and 3 no differences were found, either as a result of Mg level or moisture treatment, indicating little influence of Mg fertilization or soil moisture on K concentration in tall fescue inside the greenhouse.

Means were separated to determine differences due to environment inside or outside the greenhouse. At harvests 1 and 2, plants inside were higher in K than those outside the greenhouse (Table 13). However, at harvest 3, K concentration was higher in tall fescue grown outside the greenhouse. Temperatures for harvests 1 and 2 were higher inside the greenhouse than outside (23.6° C and 25.5° C vs. 14.2° C and 17.3° C), and thus conducive to more K uptake. At harvest 3, mean temperatures were about equal (23.4° C outside vs. 25.4° C inside), and plant K concentration was higher for tall fescue grown outside the greenhouse (Figure 11).

When harvest 1 outside the greenhouse was examined for differences in plant Mg due to treatments, no differences between wet and drained treatments were apparent (Table 14). Forage

TABLE 13. Potassium Concentration in Tall Fescue in the Greenhouse Experiment as Affected by Environment

Environment	17 Mar 82 Harvest 1	8 Apr 82 Harvest 2	13 May 82 Harvest 3
	----------------	%	----------------
Inside Greenhouse	2.53 a[1]	2.56 a	2.20 b
Outside Greenhouse	1.53 b	2.09 b	2.48 a

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

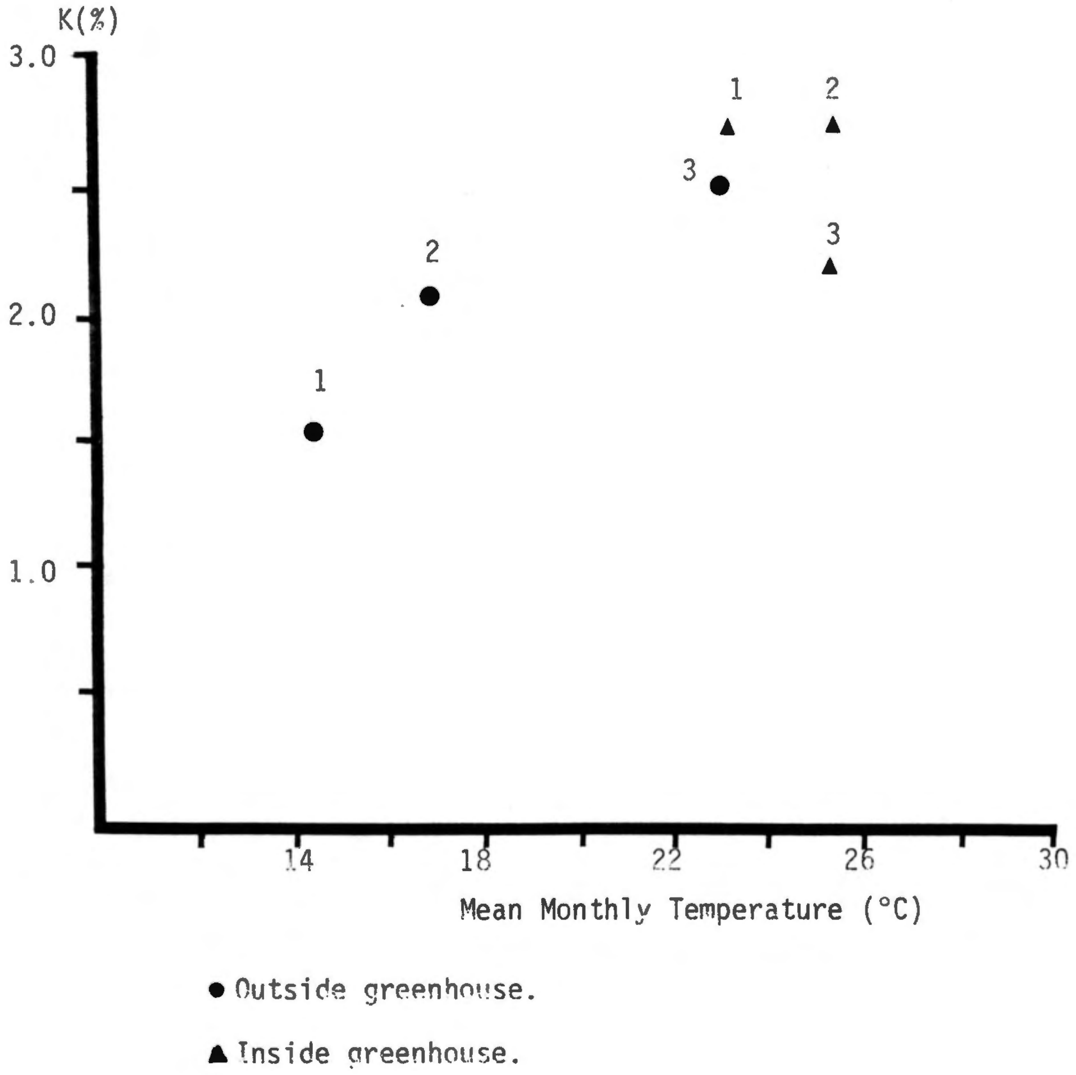

FIGURE 11. Potassium Concentration in Three Harvests of Tall Fescue Outside and Inside Greenhouse in Relation to Air Temperature

TABLE 14. Magnesium Concentration in Tall Fescue in the Greenhouse Experiment as Affected by Mg Level and Soil Moisture

		Outside Greenhouse			Inside Greenhouse		
Mg level[1]	Soil moisture[2]	17 Mar 82 Harvest 1	8 Apr 82 Harvest 2[3]	13 May 82 Harvest 3	17 Mar 82 Harvest 1	8 Apr 82 Harvest 2	13 May 82 Harvest 3
kg/ha		----------	----------	---------- %	----------	----------	----------
	Drained	.218 a[4]	.267	.307 b	.344 a	.391 a	.349 a
	Wet	.212 a	.283	.352 a	.296 b	.408 a	.359 a
0		.203 b	.250	.298 b	.287 b	.379 b	.320 b
84		.203 b	.270	.345 a	.316 ab	.369 b	.315 b
168		.240 a	.305	.346 a	.357 a	.451 a	.427 a

[1] Includes both soil moisture treatments in each Mg level.

