SOIL AND ENVIRONMENTAL EFFECTS ON FORAGE QUALITY WITH RESPECT TO GRASS TETANY

by

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INTRODUCTION

Grass tetany is a metabolic disorder that occurs in runinants which commonly results in the death of the affected animal (28,29,43). Grass tetany is caused by either a dietary deficiency of Mg or by a reduction in the ability of the animal to utilize dietary Mg. Grass tetany, when it occurs, generally affects pregnant, older, or lactating cows grazing cool-season grasses or small grain forages. Grass tetany has also been known to occur in stocker cattle, goats, and sheep. Grass tetany outbreaks can occur in late fall or early spring, when the weather is cool and the soil is at or near water saturated conditions. Animal losses as high as 20 percent have been reported. Yet because of the complexity of the disorder it is difficult to predict when, where, and how severe an outbreak of grass tetany will be.

Forage quality indices have been related to the occurrence of grass tetany in cattle. Small grain forage and cool-season grass forages with less than 0.2 percent Mg, or more than 3 percent K, or more than 4 percent N are considered to be tetany prone. Forage with a ratio of K/(Ca+Mg), on a milliequivalent basis, greater than 2.2 is also considered to be tetany prone.

In Kansas and other Great Plains states, winter wheat (*Triticum aestivum* L.) and the cool-season grasses tall fescue (*Festuca arundinacea* Schreb.) and bromegrass (*Bromus inermis*), are major sources of early spring pasture for cattle. These forages are nutritious and animals gain well on them. However, outbreaks of grass tetany have been reported on these forages and in some years animal losses have been high.

To gain insight into tall fescue and winter wheat forage quality, with respect to grass tetany potential, field studies were initiated with the following objectives: 1) to determine the effect of recommended N fertilization on the chemical composition of tall fescue forage; 2) to determine the effect of liming at the recommended rate, using dolomitic limestone [$CaMg(CO_3)_2$] and calcitic limestone [$CaCO_3$], on the chemical composition of winter wheat forage; 3) to determine the effect of soil moisture on the chemical composition of tall fescue and winter wheat forages; and 4) to determine the effect of root zone temperatures on the chemical composition of tall fescue and winter wheat forages.

LITERATURE REVIEW

Grass tetany is a world wide problem. Outbreaks occur annually with some years being more severe than others in terms of actual animal losses. New Zealand and northern Europe are two of the hardest hit areas on a regular basis. Outbreaks of grass tetany have been reported in most parts of the United States. It is a common practice of cattlemen in the United States to pasture animals on lush fast growing cool-season grasses and small grain forages during vegetative plant growth. Animals gain well on these types of forage; however, animal losses from grass tetany can and do occur (29,49,73).

Outbreaks of grass tetany usually occur when the soil is at or near water saturation, when the weather is cool and when the forage is experiencing rapid growth (29,43). The incidence of grass tetany has been correlated to plant genetic factors (10, 14,72), soil moisture (40), low soil oxygen (19), native soil fertility (56), air temperature (43), solar radiation (54), and soil fertilization practices (28,29). Due to the complexity of the disorder, its sporadic occurence, and its unknown initiation mechanisim, it is difficult to predict when, where, and how severe an outbreak of grass tetany will be.

Grass tetany research has produced several indices to judge how tetanigenic a small grain or cool-season forage is. The most widely used indices are the milliequivalent ratio, which is the ratio of the milliequivalents of K (meq K) to the sum of the milliequivalents of Ca (meq Ca) plus Mg (meq Mg), (milliequivalent ratio = meq K /(meq Ca + meq Mg)), in the forage, and the percent Mg in the forage. Forage milliequivalent ratios less than 2.2 are considered non-tetany prone. Milliequivalent ratios greater than 2.2 have been strongly correlated with the incidence of grass tetany (43). A forage with below 0.2 percent Mg increases the potential hazard of grass tetany (29). Forages with greater than 3 percent K and 4 percent N are also considered to be tetany prone (48).

Mayland and Grunes (48) have reviewed other plant components that may contribute to decreased efficiency of ingested forage Mg. These include total water soluble carbohydrates, higher fatty acids, and organic acids.

The fundamental problem with the prevention of grass tetany is insuring sufficient metabolizable Mg in pasture forage throughout the tetany prone grazing seasons of the fall and spring. If soil Mg is not limiting, then it would seem that there should be sufficient Mg taken up by the forage plants. Researchers have found that soil Mg does not necessarily correlate with plant Mg (5,20,32,55,56,69,76). Recently Turner et al. (76) had good success relating plant Mg to the "ratio index", which is the ratio of milliequivalents of exchangeable K to the sum of milliequivalents of exchangeable K, Ca, Mg plus pH. A possible reason for the success of the ratio index is that it includes terms for ions that compete and interfere with Mg absorption. Horvath et al. (37) recommend for soils that the ratio of exchangeable Mg to exchangeable K (on a milliequivalent basis) be at least 2.0 and the ratio of exchangeable Ca to exchangeable Mg (on a milliequivalent basis) should not be more than 5 to prevent the production of a tetany prone forage. For Ohio soils, Barta et al. (8) (cited by Stewart et al. (73)) suggest that Mg should occupy at least 15 perecnt of the soil cation exchange capacity to prevent Mg deficient tetany prone forages.

Fried et al. (25) and Haynes (33) describe a four step theoretical pathway for nutrient absorption by plants growing in soil. With respect to Mg these steps are: 1) release of Mg from the soil solid phase to the soil solution, 2) movement of Mg to the plant root, 3) absorption of Mg into the plant, and 4) transport of Mg from the root to the shoot. Steps 1 and 2 are equilibrium processes, whereas steps 3 and 4 are non-equilibrium processes which are controlled by the plant; however, all four steps are influenced by external factors. The formation of a Mg deficient and consequently a tetanigenic forage is therefore either a result of an insufficient Mg supply, a breakdown in one of the four steps, or the Mg needs of the plant being lower than needed to meet the animals Mg requirements.

Common agricultural practices may aggravate the grass tetany problem. Potassium fertilization has been shown to increase the K content of forages and which results in increased forage milli-equivalent ratios. In a greenhouse pot study, Adams et al. (2) found that sudangrass (Sorghum sudanensis) and ladino clover (Trifolium repens f. giganteum Lagr.Foss.) had higher Mg contents on soils low in K than on soils high in K. They found that K fertilization on soils deficient in Mg increased the Mg content of the test plants. They believed that K induced more vigorous plant growth and that the K displaced Mg off the soil exchange sites which made Mg more available for plant uptake. In that same study, K fertilization on Mg sufficient soils decreased plant Mg. Welte et al. (78) found similar results. They proposed that K fertilization on Mg sufficient soils results in decreased Mg uptake because of increased ionic competition for the active sites of nutrient absorption.

Nitrogen fertilization has also been shown to affect forage quality with respect to grass tetany (50,51). High rates of N fertilization on pastures increases the livestock carrying capacity of the pasture (21), but high forage N concentrations can decrease Mg availability to ruminants (48). Besides increasing the N content of the forage, changes in the cation composition of the forage can result from N fertilization. Nitrogen, depending on form, can either increase Ca and Mg (51) in the forage or it can decrease them (18). In a field study on bromegrass, Follett et al. (21) found that N applied as NH_4NO_3 increased the K and N concentrations of the forage and made it more tetany prone. In another field study on bromegrass (22), NH_4^+-N from $(NH_4)_2SO_4$ decreased plant Mg and increased the tetany hazard. Yet another study on bromegrass (26) found that N fertilization decreased the tetany hazard.

In two solution culture experiments (17,18) on wheat (Triticum aestivum L.), it was found that NO_3^--N increased divalent cations in the plant, whereas NH_4^+-N decreased them. Potassium was not affected by the form of N. The increase in divalent cations was attributed to nitrate being an anion which was needed to maintain the anion-cation balance in nutrient uptake. The decrease in divalents by NH_4^+-N was explained as being either a result of NH_4^+ being competitive for the same sites of cation absorption, or to hydrogen ion (H^+) effects associated with NH_4^+. In these same studies, NH_4^+ in combination with NO_3^- produced higher yields of plant material.

Another deleterious effect of N fertilization is the possibility of increasing the H^+ concentration in the soil and lowering the pH (23). Yearly applications of the acid producing N fertilizers may subtly lower the soil pH with time and make changes in the soil environment that can produce a tetany prone forage. Soil with pHs at or below 5.5 may have Al and Mn compounds, which are otherwise slightly soluble, go into solution (6,52). Since Al and Mn are toxic to plants, even low concentrations in the soil solution can drastically reduce yields and reduce forage quality.

Recent research has implicated Al and Mn as possible cofactors in the etiology of grass tetany (3). High Al and Mn in forages was thought to be directly responsible for several cases of grass tetany. Mayland and Grunes (48) suggest that Al may either reduce Mg uptake by plants or interfere with Mg absorption in the animal. Allen et al. (3) found that Al present in the rumen of cattle decreased Ca and Mg absorption. They suggest that plants on acid soils that accumulate Al may cause grass tetany. Grunes et al. (29) report that Mn introduced into the rumen of cattle and sheep lowered blood serum Mg levels.

In a solution culture experiment with wheat, Ohno (T. Ohno, 1981. Influence of aluminum on the chemical composition of winter wheat. M.S. Thesis. Cornell University, Ithaca, New York) found that increasing Al concentrations in nutrient solutions depressed root Mg levels. The roots were affected to a greater extent than the shoots. This effect was attributed to Al being a stronger competitor than Mg for sites of active cation absorption, or possibly to Al induced root injury. Guerrier (31) found that increasing Al, in solution culture, decreased K, Ca, and Mg on the root cation exchange sites as well as decreasing them in the plants.

Foy (24) has found that there is an antagonism of Al on Ca and possibly an antagonism of Mn on Ca with respect to Ca absorption by plants. In soils with Al and Mn in the soil solution, Ca uptake would be expected to be low, this can probably be expected for Mg too. In either case, lowered Ca or Mg increases the forage milliequivalent ratios which produces a more tetany prone forage. Foy (23) has also found that Al will generally accumulate in the roots and not in the shoots of Al injured plants. Aluminum may interrupt the translocation of ions from roots to shoots.

The best way to control a soluble Al problem in soils is to raise the soil pH (65). Above pHs of 5.5 Al precipitates out of solution as the hydroxide. Liming a soil is an effective way to raise the pH and eliminate an Al problem. Liming and acid soil (pH 4.6-4.7) with calcitic limestone increased the Mg uptake of oats (*Avena sativa* L.) more than applying Mg fertilizer to the acid unlimed soil (13). At high rates of lime additions Ca can have antagonistic effects on Mg uptake (4). Applying dolomitic limestone [$CaMg(CO_3)_2$] to a soil will raise the pH as well as increase the available supply of Mg. Gross (27) has recommended dolomitic liming as a long-term solution to grass tetany on acid, low Mg Pennsylvania soils. Reid and Jung (66) report that dolomite, when incorporated into the soil, significantly increased the Mg content of orchardgrass (*Dactylis glomerata* L.). Burns et al. (11) (cited by Reid and Jung (66)) in a review on methods for treating pastures to prevent grass tetany, concluded that on acid soils the use of dolomitic limestone would provide a long-term Mg supply and consequent long-term protection from grass tetany. Since dolomitic limestone is less soluble (0.5 gram/liter) than calcitic limestone (0.9 gram/liter), the dolomitic limestone will be slower acting and may take 2 to 3 years to reach maximum effectiveness (27).

Environmental factors, including air temperatures and soil moisture have been related to the incidence of grass tetany. 't Hart (75) (cited by Grunes et al. (29)) found that 95 percent of the cases of grass tetany he studied in Holland occurred when the mean air temperature was between 8C and 14C. It was also reported that an air temperature range of 5C to 15C would include most areas of the world where grass tetany occurs.

Air temperature has a direct effect on the transpiration rate of plants and consequently on the transpiration pull of water by plants. This phenomena is a major requirement of the convective flow (mass flow) of nutrients to the plant root (7,15). Possibly, since transpiration is so low at the temperatures at which grass tetany commonly occurs (39), the plants may not be able to pull enough nutrient rich water to accumulate sufficient Mg to prevent grass tetany. Changes in the viscosity of water may also be a factor (58). Grunes et al. (30) in a sand culture study found that at higher air temperatures (20C vs 10C), increased Mg and Ca were taken into perennial ryegrass (Lolium perrenne).

One effect of air temperature which may play a role in the etiology of grass tetany is its effect upon soil temperature. Soil temperature is a function of air temperature, soil type, and the amount of water present in the soil (68). Soil temperature under field conditions has been given little attention in the literature (44) even though it has a great influence on plant behavior. Neilsen et al. (59) found that as the root zone temperature increased, the percent of Ca and Mg in ryegrass forage increased markedly. Kleinendorst et al. (45) and Nordin (60) have concluded that plant growth is directly related to root zone temperatures.

Neilsen (58) in a review on root zone temperatures finds that since root temperatures are usually lower than air temperatures, plant roots have optimum temperatures for growth lower than the above ground plant parts. A field study with barley (Hordeum vulgare L.) found that barley has an optimum root temperature for optimum nutrient uptake and yield that is lower than the ambient air temperature (47). Neilsen (58) suggests that soil temperatures may have a greater effect on plant growth than air temperatures. He proposed that the main effect of temperature is on the kinetics of reactions. This means that the rates of reactions in the root zone would be slower because of lower temperatures. This may partially explain why decreased amounts of Mg are taken up at lower temperatures resulting in tetany prone forages. Langridge et al. (46) propose that temperature affects the synthesis, stability, and activity of membranes and controlling molecules such as enzymes. In tall fescue (Festuca arundinacea Schreb.) higher root to shoot ratios were found at lower root temperatures (16). This suggests that translocation from roots to shoots is a temperature sensitive process.

Low soil temperature may affect the sites of active nutrient uptake located in the roots. Hodges (36) describes one of the most viable models to date for nutrient absorption by plants. The model consists of cation and anion carrier mechanisms. The cation carrier is a cation activated adenosine triphosphatase (ATPase) which is bound to the cell membrane. This ATPase (called ATPase because it requires ATP energy to function) brings about the exchange of cations across the membrane. Since this mechanism is located in plant roots, root zone temperatures will affect it. Raisen et al. (61) found that changes in temperature brought about changes in the molecular ordering of membranes in mung bean (Vigna radiata L. em Wilczek) hypocotyls. Raisen et al. (63) and others (12,53,62) have also found that the activation energy (Ea) for membrane-bound ATPases is a function of temperature and that this relationship with temperature depends upon the type of ATPase. At low temperatures the Ea of the divalent ATPases are greater than the Ea of the monovalent ATPases. At higher temperatures the difference between the Ea of these two ATPases is smaller. This may have bearing on the grass tetany problem. At low temperatures the active absorption of monovalent ions could proceed at a greater rate than the active divalent uptake. This may be why lower Ca and Mg concentrations and greater milliequivalent ratios are found at lower temperatures (30,43,47,59,75).

Soil moisture has been correlated to the incidence of grass tetany. 't Hart (73) has reported that grass tetany occurred only when there was an abundance of soil water. Other researchers report similar findings (29,41). Soil moisture content will affect soil solution cation concentrations. Schofield (71) discussed this phenomena and called it the "ratio law". The ratio law is derived from the Mass Law, the Donnan Theory, and the Gouy Theory (57). It shows theoretically, that the ratio of the activity of any two or any combination of cations in an equilibrium soil solution is a constant and is independent of moisture content (79). An application of the ratio law says that, in the soil solution, the activity of the monovalent K^+ divided by the square root of the sum of the activities of divalent Ca^{2+} and Mg^{2+} is a constant and is independent of soil moisture. With respect to grass tetany, this law will determine what the concentrations of the cations in the soil solution will be at different moisture levels. As the soil system is diluted, to maintain a constant activity ratio, the divalent cations will be removed from the soil solution at a faster rate than the monovalents. This will result in a higher concentration of K in proportion to Ca and Mg in dilute soil solutions. This suggests that K will have a better chance for root interception and absorption than Ca and Mg when the soil is near water saturation. Karlen et al. (41) in a growth chamber experiment with winter wheat found that plants grown under high soil water potentials had greater milliequivalent ratios than plants grown under a moderate soil water potential.

MATERIALS AND METHODS

During the springs of 1979 and 1980, studies were conducted at the Kansas State University Agronomy North Farm on the effect of N fertilization and environment upon the grass tetany potential of tall fescue (*Festuca arundinacea* Schreb.) forage. During these same time periods, studies were conducted at the Kansas State University Kansas River Valley Experiment Field-Rossville on the effects of liming and environment upon the grass tetany potential of winter wheat (*Triticum aestivum* L.) forage.

Tall Fescue Studies

In both 1979 and 1980, a randomized complete block design with three replications was used to study the effect of N fertilization and environment on tall fescue. The established tall fescue was on a Wymore silty clay loam; an Aquic Argiudoll described as fine, montmorillonitic, mesic, with 1 to 4 percent slope and developed from loess (38). Nitrogen, as NH_4NO_3, was broadcast applied at 0 and 135 kg N/ha prior to the end of the winter dormancy period. Weekly plant subsampling was initiated approximately one week after fertilization and continued until the end of vegetative plant growth.

Environmental measurements included weekly maximum (max) and minimum (min) root zone temperatures at 5 and 10 cm below the soil surface. Soil moisture was measured in the top 15.2 cm. The temperatures were recorded and the soil moisture samples were collected at the weekly plant sampling.

Winter Wheat Studies

In both 1979 and 1980, a randomized complete block design with four replications was used to study the effect of liming upon the grass tetany potential of winter wheat forage. The soil at the Rossville location is a Eudora loam; a Fluventic Hapludoll described as coarse-silty, mixed, mesic, and developed from alluvium (1). During the 1979 study, the wheat variety "Centurk" (Triticum aestivum L. em Thell) (70) was used. During the 1980 study, the variety "Newton" (Triticum aestivum L. em Thell) (34) was used.

The lime treatments were applied prior to seeding in the fall of 1977 at the recommended rate of 10,750 kg/ha effective calcium carbonate (ECC) (42). Two lime sources were used: dolomite [$CaMg(CO_3)_2$, 10.6% Mg] and finely divided stackdust [$CaCO_3$], both having ECC ratings of 100. One-half of the lime was applied and incorporated by discing and plowing to a depth of 25 cm. The remaining lime was then applied and disced in. The dolomite supplied 1140 kg Mg/ha.

Weekly plant sampling was initiated at the end of the winter dormancy period, and was terminated at the jointing stage of plant growth. Weekly max and min root zone temperatures were measured at 5 and 10 cm below the soil surface and random soil samples from each plot, to a depth of 15.2 cm, were taken for the determination of soil moisture content.

Sample Preparation and Analytical Methods

Plant sampling was at random within each plot. Entire plants were excavated and returned to the laboratory where they were washed with distilled deionized water to remove soil particles and other contamination on the exterior plant surfaces. The plants were then fractionated with shears into the plant forage (aerial portion of the plant), crowns (plant part between the top and the roots), and the roots. The roots were discarded. The forage and crowns were dried in a forced air oven at 60C and then ground in a Udy Cyclo mill to pass a 1 mm screen. The samples were redried for 24 hours prior to digestion.

Two subsamples of each fescue tissue sample were taken. One was digested with concentrated H_2SO_4-H_2O_2 for N analysis and the other was digested with a 1:1 (v:v) mixture of concentrated HNO_3-$HClO_4$ for K, Ca, and Mg analysis. A HNO_3-$HClO_4$ digest was done on wheat tissue subsamples for K, Ca, Mg, Mn, and Al analysis.

Nitrogen was determined using a Technicon Autoanalyzer (74). Potassium was determined by air-acetylene flame emission. Calcium, Mg, and Mn were determined with air-acetylene flame atomic absorption. Calcium and Mg determinations were made in the presence of 0.1% La_2O_3 to reduce interferences in the flame. Aluminum was determined by inductively coupled plasma atomic emission at the U.S. Plant, Soil and Nutrition Laboratory, Ithaca, New York.

Soil samples were taken to a depth of 15.2 cm at each study location in the spring of each year for determination of exchangeable cations and pH. The soils were dried in a forced air oven at 60C and ground to pass a 10 mesh sieve. Exchangeable K, Ca, and Mg were determined in 1:5 soil to 1<u>N</u> NH_4OAc (pH=7) extracts. Exchangeable Mn and Al were determined in 1:5 soil to 1<u>N</u> KCl extracts for the wheat study Eudora soil. Potassium was analyzed by air-acetylene flame emission. Calcium, Mg, and Mn were determined by air-acetylene flame atomic absorption, with 0.1% La_2O_3 present in the Ca and Mg determinations to reduce interferences in the flame. Exchangeable Al was determined spectrophotometrically using the method of Bloom et al. (9). Determination of pH was in a 1:1 soil to water suspension using the recommended pH test procedure for the North Central Region (64).

Soil cation exchange capacity (CEC) was determined by saturating the soil exchange sites with Ba from an unbuffered salt solution of 1 N $BaCl_2$, removing excess Ba with alcohol, and replacement of Ba on the exchange sites with NH_4^+ from 1 N NH_4OAc. Determination of Ba in the NH_4OAc extracts was by nitrous oxide-acetylene flame emission.

Soil cores were taken weekly at random within each plot to a depth of 15.2 cm for soil moisture content determination. The fresh moist soils were placed in pre-weighed soil tins, capped and returned to the laboratory for weighing, drying, and reweighing after cooling. Soil water content was calculated on a mass basis (grams H_2O/grams dry soil). Reported soil moisture values determined for the fescue and wheat studies are the mean of 6 and 12 values, respectively. Characteristic soil-moisture release curves for the Wymore and Eudora soils were determined using the pressure plate technique (35,67). Weekly soil water potential values were extrapolated using the mean soil water content, on a mass basis, from the respective characteristic soil-moisture release curve (See Appendix Figure 1).

Root zone temperature was measured at two random sites at each study location. Weekly max and min temperatures were measured by recording max-min thermometers that had 1 meter flexible leads between the temperature sensor and the recording devices. The sensors were placed parallel to the soil surface at 5 and 10 cm below the soil surface. Before installation, the soil thermometers were calibrated against mercury thermometers. The reported values have been corrected and are the mean of the two values.

Assistance with statistical analysis was provided by the Statistical Analysis Systems (SAS) program packages available at the Kansas State University Computer Center.

TALL FESCUE RESULTS AND DISCUSSION

Soil and Environment 1979 and 1980

The chemcial properties of the Wymore soil for the 1979 and 1980 tall fescue studies are shown in Table 1. Exchangeable Mg was 20 and 18 percent of the CEC in 1979 and 1980, respectively. These values are above the 15% exchangeable Mg that has been recommended to obtain forages with sufficient Mg to prevent grass tetany (8). A Mg/K ratio, on a milliequivalent basis, of at least 1.2 has been suggested to obtain a forage with at least 0.2% Mg (37). In 1979 and 1980 the soil Mg/K ratios were in excess of 1.2. The Ca/Mg ratios, on a milliequivalent basis, were less than 5 which is considered to be the upper limit in the Ca/Mg ratio to prevent the formation of a tetany prone forage. Applying the regression equation of Turner et al. (76) (Y=0.1433 + 0.6987X, Y=Mg in the plant, X=the ratio index (RI)) to estimate plant Mg concentrations from soil chemical data, the predicted values for 1979 and 1980 are 0.269% Mg and 0.276% Mg, respectively. The predicted values for both years are well above the forage Mg critical value of 0.2%. The soil results suggest that a tetany prone forage should not be produced by the tall fescue.

Environmental data by year and sampling date are shown for 1979 and 1980 in Tables 2 and 3, respectively. Soil temperatures for weeks 1 and 2 in 1979 were not available.

In general, the maximum and minimum soil temperatures at both the 5 and 10 cm depths were higher in 1980 than in 1979 for corresponding sampling dates. Soil water in 1979 had a decreasing trend with time without much variability. Soil water in 1980 did not have a general trend. It had a high value of 29.8% and a low value of 14.0% for a difference of 15.8%. If plant chemical

Table 1. Soil chemical properties for tall fescue studies.

Year	pH	CEC	K	Ca	Mg	Mg/CEC	Mg/K	Ca/Mg	RI*
		-----------	---meq/100 g---	-----------					
1979	6.1	20.6	0.88	11.39	4.11	0.20	4.63	2.77	0.18
1980	5.6	20.6	0.92	10.16	3.74	0.18	4.11	2.73	0.19

*$RI = \frac{Mg}{(K + Ca + Mg) + pH}$; K, Ca, and Mg on a milliequivalent basis.

Table 2. Environmental data for 1979 tall fescue study.

Week	Sample date	Percent soil water	Soil-water potential (PSI)	Max. soil temperature 5 cm	Min. soil temperature 5 cm	Max. soil temperature 10 cm	Min. soil temperature 10 cm
				°C			
1	3-6	28.8	5.6	-	-	-	-
2	3-13	27.3	7.3	-	-	-	-
3	3-20	26.5	8.4	10.8	1.9	10.6	3.1
4	3-27	26.7	8.2	10.6	1.1	10.3	2.5
5	4-3	27.7	6.9	13.6	2.2	13.9	2.5
6	4-10	26.0	9.2	11.1	3.6	10.6	5.3
7	4-17	20.8	30.0	16.7	5.6	16.4	6.9
8	4-24	19.3	62.0	16.4	10.0	16.9	11.7
9	5-1	20.3	35.0	16.4	8.1	16.7	10.3

Table 3. Environmental data for 1980 tall fescue study.

Week	Sample date	Percent soil water	Soil-water potential (PSI)	Max. soil temperature 5 cm	Min. soil temperature 5 cm	Max. soil temperature 10 cm	Min. soil temperature 10 cm
				°C			
1	3-14	26.6	8.2	10.0	0.5	8.3	2.0
2	3-21	29.8	4.7	9.2	2.2	7.8	2.8
3	3-28	29.7	4.8	10.0	3.3	8.9	4.5
4	4-4	29.5	4.9	12.8	4.7	11.7	5.9
5	4-11	25.8	9.8	11.9	3.9	10.5	5.3
6	4-18	19.8	46.0	20.0	7.2	17.5	7.5
7	4-25	14.5	409.7	19.7	9.2	18.0	10.3
8	5-2	14.0	482.9	20.5	9.2	18.6	10.6
9	5-9	20.9	30.0	19.4	10.5	17.8	12.0

composition is closely related to soil water the plant data for 1980 should show this relationship because of the wide range in soil water.

Plant Results 1979

The effects of N fertilization on tall fescue forage N, K, Ca and Mg content and milliequivalent ratio during 1979 are shown in Tables 4,5,6,7, and 8, respectively. Similar tables for the tall fescue crowns are Tables 9-13. These results for the forage and crowns are also shown graphically in Figures 1 and 2. Included in these figures are plots of the maximum and minimum soil temperatures at 5 and 10 cm and the percent soil water.

In this discussion and others that follow the term "forage" will refer to the aerial plant parts that are likely to be consumed by grazing ruminants. The term "crown" will refer to the portion of the plant that is between the aerial plant parts and the plant roots, which is not likely to be consumed.

Fescue Forage

Nitrogen fertilization increased the mean forage N content for the nine weeks from 1.60% N to 2.88% N (see Table 4). Nitrogen content was greater in the fertilized forage within each week except for week 1 where there was no difference. The N content in the fertilized forage showed a gradual increase for the first 4 or 5 sampling dates and a leveling off after that (see Figure 1). The unfertilized forage N content remained fairly constant with time. The lack of forage response to N fertilization in the first week may be due to plant physiological inactivity or to a need for a greater lag period between fertilizer application and plant response. When N content in a forage is 4% or more the forage is considered to be tetany prone. The forage N concentrations

Table 4. The effect of N fertilization on percent N in tall fescue forage at nine sampling dates (1979).

	Date (Week)									
	3-6	3-13	3-20	3-27	4-3	4-10	4-17	4-24	5-1	
Treatment	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Means*
0 kg N/ha	1.28	1.45	1.52	1.65	1.86	1.62	1.74	1.81	1.49	1.60b
135 kg N/ha	1.53	2.08	2.84	2.42	3.41	3.60	3.74	3.60	2.71	2.88d
Means*	1.41d	1.77c	2.18b	2.04b	2.64a	2.61a	2.74a	2.70a	2.10b	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5%: between weeks with the same treatment, 0.33; between treatments within the same week, 0.32.

THIS BOOK CONTAINS NUMEROUS PAGES THAT WERE BOUND WITHOUT PAGE NUMBERS.

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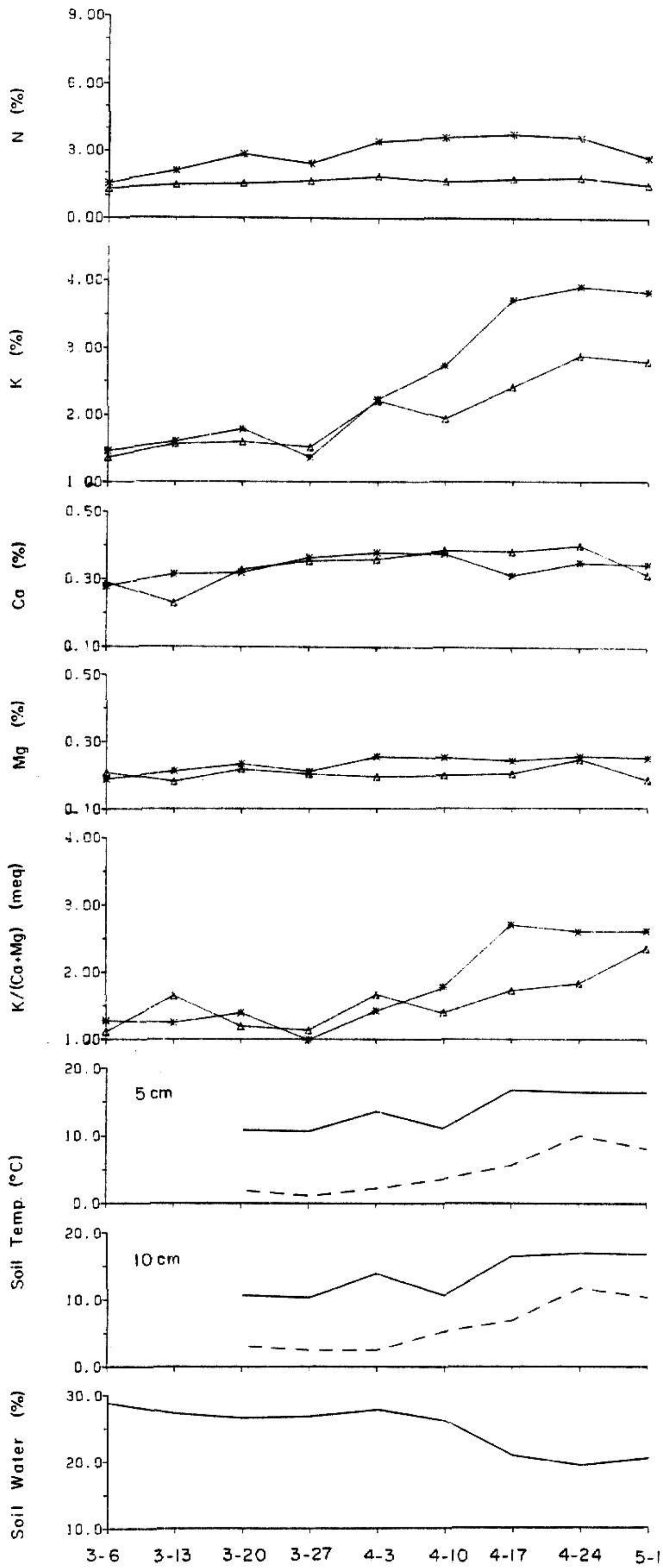
Figure 1. Seasonal trends in chemical composition of tall fescue forage in 1979, as affected by 0 (Δ–Δ), or 135 (✱–✱) kg N/ha applied as NH_4NO_3. Soil water and maximum (——) and minimum (---) soil temperature at 5 and 10 cm are also shown.


