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To the Graduate Council:

I am submitting herewith a thesis written by William Eugene Bryan entitled "The Effect of Calcium, Potassium, and Boron Fertilization Upon the Chemical Composition and Yield of Alfalfa." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agronomy.

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Major Professor

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THE EFFECT OF CALCIUM, POTASSIUM, AND BORON FERTILIZATION UPON THE CHEMICAL COMPOSITION AND YIELD OF ALFALFA

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

William Eugene Bryan

August 1961

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CHAPTER I

INTRODUCTION

The alfalfa plant is believed to have had its origin in a relatively dry area, possibly Persia (41). This plant grows luxuriantly under its adapted environment, but will not grow well at low fertility levels. In 1952, alfalfa production in Tennessee was only a little more than half that of 1949. Until this time, even though much research had been done with lime and phosphate in alfalfa production, very little attention had been given potassium and boron and the importance of a proper proportion of these elements to meet the crop's needs. Added information from research and farmer experience concerning fertilization, management, and soil adaptation of alfalfa has resulted in more persistent stands and higher yields, thus contributing to a greater emphasis in alfalfa production.

The purpose of this investigation was to evaluate the effect of various rates of annual topdressings of fertilizer on the yield and composition of alfalfa plants, on soil tests. These effects were measured by determining the exchangeable potassium, calcium, magnesium, and available boron in the soils on which the alfalfa grew and the potassium, calcium, magnesium, and boron content of the alfalfa forage. These values when related to yield may aid in determining the desired levels for optimum yields.

CHAPTER II

REVIEW OF LITERATURE

A large number of greenhouse and field experiments have been conducted on the effect of liming and fertilizing acid soils upon the yield and composition of alfalfa plants.

Even though the relationship between the composition of plants and the soils on which they were grown has been studied for more than 300 years (8), man has yet to fully understand this complex relationship. A concept which has received considerable attention in recent years as being an important controlling factor in determining the plant growth responses and symptom expressions is the nutrient-element balance and concentration-activity within the plant (39). Under conditions of optimum balance, whether nutritional intensity is high or low, any critical change in the accumulation of one or more elements not accompanied by appropriate changes in all the other essential elements will result in unbalanced nutrition which will be reflected in decreased growth, and if the unbalance is intensified, in additional reduction in growth or yields.

Although there is extensive data supporting an ideal balance of nutrients for optimum growth (21, 23), the exact relationship of K to B, Mg to B, and Ca to B in alfalfa production is not well established.

Longevity of stand of alfalfa has long been related to the fertilization of the crop (7, 18, 19, 43, 53), but only recently have the roles of potassium and boron on length of life and yields been studied extensively (9, 29, 31, 45, 51). Therefore, maximum growth and yield occur when the proper balance of nutrient elements occur in combination with their optimum concentration. It is also generally agreed that growth and survival of alfalfa is a function, not only of the equilibrium concentration of the nutrients in the soil, but also its rate of replenishment.

Bear, et al. (6, 22), have established the approximate levels of above 1% potassium and below 2% calcium for maximum alfalfa yields, while the "critical values" reported for the boron content of alfalfa range from 6.9 to 23.0 ppm. (32). The "critical percentage" for potassium as determined by Gerwig and Ahlgren (19) varied between 1.42 and 1.84% depending upon the season. Stivers and Ohlrogge (43) found the critical level necessary for alfalfa survival to be between 0.9 and 1.1% while Chandler, et al. (13) determined it to be 1.25%. Bear and Wallace (7), suggested 80 pounds exchangeable potassium in a plow-layer acre, a pH value below 6.5 and an available boron content below 0.35 ppm. as being the critical levels for growing alfalfa. Berger (9) states that soils should contain about 1.5 pounds or more per acre plow-layer of available boron for normal growth of alfalfa.

MacLean and Langille (26) found unhealthy alfalfa to be deficient in potassium and/or boron, the critical levels being 1% and 20 ppm. respectively, and their work also indicated a direct correlation

between available boron and plant tissue boron.

Some relationships have been found to exist between the soil fertility level of potassium and the potassium content of the alfalfa plant. As the soil potassium level increased, a higher potassium content and lower magnesium and calcium contents were found in alfalfa (19). It has also been noted by many investigators (4, 7, 54) that the alfalfa plant has a phenomenal capacity to absorb a much larger quantity of potassium than is necessary for optimum growth. This is generally termed "luxury consumption." This does not necessarily result in any lowering in the yield but has a tendency to deplete the soil's available supply of this element. Wallace (50) further adds that a Ca-K ratio of 2.0 in the nutrient medium does not necessarily have the same effects when both calcium and potassium are high as does the same ratio when both are low. In dilute cultures, the potassium content of alfalfa, both absolute and relative, decreased. According to Elgabaly and Wiklander (17) this behavior of monovalent and polyvalent ions between plant roots and their environment is attributed to a Donnan distribution in which dilute solutions favor the absorption of divalent ions. Vandecaveye and Bond (47) found in field experiments that the calcium content of alfalfa did not seem to be affected appreciably by the application of fertilizers, but had a tendency to vary inversely with yield.