[2] Includes all Mg levels in each soil moisture treatment.

[3] Significant interaction discussed in text.

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

receiving 168 kg Mg/ha contained higher plant Mg concentrations than forage from other treatments. Harvest 2 had a significant interaction between moisture and fertility treatments. Within the wet treatment, a significant interaction between moisture treatments and Mg levels occurred, with 84 and 168 kg Mg/ha in the wet treatment causing higher levels of Mg in the plant than the treatment receiving no Mg (.302, .311, and .237%, respectively). No differences were found within the drained treatment. When means from harvest 3 were examined, differences in plant Mg concentration due to moisture treatments were apparent, with forage from wet treatments having higher Mg concentrations. This is in contrast to results reported by Elkins et al. (19). However, Elkins and Hoveland (20), using rye, found that Mg concentrations in the plant varied little with changing soil O_2. At harvest 3, treatments fertilized with Mg had higher plant Mg concentrations than the treatment not fertilized with Mg.

The only apparent difference between wet and drained forage inside the greenhouse was at harvest 1 with the wet forage lower in plant Mg concentration than the drained forage. Addition of 168 kg Mg/ha resulted in higher plant Mg at all three harvests, although at harvest 1, 168 kg Mg/ha was not significantly different from 84 kg Mg/ha.

Elkins et al. (19) found plant tissue Mg concentrations to be increased by increased soil O_2. However, soil depth in these trays may not have been great enough to reduce soil O_2 to the plant roots. Differences as a result of Mg levels were not large, although 168 kg Mg/ha usually resulted in highest plant Mg concentrations.

Plant tissue Mg was significantly higher for harvest 1 and 2 inside the greenhouse than outside the greenhouse (Table 15). No differences were found at harvest 3. When mean plant Mg was compared by harvest dates inside and outside the greenhouse, plant Mg rose from harvest 1 through 3 outside the greenhouse, but inside the greenhouse plant Mg rose from harvest 1 to 2 and declined at harvest 3 (Figure 12). The increase in Mg in the plants outside the greenhouse followed an increase in mean temperatures from harvests 1 through 3. Mean air temperatures gradually climbed from 14.2° C at harvest 1 to a high of 23.4° C at harvest 3. During this same period plant Mg declined from harvests 2 to 3, even though mean temperatures were approximately the same at both harvests. The fact that there is no significant difference between environments at harvest 3 probably is a result of temperatures being quite similar.

When wet and drained treatments were compared for forage Ca, there were no significant differences between moisture treatments at harvest 1 outside the greenhouse (Table 16). The 0 Mg fertilizer treatment produced significantly higher plant tissue Ca than treatments receiving 84 and 168 kg Mg/ha. The indication is that there was Mg-Ca antagonism occurring here, since Ca concentrations were highest where no Mg fertilizer was applied. At harvest 2, a significant interaction between moisture treatment and Mg level was noted. Plant Ca was higher in the wet treatment at no Mg than

TABLE 15. Magnesium Concentration in Tall Fescue in the Greenhouse Experiment as Affected by Environment

Environment	17 Mar 82 Harvest 1	8 Apr 82 Harvest 2	13 May 82 Harvest 3
		%	
Inside greenhouse	.320 a[1]	.400 a	.354 a
Outside greenhouse	.215 b	.255 b	.330 a