N (%)
K (%)
Ca (%)
Mg (%)
K/(Ca+Mg) (meq)
5 cm
10 cm
Soil Temp. (°C)
Soil Water (%)
3-6 3-13 3-20 3-27 4-3 4-10 4-17 4-24 5-1

approached the 4% critical value in the fertilized forage but remained below it. It is reasonable to conclude that there would have been minimal tetany hazard to ruminants grazing these forages due to the N content of the forage.

The mean K content of the fescue forage was greater with N fertilization compared to no N application (see Table 5). Only weeks 6-9 showed differences between N treatments within weeks. Prior to week 6 the forage K content was not different between N treatments. At week 5 the N fertilized forage had 2.22% K and the unfertilized forage had 2.20% K. In week 6 the fertilized forage had increased to 2.72% and the unfertilized forage K had decreased to 1.93% (see Figure 1). In the weeks that followed the N fertilized forage K content remained greater than the K content of the unfertilized forage. This K increase could have been caused by the increase in soil temperature coupled with the N fertilizer stimulating rapid plant growth. Large increases in forage K concentraions can be resposible for increases in the forage milliequivalent ratio, which increases the tetany hazard. When between treatment differences in forage K content occurred the fertilized forage always had the higher K. Sometimes these differences were quite large. In week 7 the unfertilized forage had 2.40% K and the fertilized forage had 3.69% K. Potassium in forage above 3% is considered hazardous. The fertilized forage had K concentrations above 3% in weeks 7,8 and 9.

Forage Ca remained relatively constant over the sampling period (see Figure 1). There was no difference in mean Ca concentration in the forage between treatments (see Table 6). Only weeks 2 and 7 showed a difference within weeks with the fertilized forage having a greater Ca content at week 2 and the unfertilized

Table 5. The effect of N fertilization on percent K in tall fescue forage at nine sampling dates (1979).

	Date (Week)									
	3-6	3-13	3-20	3-27	4-3	4-10	4-17	4-24	5-1	
Treatment	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Means*
0 kg N/ha	1.36	1.56	1.59	1.51	2.20	1.93	2.40	2.87	2.78	2.02b
135 kg N/ha	1.46	1.60	1.78	1.36	2.22	2.72	3.69	3.89	3.81	2.50a
Means*	1.41e	1.58de	1.68d	1.44e	2.21c	2.32c	3.05b	3.38a	3.29a	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5%: between weeks with the same treatment, 0.27; between treatments within the same week, 0.32.

Table 6. The effect of N fertilization on percent Ca in tall fescue forage at nine sampling dates (1979).

	Date (Week)									
	3-6	3-13	3-20	3-27	4-3	4-10	4-17	4-24	5-1	
Treatment	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Means*
0 kg N/ha	0.289	0.228	0.328	0.354	0.360	0.386	0.383	0.402	0.316	0.339a
135 kg N/ha	0.278	0.314	0.319	0.364	0.380	0.376	0.312	0.351	0.346	0.338a
Means*	0.284de	0.271e	0.323cd	0.359abc	0.381a	0.348abc	0.377ab	0.331bc		

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5%: between weeks with the *same treatment*, 0.063; between treatments within the same week, 0.066.

forage having a greater Ca content in week 7. No explanation is offered for this anomalous result.

Nitrogen fertilization did increase the mean Mg content in the forage compared to no N fertilization (see Table 7). The fertilized forage Mg mean was 0.232% and the unfertilized forage Mg mean was 0.203%. Both values are above the recommended minimum forage Mg content of 0.2% to reduce the incidence of grass tetany. The unfertilized forage Mg value is borderline but the fertilized forage offers a margin of safety. Both the fertilized and the unfertilized forage Mg content increased slightly with time (see Figure 1), but the overall change was not great. There were differences between treatments in weeks 2,5-7 and 9. In each case the fertilized forage had the greater Mg content. In weeks 2,5,6 and 9 the unfertilized forage Mg content was below 0.2% but only in week 1 was the fertilized forage Mg below that value. The N fertilization resulted in the forage having more weeks with sufficient Mg to prevent grass tetany than did not fertilizing with N.

Nitrogen fertilization only slightly increased the mean milliequivalent ratio of the fescue forage (see Table 8). Even with this slight increase the means were still below the critical value of 2.2. However, this result may be misleading. Even though the mean over all weeks was below 2.2 there were three weeks in which the fertilized forage exceeded this value and only one week in the unfertilized forage. In weeks 7 and 8 there was a difference in forage milliequivalent ratios due to treatment. In both weeks the fertilized forage ratio was well above 2.2 and the unfertilized forage was below it. In week 9 there was not a difference between treatments but both forage milliequivalent ratios were above 2.2. It is these rapid fluctuations in forage chemical

Table 7. The effect of N fertilization on percent Mg in tall fescue forage at nine sampling dates (1979).

	Date (Week)									
Treatment	3-6 (1)	3-13 (2)	3-20 (3)	3-27 (4)	4-3 (5)	4-10 (6)	4-17 (7)	4-24 (8)	5-1 (9)	Means*
0 kg N/ha	0.207	0.181	0.217	0.203	0.194	0.198	0.202	0.244	0.183	0.203b
135 kg N/ha	0.189	0.212	0.233	0.210	0.254	0.250	0.240	0.253	0.248	0.232a
Means*	0.198c	0.196c	0.255b	0.206bc	0.224b	0.224b	0.221b	0.248a	0.216bc	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5%: between weeks with the same treatment, 0.026; between treatments within the same week, 0.027.

Table 8. The effect of N fertilization on the milliequivalent ratio in tall fescue forage at nine sampling dates (1979).

	Date (Week)									
	3-6	3-13	3-20	3-27	4-3	4-10	4-17	4-24	5-1	
Treatment	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Means*
0 kg N/ha	1.11	1.64	1.19	1.13	1.66	1.39	1.72	1.83	2.35	1.56b
135 kg N/ha	1.27	1.24	1.39	0.99	1.42	1.77	2.70	2.60	2.61	1.78a
Means*	1.19cd	1.44bc	1.29bcd	1.06d	1.54b	1.58b	2.21a	2.22a	2.48a	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5%: between weeks with the same treatment, 0.42; between treatments within the same week, 0.43.

composition that gives the grass tetany syndrome its unpredictable and sporadic nature.

The milliequivalent ratios above 2.2 can be attributed to high K levels in the forage (see Figure 1). The K increases correspond to an increase in soil temperature and a decrease in soil water. The increase above 2.2 in the unfertilized forage in week 9 was due to a drop in the Ca and Mg concentrations in the forage without a change in the forage K level. The minimum soil temperature at 5 and 10 cm dropped in week 9 also.

Fescue Crowns

Results similar to the forage results were found for the fescue crowns in 1979. Nitrogen fertilization resulted in higher mean N concentrations in the crowns (see Table 9). As with the forage, the fertilized crowns had higher N concentrations than the unfertilized crowns in weeks 2-9. The unfertilized crown N content remained fairly constant with time but the N fertilized crown N content increased with time until it reached a maximum in week 5 with 4.72% N after which it decreased slightly (see Figure 2).

Nitrogen fertilization increased the mean crown K content (see Table 10). Crown K had an increasing trend for the first 7 sampling dates and decreased in the last two (see Figure 2). The unfertilized crown K content was never above 3% but the N fertilized crowns were in weeks 5-8. This level of K in the fertilized crowns suggests that a tetany prone forage could be produced if the K were translocated out of the crowns to the forage.

Nitrogen fertilization did not affect the mean crown Ca concentration nor did it have a significant effect on crown Ca concentrations within weeks (see Table 11). Crown Ca over time had

Table 9. The effect of N fertilization on percent N in tall fescue crowns at nine sampling dates (1979).

	Date (Week)									
	3-6	3-13	3-20	3-27	4-3	4-10	4-17	4-24	5-1	
Treatment	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Means*
0 kg N/ha	1.27	1.26	1.27	1.58	1.47	1.05	1.00	0.96	0.75	1.18b
135 kg N/ha	1.23	2.10	3.53	3.57	4.72	4.37	3.90	3.67	2.36	3.27a
Means*	1.25e	1.68d	2.40bc	2.57bc	3.09a	2.71b	2.45bc	2.32c	1.56de	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5%: between weeks with the same treatment, 0.50; between treatments within the same week, 0.49.

Figure 2. Seasonal trends in chemical composition of tall fescue crowns in 1979, as affected by 0 (Δ—Δ), or 135 (✱—✱) kg N/ha applied as NH_4NO_3. Soil water and maximum (——) and minimum (---) soil temperature at 5 and 10 cm are also shown.

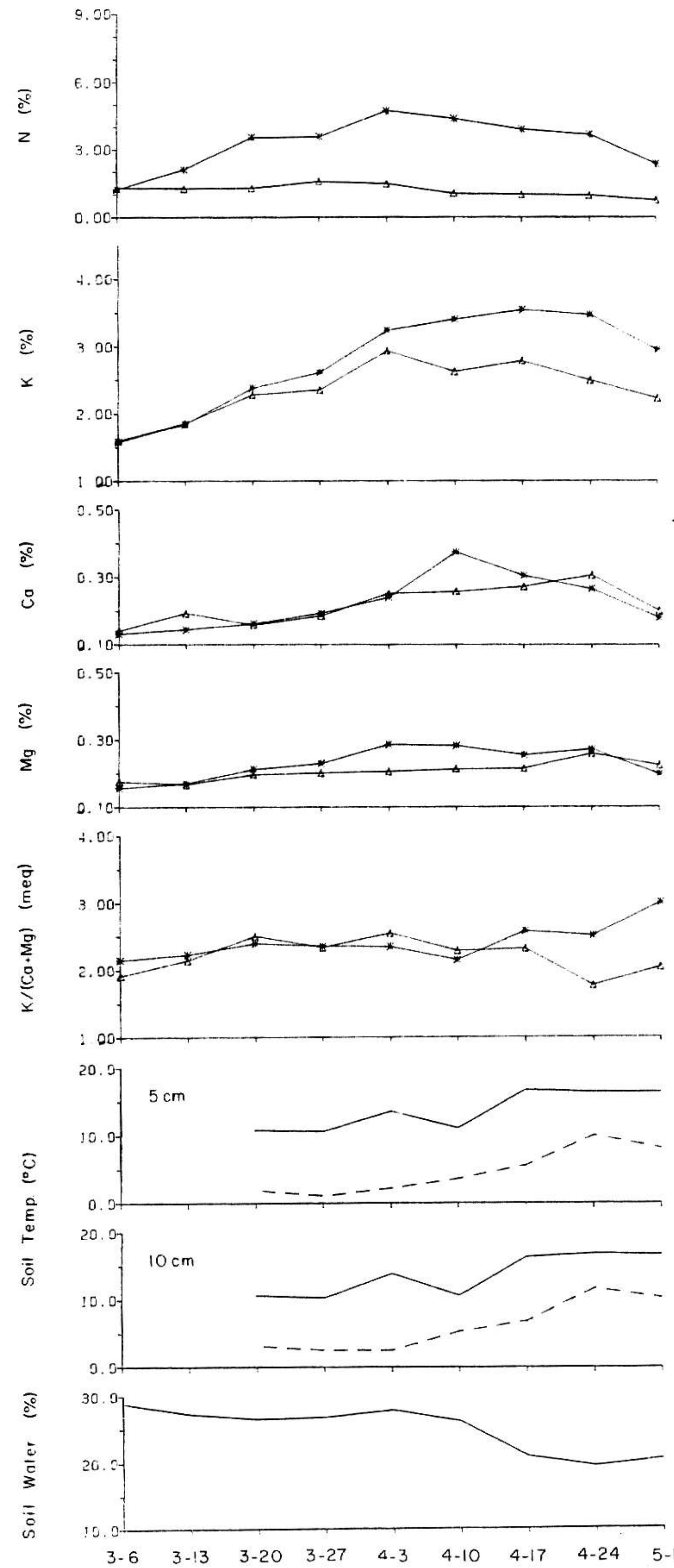

N (%)
9.00
6.00
3.00
0.00
K (%)
4.00
3.00
2.00
1.00
Ca (%)
0.50
0.30
0.10
Mg (%)
0.50
0.30
0.10
K/(Ca+Mg) (meq)
4.00
3.00
2.00
1.00
Soil Temp. (°C)
5 cm
20.0
10.0
0.0
10 cm
20.0
10.0
0.0
Soil Water (%)
30.0
20.0
10.0
3-6
3-13
3-20
3-27
4-3
4-10
4-17
4-24
5-1

Table 10. The effect of N fertilization on percent K in tall fescue crowns at nine sampling dates (1979).

	Date (Week)									
	3-6	3-13	3-20	3-27	4-3	4-10	4-17	4-24	5-1	
Treatment	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Means*
0 kg N/ha	1.60	1.85	2.28	2.35	2.93	2.62	2.78	2.49	2.22	2.35b
135 kg N/ha	1.58	1.84	2.38	2.61	3.24	3.40	3.54	3.47	2.94	2.78a
Means*	1.59e	1.84d	2.33c	2.48bc	3.09a	3.01a	3.16a	2.98a	2.58b	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5%: between weeks with the same treatment, 0.32; between treatments within the same week, 0.41.

Table 11. The effect of N fertilization on percent Ca in tall fescue crowns at nine sampling dates (1979).

	Date (Week)									
	3-6	3-13	3-20	3-27	4-3	4-10	4-17	4-24	5-1	
Treatment	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Means*
0 kg N/ha	0.141	0.193	0.158	0.185	0.252	0.258	0.273	0.306	0.201	0.219a
135 kg N/ha	0.131	0.144	0.162	0.193	0.241	0.374	0.305	0.266	0.180	0.222a
Means*	0.136a	0.169bc	0.160bc	0.189bc	0.247ab	0.316a	0.289a	0.286a	0.190bc	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5%: between weeks with the same treatment, 0.133; between treatments within the same week, 0.122.

somewhat more variability than the forage Ca and was slightly decreasing (see Figure 2).

The mean over all sampling dates of the crown Mg content was greater for the fertilized crowns compared to the non-fertilized (see Table 12). Like the forage, the crown means over all sampling dates were above 0.2% Mg. The crowns from the fertilized plots with 0.228% Mg have the potential of supplying more Mg to the forage than the unfertilized crowns with 0.205% Mg. Over time crown Mg increased only slightly (see Figure 2). Weeks 5, 6 and 7 showed between treatment differences. In each case the fertilized crowns had the greater Mg content. Weeks 3-9 were at or above 0.2% Mg for both treatments. The N fertilized crowns increase in Mg content from week 4 to week 5 may have been due to N fertilizer stimulated plant growth and/or to an increase in soil temperature.

There were no differences between treatments in crown milli equivalent ratios over all weeks with both means 2.2 or above (see Table 13). Only weeks 8 and 9 showed within week differences with the fertilized crowns having the higher values, both of which were above 2.2. The lower ratio at week 8 for the unfertilized crowns can be attributed to an increase in crown Mg and a decrease in crown K. The higher ratio in week 9 for the fertilized crowns was a result of a sharp drop in the Mg content of the crowns.

Correlations

Linear correlation analysis was run on the 1979 fescue forage and crown data to determine if significant correlations exist between measured plant factors and environmental factors. The results of these analyses are shown in Tables 14 and 15 for the forage and crowns, respectively. Only linear correlation

Table 12. The effect of N fertilization on percent Mg in tall fescue crowns at nine sampling dates (1979).

	Date (Week)									
	3-6	3-13	3-20	3-27	4-3	4-10	4-17	4-24	5-1	
Treatment	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Means*
0 kg N/ha	0.175	0.167	0.196	0.201	0.205	0.212	0.214	0.257	0.222	0.205b
135 kg N/ha	0.157	0.169	0.212	0.229	0.285	0.281	0.253	0.270	0.196	0.228a
Means*	0.166e	0.168e	0.204d	0.215cd	0.245ab	0.246ab	0.233bc	0.269a	0.209cd	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD. 5%: between weeks with the same treatment, 0.036; between treatments within the same week, 0.035.

Table 13. The effect of N fertilization on the milliequivalent ratio in tall fescue crowns at nine sampling dates (1979).

	Date (Week)									
Treatment	3-6 (1)	3-13 (2)	3-20 (3)	3-27 (4)	4-3 (5)	4-10 (6)	4-17 (7)	4-24 (8)	5-1 (9)	Means*
0 kg N/ha	1.91	2.14	2.50	2.33	2.54	2.28	2.31	1.76	2.03	2.20a
135 kg N/ha	2.15	2.23	2.39	2.35	2.34	2.14	2.57	2.50	2.99	2.41a
Means*	2.03a	2.18ab	2.45ab	2.34ab	2.44ab	2.21ab	2.44ab	2.13ab	2.51a	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5%: between weeks with the same treatment, 0.51; between treatments within the same week, 0.70.

coefficients with significance probabilities of 95% or higher are presented. As would be expected the milliequivalent ratio may be significantly correlated with K, Ca and Mg because they are part of the ratio only other significant correlations in the tables will be discussed.

With respect to the fescue forage a surprisingly strong negative correlation between the milliequivalent ratio and the soil water content was found. This relationship was stronger for the N fertilized forage than for the unfertilized (see Table 14). Generally, the milliequivalent ratio of cations has been positively correlated with soil water content. The forage K content was also negatively correlated to the soil water content and is the reason that the milliequivalent ratio was strongly related to the soil water content. The K relationship appears to be opposite of the result expected from a thermodynamic treatment of soil dilution which would predict that upon dilution the monovalent cation concentration will increase relative to the higher valent cations in solution. These results do not disprove the soil solution dilution phenomena, but do suggest that the plant may have ultimate control over what nutrients it will absorb. Soil water potential was negatively related to several dependent variables but in each case the soil water had a stronger relationship based on better correlation.

Forage Mg was strongly correlated to forage N content in the fertilized forage but did not significantly correlate in the unfertilized forage due to little change in N content over time. Magnesium and Ca also were positively correlated to each other. The milliequivalent ratio and the forage K were both strongly positively related to the maximum and minimum soil temperatures

Table 14. Linear correlation coefficients[*] among measured plant and environmental factors for tall fescue forage (1979).

	Treatment (kg N/ha)	Forage N	Forage K	Forage Ca	Forage Mg	Forage millieq. ratio	Soil water	Soil water potential	-------Soil Temp.------- Max. 5 cm	Min. 5 cm	Max. 10 cm	Min. 10 cm
Forage N	0	-	.52	.51	ns	ns	ns	ns	ns	ns	ns	ns
	135	-	.68	.47	.75	.58	-.55	.46	ns	ns	ns	ns
Forage K	0	.52	-	.39	ns	.79	-.85	.83	.88	.87	.89	.84
	135	.68	-	ns	.61	.96	-.93	.85	.90	.92	.88	.91
Forage Ca	0	.51	.39	-	.64	ns	-.40	.39	ns	ns	ns	ns
	135	.47	ns	-	.64	ns	ns	ns	ns	ns	ns	ns
Forage Mg	0	ns	ns	.64	-	-.39	ns	.46	ns	ns	ns	ns
	135	.75	.61	.64	-	.41	-.50	.44	ns	ns	ns	ns
Forage Milliequivalent Ratio	0	.64	.79	ns	-.39	-	-.63	ns	.78	.72	.79	.70
	135	.58	.96	ns	.41	-	-.91	.81	.88	.87	.85	.86

[*] Entry into the table required a significance probability of 0.05 or less.

at 5 and 10 cm. Again the correlation was probably due to potassium's relationship to temperature. The temperature effect was enhanced by N fertilization.

The crown data for 1979 did not show as many significant correlations as the forage did (see Table 15). One peculiar result is the correlation between the crown milliequivalent ratio and soil temperature. Without N fertilization there is a negative relationship, but with N fertilization there is a positive relationship. Nitrogen in the soil may have made the plant root more permeable to K and sensitive to temperature or it may have altered the distribution of cations in the soil solution possibly making more K available for plant uptake.

Comparison of Forage and Crowns

Forage and crowns within the same treatments were compared to see if there exists a relationship between them with respect to nutrient content. The results of these comparisons are in Tables 16 and 17 for the unfertilized and fertilized tall fescue, respectively.

The N content of the unfertilized forage and crowns were different in weeks 5-9 and in each case the forage N content was greater than crown N content (see Table 16). Differences in K content were found in every week. In weeks 1-7 the crowns were higher in K, but in weeks 8 and 9 the forage was. Calcium differences were found in weeks 1, 3-5, 8 and 9, and in each case the Ca was higher in the forage. Magnesium differences occurred only in weeks 1, 3 and 5. Weeks 1 and 3 had higher Mg in the forage and week 5 had higher Mg in the crown. The milliequivalent ratio was different in weeks 1, 3-7 and 8, but only in week 8 was the ratio higher in the forage than the crowns.

Table 15. Linear correlation coefficients* among measured plant and environmental factors for tall fescue crowns (1979).

	Treatment (kg N/ha)	Crown N	Crown K	Crown Ca	Crown Mg	Crown millieq. ratio	Soil water	Soil water potential	Soil Temp. Max. 5 cm	Soil Temp. Min. 5 cm	Soil Temp. Max. 10 cm	Soil Temp. Min. 10 cm
Crown N	0	-	ns	ns	ns	ns	.66	-.57	-.58	-.70	-.56	-.73
	135	-	.77	.55	.88	ns	ns	ns	ns	ns	ns	-.48
Crown K	0	ns	-	.65	.50	ns	ns	ns	ns	ns	ns	ns
	135	.77	-	.63	.83	ns	-.63	.54	.56	.49	.53	.44
Crown Ca	0	ns	.65	-	.63	-.42	-.44	.45	ns	ns	ns	ns
	135	.55	.63	-	.57	ns	ns	ns	ns	ns	ns	ns
Crown Mg	0	ns	.50	.63	-	-.48	-.65	.69	.50	.66	.52	.65
	135	.89	.83	.57	-	ns	ns	ns	ns	ns	ns	ns
Crown Milliequivalent Ratio	0	ns	ns	-.42	-.48	-	ns	-.44	-.45	-.68	-.46	-.69
	135	ns	ns	ns	ns	-	ns	.41	.51	.44	.52	.45

*Entry into the table required a significance probability of 0.05 or less.

Table 16. Comparison of forage and crowns from unfertilized 1979 tall fescue.

Week	Plant part	N	K	Ca	Mg	Ratio
1	Forage	1.28	1.36	0.289	0.207	1.11
	Crown	1.27	1.60	0.141	0.175	1.91
	(LSD)	(0.11)	(0.14)	(0.024)	(0.019)	(0.45)
2	Forage	1.45	1.56	0.228	0.181	1.64
	Crown	1.26	1.85	0.193	0.167	2.14
	(LSD)	(0.61)	(0.12)	(0.186)	(0.062)	(1.03)
3	Forage	1.52	1.59	0.328	0.217	1.19
	Crown	1.27	2.28	0.158	0.196	2.50
	(LSD)	(0.37)	(0.23)	(0.015)	(0.013)	(0.15)
4	Forage	1.65	1.51	0.354	0.203	1.13
	Crown	1.58	2.35	0.185	0.201	2.33
	(LSD)	(0.42)	(0.24)	(0.032)	(0.021)	(0.22)
5	Forage	1.86	2.20	0.360	0.194	1.66
	Crown	1.47	2.93	0.252	0.205	2.54
	(LSD)	(0.11)	(0.30)	(0.081)	(0.005)	(0.32)
6	Forage	1.62	1.93	0.386	0.198	1.39
	Crown	1.05	2.62	0.258	0.212	2.28
	(LSD)	(0.46)	(0.19)	(0.215)	(0.032)	(0.48)
7	Forage	1.74	2.40	0.383	0.202	1.72
	Crown	1.00	2.78	0.273	0.214	2.31
	(LSD)	(0.24)	(0.37)	(0.125)	(0.031)	(0.57)
8	Forage	1.81	2.87	0.402	0.244	1.83
	Crown	0.96	2.49	0.306	0.257	1.76
	(LSD)	(0.58)	(0.19)	(0.035)	(0.017	(0.07)
9	Forage	1.49	2.87	0.316	0.183	2.35
	Crown	0.75	2.22	0.201	0.222	2.03
	(LSD)	(0.10)	(0.14)	(0.094)	(0.048)	(0.69)

P = .05

In the fertilized fescue, differences between the N content of the forage and crowns were found in weeks 1, 3-6 and 9 (see Table 17). In weeks 1 and 9 forage N was greater than crown N. Crown K was higher in weeks 2-5 and forage K was higher in weeks 8 and 9. Calcium differences were found in weeks 1, 3-5, 8 and 9. The forage always had the higher Ca content. The Ca results are the same as found for the unfertilized fescue. Magnesium in the crowns was greater in weeks 1, 3 and 5, and greater in the forage in weeks 8 and 9. Differences in the milliequivalent ratio occurred in weeks 1, 3-5 and 8. Only in week 8 was the milliequivalent ratio higher in the forage than in the crowns.

As a rule when comparing the unfertilized and fertilized forage to crown results, in weeks 8 and 9 when differences occurred between the forage and crowns regardless of the element or indice the forage always had the greater value. This suggests that beginning in week 8, in this particular year, plant growth began changing and nutrients were translocated out of the crowns to the forage to meet changing nutrient needs. The K results from both treatments suggest that the crown may serve as a sink for K until there is a change in fescue growth and the K needs of the forage increase. When this occurs K is translocated out of the crown to the forage. When differences occurred in the Ca content of the forage and the crowns the forage always had the higher Ca content regardless of treatment. These differences occurred in the same weeks in both treatments which may mean that Ca concentration in the plant is a function of plant development or is influenced by external factors. The magnitude of the differences were erratic. It seems that the plant must either maintain a balance between the Ca in the crowns and the Ca in the forage or have a greater amount

Table 17. Comparison of forage and crowns from N fertilized 1979 tall fescue.

Week	Plant part	N	K	Ca	Mg	Ratio
1	Forage	1.53	1.46	0.278	0.189	1.27
	Crown	1.23	1.58	0.131	0.157	2.15
	(LSD)	(0.11)	(0.14)	(0.024)	(0.019)	(0.45)
2	Forage	2.08	1.60	0.314	0.212	1.24
	Crown	2.10	1.84	0.144	0.169	2.23
	(LSD)	(0.61)	(0.12)	(0.186)	(0.062)	(1.03)
3	Forage	2.84	1.78	0.319	0.233	1.39
	Crown	3.53	2.38	0.162	0.212	2.30
	(LSD)	(0.37)	(0.23)	(0.015)	(0.013)	(0.15)
4	Forage	2.42	1.36	0.364	0.210	0.99
	Crown	3.57	2.61	0.193	0.229	2.35
	(LSD)	(0.41)	(0.24)	(0.032)	(0.021)	(0.22)
5	Forage	3.41	2.22	0.380	0.254	1.42
	Crown	4.72	3.24	0.241	0.285	2.34
	(LSD)	(0.11)	(0.30)	(0.081)	(0.005)	(0.32)
6	Forage	3.60	2.72	0.376	0.250	1.77
	Crown	4.37	3.40	0.374	0.281	2.14
	(LSD)	(0.46)	(0.19)	(0.215)	(0.032)	(0.48)
7	Forage	3.74	3.69	0.312	0.240	2.70
	Crown	3.90	3.54	0.305	0.253	2.57
	(LSD)	(0.24)	(0.37)	(0.125)	(0.031)	(0.57)
8	Forage	3.60	3.89	0.351	0.253	2.60
	Crown	3.67	3.47	0.266	0.270	2.50
	(LSD)	(0.58)	(0.19)	(0.035)	(0.017)	(0.07)
9	Forage	2.71	3.81	0.346	0.248	2.61
	Crown	2.36	2.94	0.180	0.196	2.99
	(LSD)	(0.10)	(0.14)	(0.094)	(0.048)	(0.69)

P = .05

of Ca in the forage. Since Ca is not rapidly transported within a plant this concentration difference may serve as a ready reserve of Ca for plant growth. In general, the crowns will have the larger milliequivalent ratios when differences occur (the exception is week 8). In some weeks the crowns were above the 2.2 critical level, but the forage was not. This result is probably due to Ca generally being higher in the forage and K being higher in the crowns.

Plant Results 1980

The effect of N fertilization on tall fescue forage concentrations of N, K, Ca, Mg and the milliequivalent ratio are found in Tables 18-22 for the 1980 tall fescue study. Similar tables for fescue crowns are Tables 23-25. The results are presented graphically in Figures 3 and 4 for the forage and crowns, respectively. Plots of maximum and minimum soil temperatures at 5 and 10 cm and percent soil water are included in these figures.

Fescue Forage

Nitrogen fertilization increased the mean forage N content over all weeks and within each week (see Table 18 and Figure 3). In weeks 3-5 the fertilized forage had N concentrations above 4% which makes the forage tetany hazardous, however, the mean over all weeks for the fertilized forage was below 4%. The unfertilized fescue had a percent N content high value of 2.45 in week 5 and a low value of 1.07 in week 9. The fertilized fescue had a percent N content high value of 4.63 in week 3 and a low value of 1.83 in week 9. These results show that the N content of fescue forage changes with time and can be within a broad range of values.