In the comparison of yield and the composition of alfalfa plants, results by the various workers are conflicting. Some workers consider the absolute amounts of the individual elements of greater importance

than the ratio of the elements (20). However, many investigators (6, 10, 12) concluded that cations may have a mutually repressive effect on absorption of one another, depending on their nature, their relative concentration in the nutrient medium, and many other factors.

Thorp and Hobbs (44) concluded from a greenhouse study that lime applications on alfalfa greatly increased the calcium content and the total calcium uptake of the plant and that potassium uptake was also increased. They also found no significant differences in the percentage of magnesium or total magnesium uptake and they attributed this to the chemical similarity between calcium and magnesium. Halstead, et al. (21) reported that the addition of potash increased the concentration of potassium in the plants, decreased magnesium and in most cases decreased the calcium content. This relationship has been widely attributed to antagonism between the ions.

Schmehl, et al. (37) have shown that the rate of absorption of calcium by alfalfa was markedly reduced in the presence of the aluminum ion, and to a lesser degree by manganese and hydrogen ions in the nutrient medium.

York, et al. (54) and Sewell and Latshaw (38) indicated that the potassium content of alfalfa may decrease slightly with an increase in the degree of calcium saturation of the soil but that it would increase when sufficient lime was added to permit free calcium carbonate to exist. It was further concluded by Allaway and Pierre (1) that a higher level of exchangeable potassium was necessary for normal growth on high-lime soil than on "normal" soils.

York, et al. (54) found that potassium depressed very markedly the total absorption of calcium by alfalfa and that the calcium content of alfalfa was influenced more by potassium fertilization than by the additions of large quantities of lime to an acid soil, and further concluded that alfalfa may benefit very little from applications of lime to an acid soil when the supply of potassium or any other nutrient element is limiting growth. Likewise, Wallace (50) found that the Ca-K ratio in the soil influenced the plant potassium ($r = -0.80$) and the plant calcium ($r = +0.79$) more than did the absolute amount of either element on its own concentration within the plant. This substantiates the inverse relationship between potassium and calcium. Truog (46) found that by increasing the soil acidity, the amounts of potassium, calcium, and magnesium that exists in the soil in the readily available form usually decreases. MacLean (25) observed in a greenhouse experiment with six soils that the potassium and magnesium contents of alfalfa decreased with liming, whereas the calcium content increased.

Despite these changes in plant composition, Lucas, et al. (24) found that the sum total of cations tended to be a constant as calculated by the formula:

$$\frac{\% K_2O}{0.047} + \frac{\% MgO}{0.020} + \frac{\% CaO}{0.028} = \text{Constant (me./100 grams of plant material)},$$

and that a change in one would normally vary the content of the other. This theory of the total milliequivalents of Ca, Mg, and K being relatively constant is supported by many other workers (6, 48, 50, 51, 52). Bear and Prince (6) further indicated that the equivalents of K per 100 grams dry weight of alfalfa decreased from the second to the

eighth crop, whereas those of Ca and Mg increased.

Wallace, et al. (51) reported that increasing the potassium concentration sometimes resulted in an increase in the total accumulation of Ca + Mg + K and Shear, et al. (39) found that an increase in magnesium or potassium accumulation brought about by an increased available supply generally decreased the total cation-equivalent values and that an increase in calcium accumulation almost invariably resulted in an increased total equivalent accumulation of Ca + Mg + K. On the other hand, MacLean (26) and Halstead, et al. (21) observed a decrease in the sum of cations in the plant by increasing the availability of potassium.

Results obtained by Hunter, et al. (22) from growing alfalfa in a soil with Ca to K ratios ranging from 1:1 to 32:1 showed that as long as the soil contained adequate amounts of available potassium, satisfactory yields could be produced with high Ca to K ratios. They also suggested that for economic reasons, the Ca to K ratio should be maintained relatively high in order to decrease luxury absorption of potassium. They concluded from their study that alfalfa will make normal growth with wide variations in soil Ca to K ratios.