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

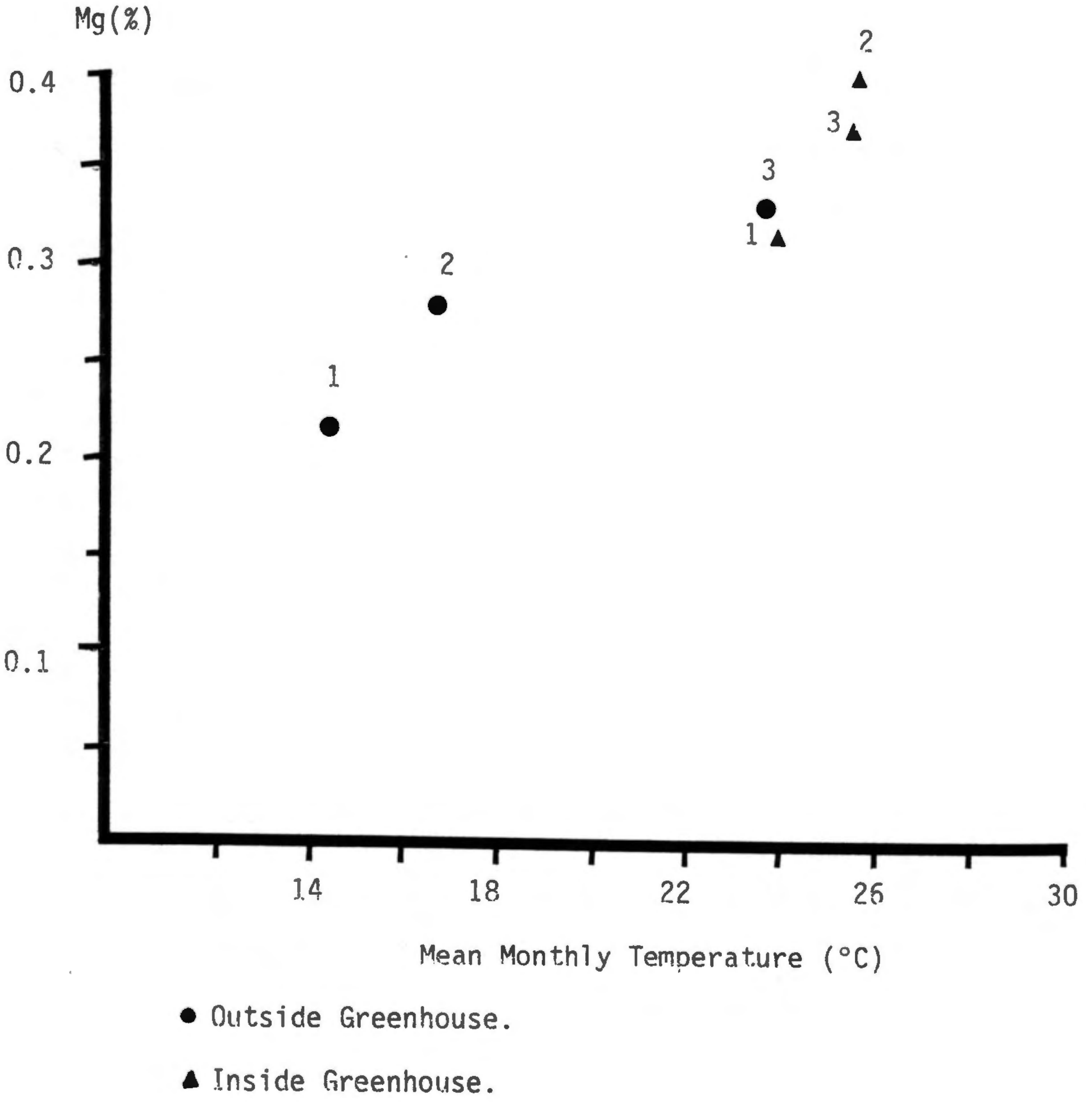

FIGURE 12. Magnesium Concentration in Three Harvests of Tall Fescue Outside and Inside Greenhouse in Relation to Air Temperature

TABLE 16. Calcium Concentration in Tall Fescue in the Greenhouse Experiment as Affected by Mg Level and Soil Moisture

		Outside Greenhouse			Inside Greenhouse		
Mg level[1]	Soil moisture[2]	17 Mar 82 Harvest 1	8 Apr 82 Harvest 2[3]	13 May 82 Harvest 3	17 Mar 82 Harvest 1	8 Apr 82 Harvest 2	13 May 82 Harvest 3
kg/ha		%					
	Drained	.343 a[4]	.391	.391 b	.387 a	.483 a	.556 a
	Wet	.344 a	.451	.444 a	.367 a	.536 a	.602 a
0		.375 a	.462	.446 a	.414 a	.582 a	.655 a
84		.335 b	.378	.412 a	.353 b	.446 b	.492 b
168		.321 b	.425	.396 a	.364 b	.501 ab	.592 ab

[1] Includes both soil moisture treatments in each Mg level.

[2] Includes all Mg levels in each soil moisture treatment.

[3] Significant interaction discussed in text.

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

at 168 kg Mg/ha (0.506 vs. 0.394%) but was not different at 84 kg Mg/ha. Results in the drained treatment were inconsistent. Elkins and Hoveland (20) found Ca levels to be quite variable under different soil O_2 levels and at times noticed a lower plant tissue Ca concentration at lower soil O_2 values. At harvest 3 outside the greenhouse, wet treatments resulted in higher plant Ca concentrations than drained treatments. However, no differences were found in forage Ca between Mg levels.

When moisture treatments were compared inside the greenhouse, no differences in plant Ca were found at any harvest. At harvest 1 plant Ca levels were higher where no Mg was applied than in forage receiving 84 and 168 kg Mg/ha, indicating a possible Mg-Ca antagonism. However, results at harvests 2 and 3 were somewhat inconclusive.

Significant differences were found between environments, with plant tissue Ca higher inside the greenhouse than outside at all three harvests (Table 17). This could be a result of the temperature, which was generally higher inside the greenhouse than outside, although the difference at third harvest was small. Plant Ca increased from harvests 1 through 3 for tall fescue inside the greenhouse, and increased for tall fescue outside the greenhouse from harvest 1 to 2, and remained constant at harvest 3 (Figure 13). This trend agrees with results reported by Baker and Reid (4), who found levels of plant tissue Ca to increase in tall fescue throughout the vegetative stage.

TABLE 17. Calcium Concentration in Tall Fescue in the Greenhouse Experiment as Affected by Environment

Environment	17 Mar 82 Harvest 1	8 Apr 82 Harvest 2	13 May 82 Harvest 3
	----------------	%	----------------
Inside greenhouse	.377 a[1]	.510 a	.579 a
Outside greenhouse	.343 b	.421 b	.418 b