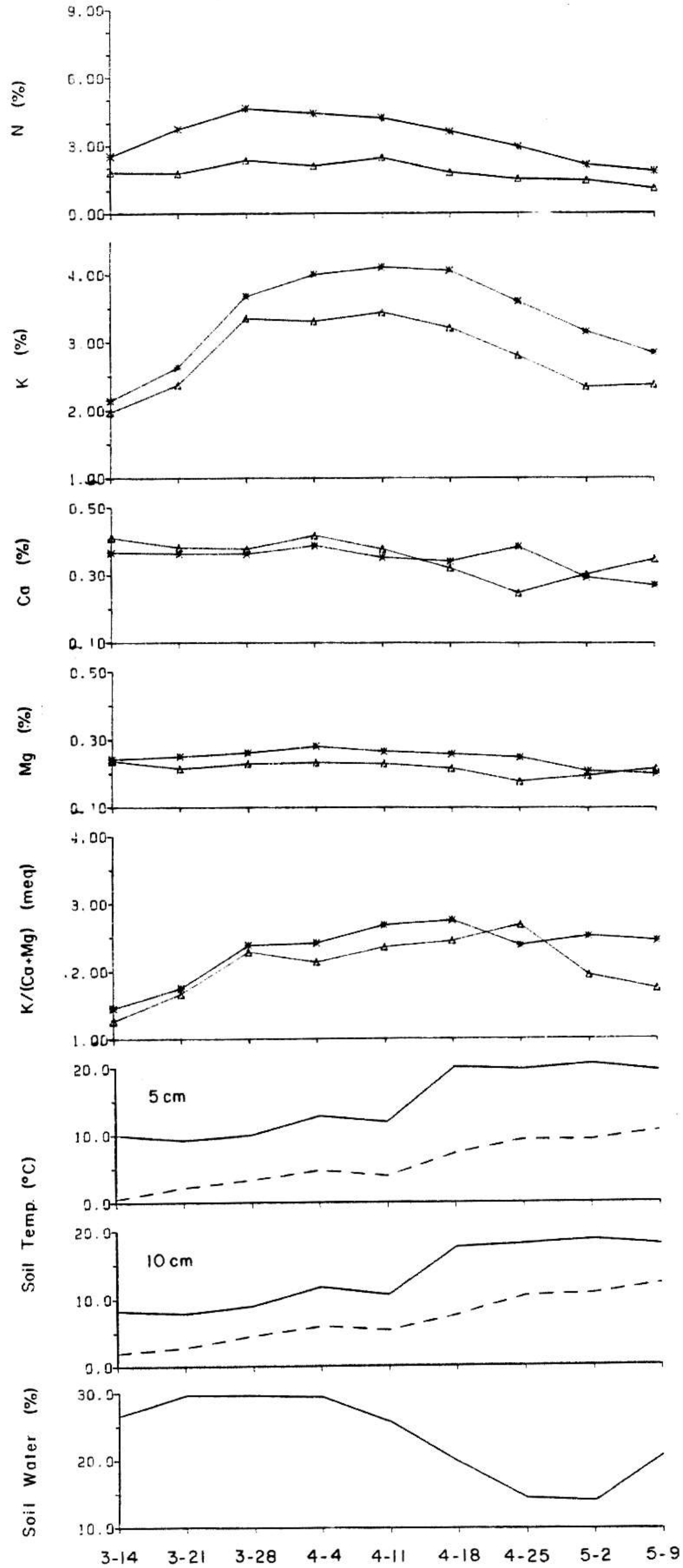
Nitrogen fertilization, as in 1979, increased mean forage K

Table 18. The effect of N fertilization on percent N in tall fescue forage at nine sampling dates (1980).

	Date (Week)									
Treatment	3-14 (1)	3-21 (2)	3-28 (3)	4-1 (4)	4-11 (5)	4-18 (6)	4-25 (7)	5-2 (8)	5-9 (9)	Means*
0 kg N/ha	1.81	1.75	2.34	2.08	2.45	1.79	1.50	1.43	1.07	1.77b
135 kg N/ha	2.52	3.73	4.63	4.40	4.20	3.60	2.93	2.12	1.83	3.33a
Means*	2.17c	2.74a	3.49a	3.24a	3.32a	2.70b	2.21c	1.63d	1.45d	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5% between weeks with the same treatment, 0.61; between treatments within the same week, 0.26.

Figure 3. Seasonal trends in chemical composition of tall fescue forage in 1980, as affected by 0 (Δ—Δ), or 135 (✱—✱) kg N/ha applied as NH_4NO_3. Soil water and maximum (——) and minimum (---) soil temperature at 5 and 10 cm are also shown.


9.00
6.00
3.00
0.00
N (%)
4.00
3.00
2.00
1.00
K (%)
0.50
0.30
0.10
Ca (%)
0.50
0.30
0.10
Mg (%)
4.00
3.00
2.00
1.00
K/(Ca+Mg) (meq)
20.0
10.0
0.0
5 cm
20.0
10.0
0.0
10 cm
Soil Temp. (°C)
30.0
20.0
10.0
Soil Water (%)
3-14
3-21
3-28
4-4
4-11
4-18
4-25
5-2
5-9

over all weeks and within weeks 4-9 (see Table 19). The mean foage K over all weeks for the fertilized fescue was 3.36% which is above the critical 3% value. The unfertilized fescue had forage K concentrations above 3% in weeks 3-6 and the fertilized fescue in weeks 3-8. With both treatments forage K increased with sampling date until week 5 and decreased thereafter (see Figure 3). The fertilized forage K increased sharply from week 1 to week 5 with a value of 2.14% in week 1 to a value of 4.11% in week 5.

There were no differences due to N fertilization in the mean Ca content over all weeks (see Table 20). Weeks 7 and 9 showed the only within week Ca differences due to treatment. Calcium was greater in the fertilized forage in week 7 and greater in the unfertilized forage in week 9. No explanation is offered for this anomalous result. The Ca level in the forage changed little with sampling date (see Figure 3).

There was not a significant difference in mean forage Mg content over all weeks (see Table 21). Forage Mg means from both treatments over all weeks were above the critical Mg value of o.2%. Weeks 4, 6 and 7 showed differences due to treatment. In each, the fertilized forage had the higher Mg content. In every week the fertilized forage Mg content was greater than the critical value except in week 9. The unfertilized forage was above 0.2% Mg in every week except weeks 7 and 8.

Nitrogen fertilization increased the mean forage milliequivalent ratio over all weeks from 2.05 to 2.31, which is above the critical value of 2.2 (see Table 22). Weeks 5, 8 and 9 show differences due to to treatment. In each, the fertilized forage had the largest ratio. In weeks 3, 5, 6 and 7 both the fertilized and unfertilized forage had milliequivalent ratios above 2.2. In

Table 19. The effect of N fertilization on percent K in tall fescue forage at nine sampling dates (1980).

	Date (Week)									
Treatment	3-14 (1)	3-21 (2)	3-28 (3)	4-4 (4)	4-11 (5)	4-18 (6)	4-25 (7)	5-2 (8)	5-9 (9)	Means*
0 kg N/ha	1.97	2.37	3.35	3.31	3.44	3.21	2.80	2.34	2.37	2.80b
135 kg N/ha	2.14	2.63	3.68	4.00	4.11	4.06	3.60	3.15	2.84	3.36a
Means*	2.06f	2.50e	3.52b	3.65ab	3.78a	3.64ab	3.20c	2.75d	2.61de	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5%: between weeks with the same treatment, 0.29; between treatments within the same week, 0.35.

Table 20. The effect of N fertilization on percent Ca in tall fescue forage at nine sampling dates (1980).

	Date (Week)									
	3-14	3-21	3-28	4-4	4-11	4-18	4-25	5-2	5-9	
Treatment	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Means*
0 kg N/ha	0.410	0.381	0.377	0.417	0.377	0.321	0.248	0.303	0.348	0.353a
135 kg N/ha	0.366	0.362	0.362	0.387	0.352	0.341	0.385	0.294	0.271	0.347a
Means*	0.388a	0.372ab	0.369ab	0.402a	0.364ab	0.331bc	0.317c	0.299c	0.309c	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5%: between weeks with the same treatment, 0.064; between treatments within the same week, 0.069.

Table 21. The effect of N fertilization on percent Mg in tall fescue forage at nine sampling dates (1980).

	Date (Week)									
	3-14	3-21	3-28	4-4	4-11	4-18	4-25	5-2	5-9	
Treatment	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Means*
0 kg N/ha	0.237	0.214	0.229	0.232	0.229	0.215	0.177	0.194	0.215	0.216a
135 kg N/ha	0.242	0.250	0.261	0.280	0.265	0.257	0.248	0.207	0.200	0.246a
Means*	0.239ab	0.232b	0.245ab	0.256a	0.247ab	0.236b	0.212c	0.201c	0.207c	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5%: between weeks wiht same treatment, 0.024; between treatments within the same week, 0.040.

Table 22. The effect of N fertilization on the millequivalent ratio in tall fescue forage at nine sampling dates (1980).

	Date (Week)									
	3-14	3-21	3-28	4-4	4-11	4-18	4-25	5-2	5-9	
Treatment	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Means*
0 kg N/ha	1.26	1.66	2.28	2.13	2.35	2.44	2.67	1.93	1.73	2.05b
153 kg N/ha	1.45	1.75	2.38	2.41	2.67	2.74	2.37	2.50	2.43	2.31a
Means*	1.36f	1.71e	2.33bc	2.27cd	2.51ab	2.59a	2.52ab	2.25cd	2.08d	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5%: between weeks with the same treatment, 0.32; between treatments within the same week, 0.31.

addition, the fertilized forage milliequivalent ratio was above 2.2 in weeks 4, 8 and 9. The high milliequivalent ratio in week 4 was due to high forage K, in weeks 8 and 9 it was due to either low forage Ca or low forage Mg. The forage milliequivalent ratios from both treatments had an increasing trend for the first six sampling dates but were somewhat erratic in the sampling dates that followed (see Figure 3).

Fescue Crowns

Nitrogen fertilization greatly increased the mean N concentration in the crowns over all weeks (see Table 23). The unfertilized crowns mean was 1.51% and the fertilized crowns mean was 4.33%, for a difference of 2.82% N. Weeks 1-7 showed differences in crown N concentrations between treatments with the fertilized crowns always having the greater value. The highest fertilized crown N concentration was 6.64% in week 3. Weeks 1-5 had N values above 4% in the fertilized crowns. This means that there is a sufficient N pool to potentially create a tetany prone forage due to N in those weeks. The large difference in N concentrations between treatments is shown clearly in Figure 4.

Mean crown K over all weeks was increased due to N fertilization with the mean for the unfertilized plots being 3.3% K. Within weeks 3-9 N fertilization increased crown K compared to no fertilization. Fertilized crowns had K values in excess of 3% in weeks 1-6. Unfertilized crowns had K above 3% in weeks 2-5 (see Table 24). The plots of the fertilized and unfertilized crown K content run almost parallel with each other over sampling dates, and the differences in crown K content between the two treatments is clear (see Figure 4). As with the crown N content, the crown K content was high enough at some sampling dates to potentially

Table 23. The effect of N fertilization on percent N in tall fescue crowns at nine sampling dates (1980).

	Date (Week)									
	3-14	3-21	3-28	4-4	4-11	4-18	4-25	5-2	5-9	
Treatment	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Means*
0 kg N/ha	2.81	2.04	2.12	1.75	2.25	1.08	0.57	0.50	0.50	1.51b
135 kg N/ha	4.26	6.07	6.64	6.59	5.78	3.75	2.75	1.68	1.44	4.33a
Means*	3.53a	4.05a	4.38a	4.17a	4.02a	2.41b	1.66bc	1.09c	0.97c	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5%: between weeks with the same treatment, 1.10; between treatments within the same week, 1.28.

Figure 4. Seasonal trends in chemical composition of tall fescue crowns in 1980, as affected by 0 (Δ—Δ), or 135 (✳—✳) kg N/ha applied as NH_4NO_3. Soil water and maximum (——) and mimimum (---) soil temperature at 5 and 10 cm are also shown.

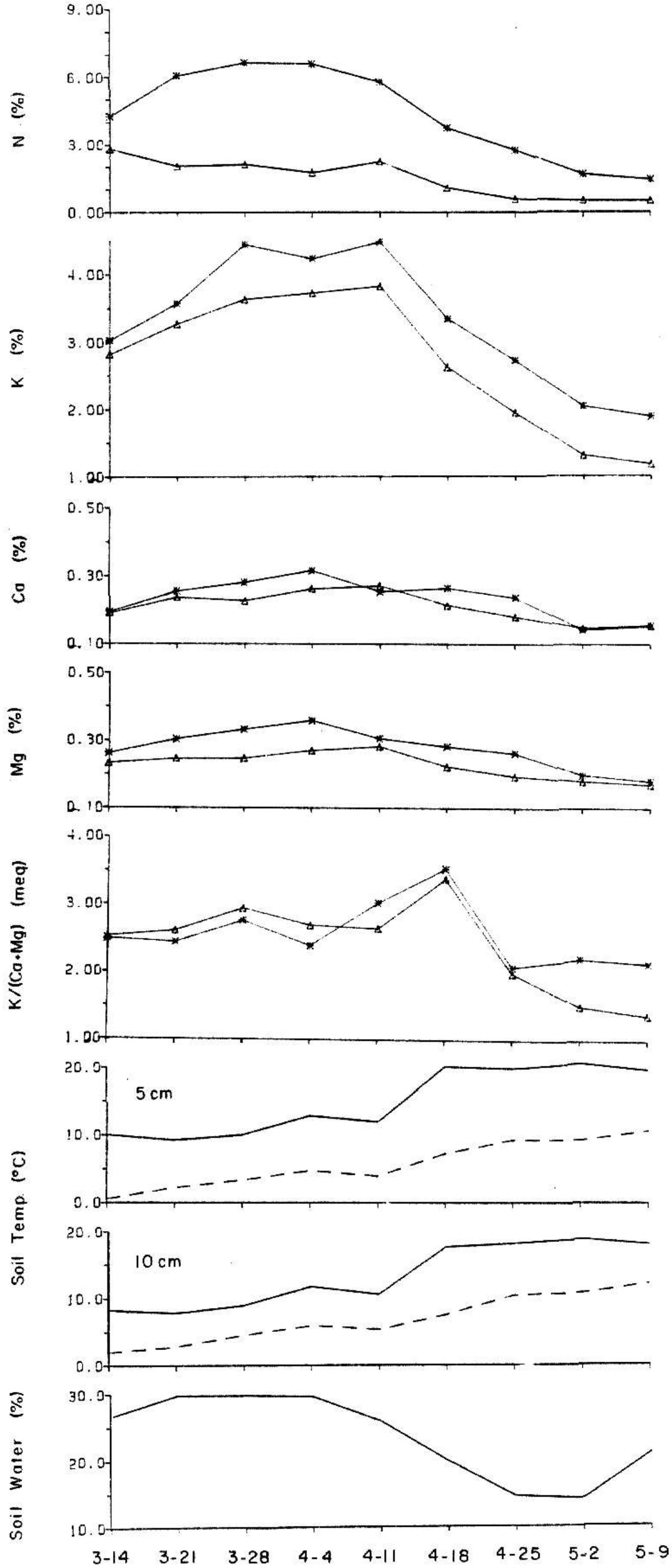

N (%)
9.00
6.00
3.00
0.00
K (%)
4.00
3.00
2.00
1.00
Ca (%)
0.50
0.30
0.10
Mg (%)
0.50
0.30
0.10
K/(Ca+Mg) (meq)
4.00
3.00
2.00
1.00
Soil Temp. (°C)
5 cm
20.0
10.0
0.0
10 cm
20.0
10.0
0.0
Soil Water (%)
30.0
20.0
10.0
3-14
3-21
3-28
4-4
4-11
4-18
4-25
5-2
5-9

Table 24. The effect of N fertilization on percent K in tall fescue crowns at nine sampling dates (1980).

	Date (Week)									
	3-14	3-21	3-28	4-4	4-11	4-18	4-25	5-2	5-9	
Treatment	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Means*
0 kg N/ha	2.82	3.27	3.63	3.72	3.82	2.62	1.94	1.30	1.17	2.70b
135 kg N/ha	3.03	3.57	4.44	4.23	4.48	3.34	2.72	2.03	1.88	3.30a
Means*	2.93c	3.42b	4.04a	3.97a	4.15a	2.98c	2.33d	1.67e	1.53e	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5%: between weeks with the same treatment, 0.30; between treatments within the same week, 0.41.

create a tetany prone forage with respect to K content.

Nitrogen fertilization increased mean crown Ca over all weeks, but only by 0.024% Ca (see Table 25). Differences between treatments were found in weeks 3, 4, 6 and 7. In each case the fertilized crowns were higher in Ca content. The unfertilized crown Ca went from an initial value of 0.191% in week 1 to a high value of 0.272% in week 5, and to a final value of 0.156% in week 9 (see Figure 4). The fertilized crown Ca went from an initial value of 0.195% in week 1 to a high value of 0.316% in week 4, and to a final value of 0.155% in week 9 (see Figure 4).

Mean crown Mg content over all weeks was increased by N fertilization but both means over all weeks were above 0.2% (see Table 26). Within week differences occurred in weeks 3, 4, 6 and 7. In each the fertilized crowns were higher in Mg. The fertilized crowns had Mg above 0.2% in weeks 1-7. The same was true for the unfertilized crowns in weeks 1-6. The greatest Mg content was in the fertilized crowns of week 4 with 0.358% Mg. This level of crown Mg is a good potential source of Mg for the subsequent forage produced. Crown Mg increased slightly for the first four or five sampling dates and decreased slightly after that (see Figure 4).

The crown milliequivalent ratio means over all weeks were not significantly different, but both means well exceeded 2.2 (see Table 27). There were no differences in the crown milliequivalent ratios between treatments within weeks. In weeks 1-6 the crown milliequivalent ratios were above 2.2 for both treatments. Week 6 had the highest milliequivalent ratios for both treatments with values for the unfertilized crowns and the fertilized crowns of 3.39 and 3.54, respectively.

Table 25. The effect of N fertilization on percent Ca in tall fescue crowns at nine sampling dates (1980).

	Date (Week)									
Treatment	3-14 (1)	3-21 (2)	3-28 (3)	4-4 (4)	4-11 (5)	4-18 (6)	4-25 (7)	5-2 (8)	5-9 (9)	Means*
0 kg N/ha	0.191	0.237	0.227	0.263	0.272	0.215	0.182	0.148	0.156	0.210b
135 kg N/ha	0.195	0.255	0.281	0.316	0.255	0.266	0.238	0.143	0.155	0.234a
Means*	0.193d	0.246bc	0.254bc	0.289a	0.263b	0.240c	0.210d	0.146e	0.155e	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5% : between weeks with the same treatment, 0.025; between treatments within the same week, 0.030.

Table 26. The effect of N fertilization on percent Mg in tall fescue crowns at nine sampling dates (1980).

	Date (Week)									
	3-14	3-21	3-28	4-4	4-11	4-18	4-25	5-2	5-9	
Treatment	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Means*
0 kg N/ha	0.232	0.246	0.247	0.270	0.283	0.223	0.194	0.180	0.170	0.227b
135 kg N/ha	0.262	0.303	0.332	0.358	0.306	0.283	0.263	0.198	0.180	0.276a
Means*	0.247cd	0.275b	0.289b	0.314a	0.294b	0.253c	0.228d	0.189e	0.175e	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5%: between weeks with the same treatment; 0.028, between treatments within the same week, 0.032.

Table 27. The effect of N fertilization on the milliequivalent ratio in tall fescue crowns at nine sampling dates (1980).

	Date (Week)									
	3-14	3-21	3-28	4-4	4-11	4-18	4-25	5-2	5-9	
Treatment	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Means*
0 kg N/ha	2.52	2.61	2.94	2.69	2.65	3.39	1.99	1.50	1.37	2.41a
135 kg N/ha	2.49	2.44	2.76	2.39	3.03	3.54	2.08	2,21	2.14	2.57a
Means*	2.51bc	2.53bc	2.85ab	2.54bc	2.84ab	3.47a	2.04bc	1.86c	1.76c	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5%: between weeks with the same treatment, 1.07; between treatments within the same week, 1.03.

Correlations

Linear correlation coefficients for fescue forage and crown nutrient content and soil temperature and moisture are listed in Tables 28 and 29, respectively. Only correlation coefficients with significance probabilities of 95% or higher are presented.

Forage N content for both the 0 and 135 kg N/ha treatments were positively correlated to forage K, Ca and Mg. The fertilized forage N had a stronger relationship to forage Ca and Mg. Forage N for both treatments was positively correlated to soil water, and negatively correlated to soil water potential and maximum and minimum soil temperature at 5 and 10 cm. Nitrogen fertilization reduced the strength of these negative relationships.

Beside its fairly strong relationship to forage N and the milliequivalent ratio, forage potassium for the fertilized treatment was positively correlated with forage Mg. Unlike 1979, forage potassium was not significantly related to any measured environmental factors.

Forage Ca was strongly postively related to forage Mg. The unfertilized forage Ca was also positively related to soil water and strongly negatively related to soil water potential and maximum and minimum soil temperature at 5 and 10 cm. The fertilized forage Ca was only weakly negatively correlated to minimum soil temperature at 5 and 10 cm.

Forage Mg for both treatments was negatively related to maximum and minimum soil temperature at 5 and 10 cm. The strongest relationships to temperature were for the unfertilized forage. Forage Mg was positively related to soil temperature, with the unfertilized forage having the stronger relationship. Unfertilized forage Mg was the only variable to have a stronger relationship

Table 28. Linear correlation coefficients* among measured plant and environmental factors for tall fescue forage (1980).

	Treatment (kg N/ha)	Forage N	Forage K	Forage Ca	Forage Mg	Forage millieq. ratio	Soil water	Soil water potential	Soil Temp. Max. 5 cm	Soil Temp. Min. 5 cm	Soil Temp. Max. 10 cm	Soil Temp. Min. 10 cm
Forage N	0	-	.65	.42	.58	ns	.64	-.53	-.65	-.65	-.65	-.65
	135	-	.60	.52	.81	ns	.62	-.46	-.55	-.50	-.54	-.53
Forage K	0	.65	-	ns	ns	.77	ns	ns	ns	ns	ns	ns
	135	.60	-	ns	.51	.76	ns	ns	ns	ns	ns	ns
Forage Ca	0	.42	ns	-	.85	-.57	.82	-.74	-.74	-.69	-.75	-.67
	135	.52	ns	-	.80	-.44	ns	ns	ns	-.42	ns	-.43
Forage Mg	0	.58	ns	.85	-	-.42	.76	-.79	-.65	-.65	-.66	-.63
	135	.81	.51	.80	-	ns	.48	ns	-.45	-.48	-.45	-.51
Forage Milliequivalent Ratio	0	ns	.77	-.57	-.42	-	ns	ns	ns	ns	.39	ns
	135	ns	.76	-.44	ns	-	-.38	ns	.55	.59	.56	.57

*Entry into the table required a significance probabality of 0.05 or less.

to soil water potential than to soil water.

The forage milliequivalent ratio for both treatments was not significantly related to forage N. The fertilized forage milliequivalent ratio was slightly related negatively to soil water. The unfertilized forage milliequivalent ratio was only slightly positively related to maximum soil temperature at 10 cm, whereas, the fertilized forage ratio had a positive relationship to maximum and minimum soil temperature at 5 and 10 cm. This relationship suggests that there is an interaction between N fertilization and temperature that results in a positive relationship between soil temperature and the forage milliequivalent ratio.

The fescue crowns had many significant correlations only some of which will be discussed here (see Table 29). Crown N, K, Ca and Mg for both treatments had negative relationships to maximum and minimum soil temperatures at 5 and 10 cm with crown N and K having the strongest relationships. With respect to the relationship with soil temperature, crown N, K, Ca and Mg for the unfertilized crowns had the strongest relationship except for crown N with maximum soil temperature at 5 cm. At 10 cm only the unfertilized crown milliequivalent ratios were significantly related to soil temperature, and then negatively and weakly.

Crown N, K, Ca and Mg for both treatments were positively related to soil water and negatively to soil water potential. Soil water had the higher correlation coefficients. The crown milliequivalent ratio was only weakly related to soil water (positively) and soil water potential (negatively) for the fertilized crowns.

The outstanding differences between the crown and forage correlations are that forage K for both treatments was not significantly related to soil water, soil water potential or soil temp-

Table 29. Linear correlation coefficients* among measured plant and environmental factors for tall fescue crowns (1980).

	Treatment (kg N/ ha)	Crown N	Crown K	Crown Ca	Crown Mg	Crown millieq. ratio	Soil water	Soil water potential	Soil Temp. Max. 5 cm	Soil Temp. Min. 5 cm	Soil Temp. Max. 10 cm	Soil Temp. Min. 10 cm
Crown N	0	-	.73	.52	.74	.44	.70	-.57	-.79	-.83	-.80	-.81
	135	-	.91	.82	.91	ns	.84	-.61	-.81	-.76	-.80	-.77
Crown K	0	.73	-	.91	.96	.61	.82	-.64	-.80	-.79	-.80	-.80
	135	.91	-	.84	.89	ns	.73	-.57	-.70	-.66	-.69	-.68
Crown Ca	0	.52	.91	-	.90	.57	.71	-.60	-.64	-.60	-.63	-.62
	135	.82	.84	-	.93	ns	.58	-.46	-.46	-.44	-.45	-.48
Crown Mg	0	.74	.96	.90	-	.55	.75	-.59	-.73	-.73	-.73	-.74
	135	.91	.89	.93	-	ns	.68	-.48	-.63	-.62	-.63	-.65
Crown Milliequivalent Ratio	0	.44	.61	.57	.55	-	.44	-.46	-.37	-.48	-.40	-.53
	135	ns	ns	ns	ns	-	ns	ns	ns	ns	ns	ns

*Entry into the table required a significance probability of 0.05 or less.

erature, but crown K was. The crown N, K, Ca and Mg appear to have a stronger negative relationship to soil temperature than for the forage. This implies that as soil temperature decreases, higher concentrations of N, K, Ca and Mg should be found in the plants and that these concentrations should be higher in the crowns than in the forage. In nitrogen fertilized forage the milliequivalent ratio will increase as soil temperature increases.

Comparison of Forage and Crowns

The results of comparison of forage to crowns with respect to nutrient content for the unfertilized fescue and the fertilized fescue are in Tables 30 and 31, respectively.

The unfertilized fescue had differences between the forage and crown N content in weeks 4 and 6-9 (see Table 30). In each week the forage had the higher N content. The largest significant difference was in week 7 (0.93% N). Crown K in the unfertilized fescue in weeks 1-5 was greater than the forage K, and in weeks 6-9 the forage K was greater. The greatest difference was 1.20% K in week 9. Differences in Ca contents occurred in weeks 1-6, 8 and 9. In each difference, as in 1979, the forage Ca content was greater than the crowns. Magnesium differences were found in weeks 2, 4, 5 and 9. Only in week 9 was the forage Mg greater than the crown Mg. The milliequivalent ratio had differences in each week except for weeks 6 and 9. In weeks 1-5 the crown had the highest ratio and in weeks 7 and 8 the forage had the highest ratio. It is interesting to note that when differences occurred, regardless of the element or indice, that from week 6 on, the forage always had the largest value.

The fertilized fescue crown N level was higher than the forage N in weeks 1-5 (see Table 31). Only in week 9 was the

Table 30. Comparison of forage and crowns from unfertilized 1980 tall fescue.

Week	Plant part	N	K	Ca	Mg	Ratio
1	Forage	1.81	1.97	0.410	0.237	1.26
	Crown	2.81	2.82	0.191	0.232	2.52
	(LSD)	(1.45)	(0.31)	(0.040)	(0.021)	(0.19)
2	Forage	1.75	2.37	0.381	0.214	1.66
	Crown	2.04	3.27	0.237	0.246	2.61
	(LSD)	(0.39)	(0.21)	(0.032)	(0.023)	(0.32)
3	Forage	2.34	3.35	0.377	0.229	2.28
	Crown	2.12	3.63	0.227	0.247	2.94
	(LSD)	(0.45)	(0.19)	(0.051)	(0.031)	(0.23)
4	Forage	2.08	3.31	0.417	0.232	2.13
	Crown	1.75	3.72	0.263	0.270	2.69
	(LSD)	(0.29)	(0.24)	(0.014)	(0.019)	(0.08)
5	Forage	2.45	3.44	0.377	0.229	2.35
	Crown	2.25	3.82	0.272	0.283	2.65
	(LSD)	(0.56)	(0.23)	(0.018)	(0.030)	(0.23)
6	Forage	1.79	3.21	0.321	0.215	2.44
	Crown	1.08	2.62	0.215	0.223	3.39
	(LSD)	(0.37)	(0.12)	(0.059)	(0.032)	(2.32)
7	Forage	1.50	2.80	0.248	0.177	2.67
	Crown	0.57	1.94	0.182	0.194	1.99
	(LSD)	(0.27)	(0.24)	(0.082)	(0.036)	(0.39)
8	Forage	1.43	2.34	0.303	0.194	1.93
	Crown	0.50	1.30	0.148	0.180	1.50
	(LSD)	(0.51)	(0.26)	(0.084)	(0.017)	(0.24)
9	Forage	1.07	2.37	0.348	0.215	1.73
	Crown	0.50	1.17	0.156	0.170	1.37
	(LSD)	(0.21)	(0.33)	(0.034)	(0.009)	(0.39)

P = .05

Table 31. Comparison of forage and crowns from N fertilized 1980 tall fescue.

Week	Plant part	N	K	Ca	Mg	Ratio
1	Forage	2.52	2.14	0.366	0.242	1.45
	Crown	4.26	3.03	0.195	0.262	2.49
	(LSD)	(1.45)	(0.31)	(0.040)	(0.021)	(0.19)
2	Forage	3.73	2.63	0.362	0.250	1.75
	Crown	6.07	3.57	0.255	0.303	2.44
	(LSD)	(0.39)	(0.21)	(0.032)	(0.023)	(0.32)
3	Forage	4.63	3.68	0.362	0.261	2.38
	Crown	6.64	4.44	0.281	0.332	2.76
	(LSD)	(0.45)	(0.190)	(0.051)	(0.031)	(0.23)
4	Forage	4.40	4.00	0.387	0.280	2.41
	Crown	6.59	4.23	0.316	0.358	2.39
	(LSD)	(0.29)	(0.24)	(0.014)	(0.019)	(0.08)
5	Forage	4.20	4.11	0.352	0.265	2.67
	Crown	5.78	4.48	0.255	0.306	3.03
	(LSD)	(0.56)	(0.23)	(0.018)	(0.032)	(0.23)
6	Forage	3.60	4.06	0.341	0.257	2.74
	Crown	3.75	3.34	0.266	0.283	3.54
	(LSD)	(0.37)	(0.12)	(0.059)	(0.032)	(2.32)
7	Forage	2.93	3.60	0.385	0.248	2.37
	Crown	2.75	2.72	0.238	0.263	2.08
	(LSD)	(0.27)	(0.24)	(0.082)	(0.036)	(0.39)
8	Forage	2.12	3.15	0.294	0.207	2.50
	Crown	1.68	2.03	0.143	0.198	2.21
	(LSD)	(0.51)	(0.26)	(0.084)	(0.017)	(0.24)
9	Forage	1.83	2.84	0.271	0.200	2.43
	Crown	1.44	1.88	0.155	0.180	2.14
	(LSD)	(0.21)	(0.33)	(0.034)	(0.009)	(0.39)

P = .05

forage N higher than the crown N. Crown K was higher in weeks 1-3 and 5, and the forage K was higher in weeks 6-9. There were significant differences in Ca content in every week with the forage Ca content higher than the crown Ca content. Differences in Mg content occurred in weeks 2-5 and week 9. The crown Mg value was higher in weeks 2-5 and the forage was higher in week 9. The milliequivalent ratio was higher for the crowns in weeks 1-3 and 5 and the forage milliequivalent ratio was higher in week 8. Again, as in the unfertilized fescue, any differences after week 5 had the forage with the higher value.

TALL FESCUE SUMMARY AND CONCLUSIONS

The effect of N fertilization on tall fescue were marked on forage and crown N and K content. In both years of this study, the mean N and K over all sampling dates were increased by N fertilization compared to no N fertilization. The Ca content of the forage was not affected by N fertilization. In 1979 the crown Ca content was not affect by N fertilization, but the 1980 crowns showed a slight increase in Ca content. Crown Mg was increased due to N fertilization in 1979 and 1980, but forage Mg was increased only in 1979. The milliequivalent ratio of the forage was increased due to N fertilization but the milliequivalent ratio of the crowns was not affected.