Since the beginning of the present century, sporadic attempts have been made to establish proof of the indispensable nature of boron which had been found in plants and soils almost universally in minute quantities only, but which were not included in the category of those elements which had been considered essential to plants. Berger (9) stated that boron is one of the essential plant food elements needed for growth

of all plants and that alfalfa has a relatively high requirement of this element, needing at least 20 to 40 pounds of borax per acre. This is substantiated by other investigators (11, 42). Eaton (16) states that factors affecting the movement and distribution of boron in the plant may be almost as important in determining the boron requirements as the boron-supplying power of the substrate.

Shear, et al. (39) expressed cation-boron relationships concerning boron "deficiency" and "toxicity" in terms of unbalanced ratios of boron and all three major bases. In other words, low levels of the bases in proportion to boron are conducive to B toxicity, and high levels of the bases are conducive to B deficiency. This is substantiated by Ewing[1] who observed B deficiency at high potassium levels and not for the lower levels of potash fertilization. The work of Brenchley and Warrington (11), Jones and Scarseth (23), and others has fairly well established the existence of a functional relationship within the plant between boron and calcium which means a high intake of one of these nutrients will increase the requirement of the plant for the other.

In regard to the ideal nutrient-cation status of the soil, Bear and Toth (5) in their eight year study with twenty New Jersey soils, observed that conditions approach the optimum for cation nutrition of alfalfa when 65% of the exchange complex is occupied by Ca, 10% by Mg, 5% by K, and 20% by H. They further concluded that the basic nutrient cations in the alfalfa plant bear little resemblance to

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[1]Ewing, J.A. Crop response to fertilization in Carter County, Tennessee. Unpub. M.S. Thesis, University of Tennessee, Knoxville, Tennessee. 1946.

those in the exchange complex of the soil on which it was grown (Ca being the dominant cation in the soil and K in the alfalfa plant). Furthermore, it has been shown that boron is absorbed by the plant out of proportion to that present in the soil (15).

Many workers have shown that soils, normally containing ample available boron for plant growth, become deficient in this nutrient when limed to pH 7.0 and above (34). However, the mechanism of rendering boron unavailable in the soil is not completely understood. Naftel (28) attributes the fixation to increased microbial activity promoted by the lime. Whereas, Parks and White (33) maintain that greater fixation normally occurs than can be accounted for by increased microbial activity and suggests that humus and organic matter are probably responsible for most of the boron being "locked up." Midgley and Dunklee (27) concluded from their studies that the fixation of boron in overlimed soils is chemical rather than biological in nature and seems to be a function of the soil organic matter, which assumes a high fixing power once it is activated by lime. Askew (2) postulated that liming causes boron-deficiency in alfalfa and calcium renders boron unavailable in soils of relatively high pH. He also found that where the supply of boron is low, an appreciable increase in available potassium intensifies boron-deficiency symptoms.

Work done by Norland and Starostka (30) showed the boron content of alfalfa can vary considerably (22 to 67 ppm.) without any apparent physiological effect on the crop.

Reeve and Shive (35) found that within limits at given calcium and boron levels, the calcium-boron ratio decreases markedly with an increase in potassium in the substrate. Calcium within the same limits has little or no significant effect on the potassium-boron ratio in plant tissues.

Baker and Cook (3) found no correlation between yield or percent of calcium, magnesium, potassium, or phosphorus in alfalfa tissue and the concentration of boron when boron levels varied between weak boron-deficiency and higher levels which did not include boron toxicity. They further noted that when environmental conditions were constant, the boron-supplying power of the soil seemed to be a function not only of the equilibrium concentration of boron in the soil solution but also the rate of equilibrium establishment.

CHAPTER III

METHODS AND PROCEDURES

Various amounts of lime, potassium, and borax were added to a Maury silt loam at Middle Tennessee Experiment Station, a Hartsells loam at the Plateau Experiment Station, and a Cumberland silt loam at the Main Experiment Station. Potassium, calcium, magnesium, and boron contents were determined in the alfalfa forage for each cutting during 1959 and 1960, and the soils were analyzed prior to and following the different fertilizer treatments. All soil and plant analyses were made in duplicates.

The Cumberland soil is a Reddish-Brown Lateritic soil derived from limestone residuum. It is a deep, well drained upland soil which is well suited for growth of alfalfa.

The Hartsells soils are in the Red-Yellow Podzolic group. They are strongly acid sandy soils and low in plant nutrients. They are well drained and the moisture-supplying capacity is moderate to moderately low. These soils are permeable to air, moisture, and plant roots and are suitable to alfalfa production if adequately fertilized and limed.

The Maury soil is a Red-Yellow Podzolic soil but has some characteristics of the Reddish-Brown Lateritic group. Maury soils have developed in residuum from highly phosphatic limestone. They are well drained soils of the Outer Basin and are well adapted for alfalfa production.