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

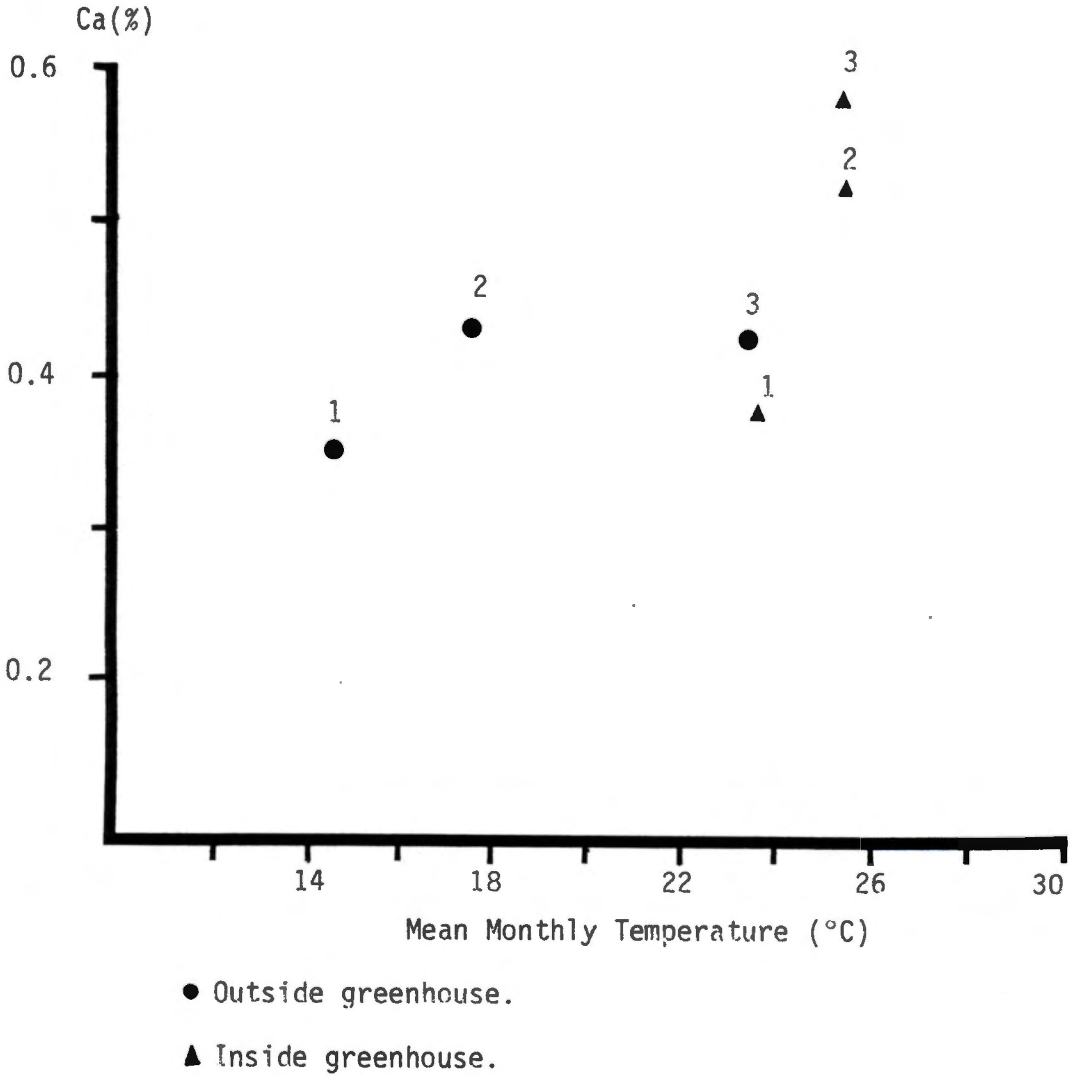


FIGURE 13. Calcium Concentration in Three Harvests of Tall Fescue Outside and Inside Greenhouse in Relation to Air Temperature

Aluminum concentrations in tall fescue outside the greenhouse were high and some were within the range of 2,000 to 8,000 ug/g Allen (1) found when studying grass tetany in ryegrass pastures. No differences in plant Al concentrations were found at any harvest outside the greenhouse from Mg treatments or from moisture treatments (Table 18). This is somewhat surprising, since Allen (1) found that high plant Al levels usually occurred in high soil moisture areas in a field.

Aluminum levels were high for tall fescue harvested inside the greenhouse at all harvests, with several means over 1,000 ug/g. No differences were found between plant tissue Al means, either between wet and drained moisture treatments, or between Mg levels. These results are quite similar to those found in tall fescue grown outside the greenhouse, and reflect the lack of dependence of plant Al concentration on these factors.

When plant Al concentrations were tested for differences due to environment, significant differences were found. At harvests 1 and 2, plant Al concentration of tall fescue grown outside the greenhouse was higher than that grown inside the greenhouse (Table 19). At harvest 3 however, means were not different between tall fescue grown inside or outside the greenhouse. These differences in Al concentration in the plant closely follow temperature changes. While mean temperatures were low outside the greenhouse, Al concentrations in the tall fescue were much higher than inside the greenhouse where temperatures were warmer (Figure 14). When mean

TABLE 18. Aluminum Concentration in Tall Fescue in the Greenhouse Experiment as Affected by Mg Level and Soil Moisture

Mg level[1]	Soil moisture[2]	Outside Greenhouse 17 Mar 82 Harvest 1	Outside Greenhouse 8 Apr 82 Harvest 2	Outside Greenhouse 13 May 82 Harvest 3	Inside Greenhouse 17 Mar 82 Harvest 1	Inside Greenhouse 8 Apr 82 Harvest 2	Inside Greenhouse 13 May 82 Harvest 3
kg/ha		ug/g					
	Drained	2109 a[3]	2064 a	1598 a	1057 a	1194 a	1663 a
	Wet	2466 a	2380 a	1166 a	1054 a	956 a	1209 a
0		1953 a	2163 a	2213 a	1034 a	1083 a	1580 a
84		2414 a	1770 a	638 a	812 a	919 a	1013 a
168		2495 a	2732 a	1295 a	1320 a	1222 a	1715 a

[1] Includes both soil moisture treatments in each Mg level.

[2] Includes all Mg levels in each soil moisture treatment.