Seasonal nutrient fluctuations in fescue were more dramatic for N and K than for Ca and Mg. In 1979, forage K was strongly positively correlated to soil temperature and strongly negatively to soil water. Nitrogen fertilization intensified this effect. In 1980, forage K was not significantly related to soil temperature or soil water. It is not clear why this difference occurred. It may be due to the interaction of rapidily increasing soil temperature with rapidly decreasing soil water. Generally, the milliequivalent ratios increased with increasing soil temperatures and N fertilization intensified this effect. The crowns usually had higher milliequivalent ratios than the forage.

In comparing the crown chemical composition to the forage chemical composition it was found that the crowns never had a greater concentration of Ca than the forage. This may be due to calcium's low mobility in the plant and the plant's need to have a ready supply of Ca available for the onset of favorable growing conditions. After week 8 in 1979 and after week 6 in 1980, when differences occurred between the forage and crown content of N, K, Ca or Mg or in the milliequivalent ratio, regardless of treatment, the forage had the higher value. This result may signal a change in the stage of plant development.

The soil properties discussed earlier predicted that a forage growing on the Wymore soil should have at least 0.2% Mg. These predictions were correct for the forage Mg means over all weeks for both years and both treatments; however, there were occasions when the forage Mg content dropped below 0.2% for individual weeks. The equation of Turner et al. (76) for estimating forage Mg content from soil chemical properties, for both years predicted forage Mg content too high.

Tables 32 and 33 are summaries of tall fescue forage in 1979 and 1980, respectively, when nutrient content was critical with respcet to one or more of the forage quality indicies (%N, %K, %Mg and milliequivalent ratio) and was considered tetany prone.

In 1979 low Mg and high milliequivalent ratios caused the unfertilized forage to be tetany prone in four of the nine weeks. Low Mg, excessive K and the milliequivalent ratio also caused the fertilized forage to be tetany prone in four of the nine weeks. In 1980 high K, low Mg and high milliequivalent ratios resulted in the unfertilized forage being tetany prone in six of the nine weeks. The fertilized forage was tetany prone in seven of the nine weeks due to high N, K, and milliequivalent ratios.

It is evident from the data presented here that tall fescue forage can undergo broad fluctuations in chemical composition over short time periods which contribute to the sporadic nature of the grass tetany syndrome. Even with the best indicies available without a feeding trial, it is difficult to know whether or

Table 32. Summary of nutrient levels critical with respect to grass tetany indices* for 1979 tall fescue forage.

Sampling		Forage						Milliequivalent Ratio	
		N		K		Mg			
		0-N[¶]	135-N[¶]	0-N	135-N	0-N	135-N	0-N	135-N
Week	Date	-----%-----		-----%-----		-----%-----			
1	3-6	-	-	-	-	-	.189	-	-
2	3-13	-	-	-	-	.181	-	-	-
3	3-20	-	-	-	-	-	-	-	-
4	3-27	-	-	-	-	-	-	-	-
5	4-3	-	-	-	-	.184	-	-	-
6	4-10	-	-	-	-	.198	-	-	-
7	4-17	-	-	-	-	-	-	-	2.70
8	4-24	-	-	-	3.81	-	-	-	2.60
9	5-1	-	-	-	3.89	-	-	2.35	2.61
Mean over weeks		-	-	-	-	-	-	-	-

*Critical grass tetany forage indices: >4% N, >3% K, <0.2% Mg, and Milliequivalent ratios >2.2.

¶kg/ha

Table 33. Summary of nutrient levels critical with respect to grass tetany indices* for 1980 tall fescue forage.

Sampling		Forage N		Forage K		Forage Mg		Milliequivalent Ratio	
		0-N¶	135-N¶	0-N	135-N	0-N	135-N	0-N	135-N
Week	Date	-----%-----		-----%-----		-----%----			
1	3-14	-	-	-	-	-	-	-	-
2	3-21	-	-	-	-	-	-	-	-
3	3-28	-	4.63	3.35	3.68	-	-	2.28	2.38
4	4-4	-	4.40	3.31	4.00	-	-	-	2.41
5	4-11	-	4.20	3.44	4.11	-	-	2.35	2.67
6	4-18	-	-	3.21	4.06	-	-	2.44	2.74
7	4-25	-	-	-	3.60	.177	-	2.67	2.37
8	5-2	-	-	-	3.15	.194	-	-	2.50
9	5-9	-	-	-	-	-	-	-	2.43
Mean over weeks		-	-	-	3.36	-	-	-	2.31

*Critical grass tetany forage indices: >4% N, >3% K, <0.2% Mg, and Milliequivalent ratios >2.2.

¶kg/ha

not ruminants grazing these forages would have suffered from grass tetany. Because grass tetany is caused by low blood serum Mg and with the unfertilized forage in both years being tetany prone due to low Mg at five of the nine sampling dates and the fertilized forage at only one, it would seem reasonable to conclude that N fertilization of tall fescue reduces the potential of grass tetany. However, N fertilization also increased the N and K content of the forage and the milliequivalent ratio. As to which index is best, that is uncertain. Until that is known it is not possible to say that N fertilization increases or decreases the grass tetany potential of tall fescue, but it can be said that N fertilization of tall fescue increases the Mg content of the forage.

WINTER WHEAT RESULTS AND DISCUSSION

Soil and Environment 1979 and 1980

The chemical properties of the Eudora silt loam for the 1979 and 1980 winter wheat studies are shown in Tables 34 and 35, respectively. Exchangeable Al and Mn were not determined in 1979.

Liming of the Eudora soil resulted in increased soil pH, increased soil cation exchange capacity (CEC), and increased exchangeable Ca for 1979 (see Table 34). The stackdust limes soil had the highest pH and Ca values, the unlimed soil had the lowest, and the dolomite limed soil was intermediate. Exchangeable K was not affected by liming. Exchangeable Mg was increased by liming with dolomitic lime, but not affected by stackdust lime.

In 1979 the exchangeable Mg was 8, 9, and 22 percent of the CEC in the unlimed, stackdust limed, and dolomite limed soils, respectively. Only the dolomite limed soil was above the recommended minimum of 15% exchangeable Mg which is the reported level needed to produce forage with greater than 0.2% Mg (8). The soil Mg/K ratios, on a milliequivalent basis, from the three treatments were above 1.2 critical value which is a minimum suggested to prevent K from reducing Mg absorption by the plant. The Ca/Mg ratios, on a milliequivalent basis, of the unlimed and dolomite limed soils were below the recommended maximum value of 5. The stackdust limed soil had a Ca/Mg ratio of 8.67 which well exceeds the index value of 5. Calcium like K, when in high concentration can be competative with Mg for uptake by the plant and can reduce the amount of Mg absorbed by the plant.

The regression model of Turner et al. (76) (Y=0.1433 + 0.6987X, Y=Mg in the plant, X=the ratio index (RI)) was developed for pre-

Table 34. Means* of soil chemical properties for 1979 winter wheat study.

Treatment	pH	CEC	K	Ca	Mg	Mg/CEC	Mg/K	Ca/Mg	RI**
		---------meq/100 g---------							
Check	5.3c	8.1b	0.57a	3.14c	0.73b	0.09b	1.31b	4.30b	0.07b
Stackdust	6.9a	9.8a	0.51a	6.34a	0.74b	0.08b	1.46b	8.67a	0.05c
Dolomite	6.6b	9.4a	0.54a	4.19b	2.05a	0.22a	3.86a	2.05c	0.15a

*Means followed by the same letter in each column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test.

**$RI = \frac{Mg}{(K + Ca + Mg) + pH}$; K,Ca, and Mg on a milliequivalent basis.

dicting forage Mg levels from soil chemical data. For the unlimed, the stackdust limed and the dolomite limed soils it predicts that the forage should contain 0.19, o.18 and 0.25 percent Mg,respectively. Only the dolomite limed soil is expected to supply sufficient Mg to prevent the formation of a tetany prone forage. The unlimed soil is expected to produce a forage with a higher Mg content than the stackdust limed soil based on the prediction of the model.

The soil chemical properties of the 1980 wheat study are shown in Table 35. The results are similar to those found in the 1979 study. Liming increased the pH, CEC and exchangeable Ca. The stackdust limed soil was higher in exchangeable Ca than the dolomite limed soil, and both of these were higher than the unlimed soil. The dolomite limed soil was higher in exchangeable Mg than both the unlimed and the stackdust limed soils. Soil K was not affected by liming. Liming decreased exchangeable Al to a level below the analytical detection limit of the Al test. Exchangeable Mn was also decreased by liming.

Magnesium occupied 8, 6, and 21 percent of the CEC in the unlimed, stackdust limed and dolomite limed soils, respectively. Again, as in 1979, only the dolomite soil was above the recommended 15% Mg saturation of the CEC, consequently the unlimed and the stackdust limed soils may not have sufficient Mg to produce forages with more than 0.2% Mg. Only the stackdust limed soil had a Mg/K ratio, on a milliequivalent basis, below 1.2. It also had the only Ca/Mg ratio, on a milliequivalent basis, greater than 5. This suggests that plants growing in the stackdust limed soil may have trouble absorbing Mg because of the dual competition for absorption by Ca and K, and the resulting forage would probably be low

Table 35. Means* of soil chemical properties for 1980 winter wheat study.

Treatment	pH	CEC	K	Ca	Mg	Al	Mn	Mg/CEC	Mg/K	Ca/Mg	RI**
		---------------meq/100 g---------------									
Check	5.2b	8.1b	0.56a	3.00c	0.66b	0.39	0.06a	0.08b	1.20b	4.56b	0.07b
Stackdust	6.6a	9.8a	0.54a	5.83a	0.66b	0.0	0.01b	0.06b	1.15b	9.39a	0.05c
Dolomite	6.4a	9.4a	0.49a	4.02b	1.99a	0.0	0.02b	0.21a	4.17a	2.02c	0.15a

*Means followed by the same letter in each column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test.

**$RI = \frac{Mg}{(K + Ca + Mg) + pH}$; K,Ca and Mg on a milliequivalent basis.

in Mg. Since the ratio indexes (RI) in 1980 were the same as those in 1979, the equation of Turner et al. (76) predicts the same forage Mg levels for 1980 as in 1979.

With the favorable increase in soil pH due to liming, improved plant performance is expected on the lime soils compared to the unlimed. The pH was increased to a level where nutrient avaliability is optimum for plant uptake. At the same time other elements less desirable are reduced in the soil solution, especially the toxic ions of Al and Mn. The solubility of Al and Mn compounds in the soil is a function of soil pH and because the soil pH did not change from 1979 to 1980, the 1980 Al and Mn values are assumed to representative for 1979. In both 1979 and 1980 liming reduced the level of exchangeable Al and Mn in the soil. This means that the plants growing on the unlimed soil will be growing with the stress of toxic ions being present in the soil solution.

The environmental data for the 1979 and 1980 wheat studies are in Tables 36 and 37, respectively.

In 1979 the soil water showed a decreasing trend with the exception of week 3 when the soil water went from 13.6% in week 2 to 25.9% in week 3. This level is close to the field capacity of the Eudora silt loam soil of 32% (field capcity = 1.5 PSI). Generally the maximum and minimum soil temperature had an increasing trend. Soil temperature increased more rapidily when the soil water content was low. This is probably due to the difference in the heat capacities of water and air.

In 1980 the soil water had a general decreasing trend with with time (see Table 37). In week 9 the soil water level was below the wilting point, which for the Eudora soil is about 5% soil water (wilting point = 218 PSI). Soil temperature increased more

Table 36. Environmental data for 1979 winter wheat study.

Week	Sample date	Percent soil water	Soil-water potential (PSI)	Max. soil temperature 5 cm	Min. soil temperature 5 cm	Max. soil temperature 10 cm	Min. soil temperature 10 cm
				°C			
1	3-16	18.8	2.9	-*	-*	-*	-*
2	3-23	13.6	4.6	9.4	0.8	8.9	2.2
3	3-30	25.9	1.9	13.6	1.9	11.9	3.1
4	4-6	14.9	4.0	19.2	0.3	16.1	1.7
5	4-13	14.1	4.4	15.6	0.6	12.8	2.8
6	4-20	16.0	3.6	19.4	0.8	14.4	3.1
7	4-27	12.6	5.1	24.4	5.0	20.0	6.1
8	5-4	11.1	6.6	23.6	6.9	20.0	9.4
9	5-11	9.4	9.0	21.4	6.7	19.2	9.4

*not available

Table 37. Environmental data for 1980 winter wheat study.

Week	Sample date	Percent soil water	Soil-water potential (PSI)	Max. soil temperature 5 cm	Min. soil temperature 5 cm	Max. soil temperature 10 cm	Min. soil temperature 10 cm
				°C			
1	3-11	22.2	2.4	6.1	-6.5	3.0	-2.8
2	3-18	14.7	4.1	11.5	-0.4	8.5	0.8
3	3-25	20.9	2.5	14.9	0.8	10.6	3.8
4	4-1	19.5	2.8	14.9	2.5	10.6	3.5
5	4-8	13.5	4.6	17.4	2.2	14.5	4.6
6	4-15	11.2	6.2	19.1	2.2	15.6	5.4
7	4-22	8.4	11.1	27.0	7.8	23.5	7.6
8	4-29	6.9	19.0	27.9	10.7	24.1	13.1
9	5-6	4.4	350.0	28.2	12.6	23.5	14.2

rapidly in 1980 than in 1979 and covered a broader range. This was due to drier soil conditions in 1980. Some soil minimum temperatures were below 0C in 1980. When the soil temperature is below 0C the soil water may freeze which could result in a physiological drought in the plants if the air temperature were to increase suddenly. The formation of ice crystals in the plant roots could be harmful to the plants also.

Plant results 1979

The effects of liming on Centurk wheat forage content of K, Ca and Mg and the milliequivalent ratio are shown in Tables 38-41, respectively. Similar results for Centurk crowns are shown in Tables 42-45. These results are also shown graphically in Figures 5 and 6. Maximum and minimum soil temperature and percent soil water are included in each figure. Due to analytical problems plant Al and Mn concentrations will not be reported here.

Wheat Forage

The mean K content of the wheat forage from the unlimed soil was lower than the mean K content of the forages from the limed soils over all weeks (see Table 38). The mean K content in the forage from the dolomite and stackdust limed soils were not different over all weeks. In weeks 1, 6 and 7 there were no between treatment differences in forage K content. In weeks 2, 5 and 9 the forage from the stackdust limed soil was higher in K than the forage from the unlimed soil, but both of these were not significantly different in K content than the forage from the dolomite limed soil. In weeks 3, 4 and 8 the forage from the dolomite and the stackdust limed soils were not significantly different in K content, but both were greater in K content than the forage from the unlimed soil. The forage K trend with time for all treat-

Table 38. The effect of liming on percent K in Centurk wheat forage at nine sampling dates (1979).

	Date (Week)									
	3-16	3-23	3-30	4-6	4-13	4-20	4-27	5-4	5-11	
Treatment	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Means*
Check	1.60	1.71	2.50	3.33	2.70	2.75	4.30	5.02	4.74	3.18b
Stackdust	1.79	2.04	3.06	3.75	3.03	2.96	4.32	5.50	5.11	3.51a
Dolomite	1.84	1.91	2.97	3.64	2.92	2.99	4.37	5.22	4.96	3.42a
Means*	1.74g	1.88f	2.84e	3.57d	2.88e	2.90e	4.33c	5.25a	4.94b	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability, based on Duncan's Multiple Range Test. LSD, 5%: between weeks with the same treatment, 0.23; between treatments within the same week, 0.26.

ments showed an increasing trend except for a slight decrease in weeks 5 and 6 (see Figure 5). These decreases correspond to decreases in maximum soil temperature at 5 and 10 cm.

Liming with stackdust increased the mean Ca content of the forage (see Table 39). Within weeks 7 and 8 there were forage Ca differences between treatments. Within weeks 1-6 and 9 the forage from the stackdust limed soil was greater in Ca content than the forages from the unlimed and the dolomite limed soils. The forage Ca content from the unlimed and dolomite limed soils were not different in those weeks. There is an apparent anomaly here. The dolomite limed soil was higher in Ca than the unlimed soil so the question is why doesn't the forage from the dolomite limed soil have a higher Ca content than the forage from the unlimed soil? The answer probably lies in the function of Ca to prevent injury to the plant from high levels of toxic ions (15,77). In soils like the unlimed soil where Al^{3+} and Mn^{2+} concentrations are high plants need a high concentration of Ca to control the toxicity of these cations(77). The reason that the forage from the stackdust limed soil was higher in Ca was because liming with stackdust increased the available Ca supply relative to other cations for plant uptake.

The mean forage Mg content over all weeks was different for each treatment (see Table 40). The forage from the dolomite limed soil was the highest, the forage from the unlimed soil the lowest, and the forage from the stackdust limed soil intermediate. Only the mean over all weeks for the forage from the dolomite limed soil was above the 0.2% Mg index, but then only slightly above that value. In weeks 1, 2 and 6-9 the forage form the dolomite limed soil was higher in Mg than the forages from the unlimed and

Figure 5. Seasonal trends in chemical composition of Centurk wheat forage in 1979, as affected by no lime (*-*), stackdust (×-×), or dolomite (◇-◇). Soil water and maximum (——) and minimum (---) soil temperature at 5 and 10 cm are also shown.

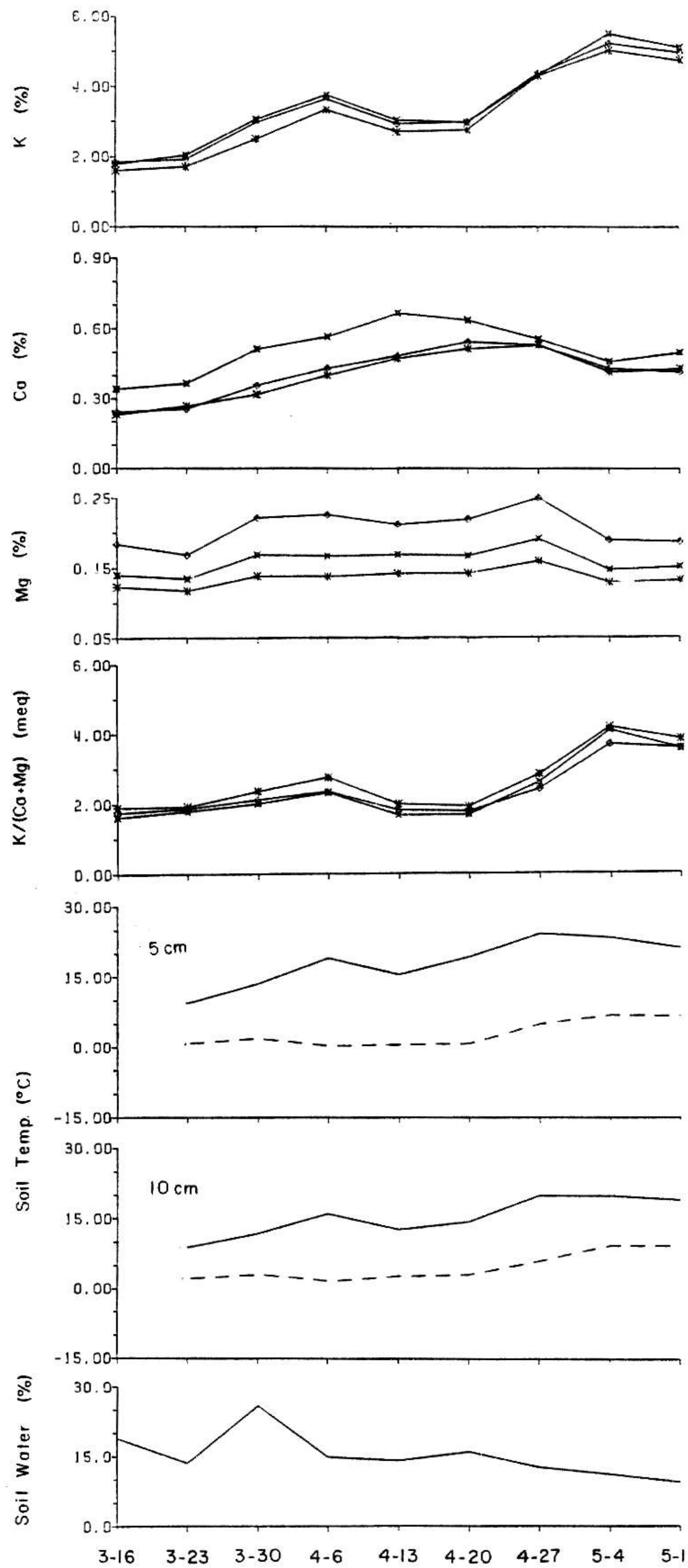

K (%)
Ca (%)
Mg (%)
K/(Ca+Mg) (meq)
5 cm
Soil Temp. (°C)
10 cm
Soil Water (%)
3-16
3-23
3-30
4-6
4-13
4-20
4-27
5-4
5-11

Table 39. The effect of liming on percent Ca in Centurk wheat forage at nine sampling dates (1979).

	Date (Week)									
Treatment	3-16 (1)	3-23 (2)	3-30 (3)	4-6 (4)	4-13 (5)	4-20 (6)	4-27 (7)	5-4 (8)	5-11 (9)	Means*
Check	0.231	0.266	0.317	0.399	0.472	0.513	0.530	0.415	0.428	0.397b
Stackdust	0.341	0.364	0.512	0.565	0.666	0.636	0.556	0.459	0.497	0.511a
Dolomite	0.241	0.253	0.356	0.430	0.484	0.543	0.530	0.429	0.414	0.409b
Means*	0.271d	0.294d	0.395c	0.465b	0.541a	0.564a	0.539a	0.434b	0.446b	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5%: between weeks with the same treatment, 0.063; between treatments within the same week, 0.069.

Table 40. The effect of liming on percent Mg in Centurk wheat forage at nine sampling dates (1979).

	Date (Week)									
Treatment	3-16 (1)	3-23 (2)	3-30 (3)	4-6 (4)	4-13 (5)	4-20 (6)	4-27 (7)	5-4 (8)	5-11 (9)	Means*
Check	0.123	0.117	0.138	0.137	0.141	0.141	0.158	0.128	0.131	0.135c
Stackdust	0.140	0.134	0.168	0.166	0.168	0.166	0.190	0.146	0.150	0.159b
Dolomite	0.184	0.168	0.221	0.225	0.211	0.218	0.248	0.188	0.185	0.205a
Means*	0.149cd	0.139d	0.176b	0.176b	0.173b	0.175b	0.198a	0.154c	0.155c	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5%: between weeks with the same treatment, 0.016; between treatments within the same week, 0.026.

stackdust limed soils but the Mg content of the forages from the unlimed and stackdust limed soils were not different. In weeks 3-5 the Mg content of the forage from the unlimed soil was lowest, the Mg content of the forage from the dolomite limed soil highest, and the Mg content of the forage from the stackdust limed soil intermediate. The Mg content of the forages from the stackdust limed and unlimed soils were never above 0.2% at any of the nine sampling dates. The forage from the dolomite limed soil was above 0.2% Mg in weeks 3-7. These results can be seen clearly in Figure 5.

Over all weeks the forage milliequivalent ratios were not different for the forages from the stackdust and dolomite limed soils, but these were significantly lower than the milliequivalent ratio of the forage from the unlimed soil (see Table 41). The three means over all weeks were above the 2.2 critical value; however, liming did decrease the magnitude of the already high milliequivalent ratios. There were no differences between treatments within weeks 1, 2, 6 and 9. In weeks 3 and 5 the milliequivalent ratios of the forage from the unlimed soil were greater than the milliequivalent ratios of the forage from the stackdust limed soil, but the milliequivalent ratios of the forage from the dolomite limed soil were not different from the others. In week 4 the milliequivalent ratios of the forage from the stackdust and dolomite limed soils were not different but both were less than the milliequivalent ratio of the forage from the unlimed soil. In week 7 the milliequivalent ratio of the forage from the unlimed soil was greater than the milliequivalent ratio of the forage from the dolomite limed soil. The milliequivalent ratio of the forage from the stackdust limed soil was not different from the

Table 41. The effect of liming on the milliequivalent ratio in Centurk wheat forage at nine sampling dates (1979).

	Date (Week)									
Treatment	3-16 (1)	3-23 (2)	3-30 (3)	4-6 (4)	4-13 (5)	4-20 (6)	4-27 (7)	5-4 (8)	5-11 (9)	Means*
Check	1.89	1.92	2.35	2.74	1.97	1.90	2.81	4.15	3.80	2.61a
Stackdust	1.61	1.78	2.00	2.31	1.66	1.67	2.58	4.06	3.53	2.35b
Dolomite	1.74	1.86	2.11	2.33	1.80	1.76	2.39	3.66	3.54	2.35b
Means*	1.75e	1.85e	2.15d	2.46c	1.81e	1.77e	2.59c	3.96a	3.62b	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5%; between weeks with the same treatment, 0.31; between treatments within the same week, 0.30.

from the milliequivalent ratios of the other two forages. In week 8 the milliequivalent ratios of the forages from the unlimed and stackdust limed soils were not different, but both were greater than the milliequivalent ratio of the forage from the dolomite limed soil. An interesting point is the similarity between the milliequivalent ratio and the forage K trends with time (see Figure 5).

Wheat Crowns

The effect of liming on Centurk crown K levels is shown in Table 42. The effect of liming on crown K was similar to the effect of liming on forage K. Over all weeks liming increased the mean K content of the crowns, yet the crowns from the stackdust and dolomite limed soils were not different. All three means over all weeks were above 3% K. Within weeks 2, 5-7 and 9 there were no between treatment differences in K content. In weeks 1, 3 and 4 the K levels in the crowns from the stackdust limed and the dolomite limed soils were not different, but both were greater than the K content of the crowns from the unlimed soil. In week 8 only the crowns from the stackdust limed soil were greater in K than the crowns from the unlimed soil. The crowns from the dolomite limed soil and the unlimed soil were not different in K content in week 8.

There were no differences due to treatment in the mean crown Ca content over all weeks (see Table 43). This result is unlike that for the forage because the forage from the stackdust limed soil was much higher in Ca content than the forages from the other two treatments. There were no differences in crown Ca contents in weeks 1-4, 6, 8 and 9. In week 5 the crowns from the stackdust and dolomite limed soils were not different but they were greater

Table 42. The effect of liming on percent K in Centurk wheat crowns at nine sampling dates (1979).

Treatment	Date (Week) 3-16 (1)	3-23 (2)	3-30 (3)	4-6 (4)	4-13 (5)	4-20 (6)	4-27 (7)	5-4 (8)	5-11 (9)	Means*
Check	1.73	1.86	2.89	3.51	2.95	3.02	4.28	4.88	5.11	3.36b
Stackdust	2.28	2.28	4.04	4.30	3.17	3.24	4.60	5.50	5.51	3.89a
Dolomite	2.28	2.19	3.91	4.40	3.27	3.20	4.54	5.32	5.48	3.84a
Means*	2.10f	2.10f	3.61d	4.07c	3.13e	3.15e	4.47b	5.23a	5.37a	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD,5%: between weeks with the same treatment, 0.32; between treatments within the same week, 0.45.

Table 43. The effect of liming on percent Ca in Centurk wheat crowns at nine sampling dates (1979).

	Date (Week)									
	3-16	3-23	3-30	4-6	4-13	4-20	4-27	5-4	5-11	
Treatment	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Means*
Check	0.106	0.123	0.166	0.177	0.263	0.341	0.522	0.262	0.231	0.243a
Stackdust	0.166	0.178	0.246	0.240	0.487	0.285	0.376	0.310	0.270	0.284a
Dolomite	0.128	0.125	0.183	0.180	0.391	0.314	0.337	0.258	0.223	0.238a
Means*	0.133e	0.142e	0.198de	0.380ab	0.313bc	0.411a	0.276c	0.241cd		

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD,5%: between weeks with the same treatment, 0.120; between treatments within the same week, 0.122.

in Ca content than the crowns from the unlimed soil. The plots of crown Ca content by sampling date show some interesting differences (see Figure 6). In week 5 the Ca content of the crowns from the stackdust and dolomite limed soils reach a maximum, whereas, the crowns from unlimed soil reach a maximum in week 7. This may indicate that the plants growing on the unlimed soil are maturing at a slower rate than the plants on the stackdust and dolomite limed soils. This may indicate that either Al or Mn in the unlimed soil may be slowing plant growth or that liming increases plant growth.

The crown Mg results are shown in Table 44. Over all weeks the crowns from the dolomite limed soil were higher in Mg than either the crowns from the stackdust limed soil or the unlimed soil, and the crowns from the stackdust limed soil were significantly higher in Mg than the crowns from the unlimed soil.These results do not follow the soil Mg results. The dolomite limed soil was higher in exchangeable Mg and as expected the crowns from it were higher in Mg, but the stackdust limed and the unlimed soil had the same amount of exchangeable Mg, yet the crowns from the stackdust limed soil had a higher Mg content. In weeks 6-8 the crowns from the unlimed and stackdust limed soils were not different but both had less Mg than the crowns from the dolomite limed soil. In weeks 3 and 4 the crowns from the dolomite limed soil had the highest Mg content followed by the crowns from the stackdust limed soil with an intermediate value and lastly the crowns from the unlimed soil with the lowest Mg content. In week 5 the crowns from the dolomite limed soil were greater in Mg content the crowns from the unlimed soil, but the crowns from the stackdust limed soil were not different from the other two. In weeks 1, 2 and 9 the crowns from the stackdust limed and the dolomite limed soils

Figure 6. Seasonal trends in chemical composition of Centurk wheat crowns in 1979, as affected by no lime (✱-✱), stackdust (✕-✕), or dolomite (◇-◇). Soil water and maximum (——) and minimum (---) soil temperature at 5 and 10 cm are also shown.