The experiments were initiated at the Plateau Experiment Station and Main Experiment Station in the fall of 1958 and at the Middle Tennessee Experiment Station in the fall of 1959. The Buffalo variety of alfalfa was used in each experiment and seeded at the rate of 20-30 pounds per acre. All soils received initial fertilization as need was indicated by the standard soil test procedures and enough lime to establish different soil pH levels.

Annual fertilization treatments consisted of 100 and 300 pounds of K_2O; 0, 20, and 40 pounds of borax. These rates were combined to give a split-split plot design with lime being the main plot, potash the split plot, and boron the split-split plot.

There were four replications of each treatment on the Cumberland soil and three replications on the Hartsells and Maury soils.

Soil samples were taken from each plot in each experiment and analyzed for exchangeable potassium, calcium, and magnesium, and for available boron.

All soil sampling was done with soil sampling tubes and taken at a depth of 0-6 inches on all soils. The soil samples represented six cores which were randomly distributed over the area used for the plant samples. These samples were transferred to paper bags and air dried. The samples were then ground, sieved through a 2 mm. sieve, mixed, and stored in glass bottles with plastic caps. The Cumberland soil was sampled in February of 1959. The sampling dates of Maury and Hartsells soils for 1960 was April and that of Cumberland was March, 1960.

Representative samples of alfalfa forage for each cutting were

taken from each plot and dried in an oven at 70° C. They were then ground in a Wiley mill, mixed thoroughly, and stored in glass bottles for analysis. The plant samples were ashed for calcium, magnesium, and potassium determinations using a Beckman Model DU flame spectrophotometer equipped with a photomultiplier. Boron was determined by the carmine method using an Evelyn photoelectric colorimeter (36).

Detailed analytical procedures as used in this study are shown in Appendixes A through D.

CHAPTER IV

RESULTS AND DISCUSSION

I. SOIL NUTRIENT STUDIES

The results of the soil tests are presented in Tables 1 through 15. Available boron and exchangeable calcium, potassium and magnesium were determined on samples obtained prior to the various annual fertilizer treatments. These data were subjected to the analysis of variance as outlined by Cochran and Cox (14) for split-plot designs. The important findings for each nutrient ion were as follows:

Calcium and pH

Lime treatments significantly[1] increased the exchangeable calcium content only in the Maury soil. The lime treatment resulted in a small but nonsignificant increase in exchangeable calcium in the Cumberland soil. The two lime treatments on the Hartsells soil did not result in greatly different levels of exchangeable calcium. This could possibly be due to soil sampling errors or non-uniformity in lime applications.

The lime treatments raised the pH in all soils. The soil pH change per ton of lime was not the same in all cases. On the Cumberland soil, a four ton lime rate resulted in a pH change of only 0.12 units per ton. A three ton lime rate on the Hartsells soil resulted in a pH change of

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[1] "Significance" will refer to differences at the 0.05 level of probability unless otherwise stated.

0.33 units per ton while an eight ton rate resulted in a pH change of only 0.14 units per ton. A five ton rate on the Maury soil resulted in a pH change of 0.16 units per ton. These results indicate that for lime rates of four to eight tons per acre, the pH change will be about 0.12 to 0.16 units per ton. In the one case observed a lower lime rate on a moderately acid soil resulted in a pH change of 0.33 units per ton of lime.

Potassium

Exchangeable potassium levels of the three soils studied show that the potassium level was significantly increased by annual additions of 300 pounds K_2O per acre. Annual K_2O applications of 100 pounds per acre increased the soil potassium level in the Maury soil, maintained it in the Cumberland soil and resulted in a decreased level in the Hartsells soil. This shows a lower potassium supplying capacity in the Hartsells soil as compared to the Maury and Cumberland soils as considerable potassium was being removed in the alfalfa forage.

Data from Cumberland and Hartsells showed no significant effect on exchangeable potassium content attributable to differences in lime or borax levels studied. However, the higher lime treatments significantly lowered the exchangeable potassium content on the Maury soil while borax had no significant influence on the potassium level.

Boron

All of the soils prior to treatment were fairly uniform in available boron content.

The borax treatments caused a significant increase in the available boron content of all three soils. Neither the lime nor potash treatments significantly affected the available boron content in any of the soils studied.

Magnesium

Although magnesium was not included in the treatments studied, the effect of the treatments studied on the magnesium content were determined. These results show that the exchangeable magnesium in the soil was not significantly different at any of the treatments used in this investigation.

The exchangeable magnesium in the soil changed very little during the period under study. This small difference possibly could be accounted for by experimental error. As far as the interrelationship between magnesium and calcium, and magnesium and boron is concerned, no consistent results were found.