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

TABLE 19. Aluminum Concentration in Tall Fescue in the Greenhouse Experiment as Affected by Environment

Environment	17 Mar 82 Harvest 1	8 Apr 82 Harvest 2	13 May 82 Harvest 3
	----------------	ug/g	----------------
Inside greenhouse	1055 b[1]	1074 b	1436 a
Outside greenhouse	2287 a	2222 a	1382 a

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

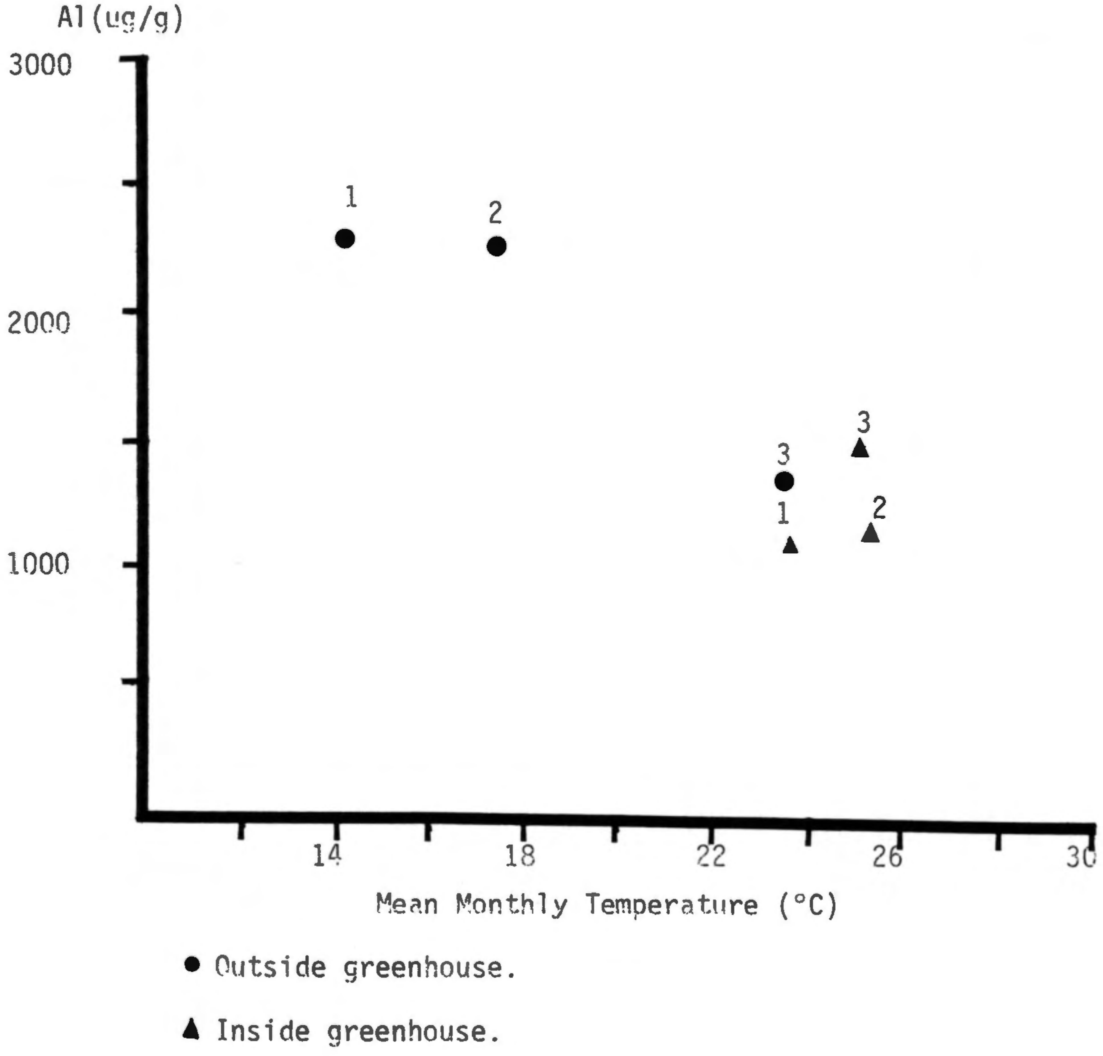


FIGURE 14. Aluminum Concentration in Three Harvests of Tall Fescue Outside and Inside Greenhouse in Relation to Air Temperature

temperatures inside and outside the greenhouse were about equal, differences in Al were no longer apparent. This trend indicates that differences in plant Al concentrations are temperature related, and Al is higher during cooler temperatures. Allen (1) and Allen and Robinson (2) have reported that high plant tissue Al concentrations may result in conditions conducive to grass tetany. Kemp and t'Hart (42) found that grass tetany cases increased five days after temperatures increased to about 14° C, while Dijkshoorn and t'Hart (18) reported an increase in cations when the temperature at which perennial ryegrass was grown was increased from 10° C to 20° C. Potassium was the cation most affected. The possibility exists that aluminum may be affected in a similar manner, resulting in high plant tissue Al concentrations. Above 22° C Al concentrations were lower than previously.

The equivalent K/(Ca + Mg) ratios in tall fescue outside the greenhouse in no case exceeded the 2.2 level above which Kemp and t'Hart (42) found an increased likelihood of grass tetany. No significant differences were found at harvest 1 (Table 20). At harvest 2, a significant interaction between Mg level and moisture treatment was found, but only one treatment (84 kg Mg/ha drained) had a significantly higher ratio than 0 and 168 kg Mg/ha (1.59, 1.33, and 1.06%, respectively). At harvest 3, K concentrations in forage were higher in drained treatments while Ca and Mg concentrations in forage were lower in drained treatments. The result was higher K/(Ca + Mg) ratios in drained treatments than in wet treatments.

TABLE 20. Equivalent Ratio of K/(Ca + Mg) in Tall Fescue in the Greenhouse Experiment as Affected by Mg Level and Soil Moisture

Mg level[1]	Soil moisture[2]	Outside Greenhouse 17 Mar 82 Harvest 1	Outside Greenhouse 8 Apr 82 Harvest 2[3]	Outside Greenhouse 13 May 82 Harvest 3	Inside Greenhouse 17 Mar 82 Harvest 1	Inside Greenhouse 8 Apr 82 Harvest 2	Inside Greenhouse 13 May 82 Harvest 3
kg/ha							
	Drained	1.13 a[4]	1.33	1.54 a	1.37 a	1.20 a	1.10 a
	Wet	1.12 a	1.15	1.13 b	1.51 a	1.11 a	0.90 a
0		1.15 a	1.20	1.39 a	1.47 a	1.11 ab	1.07 a
84		1.10 a	1.38	1.32 a	1.50 a	1.34 a	1.15 a
168		1.13 a	1.14	1.32 a	1.36 a	1.01 b	0.78 a

[1] Includes both soil moisture treatments in each Mg level.