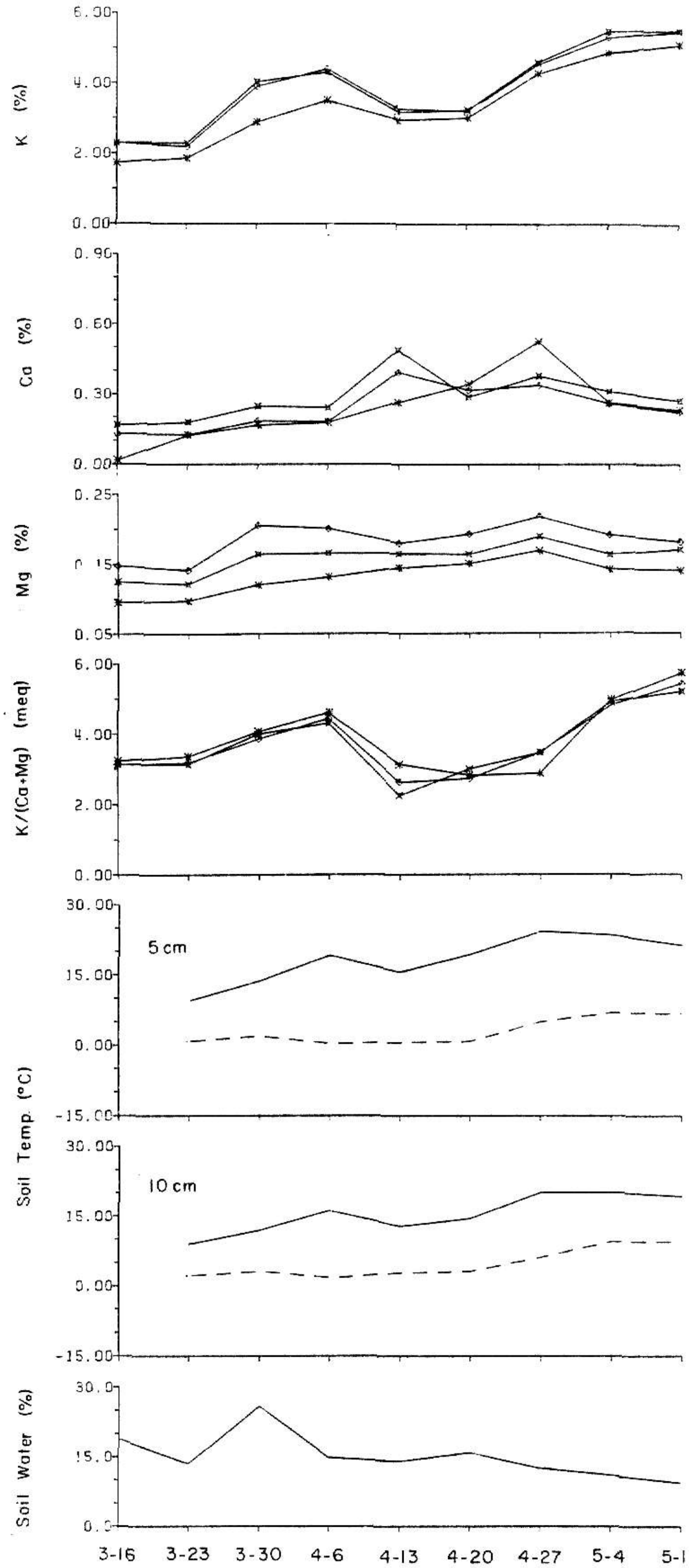

K (%)
6.00
4.00
2.00
0.00
Ca (%)
0.90
0.60
0.30
0.00
Mg (%)
0.25
0.15
0.05
K/(Ca+Mg) (meq)
6.00
4.00
2.00
0.00
5 cm
30.00
15.00
0.00
-15.00
Soil Temp. (°C)
10 cm
30.00
15.00
0.00
-15.00
Soil Water (%)
30.0
15.0
0.0
3-16
3-23
3-30
4-6
4-13
4-20
4-27
5-4
5-11

Table 44. The effect of liming on percent Mg in Centurk wheat crowns at nine sampling dates (1979).

	Date (Week)									
Treatment	3-16 (1)	3-23 (2)	3-30 (3)	4-6 (4)	4-13 (5)	4-20 (6)	4-27 (7)	5-4 (8)	5-11 (9)	Means*
Check	0.095	0.097	0.120	0.131	0.144	0.150	0.168	0.141	0.139	0.132c
Stackdust	0.125	0.121	0.164	0.165	0.164	0.163	0.188	0.162	0.169	0.158b
Dolomite	0.148	0.141	0.205	0.200	0.179	0.192	0.216	0.190	0.180	0.182a
Means*	0.123c	0.120c	0.163b	0.165b	0.162b	0.168b	0.187a	0.164b	0.162b	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5%: between weeks with the same treatment, 0.021; between treatments within the same week, 0.023.

were not different in Mg content, but both were greater than the crowns from the unlimed soils. These differences over time are shown clearly in the plots of crown Mg content by sampling date in Figure 6.

Over all weeks there were no differences in the mean crown milliequivalent ratios between treatments with the means all above 2.2 (see Table 45). There were no differences between treatments in weeks 1-4 and 6-9. In week 5 the milliequivalent ratio of the crowns from the unlimed soil was greater than the milliequivalent ratio of the crowns from the stackdust limed soil, but the milliequivalent ratio of the crowns from the dolomite limed soil was not significantly different than the other two. Regardless of treatment the crown milliequivalent ratios were always greater and sometimes much greater than the forage index value of 2.2. Like the forage, the crown milliequivalent ratio change with time followed the crown K change (see Figure 6).

Correlations

Linear correlation coefficients for the significant correlations of plant factors with environmental factors are shown in Tables 46 and 47 for the 1979 Centurk wheat forage and crowns, respectively.

Forage K was negatively related to soil water in all three treatments and positively related to soil-water potential and maximum and minimum soil temperature at 5 and 10 cm (see Table 46). Forage from the unlimed and dolomite limed soils had significant positive relationships between forage K and forage Ca.

Forage Ca content was positively related to forage Mg levels and to maximum soil temperature at 5 and 10 cm, but only for the forages from the unlimed and dolomite limed soils.

Table 45. The effect of liming on the milliequivalent ratio in Centurk wheat crowns at nine sampling dates (1979).

	Date (Week)									
Treatment	3-16 (1)	3-23 (2)	3-30 (3)	4-6 (4)	4-13 (5)	4-20 (6)	4-27 (7)	5-4 (8)	5-11 (9)	Means*
Check	3.24	3.36	4.07	4.61	3.13	2.82	2.88	4.98	5.74	3.87a
Stackdust	3.13	3.13	4.00	4.30	2.25	3.00	3.47	4.92	5.21	3.71a
Dolomite	3.14	3.17	3.86	4.44	2.63	2.73	3.46	4.82	5.42	3.74a
Means*	3.17e	3.22 e	3.98d	4.45 c	2.67f	2.85 ef	3.27e	4.91b	5.46a	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5%: between weeks with the same treatment, 0.68; between treatments within the same week, 0.73.

Table 46. Linear correlation coefficients* among measured plant and environmental factors for Centurk wheat forage (1979).

	Treatment (lime source)	Forage K	Forage Ca	Forage Mg	Forage meq. ratio	Soil water	Soil water potential	Soil Temp. Max. 5 cm	Soil Temp. Min. 5 cm	Soil Temp. Max. 10 cm	Soil Temp. Min. 10 cm
Forage K	Unlimed	-	.58	ns	.89	-.49	.76	.90	.89	.96	.89
	Stackdust	-	ns	ns	.90	-.43	.72	.85	.88	.93	.89
	Dolomite	-	.52	ns	.88	-.43	.73	.88	.88	.95	.88
Forage Ca	Unlimed	.58	-	.65	ns	-.43	ns	.69	ns	.57	ns
	Stackdust	ns	-	ns	ns	ns	ns	ns	ns	ns	ns
	Dolomite	.52	-	.54	ns	ns	ns	.66	ns	.52	ns
Forage Mg	Unlimed	ns	.65	-	ns	ns	ns	.44	ns	.35	ns
	Stackdust	ns	ns	-	ns	ns	ns	ns	ns	ns	ns
	Dolomite	ns	.54	-	ns	ns	ns	ns	ns	ns	ns
Forage Milliequivalent Ratio	Unlimed	.89	ns	ns	-	-.37	.75	.66	.86	.78	.86
	Stackdust	.90	ns	ns	-	-.40	.77	.65	.88	.76	.88
	Dolomite	.88	ns	ns	-	-.37	.80	.61	.88	.74	.89

*Entry into the table required a significance probability of 0.05 or less.

Forage Mg from the stackdust limed soil was not significantly related to any other factors and forage Mg from the dolomite limed soil was related positively to only forage Ca. The Mg content of the forage from the unlimed soil was positively related to forage Ca and maximum soil temperature at 5 and 10 cm.

The forage milliequivalent ratios were negatively related to soil water content and positively related to soil-water potential and maximum and minimum soil temperature at 5 and 10 cm for all treatments. The soil-water potential had a stronger relationship to the milliequivalent ratio than did the soil water content. The strong relationship between soil temperature and the milliequivalent ratio is probably due to the strong relationship of forage K to temperature because forage Mg and Ca did not have a linear relationship to soil temperature.

The significant linear correlation coefficients for Centurk crowns are presented in Table 47. Similar to forage K, crown K was positively related to maximum and minimum soil temperature at 5 and 10 cm, soil-water potential and crown Mg content for all three treatments. Crown Ca for all three treatments was positively related to crown Mg content. This relationship was strongest for the Ca content of the crowns from the unlimed soil. Beside the relationships mentioned above, crown Mg from all three treatments was positively related to maximum soil temperature at 5 cm. The crown milliequivalent ratio from each treatment was positively related to soil-water potential and maximum and minimum soil temperature at 5 and 10 cm with the exception of the milliequivalent ratio of the crowns from the unlimed soil and the maximum soil temperature at 5 cm.

Table 47. Linear correlation coefficients* among measured plant and environmental factors for Centurk wheat crowns (1979).

	Treatment (lime source)	Crown K	Crown Ca	Crown Mg	Crown meq. ratio	Soil water	Soil water potential	--------Soil Max. 5 cm	Temp. Min. 5 cm	Max. 10 cm	--------Min. 10 cm
Crown K	Unlimed	-	.44	.63	.61	-.42	.76	.87	.87	.94	.88
	Stackdust	-	ns	.64	.78	ns	.64	.78	.82	.87	.81
	Dolomite	-	ns	.60	.77	ns	.65	.79	.80	.88	.79
Crown Ca	Unlimed	.44	-	.73	-.40	-.35	ns	.57	ns	.49	ns
	Stackdust	ns	-	.42	-.34	ns	ns	ns	ns	ns	ns
	Dolomite	ns	-	.37	-.41	ns	ns	ns	ns	ns	ns
Crown Mg	Unlimed	.63	.73	-	ns	-.35	ns	.73	ns	.64	ns
	Stackdust	.64	.42	-	ns	ns	ns	.61	ns	.57	ns
	Dolomite	.60	.37	-	ns	ns	ns	.50	ns	ns	ns
Crown Milliequivalent Ratio	Unlimed	.61	-.40	ns	-	ns	.58	ns	.52	.40	.54
	Stackdust	.78	-.34	ns	-	ns	.55	.44	.66	.57	.65
	Dolomite	.77	-.41	ns	-	ns	.62	.41	.64	.55	.63

*Entry into the table required a significance probability of 0.05 or less.

Comparison of Forage and Crowns

Forage and crown K, Ca, Mg and milliequivalent ratios were compared within treatments. The results are shown in Tables 48, 49 and 50 for the forage and crowns from the unlimed, stackdust limed, and the dolomite limed soils, respectively.

For the forage and crowns from the unlimed soil the K content of the crowns was greater than the forage K content in weeks 3, 5, 6 and 9 (see Table 48). In the remaining weeks (1, 2, 4, 7 and 8) there were no differences between the forage K content and the crown K content. There were differences in the forage and crown Ca content in every week except week 7. In each week when differences were found the forage was higher in Ca content than the crowns. Magnesium in the forage was greater in weeks 1-3 and and lower in week 8. There were differences between the forage and crown milliequivalent ratios in every week except week 7. When differences when differences occurred the crown had the higher milliequivalent ratio. The weeks where these differences occurred correspond to the weeks when differences in the forage and crown Ca content occurred.

With respect to the wheat plants grown on the stackdust limed soil, the K content of the crowns was higher in weeks 1-4, 6 and 9 (see Table 49). The remaining weeks showed no differences. The Ca content of the forage was higher in every week. The Mg content was different only in weeks 2 and 8. In week 2 the forage was higher in Mg and in week 8 the crown was. The milliequivalent ratio was greater in the crowns in every week except in week 5 where there was no difference in the forage and crown milliequivalent ratios.

The forage and crowns from the dolomite limed soil had higher

Table 48. Comparison of forage and crowns from Centurk wheat growing on unlimed Eudora soil in 1979.

Week	Plant part	K	Ca	Mg	Ratio
1	Forage	1.60	0.231	0.123	1.89
	Crown	1.73	0.106	0.095	3.24
	(LSD)	(0.19)	(0.025)	(0.013)	(0.33)
2	Forage	1.71	0.266	0.117	1.92
	Crown	1.86	0.123	0.097	3.36
	(LSD)	(0.16)	(0.027)	(0.006)	(0.31)
3	Forage	2.50	0.317	0.138	2.35
	Crown	2.89	0.166	0.120	4.07
	(LSD)	(0.34)	(0.047)	(0.009)	(0.38)
4	Forage	3.33	0.399	0.137	2.74
	Crown	3.51	0.177	0.131	4.61
	(LSD)	(0.46)	(0.029)	(0.009)	(0.52)
5	Forage	2.70	0.472	0.141	1.97
	Crown	2.95	0.263	0.144	3.13
	(LSD)	(0.18)	(0.176)	(0.010)	(0.74)
6	Forage	2.75	0.513	0.141	1.90
	Crown	3.02	0.341	0.150	2.82
	(LSD)	(0.16)	(0.147)	(0.024)	(0.69)
7	Forage	4.30	0.530	0.158	2.81
	Crown	4.28	0.522	0.168	2.88
	(LSD)	(0.32)	(0.093)	(0.024)	(0.61)
8	Forage	5.02	0.415	0.128	4.15
	Crown	4.88	0.262	0.141	4.98
	(LSD)	(0.33)	(0.052)	(0.010)	(0.55)
9	Forage	4.74	0.428	0.131	3.80
	Crown	5.11	0.231	0.139	5.74
	(LSD)	(0.23)	(0.025)	(0.043)	(0.41)

P = .05

Table 49. Comparison of forage and crowns from Centurk wheat growing on stackdust limed Eudora soil in 1979.

Week	Plant part	K	Ca	Mg	Ratio
1	Forage	1.79	0.341	0.140	1.61
	Crown	2.28	0.166	0.125	3.13
	(LSD)	(0.19)	(0.025)	(0.013)	(0.33)
2	Forage	2.04	0.364	0.134	1.78
	Crown	2.28	0.178	0.121	3.13
	(LSD)	(0.16)	(0.027)	(0.006)	(0.31)
3	Forage	3.06	0.512	0.168	2.00
	Crown	4.04	0.246	0.164	4.00
	(LSD)	(0.34)	(0.047)	(0.009)	(0.52)
4	Forage	3.75	0.565	0.166	2.31
	Crwon	4.30	0.240	0.165	4.30
	(LSD)	(0.46)	(0.029)	(0.009)	(0.52)
5	Forage	3.03	0.666	0.168	1.66
	Crown	3.17	0.487	0.164	2.25
	(LSD)	(0.18)	(0.176)	(0.010)	(0.74)
6	Forage	2.96	0.636	0.166	1.67
	Crown	3.24	0.285	0.163	3.00
	(LSD)	(0.16)	(0.147)	(0.024)	(0.69)
7	Forage	4.32	0.556	0.190	2.58
	Crown	4.60	0.376	0.188	3.47
	(LSD)	(0.32)	(0.093)	(0.024)	(0.61)
8	Forage	5.50	0.459	0.146	4.06
	Crown	5.50	0.310	0.162	4.92
	(LSD)	(0.33)	(0.052)	(0.010)	(0.55)
9	Forage	5.11	0.497	0.150	3.53
	Crown	5.51	0.270	0.169	5.21
	(LSD)	(0.23)	(0.025)	(0.043)	(0.41)

P = .05

K in the crowns than in the forage in weeks 1-6 and 9 (see Table 50). Differences in Ca appeared in every week except week 5. Again the Ca content of the forage was greater than that of the crowns when differences occurred. Magnesium content was different in weeks 1-7. In each difference the forage had higher Mg content than the crowns. The milliequivalent ratio was greater in the crowns than in the forage in every week of the study.

Plant Results 1980

The effect of liming on Newton wheat forage content of K, Ca and Mg and the milliequivalent ratio are shown in Tables 51-54, respectively. The crown data is shown in Tables 55-58. These results are shown graphically in Figures 7 and 8. Maximum and minimum soil temperature and percent soil water are included in each figure. Due to analytical problems the plant Al and Mn contents will not be reported here.

Wheat Forage

The mean percent K in the wheat forage was increased by liming over all weeks (see Table 51). The mean percent K over all weeks was above the 3% critical value for all three treatments. In weeks 2 and 9 there were no treatment differences. In weeks 1, 3-6 and 7 the forage from the stackdust and the dolomite limed soils were not different in K content, but both were greater in K than the forage from the unlimed soil. In week 8 the forage from the stackdust limed soil was greater in K than the forage from the unlimed soil, but the forage from the dolomite limed soil was not different than the other two. The forage from the unlimed soil was below 3% K in weeks 1, 2 and 9. The forage from the limed soils were below 3% K only in week 1. Forage K was increasing by sampling date for the first 7 sampling dates and decreased slightly in the

Table 50. Comparison of forage and crowns from Centurk wheat growing on dolomite limed Eudora soil in 1979.

Week	Plant part	K	Ca	Mg	Ratio
1	Forage	1.84	0.241	0.184	1.74
	Crown	2.28	0.128	0.148	3.14
	(LSD)	(0.19)	(0.025)	(0.013)	(0.33)
2	Forage	1.91	0.253	0.168	1.86
	Crown	2.19	0.125	0.141	3.17
	(LSD)	(0.16)	(0.027)	(0.006)	(0.31)
3	Forage	2.97	0.356	0.221	2.11
	Crown	3.91	0.183	0.205	3.86
	(LSD)	(0.34)	(0.047)	(0.009)	(0.38)
4	Forage	3.64	0.430	0.225	2.33
	Crown	4.40	0.180	0.200	4.44
	(LSD)	(0.46)	(0.029)	(0.009)	(0.52)
5	Forage	2.92	0.484	0.211	1.80
	Crown	3.27	0.391	0.179	2.63
	(LSD)	(0.18)	(0.176)	(0.010)	(0.74)
6	Forage	2.99	0.543	0.218	1.76
	Crown	3.20	0.314	0.192	2.73
	(LSD)	(0.16)	(0.147)	(0.024)	(0.69)
7	Forage	4.37	0.530	0.248	2.39
	Crown	4.54	0.337	0.216	3.46
	(LSD)	(0.32)	(0.093)	(0.024)	(0.61)
8	Forage	5.22	0.429	0.188	3.66
	Crown	5.32	0.258	0.190	4.82
	(LSD)	(0.33)	(0.052)	(0.010)	(0.55)
9	Forage	4.96	0.414	0.185	3.54
	Crown	5.48	0.223	0.180	5.42
	(LSD)	(0.23)	(0.025)	(0.043)	(0.41)

P = .05

Table 51. The effect of liming on percent K in Newton wheat forage at nine sampling dates (1980).

	Date (Week)									
	3-11	3-18	3-25	4-1	4-8	4-15	4-22	4-29	5-6	
Treatment	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Means*
Check	2.23	2.99	3.24	3.68	4.20	3.64	4.22	3.43	2.96	3.40b
Stackdust	2.87	3.31	3.95	4.53	4.61	4.51	4.93	3.97	3.32	4.00a
Dolomite	2.66	3.35	3.79	4.61	4.87	4.56	4.71	3.77	3.27	3.95a
Means*	2.48e	3.22d	3.66c	4.27b	4.56a	4.23b	4.62a	3.72c	3.18d	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5%: between weeks with the same treatment, 0.32; between treatments within the same week, 0.41.

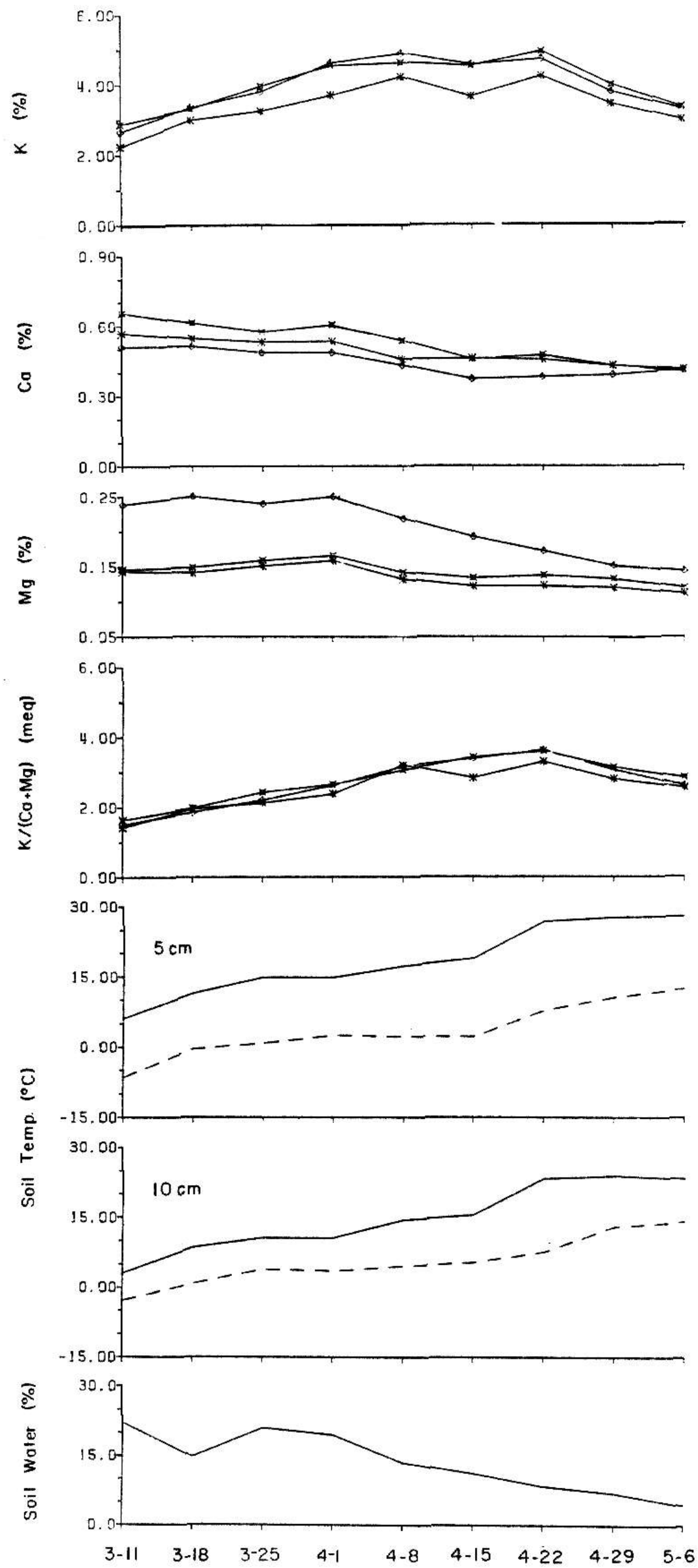
last two sampling dates (see Figure 7).

Over all weeks the mean Ca content of the forage was increased by liming with stackdust, but was decreased by liming with dolomite (see Table 52). In week 1 the forage from the stackdust limed soil was the highest in Ca, the forage from the unlimed soil intermediate and the forage from the dolomite limed soil the lowest. In weeks 2, 4 and 5 the forage from the unlimed and dolomite limed soils were not different in Ca content, but both were significantly lower than the forage from the stackdust limed soil. In weeks 3 and 6-8 the Ca content of the forages from the unlimed and the stackdust limed soil were not different, but both were greater in Ca than the forage from the dolomite limed soil. Forage Ca content decreased slightly with sampling date (see Figure 7).

The mean Mg content over all weeks was greatest for the forage from the dolomite limed soil and was above the 0.2% grass tetany index (see Table 53). Magnesium in the forages from the unlimed and stackdust limed soils were not different over all weeks, but both were below o.2% Mg. In weeks 1-7 and in week 9 the Mg content of the forage from the unlimed and stackdust limed soils were not different, but both were less than the forage from the dolomite limed soil. In week 8 the forage from the dolomite limed soil had a greater Mg content than the forage from the unlimed soil, but the Mg content of the forage from the stackdust limed soil was not significantly different from the other two. The forages from the stackdust limed and unlimed soils were never above 0.2% Mg content at any sampling date. The forages from the dolomite limed soil was above o.2% Mg for the first 5 sampling dates. Figure 7 shows these differences clearly.

Over all weeks the mean milliequivalent ratio for the forage

Figure 7. Seasonal trends in chemical composition of Newton wheat forage in 1980, as affected by no lime (*-*), stackdust (*-*), or dolomite (◇-◇). Soil water and maximum (——) and minimum (---) soil temperature at 5 and 10 cm are also shown.



K (%)
0.00
2.00
4.00
6.00
Ca (%)
0.00
0.30
0.60
0.90
Mg (%)
0.05
0.15
0.25
K/(Ca+Mg) (meq)
0.00
2.00
4.00
6.00
Soil Temp. (°C)
5 cm
-15.00
0.00
15.00
30.00
10 cm
-15.00
0.00
15.00
30.00
Soil Water (%)
0.0
15.0
30.0
3-11
3-18
3-25
4-1
4-8
4-15
4-22
4-29
5-6

Table 52. The effect of liming on percent Ca in Newton wheat forage at nine sampling dates (1980).

	Date (Week)									
	3-11	3-18	3-25	4-1	4-8	4-15	4-22	4-29	5-6	
Treatment	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Means*
Check	0.568	0.547	0.531	0.535	0.457	0.461	0.455	0.430	0.412	0.488b
Stackdust	0.655	0.613	0.574	0.605	0.537	0.457	0.475	0.429	0.404	0.528a
Dolomite	0.511	0.513	0.486	0.486	0.431	0.372	0.381	0.390	0.411	0.442c
Means*	0.578a	0.558ab	0.530b	0.542b	0.475c	0.430d	0.437d	0.416d	0.409d	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5%: between weeks with the same treatment, 0.051; between treatments within the same week, 0.052.

Table 53. The effect of liming on percent Mg in Newton wheat forage at nine sampling dates (1980).

	Date (Week)									
	3-11	3-18	3-25	4-1	4-8	4-15	4-22	4-29	5-6	
Treatment	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Means*
Check	0.143	0.141	0.151	0.159	0.132	0.122	0.123	0.120	0.112	0.134b
Stackdust	0.146	0.149	0.159	0.166	0.142	0.134	0.138	0.133	0.120	0.143b
Dolomite	0.239	0.251	0.240	0.251	0.219	0.193	0.173	0.152	0.144	0.207a
Means*	0.176b	0.180b	0.183b	0.192a	0.165c	0.150d	0.145d	0.135c	0.125f	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5%: between weeks with the same treatment, 0.014; between treatments within the same week, 0.022.

from the stackdust limed soil was greater than the milliequivalent ratio of the forage from the unlimed soil (see Table 54). The milliequivalent ratio of the forage from the dolomite limed soil over all weeks was not different than the milliequivalent ratios of the forages from the unlimed and stackdust limed soils. There were no between treatment differences in the forage milliequivalent ratios in weeks 1, 2, 4-6 and 9. In weeks 3 and 8 the milliequivalent ratio of the forage from the stackdust limed soil was greater than the milliequivalent ratio of the forage from the unlimed soil, and the milliequivalent ratio of the forage from the dolomite limed soil was not significantly different than the forage milliequivalent ratios from the other two treatments. In week 7 the milliequivalent ratios of the forages from the stackdust and dolomite limed soils were not different, but both were greater than the milliequivalent ratio of the forage from the unlimed soil. The means over all weeks for each treatment was greater than 2.2. Only in weeks 1 and 2 were all three forage milliequivalent ratios below 2.2 and in week 3 the forage from the unlimed soil had a milliequivalent ratio below 2.2. Over time the forage milliequivalent ratio curve had the same general shape as the forage K curve (see Figure 7).

Wheat Crowns

The effect of liming on crown K content is shown in Table 55. Over all weeks the mean crown K content was not different for the crowns from the stackdust and dolomite limed soils, but both were greater in K content than the crowns from the unlimed soil. The over all week crown K means were above 3%, but the crowns from the unlimed soil were only slightly above the 3% level. There were no between treatment differences in crown K content in weeks 8 and 9.

Table 54. The effect of liming on the milliequivalent ratio in Newton wheat forage at nine sampling dates (1980).

	Date (Week)									
	3-11	3-18	3-25	4-1	4-8	4-15	4-22	4-29	5-6	
Treatment	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Means*
Check	1.43	1.97	2.13	2.38	3.20	2.83	3.30	2.80	2.55	2.51b
Stackdust	1.64	1.98	2.43	2.65	3.06	3.42	3.60	3.14	2.84	2.75a
Dolomite	1.51	1.86	2.21	2.63	3.16	3.39	3.63	3.06	2.61	2.67ab
Means*	1.53g	1.94f	2.26e	2.55d	3.14bc	3.21b	3.51a	3.00c	2.66d	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5%: between weeks with the same treatment, 0.25; between treatments within the same week, 0.30.

Table 55. The effect of liming on percent K in Newton wheat crowns at nine sampling dates (1980).

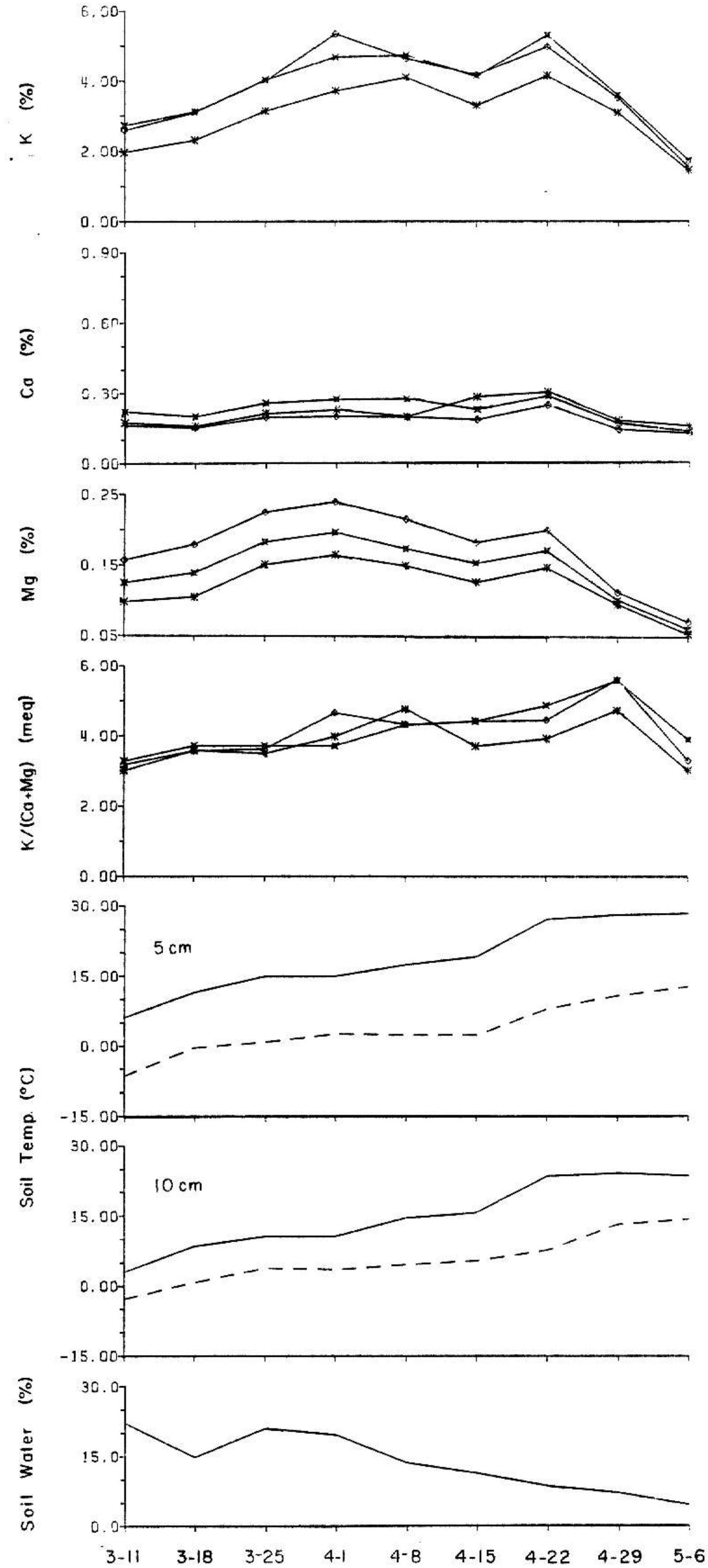
	Date (Week)									
	3-11	3-18	3-25	4-1	4-8	4-15	4-22	4-29	5-6	
Treatment	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Means*
Check	1.97	2.31	3.14	3.72	4.10	3.30	4.15	3.09	1.45	3.03b
Stackdust	2.73	3.11	4.03	4.68	4.72	4.14	5.30	3.60	1.73	3.78a
Dolomite	2.59	3.10	4.00	5.34	4.63	4.17	4.97	3.52	1.54	3.76a
Means*	2.43f	2.84e	3.72c	4.58ab	4.48b	3.87c	4.80a	3.40d	1.57g	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5%: between weeks with the same treatment, 0.52; between treatments within the same week, 0.58.

In weeks 1-3, 6 and 7 the K content of the crowns from the stackdust and dolomite limed soils were not different, but both were greater than the K content of the crowns from the unlimed soil. In week 4 the crowns from the dolomite limed soil were highest in K, the crowns from the stackdust limed soil were intermediate and the crowns from the unlimed soil were lowest in K. In week 5 the crowns from the stackdust limed soil were greater in K than the crowns from the unlimed soil, and the crowns from the dolomite limed soil were not significantly different from the crowns of the other treatments. The K content of the crowns covered quite a broad range over the 9 sampling dates (see Figure 8). The crowns from the unlimed soil had an initial K content of 1.97% and a maximum content of 4.15% K in week 7 and a final K content of 1.45%. The crowns from the stackdust limed soil had an initial K content of 2.73%, a high value of 5.30% in week 7, and a final value of 1.73% K. The crowns from the dolomite limed soil initially had 2.59% K and reached a high value of 5.34% K in week 4, and had a final value of 1.54% K. These changes in K content show how quickly and to what extremes K can vary in wheat plant tissue. It is rapid changes like these that give the grass tetany syndrome its sporadic nature.

The mean Ca content over weeks was highest for the crowns from the stackdust limed soil. In weeks 1 and 3-5 the crowns from the unlimed and dolomite limed soils were not different in Ca content, but both were lower than the crowns from the stackdust limed soil. In week 6 the crowns from the unlimed soil were greater in Ca content than the crowns from the other two treatments. In week 7 the crowns from the unlimed soil were greater in Ca content than the crowns from the dolomite limed soil, but the crowns from the

Figure 8. Seasonal trends in chemical composition of Newton wheat crowns in 1980, as affected by no lime (✱-✱), stackdust (✖-✖), or dolomite (◇-◇). Soil water and maximum (——) and minimum (---) soil temperature at 5 and 10 cm are also shown.



K (%)
Ca (%)
Mg (%)
K/(Ca+Mg) (meq)
Soil Temp. (°C)
5 cm
10 cm
Soil Water (%)
3-11
3-18
3-25
4-1
4-8
4-15
4-22
4-29
5-6

Table 56. The effect of liming on percent Ca in Newton wheat crowns at nine sampling dates (1980).

	Date (Week)									
Treatment	3-11 (1)	3-18 (2)	3-25 (3)	4-1 (4)	4-8 (5)	4-15 (6)	4-22 (7)	4-29 (8)	5-6 (9)	Means*
Check	0.174	0.158	0.211	0.227	0.196	0.281	0.301	0.178	0.153	0.209b
Stackdust	0.220	0.199	0.256	0.272	0.273	0.226	0.283	0.163	0.129	0.225a
Dolomite	0.161	0.151	0.195	0.198	0.195	0.183	0.244	0.137	0.123	0.176c
Means*	0.185c	0.169c	0.220b	0.232b	0.221b	0.230b	0.276a	0.159cd	0.135d	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5%: between weeks with the same treatment, 0.044; between treatments within the same week, 0.044.

stackdust limed soil were not significantly different than the crowns from the other two treatments (see Figure 56). There were no between treatment differences in crown Ca content in weeks 8 and 9. Crown Ca did not change much with time as is seen in Figure 8.

Over all weeks mean crown Mg was highest in the crowns from the dolomite limed soil, intermediate in the crowns from the stackdust limed soil, and lowest in the crowns from the unlimed soil (see Table 57). In weeks 8 and 9 there were no between treatment differences in Mg content. In weeks 1-7 crown Mg was greatest in the crowns from the dolomite limed soil, intermediate in the crowns from the stackdust limed soil, and lowest in the crowns from the unlimed soil. The crown Mg trends with sampling date show these differences very well (see Figure 8).

The mean crown milliequivalent ratios over all weeks were not different between treatments (see Table 58). This may indicate that Newton wheat maintains a balance between the K, Ca and Mg concentrations in the crowns. There were no between treatment differences in the crown milliequivalent ratios in weeks 1-3, 5 and 6. In week 4 the crowns from the dolomite limed soil had a greater milliequivalent ratio than the crowns from the stackdust limed soil. The milliequivalent ratio of the crowns from the unlimed soil were not different from the other two treatment crown milliequivalent ratios in week 4. In weeks 7 and 9 the crowns from the stackdust limed soil had a higher milliequivalent ratio than the crowns from the unlimed soil, but neither were different than the milliequivalent ratio of the crowns from the dolomite limed soil. In week 8 the crowns from the stackdust and the dolomite limed soil did not have significantly different milliequi-

Table 57. The effect of liming on percent Mg in Newton wheat crowns at nine sampling dates (1980).

	Date (Week)									
	3-11	3-18	3-25	4-1	4-8	4-15	4-22	4-29	5-6	
Treatment	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Means*
Check	0.098	0.105	0.151	0.165	0.150	0.127	0.148	0.096	0.054	0.121c
Stackdust	0.125	0.139	0.183	0.197	0.174	0.154	0.172	0.102	0.061	0.145b
Dolomite	0.157	0.179	0.225	0.240	0.216	0.183	0.201	0.113	0.071	0.176a
Means*	0.127f	0.141e	0.186b	0.200a	0.180bc	0.155d	0.173c	0.104g	0.062h	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5%: between weeks with the same treatment, 0.016; between treatments within the same week, 0.021.

Table 58. The effect of liming on the milliequivalent ratio in Newton wheat crowns at nine sampling dates (1980).

	Date (Week)									
	3-11	3-18	3-25	4-1	4-8	4-15	4-22	4-29	5-6	
Treatment	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Means*
Check	3.01	3.58	3.49	3.97	4.76	3.70	3.91	4.72	3.01	3.79a
Stackdust	3.28	3.72	3.71	3.71	4.31	4.41	4.86	5.58	3.89	4.16a
Dolomite	3.17	3.57	3.62	4.65	4.32	4.41	4.44	5.60	3.29	4.12a
Means*	3.15d	3.62c	3.61c	4.11b	4.46b	4.17b	4.40b	5.30a	3.40cd	

*Values followed by the same letter in the Means row or in the Means column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test. LSD, 5%: between weeks with the same treatment, 0.66; between treatments within the same week, 0.72.

valent ratios, but both were greater than the milliequivalent ratio of the crowns from the unlimed soil. The crown milliequivalent ratios were quite variable with sampling as seen in Figure 8.

Correlations

Linear correlation coefficients for the significant correlations of plant factors with environmental factors are shown in Tables 59 and 60 for the 1980 Newton wheat forage and crowns, respectively.

Potassium in the forages from the unlimed and dolomite limed soils was negatively related to forage Ca (see Table 59). Calcium in the forage from the stackdust limed soil was negatively related to soil-water potential. Forage K from all three treatments was positively related to maximum soil temperature at 10 cm. This depth may have been the site of most active K absorption by the plant.

Forage Ca from all three treatments was strongly positively related to forage Mg and soil water content. All three were also strongly negatively related to maximum and minimum soil temperature at 5 and 10 cm. The Ca content of the forage from the stackdust limed soil had the strongest relationship to soil temperature.

Forage Mg was strongly positively related to soil water content for forages from all three treatments, and negatively related to soil-water potential. Forage Mg was negatively related to maximum and minmum soil temperature at 5 and 10 cm. Magnesium in the forage from the dolomite limed soil had the strongest relationship to soil temperature.

The forage milliequivalent ratio was negatively related to soil water content for each treatment. This is contrary to findings by other researchers that have found a positive relationship to

Table 59. Linear correlation coefficients* among measured plant and environmental factors for Newton wheat forage (1980).

	Treatment (lime source)	Forage K	Forage Ca	Forage Mg	Forage meq. ratio	Soil water	Soil water potential	Soil Temp. Max. 5 cm	Soil Temp. Min. 5 cm	Soil Temp. Max. 10 cm	Soil Temp. Min. 10 cm
Forage K	Unlimed	-	-.36	ns	.89	ns	ns	.45	.36	.47	ns
	Stackdust	-	ns	ns	.79	ns	-.33	.39	ns	.40	ns
	Dolomite	-	-.40	ns	.79	ns	ns	ns	ns	.34	ns
Forage Ca	Unlimed	-.36	-	.81	-.72	.80	-.47	-.81	-.77	-.82	-.80
	Stackdust	ns	-	.71	-.75	.85	-.51	-.86	-.83	-.87	-.86
	Dolomite	-.40	-	.79	-.86	.71	ns	-.74	-.63	-.75	-.65
Forage Mg	Unlimed	ns	.81	-	-.49	.80	-.48	-.67	-.61	-.69	-.64
	Stackdust	ns	.71	-	-.41	.71	-.53	-.55	-.52	-.57	-.56
	Dolomite	ns	.79	-	-.58	.85	-.55	-.85	-.80	-.85	-.84
Forage Milliequivalent Ratio	Unlimed	.89	-.72	-.49	-	-.63	ns	.71	.61	.73	.57
	Stackdust	.78	-.75	-.41	-	-.67	ns	.78	.67	80	.65
	Dolomite	.79	-.86	-.58	-	-.62	ns	.72	.60	.74	.57

*Entry into the table required a significance probability of 0.05 or less.

exist between soil water and the forage milliequivalent ratio. The forage milliequivalent ratio was also positively related to maximum and minimum soil temperature at 5 and 10 cm. The forage from the stackdust limed soil had the strongest relationship between the milliequivalent ratio and soil temperature.

Crown K content was positively related to crown Ca content, crown Mg content and negatively related to soil-water potential for the crowns from all three treatments (see Table 60). Crown K content was not significantly related to soil temperature at either depth. Crown Ca was positively related to crown Mg with the crowns from the stackdust limed soil having the strongest relationship. Crown Mg was positively related to soil water and negatively related to soil-water potential. The Mg in crowns from the stackdust and dolomite limed soils was negatively related to the maximum and minimum soil temperatures at 5 and 10 cm with the crowns from the dolomite limed soil having the strongest relationship. The crown milliequivalent ratio was positively related to the maximum and minimum soil temperatures at 5 and 10 cm, but only for the crowns from the stackdust and dolomite limed soils.

Comparison of Forage and Crowns

The comparison of forage chemical composition to that of the crowns are shown in Tables 61, 62 and 63 for the unlimed, stackdust limed and the dolomite limed soils, respectively.

The forage and crowns from the unlimed soil were different in K content in weeks 1, 2, 6, 8 and 9 (see Table 61). In each difference the forage was higher in K content than the crowns. Calcium was higher in the forage at every sampling date. Forage and crown Mg contents were different in weeks 1, 2, 5 and 7-9. In weeks 5 and 7 the crowns were higher in Mg than the forage. The

Table 60. Linear correlation coefficients* among measured plant and environmental factors for Newton wheat crowns (1980).

	Treatment (lime source)	Crown K	Crown Ca	Crown Mg	Crown meq. ratio	Soil water	Soil water potential	Soil Temp. Max. 5 cm	Soil Temp. Min. 5 cm	Soil Temp. Max. 10 cm	Soil Temp. Min. 10 cm
Crown K	Unlimed	-	.55	.84	.68	ns	-.57	ns	ns	ns	ns
	Stackdust	-	.82	.83	.37	ns	-.67	ns	ns	ns	ns
	Dolomite	-	.76	.78	.62	ns	-.64	ns	ns	ns	ns
Crown Ca	Unlimed	.55	-	.60	ns	ns	ns	ns	ns	ns	ns
	Stackdust	.82	-	.92	ns	.51	-.66	ns	-.43	ns	-.50
	Dolomite	.76	-	.77	ns	ns	-.52	ns	ns	ns	ns
Crown Mg	Unlimed	.84	.60	-	ns	.46	-.66	ns	ns	ns	-.37
	Stackdust	.84	.92	-	ns	.58	-.73	-.38	-.45	-.38	-.52
	Dolomite	.78	.77	-	ns	.63	-.72	-.46	-.52	-.46	-.59
Crown Milliequivalent Ratio	Unlimed	.68	ns	ns	-	ns	-.35	ns	ns	ns	ns
	Stackdust	.37	ns	ns	-	-.61	ns	.67	.58	.70	.59
	Dolomite	.62	ns	ns	-	ns	ns	.43	.38	.45	.38

*Entry into the table required a significance probability of 0.05 or less.

Table 61. Comparison of forage and crowns from Newton wheat growing on unlimed Eudora soil in 1980.

Week	Plant part	K	Ca	Mg	Ratio
1	Forage	2.23	0.568	0.143	1.43
	Crown	1.97	0.174	0.098	3.01
	(LSD)	(0.17)	(0.044)	(0.009)	(0.20)
2	Forage	2.99	0.547	0.141	1.97
	Crown	2.31	0.158	0.105	3.58
	(LSD)	(0.47)	(0.030)	(0.014)	(0.39)
3	Forage	3.24	0.531	0.151	2.13
	Crown	3.14	0.211	0.151	3.49
	(LSD)	(0.29)	(0.021)	(0.011)	(0.23)
4	Forage	3.68	0.535	0.159	2.38
	Crown	3.72	0.227	0.165	3.97
	(LSD)	(0.88)	(0.039)	(0.016)	(1.01)
5	Forage	4.20	0.457	0.132	3.20
	Crown	4.10	0.196	0.150	4.76
	(LSD)	(0.43)	(0.025)	(0.004)	(0.39)
6	Forage	3.64	0.461	0.122	2.83
	Crown	3.30	0.281	0.127	3.70
	(LSD)	(0.15)	(0.094)	(0.013)	(0.68)
7	Forage	4.22	0.455	0.123	3.30
	Crown	4.15	0.301	0.148	3.91
	(LSD)	(0.22)	(0.026)	(0.015)	(0.46)
8	Forage	3.43	0.430	0.120	2.80
	Crown	3.09	0.178	0.096	4.72
	(LSD)	(0.32)	(0.041)	(0.014)	(0.46)
9	Forage	2.96	0.412	0.112	2.55
	Crown	1.45	0.153	0.054	3.01
	(LSD)	(0.40)	(0.069)	(0.014)	(0.62)

P = .05

milliequivalent ratio showed differences in weeks 1-8. The crowns always had the higher ratio when differences occurred.

The forage and crowns from the stackdust limed soil had differences in K content in weeks 6-9 (see Table 62). In weeks 6, 8 and 9 the forage was higher in K than the crowns. Calcium was higher in the forage at all 9 sampling dates. In weeks 1, 8 and 9 the forage was higher in Mg than the crowns and in weeks 3-7 the opposite was true. The milliequivalent ratio was greater in the crowns at all 9 sampling dates.

In the wheat from the dolomite limed soil differences in the K content between the forage and crowns occurred in weeks 6, 7 and 9. The forage was higher in K in weeks 6 and 9. Calcium was greater in the forage than in the crowns at all 9 sampling dates. The forage Mg content was greater than the crown Mg content in weeks 1-3, 8 and 9, and higher in the crowns only in week 7. The milliequivalent ratio was higher in the crowns at all 9 sampling dates of the study.

Table 62. Comparison of forage and crowns from Newton wheat growing on stackdust limed Eudora soil in 1980.

Week	Plant part	K	Ca	Mg	Ratio
1	Forage	2.87	0.655	0.146	1.64
	Crown	2.73	0.220	0.125	3.28
	(LSD)	(0.17)	(0.044)	(0.009)	(0.020)
2	Forage	3.31	0.613	0.149	1.98
	Crown	3.11	0.199	0.139	3.72
	(LSD)	(0.47)	(0.030)	(0.014)	(0.39)
3	Forage	3.95	0.574	0.159	2.43
	Crown	4.03	0.256	0.183	3.71
	(LSD)	(0.29)	(0.021)	(0.011)	(0.23)
4	Forage	4.53	0.605	0.166	2.65
	Crown	4.68	0.272	0.197	3.71
	(LSD)	(0.88)	(0.039)	(0.016)	(1.01)
5	Forage	4.61	0.537	0.142	3.06
	Crown	4.72	0.273	0.174	4.31
	(LSD)	(0.43)	(0.025)	(0.004)	(0.39)
6	Forage	4.51	0.457	0.134	3.42
	Crown	4.14	0.226	0.154	4.41
	(LSD)	(0.15)	(0.094)	(0.013)	(0.68)
7	Forage	4.93	0.475	0.138	3.60
	Crown	5.30	0.283	0.172	4.86
	(LSD)	(0.22)	(0.026)	(0.015)	(0.46)
8	Forage	3.97	0.429	0.133	3.14
	Crown	3.60	0.163	0.102	5.58
	(LSD)	(0.32)	(0.041)	(0.014)	(0.46)
9	Forage	3.32	0.404	0.120	2.84
	Crown	1.73	0.129	0.061	3.89
	(LSD)	(0.40)	(0.069)	(0.014)	(0.62)

P = .05

Table 63. Comparison of forage and crowns from Newton wheat growing on dolomite limed Eudora soil in 1980.

Week	Plant part	K	Ca	Mg	Ratio
1	Forage	2.66	0.511	0.239	1.51
	Crown	2.59	0.161	0.157	3.17
	(LSD)	(0.17)	(0.044)	(0.009)	(0.20)
2	Forage	3.35	0.513	0.251	1.86
	Crown	3.10	0.151	0.179	3.57
	(LSD)	(0.47)	(0.030)	(0.014)	(0.39)
3	Forage	3.79	0.486	0.240	2.21
	Crown	4.00	0.195	0.225	3.62
	(LSD)	(0.29)	(0.021)	(0.011)	(0.23)
4	Forage	4.61	0.486	0.251	2.63
	Crown	5.34	0.198	0.240	4.65
	(LSD)	(0.88)	(0.039)	(0.016)	(1.01)
5	Forage	4.87	0.431	0.219	3.16
	Crown	4.63	0.195	0.216	4.32
	(LSD)	(0.43)	(0.025)	(0.004)	(0.39)
6	Forage	4.56	0.372	0.193	3.39
	Crown	4.17	0.183	0.183	4.41
	(LSD)	(0.15)	(0.094)	(0.013)	(0.68)
7	Forage	4.71	0.381	0.173	3.63
	Crown	4.97	0.244	0.201	4.44
	(LSD)	(0.22)	(0.026)	(0.015)	(0.46)
8	Forage	3.77	0.390	0.152	3.06
	Crown	3.52	0.137	0.113	5.60
	(LSD)	(0.32)	(0.041)	(0.014)	(0.46)
9	Forage	3.27	0.411	0.144	2.61
	Crown	1.54	0.123	0.071	3.29
	(LSD)	(0.40)	(0.069)	(0.014)	(0.62)

P = .05

WINTER WHEAT SUMMARY AND CONCLUSIONS

The 1979 results show that liming can have a large influence on the chemical composition of Centurk wheat forage and crowns. Liming with both stackdust and dolomite increased the forage K levels and the crown K and Ca levels. The K result is interesting because the soil exchangeable K levels were the same for the limed and unlimed soils. The probable effect of the liming which resulted in the K increases is the increase in soil pH. With the increase in pH exchangeable Al and Mn levels are reduced. This reduction in potentially toxic ions improved plant growth, health and vigor. This improved performance is reflected in the higher K levels.

Another interesting result is the forage Ca content from the unlimed soil. The forage Ca content over all weeks from the unlimed soil was greater than the Ca content of the dolomite limed soil, even though the exchangeable Ca in the dolomite limed soil was greater than the exchangeable Ca in the unlimed soil. One function of Ca in a plant is to reduce the injurious effects of toxic levels of certain nutrients (15,77). Because the unlimed soil is known to be high in both Al and Mn, the plants growing on this soil are probably trying to reduce injury by actively increasing the tissue Ca levels (77).

The milliequivalent ratios were strongly positively related to soil temperature. This was a result of potassiums strong positive relationship to soil temperature. Potassium in the forage and crowns increased with increasing soil-water potential and soil temperature. These two environmental factors are interelated. As the soil-water potential increases the soil becomes drier, and as the soil becomes drier the soil temperature can increase faster. A warmer soil means greater plant growth and activity, and thus a greater need for K.

The forage Mg and crown Mg levels were increased by liming. Of the two limes, the dolomite lime supplied more Mg to the soil and consequently, the wheat plants growing on the dolomite limed soil had higher Mg contents. The forage and crowns from the stackdust limed soil had an intermediate Mg content between those from the other two treatments. Even though the soil Mg levels were the same in the unlimed and stackdust limed soils the wheat from the stackdust limed soil had the higher Mg content. The reason why this occurred is similar to the reason for the increased K uptake by the wheat plants growing on the stackdust limed soil. Even though liming with stackdust did not increase exchangeable Mg it did reduce the levels of potentially toxic Al and Mn. This resulted in a root environment more favorable for active plant growth and consequently more Mg uptake.

Forage and crown Mg and Ca did not show a strong relationship to soil temperature, but forage and crown K did. These differences may be related to the membrane bound ATPases responsible for the active uptake of the respective cations. The divalent cation ATPases in wheat may function over a much broader temperature range than the monovalent cation ATPases and at low temperatures the monovalent ATPases could even be inactive because of an increase in the activation energy of the K ATPase.

In 1980 liming increased the K content of Newton wheat forage and crowns. Stackdust lime increased the Ca content of the forage and crowns, but liming with dolomite decreased the Ca content of both plant parts when compared to wheat plants growing on unlimed soil. The reason for this is probably the same as discussed previously. Liming reduced the levels of potentially toxic Al and Mn in the soil which provided a better soil environment for the wheat to grow in. The wheat growing in the stackdust limed soil assimilated more Ca because the supply of Ca was greatest. In the unlimed soil the wheat assimilated more Ca to ward off the potentially injurious effects of Al and Mn in the soil solution (77). In the dolomite limed soil there was a better balance in the soil levels of Ca and Mg and the wheat growing there assimilated more Mg than the wheat growing in the stackdust limed soil.

In 1980 only the Mg in the wheat from the dolomite limed soil was increased. This is different than the results from 1979 where the wheat from the stackdust limed soil had an increase in Mg content due to liming also. Magnesium uptake in 1980 seems to be a function of supply rather than both plant health and supply as it was in 1979.

In 1980, unlike 1979, the forage and crown K was not significantly related to soil temperature. This may be due to varietal differences between Centurk and Newton wheats. Forage Ca and Mg were negatively related to soil temperature and positively related to soil water content. This too is unlike the 1979 results. The milliequivalent ratios in 1980 like those in 1979 were positively related to soil temperature. With respect to grass tetany etiology this temperature effect may be more severe for the 1980 Newton wheat, because instead of having higher milliequivalent ratios due to K increasing with temperature the ratios increased because the divalent cations were decreasing with increasing temperature. This results in lower forage Mg which is needed in high concentration in the forage to prevent grass tetany.

Comparing the crown chemical composition to that of the forage, it was found in both years for both varieties of wheat that the crowns never had a higher Ca content than the forage. This may be due to calciums low mobility and the plants need to have a ready supply of Ca available for the onset of more favorable growing conditions. It was also found that the forage never had a milliequivalent ratio higher than the crowns. This is good with respect to grass tetany, because the crown milliequivalent ratios were very high in some instances.

The soil properties discussed previously predicted that only a forage from the dolomite limed soil would have a Mg content above 0.2%. This prediction was true for both years for the forage Mg means over all weeks. There were weeks in which the forage Mg level did drop below 0.2% though. The regression equation of Turner et al. (76) predicted lower than found forage Mg contents in both years.

Tables 64 and 65 are summaries for 1979 and 1980 respectively, of when the K or Mg content or the milliequivalent ratio were above or below their respective indexes and were creating a tetany prone forage. When forage K is 3% or above the forage is considered to be tetany prone and when the forage Mg content is below 0.2% the forage is also considered tetany prone. When the forage milliequivalent ratio is above 2.2 the forage is considered to be tetany prone.

In 1979 the forage from the unlimed and dolomite limed soils had four weeks in which the K content was above 3% (see Table 64). Liming with stackdust increased the number of weeks in which the forage K was above 3% to six weeks. The forage K means over all weeks for all three treatments were above 3%.

The forage from the unlimed and stackdust limed soils were

Table 64. Summary of nutrient levels critical with respect to grass tetany indices* for Centurk wheat forage in 1979.

Sampling		Forage						Milliequivalent Ratio		
		K			Mg					
		U¶	S¶	D¶	U	S	D	U	S	D
Week	Date	--------%--------			---------%-------					
1	3-16	-	-	-	.123	.140	.184	-	-	-
2	3-23	-	-	-	.117	.134	.168	-	-	-
3	3-30	-	3.06	-	.138	.168	-	2.35	-	-
4	4-6	3.33	3.75	3.64	.137	.166	-	2.74	2.31	2.33
5	4-13	-	3.03	-	.141	.168	-	-	-	-
6	4-20	-	-	-	.141	.166	-	-	-	-
7	4-27	4.30	4.32	4.37	.158	.190	-	2.81	2.58	2.39
8	5-4	5.02	5.50	5.22	.128	.146	.188	4.15	4.06	3.66
9	5-11	4.74	5.11	4.96	.131	.150	.185	3.80	3.53	3.54
Mean over weeks		3.18	3.51	3.42	.135	.159	-	2.61	2.35	2.35

*Critical grass tetany forage indices: >4% N, >3% K, <0.2% Mg, and Milliequivalent ratios >2.2.

¶U=unlimed, S=stackdust, and D=dolomite.

below 0.2% Mg at all nine sampling dates. Liming with dolomite increased the forage Mg content above 0.2% in four of the nine sampling dates. The forage Mg means over all weeks for the forages from the unlimed and stackdust limed soils were below 0.2%.

Liming with either stackdust or dolomite decreased the number of sampling dates the forage milliequivalent ratio was above 2.2 by one. The milliequivalent ratio of the forage from the unlimed soil was above 2.2 in five weeks. Liming reduced the magnitude of the mean forage milliequivalent ratio over all weeks, but the milliequivalent ratio means over all weeks remained above 2.2 for all treatments.

In 1980 liming increased forage K content above the critical 3% level in six weeks, an additional two weeks over 1979 (see Table 65). The forage K means over all weeks for all three treatments were well above the 3% critical level.

Liming with dolomite increased forage Mg above 0.2% in five sampling dates. The Mg content of the forage from the unlimed and stackdust limed soils were never above the 0.2% level. Only the forage from the dolomite limed soil had a Mg content mean over all weeks above the critical 0.2% Mg level.

The milliequivalent ratio of the forage from the unlimed soil was above 2.2 at six sampling dates. Liming with either stackdust or dolomite increased the number of sampling dates the milliequivalent ratio was above 2.2 by one. The means over all weeks for the forage milliequivalent ratios from all the treatments were above 2.2. The 1980 forage milliequivalent ratio results are different than the 1979 results in that liming in 1979 reduced the magnitude of the milliequivalent ratio and in 1980 liming increased it.

Table 65. Summary of nutrient levels critical with respect to grass tetany indices* for Newton wheat forage in 1980.

Sampling		Forage						Milliequivalent Ratio		
		K			Mg					
		U¶	S¶	D¶	U	S	D	U	S	D
Week	Date	--------%--------			--------%--------					
1	3-11	-	-	-	.143	.146	-	-	-	-
2	3-18	-	3.31	3.35	.141	.149	-	-	-	-
3	3-25	3.24	3.95	3.79	.151	.159	-	-	2.43	2.21
4	4-1	3.68	4.53	4.61	.159	.166	-	2.38	2.65	2.63
5	4-8	4.20	4.61	4.87	.132	.142	-	3.20	3.06	3.16
6	4-15	3.64	4.51	4.56	.122	.134	.193	2.83	3.42	3.39
7	4-22	4.22	4.93	4.71	.123	.138	.173	3.30	3.60	3.63
8	4-29	3.42	3.97	3.77	.120	.133	.152	2.80	3.14	3.06
9	5-6	-	3.32	3.27	.112	.120	.144	2.55	2.84	2.61
Mean over weeks		3.40	4.00	3.95	.134	.143	-	2.51	2.75	2.67

*Critical grass tetany forage indices: >4% N, >3% K, <0.2% Mg, and Milliequivalent ratios >2.2.

¶U=unlimed, S=stackdust, and D=dolomite.

In conclusion, liming increased plant K. Liming with stack-dust ($CaCO_3$) increased plant Ca and liming with dolomite [$CaMg(CO_3)_2$] increased plant Mg. In 1979 liming reduced the milliequivalent ratios but in 1980 it increased them. Without a feeding trial or knowing which grass tetany indice is best it is difficult to know if liming increased or decreased the tetany hazard of the wheat forage. But, it is very clear that liming with dolomite increases forage Mg which is the critical element with respect to grass tetany etiology.