[2] Includes all Mg levels in each soil moisture treatment.

[3] Significant interaction discussed in text.

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

Elkins and Hoveland (20), using rye, reported K levels in plant tissue increased at higher soil O_2 levels, while Ca and Mg were relatively unaffected, or slightly decreased.

The ratio of K/(Ca + Mg) at no time exceeded the 2.2 point in forage inside the greenhouse. In no harvest did differences in plant K/(Ca + Mg) ratios occur as a result of moisture treatments. Only in forage at harvest 2 did differences in the K/(Ca + Mg) ratio occur from Mg level, although these results were inconclusive.

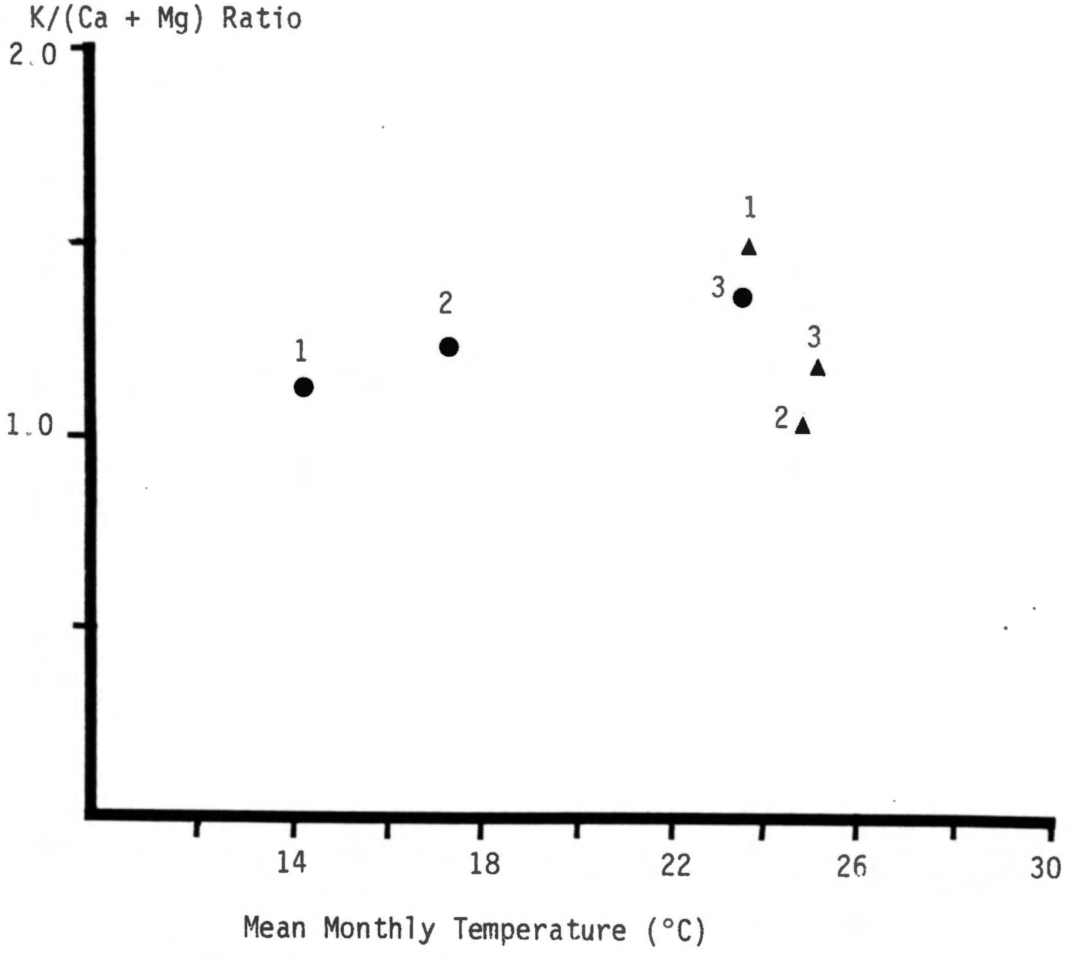
Ratios of K/(Ca + Mg) were examined for differences due to environments, that is between sod inside and outside the greenhouse. Ratios did not approach the 2.2 point, but some differences were apparent (Table 21). At harvest 1 temperatures were much different, with mean temperature inside the greenhouse over 9° C higher than outside (Figure 15), and the equivalent ratio was higher inside the greenhouse. At harvest 2, mean temperatures were slightly closer with an 8° C difference and no significant difference in equivalent ratio. At harvest 3, mean temperatures were within 2°C (in the 23-25° C range) and the ratio was higher for tall fescue grown outside the greenhouse. Differences at harvest 3 when temperatures were similar are not readily understandable.

No differences were seen in soil K between moisture treatments inside the greenhouse. Differences in soil K as a result of Mg fertilization were inconclusive. No differences in soil Mg were seen as a result of moisture treatment, but addition of 168 kg Mg/ha resulted in higher levels of soil Mg than 84 and 0 kg Mg/ha. Calcium

TABLE 21. Equivalent Ratio of K/(Ca + Mg) in Tall Fescue in the Greenhouse Experiment as Affected by Environment

Environment	17 Mar 82 Harvest 1	8 Apr 82 Harvest 2	13 May 82 Harvest 3
Inside greenhouse	1.44 a[1]	1.15 a	1.00 b
Outside greenhouse	1.12 b	1.24 a	1.34 a

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



● Outside greenhouse.