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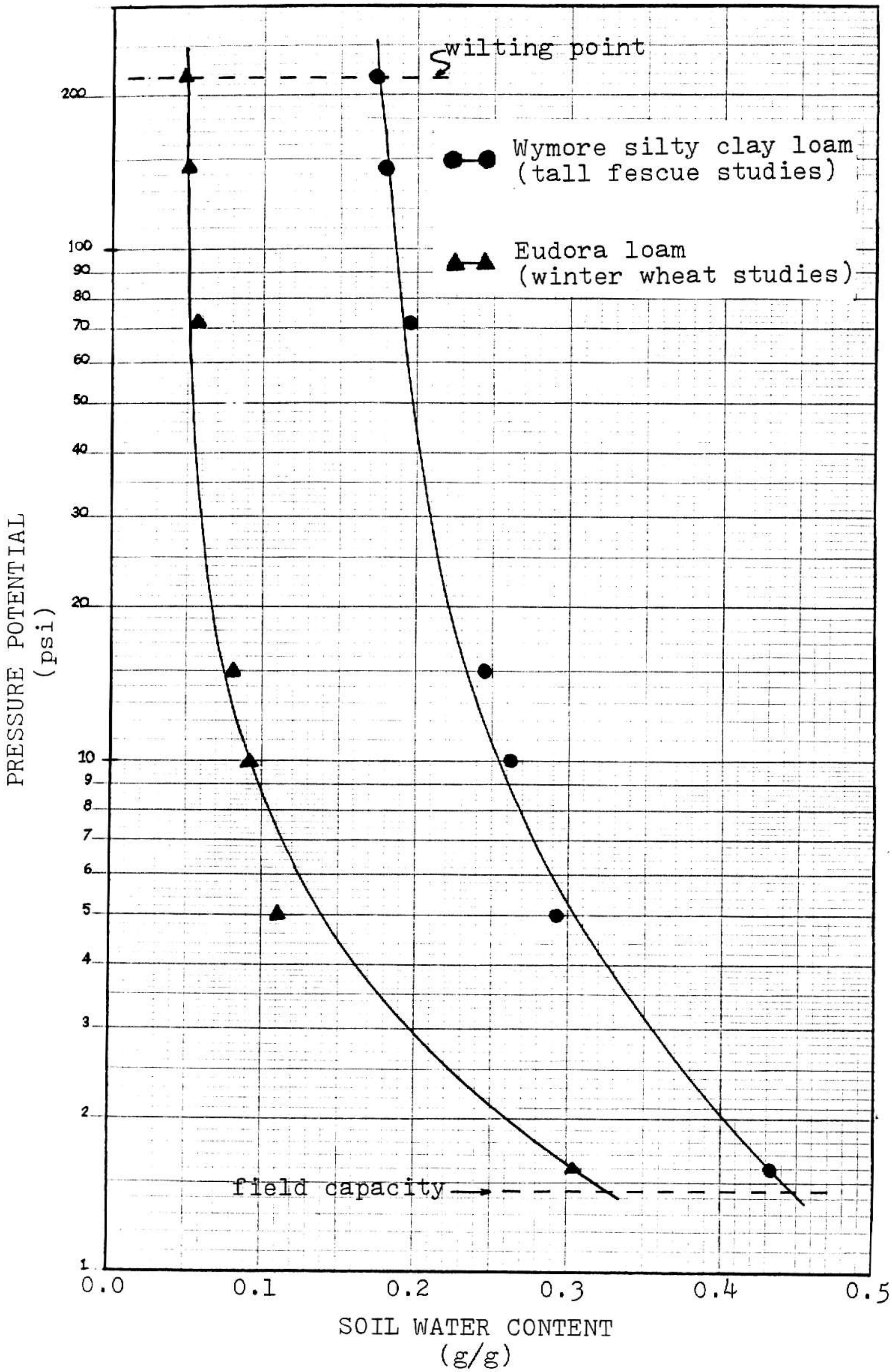
APPENDIX

Appendix Figure 1. Soil moisture release curves.



SPRING 1979 DATA-CENTURK WHEAT

APPENDIX TABLE 1

PLANT PART	TREATMENT	WEEK	REP	%K	%CA	%MG	MEQ RATIO
CROWN	AGLIM	1	1	1.77	0.1600	0.1248	2.48
CROWN	AGLIM	1	2	2.29	0.1710	0.1225	3.15
CROWN	AGLIM	1	3	2.40	0.1670	0.1229	3.33
CROWN	AGLIM	1	4	2.64	0.1650	0.1608	3.56
CROWN	AGLIM	2	1	2.23	0.1470	0.1143	3.41
CROWN	AGLIM	2	2	2.37	0.1630	0.1236	3.31
CROWN	AGLIM	2	3	2.33	0.2380	0.1263	2.68
CROWN	AGLIM	2	4	2.18	0.1630	0.1197	3.10
CROWN	AGLIM	3	1	3.65	0.2620	0.1427	3.76
CROWN	AGLIM	3	2	4.03	0.2200	0.1693	4.14
CROWN	AGLIM	3	3	4.19	0.2630	0.1564	4.12
CROWN	AGLIM	3	4	4.27	0.2370	0.1892	3.99
CROWN	AGLIM	4	1	3.50	0.2250	0.1386	3.96
CROWN	AGLIM	4	2	4.62	0.2380	0.1679	4.60
CROWN	AGLIM	4	3	4.62	0.2450	0.1827	4.34
CROWN	AGLIM	4	4	4.47	0.2520	0.1704	4.30
CROWN	AGLIM	5	1	2.96	0.5540	0.1400	1.93
CROWN	AGLIM	5	2	3.42	0.7340	0.1700	1.73
CROWN	AGLIM	5	3	3.26	0.2680	0.1790	2.97
CROWN	AGLIM	5	4	3.04	0.3920	0.1650	2.35
CROWN	AGLIM	6	1	3.31	0.3020	0.1560	3.03
CROWN	AGLIM	6	2	3.54	0.2730	0.1610	3.37
CROWN	AGLIM	6	3	3.08	0.2540	0.1780	2.88
CROWN	AGLIM	6	4	3.02	0.3190	0.1580	2.71
CROWN	AGLIM	7	1	4.20	0.3320	0.1790	3.43
CROWN	AGLIM	7	2	4.73	0.4920	0.1920	3.30
CROWN	AGLIM	7	3	4.75	0.3650	0.1830	3.65
CROWN	AGLIM	7	4	4.74	0.3130	0.1970	3.81
CROWN	AGLIM	8	1	5.55	0.2600	0.1500	5.61
CROWN	AGLIM	8	2	5.72	0.3360	0.1630	4.85
CROWN	AGLIM	8	3	5.58	0.3460	0.1580	4.72

SPRING 1979 DATA-CENTURK WHEAT

APPENDIX TABLE 1

PLANT PART	TREATMENT	WEEK	REP	%K	%CA	%MG	MEQ RATIO
CROWN	AGLIM	8	4	5.13	0.2960	0.1750	4.50
CROWN	AGLIM	9	1	5.18	0.3020	0.1820	4.41
CROWN	AGLIM	9	2	5.94	0.2920	0.2010	4.88
CROWN	AGLIM	9	3	5.09	0.2180	0.1590	5.43
CROWN	AGLIM	9	4	5.81	0.2690	0.1320	6.12
CROWN	CHECK	1	1	1.47	0.0960	0.0762	3.40
CROWN	CHECK	1	2	1.81	0.1080	0.1064	3.27
CROWN	CHECK	1	3	1.80	0.1110	0.0884	3.59
CROWN	CHECK	1	4	1.85	0.1070	0.1092	2.68
CROWN	CHECK	2	1	1.79	0.1190	0.0962	3.31
CROWN	CHECK	2	2	1.83	0.1200	0.1045	3.06
CROWN	CHECK	2	3	1.96	0.1250	0.0966	3.53
CROWN	CHECK	2	4	1.84	0.1190	0.0904	3.52
CROWN	CHECK	3	1	2.98	0.1810	0.1238	3.97
CROWN	CHECK	3	2	2.60	0.1730	0.1247	3.52
CROWN	CHECK	3	3	2.87	0.1510	0.1140	4.34
CROWN	CHECK	3	4	3.09	0.1600	0.1193	4.44
CROWN	CHECK	4	1	3.69	0.1780	0.1332	4.76
CROWN	CHECK	4	2	3.00	0.1870	0.1440	3.62
CROWN	CHECK	4	3	3.80	0.1820	0.1221	5.08
CROWN	CHECK	4	4	3.54	0.1600	0.1247	4.96
CROWN	CHECK	5	1	3.17	0.4360	0.1530	2.36
CROWN	CHECK	5	2	2.74	0.2110	0.1450	3.12
CROWN	CHECK	5	3	2.84	0.2280	0.1410	3.16
CROWN	CHECK	5	4	3.04	0.1760	0.1380	3.86
CROWN	CHECK	6	1	3.07	0.2170	0.1460	3.44
CROWN	CHECK	6	2	3.05	0.2490	0.1470	3.24
CROWN	CHECK	6	3	2.91	0.2820	0.1480	2.84
CROWN	CHECK	6	4	3.04	0.6250	0.1570	1.76
CROWN	CHECK	7	1	4.58	0.3330	0.1790	3.92
CROWN	CHECK	7	2	4.06	0.5610	0.1770	2.44

SPRING 1979 DATA-CENTURK WHEAT

APPENDIX TABLE 1

PLANT PART	TREATMENT	WEEK	REP	%K	%CA	%MG	MEQ RATIO
CROWN	CHECK	7	3	4.35	0.6410	0.1910	2.33
CROWN	CHECK	7	4	4.13	0.5510	0.1230	2.81
CROWN	CHECK	8	1	4.94	0.2390	0.1420	5.46
CROWN	CHECK	8	2	4.73	0.2800	0.1390	4.76
CROWN	CHECK	8	3	4.98	0.3040	0.1490	4.64
CROWN	CHECK	8	4	4.88	0.2330	0.1330	5.06
CROWN	CHECK	9	1	5.37	0.2390	0.1460	5.85
CROWN	CHECK	9	2	4.71	0.2420	0.1490	4.95
CROWN	CHECK	9	3	5.24	0.2430	0.1360	5.75
CROWN	CHECK	9	4	5.12	0.2080	0.1230	6.39
CROWN	DOLOM	1	1	2.42	0.1160	0.1579	3.30
CROWN	DOLOM	1	2	2.39	0.1270	0.1658	3.06
CROWN	DOLOM	1	3	2.42	0.1250	0.1637	3.14
CROWN	DOLOM	1	4	1.90	0.1420	0.1030	3.07
CROWN	DOLOM	2	1	2.25	0.1170	0.1350	3.40
CROWN	DOLOM	2	2	2.35	0.1430	0.1646	2.91
CROWN	DOLOM	2	3	2.20	0.1290	0.1456	3.06
CROWN	DOLOM	2	4	1.96	0.1090	0.1175	3.32
CROWN	DOLOM	3	1	4.41	0.1950	0.2365	3.87
CROWN	DOLOM	3	2	3.73	0.1970	0.2002	3.63
CROWN	DOLOM	3	3	4.29	0.1930	0.2150	4.02
CROWN	DOLOM	3	4	3.21	0.1470	0.1663	3.91
CROWN	DOLOM	4	1	4.49	0.1870	0.2150	4.25
CROWN	DOLOM	4	2	4.46	0.1990	0.2147	4.20
CROWN	DOLOM	4	3	4.33	0.1790	0.1899	4.51
CROWN	DOLOM	4	4	4.33	0.1630	0.1820	4.79
CROWN	DOLOM	5	1	3.47	0.2880	0.1780	3.06
CROWN	DOLOM	5	2	3.36	0.2070	0.1770	3.45
CROWN	DOLOM	5	3	3.19	0.3810	0.1740	2.45
CROWN	DOLOM	5	4	3.06	0.6880	0.1880	1.57
CROWN	DOLOM	6	1	3.30	0.1960	0.1750	3.49

SPRING 1979 DATA-CENTURK WHEAT

APPENDIX TAPLE 1

PLANT PART	TREATMENT	WEEK	REP	%K	%CA	%MG	MEQ RATIO
CROWN	DOLOM	6	2	3.22	0.4890	0.1890	2.09
CROWN	DOLOM	6	3	3.35	0.1990	0.2000	3.25
CROWN	DOLOM	6	4	2.92	0.3820	0.2030	2.09
CROWN	DOLOM	7	1	4.92	0.2670	0.2130	4.08
CROWN	DOLOM	7	2	4.38	0.3630	0.2150	3.13
CROWN	DOLOM	7	3	4.23	0.2930	0.2000	3.48
CROWN	DOLOM	7	4	4.61	0.4240	0.1960	3.16
CROWN	DOLOM	8	1	5.55	0.2460	0.2040	4.89
CROWN	DOLOM	8	2	5.38	0.2570	0.1910	4.82
CROWN	DOLOM	8	3	5.06	0.2950	0.2000	4.15
CROWN	DOLOM	8	4	5.30	0.2330	0.1630	5.42
CROWN	DOLOM	9	1	5.46	0.2010	0.1650	5.92
CROWN	DOLOM	9	2	5.61	0.2290	0.1960	5.21
CROWN	DOLOM	9	3	5.32	0.2290	0.1790	5.20
CROWN	DOLOM	9	4	5.53	0.2340	0.1780	5.37
FORAGE	AGLIM	1	1	1.45	0.3150	0.1439	1.35
FORAGE	AGLIM	1	2	1.81	0.3890	0.1323	1.53
FORAGE	AGLIM	1	3	1.92	0.3310	0.1325	1.79
FORAGE	AGLIM	1	4	1.96	0.3290	0.1493	1.75
FORAGE	AGLIM	2	1	1.77	0.3580	0.1310	1.58
FORAGE	AGLIM	2	2	2.17	0.3710	0.1361	1.87
FORAGE	AGLIM	2	3	2.28	0.3850	0.1391	1.90
FORAGE	AGLIM	2	4	1.92	0.3490	0.1286	1.78
FORAGE	AGLIM	3	1	3.05	0.4500	0.1534	2.22
FORAGE	AGLIM	3	2	3.17	0.5490	0.1720	1.97
FORAGE	AGLIM	3	3	3.10	0.5790	0.1596	1.89
FORAGE	AGLIM	3	4	2.93	0.4790	0.1857	1.91
FORAGE	AGLIM	4	1	3.81	0.5090	0.1324	2.69
FORAGE	AGLIM	4	2	3.68	0.6080	0.1708	2.12
FORAGE	AGLIM	4	3	3.82	0.5650	0.1931	2.22
FORAGE	AGLIM	4	4	3.69	0.5790	0.1688	2.21

SPRING 1979 DATA-CENTURK WHEAT

APPENDIX TABLE 1

PLANT PART	TREATMENT	WEEK	REP	%K	%CA	%MG	MEQ RATIO
FORAGE	AGLIM	5	1	2.84	0.7230	0.1480	1.51
FORAGE	AGLIM	5	2	3.17	0.7760	0.1580	1.57
FORAGE	AGLIM	5	3	2.95	0.5490	0.2010	1.72
FORAGE	AGLIM	5	4	3.16	0.6170	0.1640	1.83
FORAGE	AGLIM	6	1	3.01	0.6210	0.1420	1.80
FORAGE	AGLIM	6	2	3.08	0.6740	0.1690	1.66
FORAGE	AGLIM	6	3	2.90	0.6380	0.1930	1.55
FORAGE	AGLIM	6	4	2.85	0.6120	0.1610	1.66
FORAGE	AGLIM	7	1	4.10	0.5150	0.1620	2.69
FORAGE	AGLIM	7	2	4.24	0.6460	0.1810	2.30
FORAGE	AGLIM	7	3	4.27	0.6100	0.2050	2.31
FORAGE	AGLIM	7	4	4.68	0.4540	0.2100	3.00
FORAGE	AGLIM	8	1	5.33	0.4240	0.1450	4.12
FORAGE	AGLIM	8	2	5.83	0.4800	0.1430	4.18
FORAGE	AGLIM	8	3	5.37	0.5530	0.1430	3.49
FORAGE	AGLIM	8	4	5.47	0.3770	0.1540	4.44
FORAGE	AGLIM	9	1	5.02	0.5450	0.1430	3.30
FORAGE	AGLIM	9	2	5.22	0.5270	0.1490	3.46
FORAGE	AGLIM	9	3	4.96	0.4140	0.1780	3.59
FORAGE	AGLIM	9	4	5.23	0.5000	0.2190	3.76
FORAGE	CHECK	1	1	1.47	0.2240	0.1084	1.87
FORAGE	CHECK	1	2	1.53	0.2210	0.1413	1.73
FORAGE	CHECK	1	3	1.79	0.2650	0.1160	2.01
FORAGE	CHECK	1	4	1.62	0.2120	0.1282	1.96
FORAGE	CHECK	2	1	1.65	0.2750	0.1189	1.80
FORAGE	CHECK	2	2	1.64	0.2450	0.1209	1.89
FORAGE	CHECK	2	3	1.82	0.2590	0.1133	2.09
FORAGE	CHECK	2	4	1.74	0.2860	0.1141	1.88
FORAGE	CHECK	3	1	2.51	0.3080	0.1470	2.34
FORAGE	CHECK	3	2	2.56	0.2980	0.1488	2.42
FORAGE	CHECK	3	3	2.40	0.3100	0.1251	2.38

SPRING 1979 DATA-CENTURK WHEAT

APPENDIX TABLE 1

PLANT PART	TREATMENT	WEEK	REP	%K	%CA	%MG	MEQ RATIO
FORAGE	CHECK	3	4	2.53	0.3530	0.1329	2.27
FORAGE	CHECK	4	1	3.22	0.4080	0.1349	2.62
FORAGE	CHECK	4	2	3.39	0.4110	0.1520	2.63
FORAGE	CHECK	4	3	3.48	0.3910	0.1292	2.95
FORAGE	CHECK	4	4	3.24	0.3850	0.1319	2.76
FORAGE	CHECK	5	1	2.96	0.4790	0.1430	2.12
FORAGE	CHECK	5	2	2.56	0.4470	0.1400	1.94
FORAGE	CHECK	5	3	2.62	0.5330	0.1410	1.75
FORAGE	CHECK	5	4	2.65	0.4300	0.1380	2.07
FORAGE	CHECK	6	1	2.92	0.5250	0.1480	1.97
FORAGE	CHECK	6	2	2.54	0.4760	0.1370	1.86
FORAGE	CHECK	6	3	2.83	0.5530	0.1400	1.85
FORAGE	CHECK	6	4	2.69	0.4990	0.1370	1.90
FORAGE	CHECK	7	1	4.26	0.5290	0.1610	2.75
FORAGE	CHECK	7	2	4.59	0.5030	0.1630	3.05
FORAGE	CHECK	7	3	4.20	0.6320	0.1600	2.40
FORAGE	CHECK	7	4	4.14	0.4540	0.1470	3.05
FORAGE	CHECK	8	1	5.16	0.4310	0.1390	4.01
FORAGE	CHECK	8	2	4.82	0.4140	0.1330	3.89
FORAGE	CHECK	8	3	5.03	0.4670	0.1270	3.81
FORAGE	CHECK	8	4	5.07	0.3490	0.1120	4.87
FORAGE	CHECK	9	1	4.88	0.4060	0.1340	3.99
FORAGE	CHECK	9	2	4.44	0.4650	0.1410	3.26
FORAGE	CHECK	9	3	4.78	0.4560	0.1270	3.68
FORAGE	CHECK	9	4	4.84	0.3830	0.1210	4.26
FORAGE	DOLOM	1	1	1.92	0.2290	0.1879	1.86
FORAGE	DOLOM	1	2	1.86	0.2490	0.2091	1.61
FORAGE	DOLOM	1	3	1.84	0.2230	0.1846	1.79
FORAGE	DOLOM	1	4	1.75	0.2720	0.1546	1.70
FORAGE	DOLOM	2	1	2.15	0.2580	0.1684	2.06
FORAGE	DOLOM	2	2	1.87	0.2700	0.1857	1.66

SPRING 1979 DATA-CENTURK WHEAT

APPENDIX TABLE 1

PLANT PART	TREATMENT	WEEK	REP	%K	%CA	%MG	MEQ RATIO
FORAGE	DOLOM	2	3	1.85	0.2690	0.1793	1.68
FORAGE	DOLOM	2	4	1.75	0.2130	0.1379	2.04
FORAGE	DOLOM	3	1	3.29	0.3600	0.2550	2.16
FORAGE	DOLOM	3	2	2.84	0.3750	0.2124	2.01
FORAGE	DOLOM	3	3	3.02	0.3750	0.2221	2.09
FORAGE	DOLOM	3	4	2.71	0.3120	0.1959	2.19
FORAGE	DOLOM	4	1	3.70	0.4330	0.2258	2.36
FORAGE	DOLOM	4	2	3.67	0.4600	0.2371	2.21
FORAGE	DOLOM	4	3	3.69	0.4470	0.2262	2.31
FORAGE	DOLOM	4	4	3.49	0.3810	0.2123	2.45
FORAGE	DOLOM	5	1	3.10	0.4590	0.2160	1.95
FORAGE	DOLOM	5	2	2.83	0.4570	0.2050	1.82
FORAGE	DOLOM	5	3	2.79	0.5650	0.2020	1.59
FORAGE	DOLOM	5	4	2.94	0.4530	0.2220	1.84
FORAGE	DOLOM	6	1	3.07	0.5010	0.2490	1.73
FORAGE	DOLOM	6	2	2.97	0.6320	0.2080	1.76
FORAGE	DOLOM	6	3	3.09	0.5030	0.2090	1.87
FORAGE	DOLOM	6	4	2.83	0.5370	0.2050	1.66
FORAGE	DOLOM	7	1	4.46	0.4850	0.2750	2.44
FORAGE	DOLOM	7	2	4.16	0.5620	0.2580	2.16
FORAGE	DOLOM	7	3	4.20	0.5070	0.2470	2.36
FORAGE	DOLOM	7	4	4.64	0.5670	0.2100	2.60
FORAGE	DOLOM	8	1	4.82	0.3870	0.1930	3.50
FORAGE	DOLOM	8	2	5.44	0.3920	0.1930	3.93
FORAGE	DOLOM	8	3	5.28	0.5330	0.2080	3.09
FORAGE	DOLOM	8	4	5.35	0.4930	0.1580	4.13
FORAGE	DOLOM	9	1	5.04	0.3910	0.1880	3.69
FORAGE	DOLOM	9	2	4.93	0.4210	0.2010	3.36
FORAGE	DOLOM	9	3	4.91	0.3940	0.1850	3.60
FORAGE	DOLOM	9	4	4.97	0.4510	0.1650	3.52

SPRING 1980 DATA-NEWTON WHEAT

APPENDIX TABLE 2

PLANT PART	TREATMENT	WEEK	REP	%K	%CA	%MG	MEQ RATIO
CROWN	AGLIM	1	1	2.87	0.2350	0.1289	3.29
CROWN	AGLIM	1	2	2.75	0.2060	0.1260	3.41
CROWN	AGLIM	1	3	2.63	0.2000	0.1300	3.25
CROWN	AGLIM	1	4	2.68	0.2490	0.1170	3.17
CROWN	AGLIM	2	1	3.04	0.1850	0.1370	3.79
CROWN	AGLIM	2	2	3.28	0.2090	0.1450	3.75
CROWN	AGLIM	2	3	3.14	0.1940	0.1440	3.73
CROWN	AGLIM	2	4	2.96	0.2060	0.1310	3.60
CROWN	AGLIM	3	1	3.90	0.2631	0.1750	3.64
CROWN	AGLIM	3	2	4.00	0.2580	0.1810	3.69
CROWN	AGLIM	3	3	4.28	0.2613	0.1950	3.76
CROWN	AGLIM	3	4	3.95	0.2438	0.1788	3.76
CROWN	AGLIM	4	1	4.68	0.2700	0.1938	4.07
CROWN	AGLIM	4	2	4.80	0.2713	0.1975	4.12
CROWN	AGLIM	4	3	4.35	0.2717	0.2050	2.44
CROWN	AGLIM	4	4	4.88	0.2767	0.1917	4.22
CROWN	AGLIM	5	1	4.23	0.2700	0.1650	4.00
CROWN	AGLIM	5	2	4.93	0.2731	0.1800	4.46
CROWN	AGLIM	5	3	4.75	0.2667	0.1700	4.45
CROWN	AGLIM	5	4	4.95	0.2867	0.1817	4.33
CROWN	AGLIM	6	1	3.88	0.2300	0.1450	4.24
CROWN	AGLIM	6	2	4.23	0.2250	0.1550	4.51
CROWN	AGLIM	6	3	4.13	0.2325	0.1650	4.20
CROWN	AGLIM	6	4	4.30	0.2175	0.1525	4.70
CROWN	AGLIM	7	1	4.95	0.3375	0.1825	3.97
CROWN	AGLIM	7	2	5.43	0.2450	0.1525	5.61
CROWN	AGLIM	7	3	5.35	0.2775	0.1900	4.64
CROWN	AGLIM	7	4	5.48	0.2725	0.1625	5.20
CROWN	AGLIM	8	1	3.58	0.1650	0.0975	5.63
CROWN	AGLIM	8	2	3.25	0.1475	0.0925	5.55
CROWN	AGLIM	8	3	3.60	0.1700	0.1025	5.44

SPRING 1980 DATA-NEWTON WHEAT

APPENDIX TABLE 2

PLANT PART	TREATMENT	WEEK	REP	%K	%CA	%MG	MEQ RATIO
CROWN	AGLIM	8	4	3.98	0.1675	0.1150	5.71
CROWN	AGLIM	9	1	1.75	0.1275	0.0750	3.57
CROWN	AGLIM	9	2	1.93	0.1250	0.0575	4.50
CROWN	AGLIM	9	3	1.58	0.1400	0.0550	3.51
CROWN	AGLIM	9	4	1.65	0.1225	0.0550	3.97
CROWN	CHECK	1	1	1.98	0.1850	0.1012	2.88
CROWN	CHECK	1	2	1.65	0.1713	0.0905	2.64
CROWN	CHECK	1	3	1.93	0.1700	0.0930	3.06
CROWN	CHECK	1	4	2.33	0.1690	0.1080	3.44
CROWN	CHECK	2	1	2.46	0.1570	0.1150	3.64
CROWN	CHECK	2	2	1.89	0.1430	0.0830	3.46
CROWN	CHECK	2	3	2.26	0.1680	0.1030	3.43
CROWN	CHECK	2	4	2.53	0.1650	0.1170	3.77
CROWN	CHECK	3	1	2.75	0.2017	0.1334	3.34
CROWN	CHECK	3	2	2.73	0.1850	0.1350	3.43
CROWN	CHECK	3	3	3.28	0.2250	0.1613	3.43
CROWN	CHECK	3	4	3.78	0.2313	0.1725	3.76
CROWN	CHECK	4	1	3.73	0.1863	0.1350	4.68
CROWN	CHECK	4	2	3.35	0.2475	0.1725	3.59
CROWN	CHECK	4	3	3.48	0.2325	0.1675	3.51
CROWN	CHECK	4	4	4.33	0.2400	0.1834	4.09
CROWN	CHECK	5	1	3.93	0.2025	0.1575	4.36
CROWN	CHECK	5	2	3.68	0.2017	0.1434	4.31
CROWN	CHECK	5	3	3.78	0.1717	0.1450	4.72
CROWN	CHECK	5	4	5.02	0.2084	0.1500	5.65
CROWN	CHECK	6	1	3.40	0.4925	0.1575	2.32
CROWN	CHECK	6	2	3.23	0.2075	0.1175	4.13
CROWN	CHECK	6	3	3.38	0.2125	0.1175	4.27
CROWN	CHECK	6	4	3.20	0.2125	0.1150	4.08
CROWN	CHECK	7	1	4.55	0.3125	0.1575	4.08
CROWN	CHECK	7	2	3.75	0.2725	0.1275	3.98

SPRING 1980 DATA-NEWTON WHEAT

APPENDIX TABLE 2

PLANT PART	TREATMENT	WEEK	REP	%K	%CA	%MG	MEQ RATIO
CROWN	CHECK	7	3	4.10	0.3125	0.1475	3.78
CROWN	CHECK	7	4	4.18	0.3050	0.1575	3.79
CROWN	CHECK	8	1	3.53	0.1875	0.1100	4.91
CROWN	CHECK	8	2	2.88	0.1750	0.0775	4.88
CROWN	CHECK	8	3	2.88	0.1825	0.0900	4.46
CROWN	CHECK	8	4	3.05	0.1650	0.1050	4.62
CROWN	CHECK	9	1	1.33	0.1425	0.0600	2.82
CROWN	CHECK	9	2	0.75	0.1475	0.0350	1.87
CROWN	CHECK	9	3	1.90	0.1625	0.0625	3.67
CROWN	CHECK	9	4	1.83	0.1575	0.0600	3.66
CROWN	DOLOM	1	1	2.58	0.1738	0.1763	2.85
CROWN	DOLOM	1	2	2.88	0.1520	0.1540	3.64
CROWN	DOLOM	1	3	2.18	0.1550	0.1370	2.93
CROWN	DOLOM	1	4	2.71	0.1620	0.1610	3.25
CROWN	DOLOM	2	1	2.96	0.1480	0.1860	3.34
CROWN	DOLOM	2	2	3.17	0.1480	0.1690	3.81
CROWN	DOLOM	2	3	2.99	0.1490	0.1770	3.48
CROWN	DOLOM	2	4	3.26	0.1590	0.1840	3.62
CROWN	DOLOM	3	1	4.37	0.1980	0.2390	3.78
CROWN	DOLOM	3	2	4.05	0.1988	0.2325	3.57
CROWN	DOLOM	3	3	3.86	0.1888	0.2088	3.71
CROWN	DOLOM	3	4	3.70	0.1938	0.2175	3.43
CROWN	DOLOM	4	1	4.85	0.2017	0.2684	3.86
CROWN	DOLOM	4	2	4.53	0.2034	0.2367	3.91
CROWN	DOLOM	4	3	7.33	0.2010	0.2250	6.57
CROWN	DOLOM	4	4	4.65	0.1850	0.2288	4.24
CROWN	DOLOM	5	1	4.90	0.1890	0.2367	4.41
CROWN	DOLOM	5	2	4.58	0.2050	0.2184	4.16
CROWN	DOLOM	5	3	4.40	0.1900	0.1888	4.59
CROWN	DOLOM	5	4	4.65	0.2034	0.2217	4.19
CROWN	DOLOM	6	1	4.13	0.1675	0.1825	4.52

SPRING 1980 DATA-NEWTON WHEAT

APPENDIX TABLE 2

PLANT PART	TREATMENT	WEEK	REP	%K	%CA	%MG	MEQ RATIO
CROWN	DOLOM	6	2	4.15	0.1975	0.1950	4.10
CROWN	DOLOM	6	3	4.15	0.1875	0.1800	4.39
CROWN	DOLOM	6	4	4.23	0.1890	0.1750	4.63
CROWN	DOLOM	7	1	5.18	0.2325	0.2175	4.49
CROWN	DOLOM	7	2	5.00	0.2290	0.1900	4.61
CROWN	DOLOM	7	3	4.73	0.2550	0.1925	4.24
CROWN	DOLOM	7	4	4.95	0.2790	0.2025	4.29
CROWN	DOLOM	8	1	3.80	0.1325	0.1175	5.97
CROWN	DOLOM	8	2	3.63	0.1350	0.1150	5.73
CROWN	DOLOM	8	3	2.93	0.1275	0.0875	5.53
CROWN	DOLOM	8	4	3.73	0.1525	0.1325	5.15
CROWN	DOLOM	9	1	1.63	0.1225	0.0825	3.23
CROWN	DOLOM	9	2	1.50	0.1250	0.0650	3.31
CROWN	DOLOM	9	3	1.38	0.1175	0.0638	3.18
CROWN	DOLOM	9	4	1.65	0.1275	0.0713	3.45
FORAGE	AGLIM	1	1	3.25	0.6920	0.1530	1.76
FORAGE	AGLIM	1	2	2.97	0.6750	0.1510	1.65
FORAGE	AGLIM	1	3	2.49	0.5650	0.1470	1.58
FORAGE	AGLIM	1	4	2.76	0.6870	0.1340	1.56
FORAGE	AGLIM	2	1	3.15	0.6030	0.1360	1.95
FORAGE	AGLIM	2	2	3.29	0.6440	0.1530	1.88
FORAGE	AGLIM	2	3	3.16	0.5950	0.1570	1.90
FORAGE	AGLIM	2	4	3.63	0.6090	0.1480	2.18
FORAGE	AGLIM	3	1	3.92	0.5750	0.1480	2.45
FORAGE	AGLIM	3	2	3.86	0.5890	0.1530	2.35
FORAGE	AGLIM	3	3	3.95	0.6030	0.1880	2.22
FORAGE	AGLIM	3	4	4.08	0.5290	0.1480	2.71
FORAGE	AGLIM	4	1	4.15	0.6030	0.1620	2.44
FORAGE	AGLIM	4	2	4.81	0.5910	0.1730	2.81
FORAGE	AGLIM	4	3	4.31	0.6470	0.1770	2.35
FORAGE	AGLIM	4	4	4.83	0.5790	0.1520	2.98