▲ Inside greenhouse.

FIGURE 15. Equivalent Ratio of K/(Ca + Mg) in Three Harvests of Tall Fescue Outside and Inside Greenhouse in Relation to Air Temperature

concentration in the soil was unaffected by soil moisture treatment, but was higher with no Mg fertilizer. Exchangeable Al concentrations were very low, around 2 ug/g.

Outside the greenhouse, soil K was unaffected by either soil moisture or level of Mg fertilization (Appendix C). Magnesium in the soil was not affected by soil moisture, but was highest at 168 kg Mg/ha, and next highest at 84 kg Mg/ha. Soil Mg was lowest at 0 kg Mg/ha. Soil Ca was unaffected by soil moisture treatment, but was highest at 0 Mg and lowest at 168 kg Mg/ha. Exchangeable Al concentrations were low (4-8 ug/g).

IV. GENERAL DISCUSSION AND CONCLUSIONS

Overall, in the field experiments, K fertilization resulted in higher plant K levels during periods of plant growth. Though small differences were sometimes noted, K fertilization in combination with Mg fertilization usually resulted in plant K concentrations as high as with K fertilization alone. This is not surprising, since K has a smaller hydrated radius, and is taken up more readily by plants than Mg. In most cases, fertilization with Mg-containing fertilizers resulted in no significant increases in plant Mg. At Knoxville some significant differences were noted in the winter months, but during the months of March, April, and May no differences due to Mg fertilization were noted. Grass tetany researchers have found that to increase plant Mg concentration it takes large amounts of Mg and/or warm temperatures except on coarse, sandy soils.

The amounts required are usually greater than it is economically feasible to apply. Calcium concentrations were often unaffected by fertilizer treatments of Mg and K. However when Ca was significantly affected by treatments it was usually lower where K, or K and Mg had been applied. This indicated that Ca uptake was sometimes in competition with K and Mg for uptake.

Aluminum concentration in tall fescue was generally high during the spring months, and sometimes within the 2,000-8,000 ug/g concentration Allen (1) discovered in tetany-producing ryegrass pastures. The plant concentration of Al was quite often over 1,000 ug/g. Two differences were found in Al concentrations due to fertilizer treatments. It is the conclusion of the author that fertilizers had little effect on Al concentrations in tall fescue. In recent times the question of whether Al found when testing tall fescue was in the plant, or on the plant in the form of soil contamination. Soils used in the field experiments were often flooded, especially at Chapel Hill. The possibility exists that rain might have splashed water and soil onto the plant surfaces, with Al contamination being the result. Also at Chapel Hill, plants were quite short at the early harvests, and direct contact between plant leaves and standing water occurred. From the results of this experiment, it is not possible to determine where Al was inside or on the outside surface of the plants.

Increases in K concentrations were associated with increases in monthly mean air temperatures until temperatures reached 12-13° C, at which point K concentrations declined. Netherlands' researchers found that the number of grass tetany cases declined when temperatures reached 14° C, which is quite similar to the temperature trend found in this research. Magnesium was high in late fall to early winter, but declined until the growing season started. During the growing season Mg concentrations remained stable. This is consistent with other researchers' findings, who found Mg concentrations in plants to remain stable through spring until an increase in summer and fall. Calcium concentrations were quite variable, and followed no clear pattern. Aluminum concentrations were highest in February and March, and declined considerably in April and May. This decline occurred at both field locations, and occurred at temperatures above 10° C. Ratios of K/(Ca + Mg) were affected by temperature variations, and followed closely the relationship between K and temperature. Changes in Mg and Ca were less drastic and more erratic in the case of Ca, so the ratio depended greatly on K fluctuations due to temperature and fertilization effects. Ratios of K/ (Ca + Mg) were usually well below the 2.2 level of tetany hazard.

In the greenhouse experiment, few differences were found in plant K concentrations, either as a result of Mg fertilization or soil moisture treatments. However, environmental differences were apparent, with warmer temperatures usually associated with higher K concentrations in tall fescue. Magnesium concentration in the plant was seldom affected by drained or wet treatments, but when differences from Mg fertilization were found, highest levels of

Mg fertilization produced higher plant Mg concentration. Soil levels of Mg were probably high enough from the cumulative effect of 5 years Mg fertilization to significantly affect Mg content in the plant. Concentrations of K and Mg in the forage were higher where temperatures were higher. When temperatures were equal in the two environments, Mg concentrations showed no difference. Few differences were found in Ca concentrations between soil moisture treatments. Differences in soil O_2 may not have been great enough to affect Ca uptake. Calcium concentrations were often highest when no Mg was added to tall fescue, indicating there was a possible Mg-Ca competition for uptake. Calcium concentration in tall fescue was greater at the warmer temperatures found inside the greenhouse, and remained higher through all harvests. Calcium concentration outside showed no great increase as temperature increased. In no instance was Al content in the plant affected by either Mg fertilization or soil moisture treatment. However, Al concentration was affected by temperature, and plant Al concentration was higher in the cooler environment. At higher temperatures Al concentrations declined. If Al is indeed involved in grass tetany, this could help explain why grass tetany cases decline at warmer temperatures. Overall, few differences in K/(Ca + Mg) ratios resulted from soil moisture treatments. In two cases, however, drained treatments had higher ratios than wet treatments. Differences in ratios seldom occurred due to level of Mg fertilization. Differences in ratios due to environment were apparent, but even though these differences were significant, they were small, and all ratios were below 2.2.

This research has borne out the dependence of cation composition in tall fescue on climatic factors. Interest in Al is relatively new, and active research into its involvement in grass tetany, as well as how it is accumulated by tall fescue should continue. Evidence is mounting that Al may indeed be involved in grass tetany, and more information concerning it is needed.