SPRING 1980 DATA-NEWTON WHEAT

APPENDIX TABLE 2

PLANT PART	TREATMENT	WEEK	REP	%K	%CA	%MG	MEQ RATIO
FORAGE	AGLIM	5	1	4.61	0.5220	0.1340	3.18
FORAGE	AGLIM	5	2	4.96	0.5790	0.1530	3.06
FORAGE	AGLIM	5	3	4.28	0.5190	0.1390	2.93
FORAGE	AGLIM	5	4	4.59	0.5290	0.1430	3.08
FORAGE	AGLIM	6	1	4.36	0.4880	0.1260	3.21
FORAGE	AGLIM	6	2	4.52	0.4640	0.1400	3.33
FORAGE	AGLIM	6	3	4.55	0.4650	0.1410	3.34
FORAGE	AGLIM	6	4	4.60	0.4190	0.1290	3.79
FORAGE	AGLIM	7	1	4.83	0.4790	0.1360	3.52
FORAGE	AGLIM	7	2	5.00	0.4690	0.1410	3.70
FORAGE	AGLIM	7	3	4.90	0.4760	0.1470	3.50
FORAGE	AGLIM	7	4	4.98	0.4830	0.1270	3.69
FORAGE	AGLIM	8	1	3.88	0.4070	0.1250	3.24
FORAGE	AGLIM	8	2	4.00	0.4470	0.1340	3.07
FORAGE	AGLIM	8	3	3.82	0.4190	0.1260	3.17
FORAGE	AGLIM	8	4	4.17	0.4530	0.1460	3.08
FORAGE	AGLIM	9	1	3.48	0.4520	0.1235	2.72
FORAGE	AGLIM	9	2	3.36	0.4120	0.1190	2.83
FORAGE	AGLIM	9	3	3.68	0.4590	0.1250	2.84
FORAGE	AGLIM	9	4	2.76	0.2930	0.1110	2.97
FORAGE	CHECK	1	1	2.26	0.6390	0.1520	1.30
FORAGE	CHECK	1	2	1.86	0.5520	0.1480	1.20
FORAGE	CHECK	1	3	2.18	0.5570	0.1340	1.44
FORAGE	CHECK	1	4	2.60	0.5240	0.1390	1.77
FORAGE	CHECK	2	1	2.82	0.5980	0.1450	1.73
FORAGE	CHECK	2	2	2.30	0.5190	0.1390	1.60
FORAGE	CHECK	2	3	3.87	0.5350	0.1370	2.61
FORAGE	CHECK	2	4	2.96	0.5460	0.1410	1.95
FORAGE	CHECK	3	1	3.00	0.5460	0.1450	1.96
FORAGE	CHECK	3	2	2.99	0.4820	0.1390	2.16
FORAGE	CHECK	3	3	3.55	0.5390	0.1520	2.30

SPRING 1980 DATA-NEWTON WHEAT

APPENDIX TABLE 2

PLANT PART	TREATMENT	WEEK	REP	%K	%CA	%MG	MEQ RATIO
FORAGE	CHECK	3	4	3.41	0.5550	0.1660	2.11
FORAGE	CHECK	4	1	3.74	0.5290	0.1590	2.42
FORAGE	CHECK	4	2	3.57	0.5913	0.1650	2.12
FORAGE	CHECK	4	3	3.69	0.4830	0.1450	2.62
FORAGE	CHECK	4	4	3.73	0.5380	0.1680	2.35
FORAGE	CHECK	5	1	4.48	0.4820	0.1390	3.23
FORAGE	CHECK	5	2	4.02	0.4740	0.1280	3.01
FORAGE	CHECK	5	3	3.94	0.4280	0.1270	3.17
FORAGE	CHECK	5	4	4.36	0.4420	0.1340	3.37
FORAGE	CHECK	6	1	3.85	0.4680	0.1300	2.89
FORAGE	CHECK	6	2	3.25	0.4950	0.1210	2.40
FORAGE	CHECK	6	3	3.79	0.4290	0.1190	3.15
FORAGE	CHECK	6	4	3.65	0.4600	0.1180	2.86
FORAGE	CHECK	7	1	4.25	0.4650	0.1340	3.18
FORAGE	CHECK	7	2	4.01	0.4350	0.1140	3.39
FORAGE	CHECK	7	3	4.33	0.4450	0.1120	3.53
FORAGE	CHECK	7	4	4.30	0.4740	0.1300	3.20
FORAGE	CHECK	8	1	3.70	0.4480	0.1330	2.84
FORAGE	CHECK	8	2	3.05	0.3970	0.0970	2.81
FORAGE	CHECK	8	3	3.45	0.4530	0.1210	2.71
FORAGE	CHECK	8	4	3.51	0.4220	0.1300	2.83
FORAGE	CHECK	9	1	2.68	0.3910	0.1170	2.35
FORAGE	CHECK	9	2	2.78	0.3990	0.0980	2.54
FORAGE	CHECK	9	3	3.17	0.3980	0.1140	2.77
FORAGE	CHECK	9	4	3.22	0.4600	0.1180	2.52
FORAGE	DOLOM	1	1	2.81	0.5160	0.2630	1.52
FORAGE	DOLOM	1	2	2.81	0.4830	0.2300	1.67
FORAGE	DOLOM	1	3	2.34	0.5370	0.2220	1.33
FORAGE	DOLOM	1	4	2.68	0.5060	0.2390	1.53
FORAGE	DOLOM	2	1	3.32	0.5210	0.2730	1.75
FORAGE	DOLOM	2	2	3.16	0.5010	0.2310	1.84

SPRING 1980 DATA-NEWTON WHEAT

APPENDIX TABLE 2

PLANT PART	TREATMENT	WEEK	REP	%K	%CA	%MG	MEQ RATIO
FORAGE	DOLOM	2	3	3.30	0.5380	0.2580	1.76
FORAGE	DOLOM	2	4	3.62	0.4900	0.2400	2.10
FORAGE	DOLOM	3	1	3.85	0.4930	0.2570	2.15
FORAGE	DOLOM	3	2	3.84	0.4970	0.2560	2.14
FORAGE	DOLOM	3	3	3.85	0.4740	0.2260	2.33
FORAGE	DOLOM	3	4	3.63	0.4890	0.2190	2.21
FORAGE	DOLOM	4	1	4.64	0.4610	0.2650	2.65
FORAGE	DOLOM	4	2	4.61	0.5210	0.2460	2.55
FORAGE	DOLOM	4	3	4.70	0.5040	0.2460	2.65
FORAGE	DOLOM	4	4	4.48	0.4590	0.2450	2.66
FORAGE	DOLOM	5	1	5.11	0.4080	0.2360	3.29
FORAGE	DOLOM	5	2	4.84	0.4590	0.2240	3.00
FORAGE	DOLOM	5	3	4.71	0.4180	0.1920	3.29
FORAGE	DOLOM	5	4	4.80	0.4380	0.2250	3.04
FORAGE	DOLOM	6	1	4.53	0.3590	0.2010	3.36
FORAGE	DOLOM	6	2	4.60	0.3830	0.1900	3.39
FORAGE	DOLOM	6	3	4.50	0.3920	0.2000	3.20
FORAGE	DOLOM	6	4	4.59	0.3530	0.1810	3.61
FORAGE	DOLOM	7	1	4.90	0.3650	0.1910	3.70
FORAGE	DOLOM	7	2	4.85	0.3710	0.1800	3.72
FORAGE	DOLOM	7	3	4.55	0.3970	0.1640	3.50
FORAGE	DOLOM	7	4	4.55	0.3900	0.1580	3.59
FORAGE	DOLOM	8	1	3.66	0.4590	0.1820	2.47
FORAGE	DOLOM	8	2	3.95	0.3760	0.1450	3.29
FORAGE	DOLOM	8	3	3.62	0.3390	0.1270	3.39
FORAGE	DOLOM	8	4	3.83	0.3860	0.1540	3.07
FORAGE	DOLOM	9	1	3.68	0.4930	0.1760	2.41
FORAGE	DOLOM	9	2	2.90	0.3390	0.1210	2.76
FORAGE	DOLOM	9	3	3.06	0.3630	0.1230	2.77
FORAGE	DOLOM	9	4	3.42	0.4480	0.1550	2.49

SPRING 1979 DATA-TALL FESCUE

APPENDIX TABLE 3

PLANT PART	KG N/HA	WEEK	REP	%N	%K	%CA	%MG	MEQ RATIO
CROWN	0	1	1	1.44	1.68	0.1360	0.1726	2.05
CROWN	0	1	2	1.24	1.67	0.1540	0.1952	1.80
CROWN	0	1	3	1.13	1.44	0.1320	0.1564	1.89
CROWN	0	2	1	1.28	2.00	0.3190	0.2018	1.57
CROWN	0	2	2	1.22	1.72	0.1310	0.1369	2.47
CROWN	0	2	3	1.27	1.83	0.1290	0.1616	2.37
CROWN	0	3	1	1.44	2.39	0.1790	0.2007	2.40
CROWN	0	3	2	1.12	2.13	0.1380	0.1861	2.45
CROWN	0	3	3	1.24	2.33	0.1570	0.1997	2.66
CROWN	0	4	1	1.44	2.48	0.2010	0.2166	2.28
CROWN	0	4	2	2.05	2.39	0.1960	0.2065	2.28
CROWN	0	4	3	1.24	2.17	0.1590	0.1812	2.43
CROWN	0	5	1	1.37	2.90	0.2120	0.1930	2.80
CROWN	0	5	2	1.24	2.48	0.2150	0.2090	2.27
CROWN	0	5	3	1.80	3.40	0.3300	0.2140	2.55
CROWN	0	6	1	0.99	2.51	0.1880	0.1730	2.72
CROWN	0	6	2	0.93	2.48	0.2030	0.2200	2.25
CROWN	0	6	3	1.23	2.86	0.3840	0.2420	1.87
CROWN	0	7	1	0.93	2.80	0.3900	0.1950	2.02
CROWN	0	7	2	0.98	2.65	0.2250	0.2400	2.19
CROWN	0	7	3	1.09	2.89	0.2040	0.2060	2.73
CROWN	0	8	1	0.87	2.38	0.2910	0.2540	1.72
CROWN	0	8	2	0.92	2.37	0.3060	0.2650	1.64
CROWN	0	8	3	1.10	2.73	0.3200	0.2510	1.91
CROWN	0	9	1	0.77	2.06	0.1990	0.2480	1.74
CROWN	0	9	2	0.75	2.32	0.2230	0.2290	1.98
CROWN	0	9	3	0.72	2.29	0.1810	0.1890	2.38
CROWN	135	1	1	1.24	1.73	0.1100	0.1239	2.82
CROWN	135	1	2	1.12	1.47	0.1330	0.1520	1.96
CROWN	135	1	3	1.33	1.54	0.1500	0.1944	1.68
CROWN	135	2	1	2.57	1.94	0.1610	0.1761	2.20

SPRING 1979 DATA-TALL FESCUE

APPENDIX TABLE 3

PLANT PART	KG N/HA	WEEK	REP	%N	%K	%CA	%MG	MEQ RATIO
CROWN	135	2	2	1.51	1.79	0.1420	0.1728	2.15
CROWN	135	2	3	2.23	1.78	0.1300	0.1592	2.33
CROWN	135	3	1	4.01	2.65	0.1620	0.2192	2.60
CROWN	135	3	2	3.44	2.23	0.1670	0.2115	2.22
CROWN	135	3	3	3.13	2.27	0.1560	0.2062	2.35
CROWN	135	4	1	3.15	2.64	0.1980	0.2319	2.33
CROWN	135	4	2	3.77	2.61	0.2050	0.2365	2.25
CROWN	135	4	3	3.79	2.57	0.1770	0.2178	2.46
CROWN	135	5	1	4.79	3.56	0.2530	0.2790	2.56
CROWN	135	5	2	4.56	2.89	0.2340	0.2970	2.05
CROWN	135	5	3	4.80	3.28	0.2360	0.2790	2.42
CROWN	135	6	1	4.89	3.35	0.2980	0.3050	2.14
CROWN	135	6	2	4.09	3.26	0.2220	0.2690	2.51
CROWN	135	6	3	4.13	3.60	0.6020	0.2680	1.77
CROWN	135	7	1	3.67	3.66	0.2580	0.2740	2.64
CROWN	135	7	2	3.91	3.79	0.2050	0.2520	3.13
CROWN	135	7	3	4.12	3.17	0.4530	0.2320	1.94
CROWN	135	8	1	3.22	3.47	0.2770	0.2660	2.49
CROWN	135	8	2	3.80	3.38	0.2540	0.2580	2.55
CROWN	135	8	3	4.00	3.56	0.2680	0.2870	2.46
CROWN	135	9	1	2.41	3.18	0.2140	0.1860	3.13
CROWN	135	9	2	2.51	2.74	0.1540	0.1990	2.91
CROWN	135	9	3	2.17	2.90	0.1710	0.2030	2.94
FORAGE	0	1	1	1.46	1.39	0.2970	0.2158	1.09
FORAGE	0	1	2	1.21	1.35	0.3060	0.2140	1.05
FORAGE	0	1	3	1.18	1.34	0.2650	0.1897	1.19
FORAGE	0	2	1	1.56	1.64	0.1260	0.1423	2.33
FORAGE	0	2	2	1.44	1.40	0.3040	0.2071	1.11
FORAGE	0	2	3	1.36	1.64	0.2540	0.1931	1.47
FORAGE	0	3	1	1.48	1.61	0.3330	0.2190	1.19
FORAGE	0	3	2	1.48	1.57	0.3200	0.2090	1.21

SPRING 1979 DATA-TALL FESCUE

APPENDIX TABLE 3

PLANT PART	KG N/HA	WEEK	REP	%N	%K	%CA	%MG	MEQ RATIO
FORAGE	0	3	3	1.60	1.58	0.3310	0.2237	1.16
FORAGE	0	4	1	1.64	1.35	0.4000	0.2019	0.94
FORAGE	0	4	2	1.91	1.66	0.3430	0.2094	1.24
FORAGE	0	4	3	1.40	1.51	0.3180	0.1961	1.21
FORAGE	0	5	1	1.82	2.09	0.3660	0.1830	1.60
FORAGE	0	5	2	1.70	1.96	0.3690	0.1980	1.44
FORAGE	0	5	3	2.06	2.55	0.3450	0.2000	1.94
FORAGE	0	6	1	1.62	2.02	0.3740	0.1820	1.54
FORAGE	0	6	2	1.55	1.76	0.3960	0.2040	1.23
FORAGE	0	6	3	1.68	2.02	0.3890	0.2080	1.41
FORAGE	0	7	1	1.72	2.80	0.3900	0.1950	2.02
FORAGE	0	7	2	1.79	2.10	0.3640	0.2090	1.52
FORAGE	0	7	3	1.71	2.30	0.3960	0.2020	1.62
FORAGE	0	8	1	1.72	2.82	0.4130	0.2480	1.76
FORAGE	0	8	2	1.80	2.66	0.3780	0.2360	1.78
FORAGE	0	8	3	1.90	3.13	0.4150	0.2470	1.95
FORAGE	0	9	1	1.48	2.76	0.3030	0.1770	2.38
FORAGE	0	9	2	1.48	2.87	0.2560	0.1690	2.75
FORAGE	0	9	3	1.50	2.70	0.3900	0.2040	1.91
FORAGE	135	1	1	1.67	1.55	0.2820	0.1729	1.40
FORAGE	135	1	2	1.35	1.30	0.2630	0.1829	1.18
FORAGE	135	1	3	1.57	1.53	0.2900	0.2114	1.23
FORAGE	135	2	1	2.13	1.59	0.3010	0.2052	1.27
FORAGE	135	2	2	2.24	1.62	0.3430	0.2192	1.18
FORAGE	135	2	3	1.88	1.59	0.2990	0.2105	1.26
FORAGE	135	3	1	2.91	1.80	0.3110	0.2238	1.63
FORAGE	135	3	2	2.95	1.75	0.3240	0.2418	1.24
FORAGE	135	3	3	2.66	1.79	0.3210	0.2333	1.30
FORAGE	135	4	1	2.32	1.45	0.3850	0.2189	1.00
FORAGE	135	4	2	2.75	1.39	0.3510	0.1988	1.05
FORAGE	135	4	3	2.19	1.25	0.3570	0.2121	0.91

SPRING 1979 DATA-TALL FESCUE

APPENDIX TABLE 3

PLANT PART	KG N/HA	WEEK	REP	%N	%K	%CA	%MG	MEQ RATIO
FORAGE	135	5	1	3.47	2.44	0.4120	0.2530	1.50
FORAGE	135	5	2	3.30	2.17	0.3940	0.2630	1.34
FORAGE	135	5	3	3.46	2.06	0.3350	0.2460	1.43
FORAGE	135	6	1	3.60	2.70	0.4040	0.2490	1.70
FORAGE	135	6	2	3.42	2.67	0.3590	0.2350	1.83
FORAGE	135	6	3	3.79	2.80	0.3660	0.2650	1.79
FORAGE	135	7	1	3.51	3.70	0.3210	0.2450	2.62
FORAGE	135	7	2	3.99	3.80	0.2630	0.2220	3.10
FORAGE	135	7	3	3.72	3.58	0.3530	0.2530	2.38
FORAGE	135	8	1	3.75	4.11	0.3930	0.2630	2.55
FORAGE	135	8	2	3.08	3.69	0.3130	0.2330	2.71
FORAGE	135	8	3	3.96	3.87	0.3490	0.2630	2.54
FORAGE	135	9	1	2.78	4.06	0.3270	0.2110	3.08
FORAGE	135	9	2	2.75	3.64	0.3290	0.2670	2.43
FORAGE	135	9	3	2.60	3.72	0.3810	0.2660	2.33

SPRING 1980 DATA-TALL FESCUE

APPENDIX TABLE 4

PLANT PART	KG N/HA	WEEK	REP	%N	%K	%CA	%MG	MEQ RATIO
CROWN	0	1	1	4.83	3.10	0.1863	0.2588	2.59
CROWN	0	1	2	1.97	2.75	0.1800	0.2180	2.61
CROWN	0	1	3	1.62	2.61	0.2060	0.2190	2.36
CROWN	0	2	1	2.13	3.33	0.2263	0.2363	2.77
CROWN	0	2	2	1.98	3.22	0.2313	0.2438	2.61
CROWN	0	2	3	2.00	3.25	0.2538	0.2575	2.46
CROWN	0	3	1	1.73	3.53	0.2275	0.2575	2.78
CROWN	0	3	2	2.50	3.85	0.2400	0.2475	3.05
CROWN	0	3	3	2.13	3.50	0.2125	0.2350	2.99
CROWN	0	4	1	1.78	3.85	0.2700	0.2750	2.73
CROWN	0	4	2	1.73	3.70	0.2775	0.2675	2.64
CROWN	0	4	3	1.73	3.60	0.2400	0.2700	2.69
CROWN	0	5	1	2.30	3.80	0.2850	0.2800	2.61
CROWN	0	5	2	2.73	4.05	0.2625	0.3075	2.70
CROWN	0	5	3	1.73	3.60	0.2675	0.2600	2.65
CROWN	0	6	1	1.23	2.50	0.2225	0.2225	5.44
CROWN	0	6	2	0.95	2.78	0.2050	0.2325	2.42
CROWN	0	6	3	1.05	2.58	0.2175	0.2150	2.31
CROWN	0	7	1	0.50	1.88	0.1825	0.2025	1.87
CROWN	0	7	2	0.70	2.00	0.1750	0.1900	2.10
CROWN	0	7	3	0.50	1.95	0.1875	0.1900	2.00
CROWN	0	8	1	0.55	1.38	0.1425	0.1825	1.60
CROWN	0	8	2	0.45	1.25	0.1400	0.1788	1.47
CROWN	0	8	3	0.50	1.28	0.1625	0.1800	1.43
CROWN	0	9	1	0.50	1.25	0.1650	0.1850	1.36
CROWN	0	9	2	0.50	1.08	0.1450	0.1600	1.35
CROWN	0	9	3	0.50	1.18	0.1575	0.1650	1.41
CROWN	135	1	1	5.53	2.85	0.2113	0.2888	2.13
CROWN	135	1	2	2.00	2.70	0.1800	0.2388	2.41
CROWN	135	1	3	5.25	3.55	0.1938	0.2575	2.94
CROWN	135	2	1	6.67	3.57	0.2950	0.3350	2.16

SPRING 1980 DATA-TALL FESCUE

APPENDIX TABLE 4

PLANT PART	KG N/HA	WEEK	REP	%N	%K	%CA	%MG	MEQ RATIO
CROWN	135	2	2	6.00	3.63	0.2490	0.3034	2.51
CROWN	135	2	3	5.53	3.52	0.2313	0.2713	2.66
CROWN	135	3	1	6.70	4.48	0.3025	0.3575	2.58
CROWN	135	3	2	6.53	4.30	0.2725	0.3088	2.82
CROWN	135	3	3	6.70	4.55	0.2675	0.3300	2.87
CROWN	135	4	1	6.75	4.20	0.3290	0.3350	2.47
CROWN	135	4	2	6.48	3.93	0.2925	0.3575	2.28
CROWN	135	4	3	6.53	4.55	0.3350	0.3800	2.43
CROWN	135	5	1	5.70	4.48	0.2650	0.3150	2.93
CROWN	135	5	2	5.45	4.60	0.2500	0.2750	3.35
CROWN	135	5	3	6.20	4.35	0.2500	0.3275	2.82
CROWN	135	6	1	4.05	3.20	0.2800	0.3900	5.71
CROWN	135	6	2	3.45	3.50	0.2550	0.2775	2.52
CROWN	135	6	3	3.75	3.33	0.2625	0.2725	2.40
CROWN	135	7	1	3.00	2.58	0.2275	0.2700	1.97
CROWN	135	7	2	2.55	2.75	0.2325	0.2525	2.17
CROWN	135	7	3	2.70	2.83	0.2525	0.2650	2.10
CROWN	135	8	1	1.30	2.05	0.1525	0.1850	2.30
CROWN	135	8	2	2.00	2.08	0.1550	0.2050	2.16
CROWN	135	8	3	1.75	1.95	0.1225	0.2050	2.17
CROWN	135	9	1	1.30	1.85	0.1475	0.1900	2.13
CROWN	135	9	2	1.25	2.05	0.1500	0.1825	2.33
CROWN	135	9	3	1.78	1.75	0.1675	0.1775	1.95
FORAGE	0	1	1	2.58	1.95	0.3740	0.2440	1.29
FORAGE	0	1	2	1.53	2.11	0.4310	0.2410	1.31
FORAGE	0	1	3	1.33	1.85	0.4250	0.2250	1.19
FORAGE	0	2	1	1.75	2.38	0.3590	0.2110	1.73
FORAGE	0	2	2	1.82	2.27	0.4020	0.2150	1.54
FORAGE	0	2	3	1.68	2.46	0.3840	0.2170	1.70
FORAGE	0	3	1	2.27	3.17	0.3410	0.2260	2.28
FORAGE	0	3	2	2.28	3.55	0.3890	0.2270	2.38

SPRING 1980 DATA-TALL FESCUE

APPENDIX TABLE 4

PLANT PART	KG N/HA	WEEK	REP	%N	%K	%CA	%MG	MEQ RATIO
FORAGE	0	3	3	2.48	3.33	0.4000	0.2330	2.18
FORAGE	0	4	1	2.15	3.44	0.4290	0.2470	2.11
FORAGE	0	4	2	2.10	3.33	0.4340	0.2285	2.11
FORAGE	0	4	3	2.00	3.15	0.3880	0.2190	2.16
FORAGE	0	5	1	2.42	3.30	0.3830	0.2370	2.19
FORAGE	0	5	2	2.61	3.60	0.3530	0.2180	2.59
FORAGE	0	5	3	2.31	3.43	0.3940	0.2310	2.27
FORAGE	0	6	1	1.77	3.15	0.3390	0.2160	2.32
FORAGE	0	6	2	1.80	3.24	0.3170	0.2290	2.39
FORAGE	0	6	3	1.80	3.25	0.3060	0.2000	2.62
FORAGE	0	7	1	1.31	2.57	0.2060	0.1610	2.79
FORAGE	0	7	2	1.68	3.05	0.2430	0.1900	2.81
FORAGE	0	7	3	1.50	2.79	0.2960	0.1790	2.42
FORAGE	0	8	1	1.18	2.50	0.2830	0.1920	2.14
FORAGE	0	8	2	1.08	2.25	0.3150	0.2000	1.79
FORAGE	0	8	3	1.17	2.27	0.3100	0.1900	1.87
FORAGE	0	9	1	1.12	2.53	0.3620	0.2210	1.79
FORAGE	0	9	2	1.00	2.27	0.3080	0.2050	1.80
FORAGE	0	9	3	1.08	2.30	0.3730	0.2180	1.61
FORAGE	135	1	1	3.00	1.98	0.4060	0.2620	1.21
FORAGE	135	1	2	1.55	2.01	0.3620	0.2110	1.45
FORAGE	135	1	3	3.00	2.44	0.3310	0.2520	1.68
FORAGE	135	2	1	4.19	2.55	0.4190	0.2600	1.56
FORAGE	135	2	2	4.12	2.92	0.3180	0.2470	2.06
FORAGE	135	2	3	2.88	2.42	0.3590	0.2420	1.64
FORAGE	135	3	1	4.89	3.55	0.3370	0.2510	2.42
FORAGE	135	3	2	4.20	3.72	0.3710	0.2550	2.41
FORAGE	135	3	3	4.81	3.77	0.3770	0.2760	2.32
FORAGE	135	4	1	4.69	4.13	0.4010	0.2760	2.47
FORAGE	135	4	2	4.52	3.83	0.3700	0.2770	2.38
FORAGE	135	4	3	4.00	4.03	0.3910	0.2870	2.39

SPRING 1980 DATA-TALL FESCUE

APPENDIX TABLE 4

PLANT PART	KG N/HA	WEEK	REP	%N	%K	%CA	%MG	MEQ RATIO
FORAGE	135	5	1	3.99	4.27	0.3570	0.2730	2.71
FORAGE	135	5	2	4.40	4.05	0.3470	0.2410	2.79
FORAGE	135	5	3	4.20	4.00	0.3520	0.2820	2.51
FORAGE	135	6	1	3.50	3.94	0.2850	0.2370	2.99
FORAGE	135	6	2	3.62	4.15	0.3770	0.2590	2.65
FORAGE	135	6	3	3.68	4.09	0.3610	0.2760	2.57
FORAGE	135	7	1	3.01	3.65	0.3930	0.2470	2.34
FORAGE	135	7	2	2.58	3.45	0.2950	0.2100	2.76
FORAGE	135	7	3	3.20	3.70	0.4680	0.2860	2.02
FORAGE	135	8	1	2.08	3.25	0.2830	0.1990	2.74
FORAGE	135	8	2	1.80	2.90	0.2310	0.1950	2.69
FORAGE	135	8	3	2.48	3.30	0.3720	0.2280	2.26
FORAGE	135	9	1	1.60	2.55	0.2480	0.1960	2.29
FORAGE	135	9	2	1.89	2.87	0.2950	0.2070	2.31
FORAGE	135	9	3	2.00	3.11	0.2690	0.1960	2.69

SOIL AND ENVIRONMENTAL EFFECTS ON FORAGE QUALITY WITH RESPECT TO GRASS TETANY

by

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B.S., Kansas State University, 1979

AN ABSTRACT OF A MASTER'S THESIS

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Grass tetany is a metabolic disorder of ruminants that is caused by low blood serum Mg levels. Grass tetany has been related to the chemical composition of cool-season grass and small grains forages. The influence of soil and environmental factors on forage quality with respect to grass tetany was investigated in field studies utilizing fall fescue and two hard red winter wheat varieties as test forages. The tetany potential was evaluated from the chemical composition of the forages.

An established tall fescue stand was used in the spring of two years to study the effect of recommended N fertilization and environmental factors on the chemical composition of the tall fescue forage. Weekly plant samples, soil moisture samples and maximum and minimum soil temperatures were taken for nine weeks in each year. The results show that N fertilization increases the forage N and K concentrations and increased the number of sampling dates the N and K levels would be considered to be tetany prone. Nitrogen fertilization did not have a great influence on the forage Ca content, but it did increase the number of sampling dates that the forage Mg levels were above the suggested level to be sufficient to prevent grass tetany. Due to increases in forage K concentrations the number of sampling dates that the forage milliequivalent ratios were considered tetany hazardous were increased.

The stage of plant development, the environment and N fertilization contributed to rapid flucuations in the forage chemical composition. Generally K content in the forage increased in response to the first seasonal soil temperature increases and appeared to be rapidly translocated out of the plant crowns to the forage. The mean forage Mg content was correctly estimated from soil chemical properties. There were no general effects due to soil water.

Two fall seeded hard red winter wheat varieties, Centurk and Newton, were used to study the effect of liming an acid soil at the recommended rate and environmental factors on the wheat forage chemical composition. After winter dormancy weekly plant samples, soil moisture samples and maximum and minimum soil temperatures were taken for nine weeks. The results show that liming increased soil pH, soil cation exchange capacity and reduced soil exchangeable Al and Mn. Liming with calcitic stackdust increased soil and forage Ca. Liming with dolomite increased soil and forage Mg and increased the number of sampling dates that the wheat forage Mg was above the level suggested to prevent grass tetany.

Centurk wheat forage K and milliequivalent ratios were positively related to soil temperature and negatively related to soil water. Newton wheat forage Ca and Mg were negatively related to soil temperature and positively related to soil water. The forage milliequivalent ratios in Newton wheat forage were positively related to soil temperature and negatively related to soil water. Liming decreased the magnitude of the Centurk wheat forage milliequivalent ratios and the number of sampling dates the ratio was making the forage tetany prone. Liming increased the magnitude of Newton forage milliequivalent ratios and the number of sampling dates that the ratio was making the forage tetany prone. From the soil chemical properties it was correctly predicted that the wheat forages growing on the dolomite limed soil would have mean Mg contents sufficient to prevent grass tetany.