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APPENDIXES

APPENDIX A

HARVEST DATES OF FIELD AND GREENHOUSE EXPERIMENTS

Chapel Hill Field Experiment

Harvest 1 - January 2, 1982
2 - March 15, 1982
3 - April 3, 1982
4 - May 1, 1982

Knoxville Field Experiment

Harvest 1 - December 1, 1981
2 - December 16, 1981
3 - January 5, 1982
4 - February 5, 1982
5 - March 5, 1982
6 - March 18, 1982
7 - April 19, 1982
8 - May 3, 1982

Knoxville Greenhouse Experiment

Harvest 1 - March 17, 1982
2 - April 8, 1982
3 - May 13, 1982

APPENDIX B

WEEKLY MEAN TEMPERATURES AT FIELD EXPERIMENTS AND INSIDE AND OUTSIDE GREENHOUSE

	Field		Greenhouse	
Week of	Chapel Hill	Knoxville	Inside	Outside
	°C			
7 Nov 81		15.4		
14 Nov 81		10.4		
21 Nov 81		9.3		
28 Nov 81		5.7		
5 Dec 81	7.2	6.0		
12 Dec 81	3.5	1.4		
19 Dec 81	1.9	1.2		
26 Dec 81	3.0	0.2		
2 Jan 82	5.5	3.2		
9 Jan 82	5.0	2.8		
16 Jan 82	-6.8	-8.8		
23 Jan 82	5.1	1.1		
30 Jan 82	4.5	0.9		
6 Feb 82	4.8	4.3		
13 Feb 82	-0.7	0.7		
20 Feb 82	10.3	10.7		
27 Feb 82	7.8	6.1		
6 Mar 82	9.2	8.0	22.6	14.2
13 Mar 82	9.8	8.8	24.4	14.2
20 Mar 82	19.1	16.2	25.6	19.5
27 Mar 82	10.1	8.3	25.7	16.4
3 Apr 82	13.9	10.9	26.1	17.7
10 Apr 82	7.6	5.6	23.3	14.5
17 Apr 82	17.3	15.4	24.4	22.6
24 Apr 82	12.5	12.2	24.7	20.1
1 May 82	15.6	14.4	24.4	20.5
8 May 82	18.3	17.1	25.5	24.2

APPENDIX C

SOIL TEST RESULTS FROM FIELD EXPERIMENTS AND GREENHOUSE EXPERIMENT

Mineral Concentration in Soil Samples taken June 11, 1982 at Two Depths at Chapel Hill as Affected by Fertilizer Treatment

Treatment	Depth	K	Mg	Ca	P	pH
	cm	ug/g	ug/g	ug/g	ug/g	
Control	0-7.6	49 b[1]	95 b	4049 a	8 a	7.1
Sul-Po-Mag		46 b	112 a	3956 a	8 a	
Epsom salts + K_2SO_4		56 a	115 a	3936 a	7 a	
Epsom salts		44 b	110 a	3983 a	7 a	
K_2SO_4		58 a	93 b	3999 a	8 a	
Control	7.6-15.2	34 a	72 a	4045 a	4 a	7.2
Sul-Po-Mag		34 a	72 a	3961 a	4 a	
Epsom salts + K_2SO_4		36 a	72 a	4005 a	5 a	
Epsom salts		33 a	72 a	4036 a	5 a	
K_2SO_4		37 a	72 a	4052 a	4 a	

Mineral Concentration in Soil Samples Taken May 27, 1982, at Two Depths at Knoxville as Affected by Fertilizer Treatment

Treatment	Depth	K	Mg	Ca	P	pH
	cm	- - - - - - - ug/g			- - - - - - -	
Control	0-7.6	36 b[1]	655 a	2827 a	8 a	7.4
Sul-Po-Mag		47 a	653 a	2660 a	8 a	
Epsom salts + K_2SO_4		48 a	657 a	2649 a	7 a	
Epsom salts		39 b	571 a	2527 a	7 a	
K_2SO_4		51 a	594 a	2577 a	9 a	
Control	7.6-15.2	22 a	304 a	2230 a	5 a	7.5
Sul-Po-Mag		23 a	364 a	2329 a	5 a	
Epsom salts + K_2SO_4		22 a	322 a	2369 a	5 a	
Epsom salts		22 a	302 a	2370 a	5 a	
K_2SO_4		23 a	301 a	2153 a	5 a	

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

Mineral Concentration in Soil Samples Taken June 5, 1982 Inside the Greenhouse as Affected by Mg Level and Soil Moisture

Mg level	Soil moisture	K	Mg	Ca	pH
kg/ha		- - - - - -	-ug/g-	- - - - - -	
	Drained	105 a[1]	276 a	1198 a	6.3
	Wet	87 a	264 a	1151 a	
0		96 ab	216 b	1404 a	6.5
84		77 b	244 b	1047 b	
168		115 a	348 a	1072 b	

Mineral Concentration in Soil Samples Taken June 5, 1982 Outside the Greenhouse as Affected by Mg Level and Soil Moisture

Mg level	Soil moisture	K	Mg	Ca	pH
kg/ha		- - - - - -	-ug/g-	- - - - - -	
	Drained	87 a[1]	233 a	865 a	6.2
	Wet	71 a	222 a	865 a	
0		79 a	178 c	1021 a	6.3
84		69 a	223 b	862 b	
168		91 a	282 a	712 c	

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

VITA

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The next three and one-half years were spent assisting in the management of the James West dairy, after which he entered graduate school at The University of Tennessee, Knoxville in the fall of 1980. He received the Master of Science degree with a major in Plant and Soil Science in December of 1982.

He is married to the former Joy Clay of Chapel Hill, Tennessee. The author is a member of Delta Tau Alpha and Gamma Sigma Delta.