II. YIELD

The average yields of air-dried alfalfa forage per acre for all of the experimental treatments are summarized in Tables 16 through 18. The yields for the years 1959 and 1960 on the Hartsells and Cumberland soils and for 1960 on the Maury soil were used in this study.

A total of four cuttings made up the yields for each year from the Cumberland soil. No significant difference in yields obtained for either year could be attributed to the treatments. However, yield of

alfalfa for 1959 showed a significant boron-lime interaction. The addition of lime increased yield at the no-borax level but decreased the yield at the 40 pound borax level. This interaction is one of the possible factors responsible for an insignificant increase in yield for 1959 on the Cumberland soil following lime or borax additions.

A total of three cuttings made up the 1959 yield average, while four cuttings went into the 1960 year average on the Hartsells soil. No significant differences in yield for either year was obtained for the treatments studied.

Yield averages from the Maury soil represent the sum of four cuttings for 1960. Again the yields were not significantly influenced by the treatments.

The results of this study show no significant difference among mean yields following the various treatments on each soil. This indicates that the level of all nutrient element effects being studied was sufficient for the production levels obtained under the conditions grown.

III. MINERAL COMPOSITION OF FORAGE

Calcium

The results of the calcium forage analysis for each cutting are summarized in Tables 19 through 23.

The calcium content for the various cuttings were found to vary considerably, ranging from 0.86% to 3.72%, the maximum being over four times the minimum. The data also show that liming to the higher pH

value, under conditions of these tests, had little influence on the average calcium content of the forage. In every cutting at all locations lime additions resulted in no significant changes in the calcium content of alfalfa forage. The calcium content of the forage varied with cuttings but the lime effect was essentially the same within cuttings.

The calcium forage content was influenced by the potassium treatments. Calcium contents in the forage were significantly lowered by the higher potassium rate in the following cuttings: the second and third cuttings for 1959, the first and second cuttings for 1960 from the Cumberland soil; the second, third, and fourth cuttings for 1960 from the Hartsells soil, and also in the first and fourth cuttings from the Maury soil in 1960. The calcium content of the forage from the first cutting of 1959 was also found to be significantly influenced by a potassium-calcium interaction in the Hartsells soil. The percent calcium in the forage for this cutting decreased at the low lime level but increased at the high lime level as the K_2O level increased.

Calcium content of forage was not significantly affected by borax additions on any of the three soils. However, the calcium content of the forage was significantly influenced by a boron-potassium interaction in the Cumberland soil for the second cutting of 1959 and in the forage from the first cutting of 1960 on the Maury soil. Calcium content of forage from the second cutting on the Cumberland soil increased at the low K_2O level but decreased at the high K_2O level, while the percent calcium in the first cutting from the Maury soil increased at both the

low and high K_2O levels but by different amounts as borax was applied to the soil.

Calcium content of forage was also significantly influenced by a boron-calcium interaction in the Hartsells soil for the first and fourth cuttings of 1960. The calcium content of the forage for the first cutting decreased at the lower lime level but increased at the higher lime level when borax was added to the soil. However, the inverse relationship was observed in the fourth cutting from the same soil --i.e., an increase in percent calcium at the low lime level and a decrease in percent calcium at the high lime level when borax was added to the soil.

Potassium

The results of the potassium analysis for each cutting are summarized in Tables 24 through 28.

The addition of higher rates of K_2O to the Cumberland soil resulted in a highly significant (0.01 level of probability) increase in the potassium content of the forage from the fourth cutting of 1959, and the first, second, and fourth cuttings of 1960 with a significant increase occurring in the third cutting of 1960.

The higher K_2O level in the Hartsells soil resulted in a significant increase in potassium content of the forage from the second and third cuttings of 1959. A highly significant increase in potassium content of the forage for all cuttings of 1960 was obtained with the 300 pound K_2O addition to the Hartsells soil.

A significant increase in percent potassium of the forage was found in the first cutting and a highly significant increase in percent

potassium of the forage from the fourth cutting of 1960 following the 300 pound K_2O additions to the Maury soil.

In all instances the alfalfa plants absorbed much larger quantities of potassium, even at the 100 pound K_2O level, than the critical value of 1.0% suggested by Bear, et al. (6, 22).

Potassium content of alfalfa was not significantly influenced by the higher lime or borax treatments in most instances, the exceptions being a slight increase in percent potassium in forage of the first cutting of 1959 with the higher lime treatment on Hartsells soil, and an increase in potassium content of the third cutting of forage in 1960 having the no-borax treatment, and a slight increase in percent potassium with the higher borax treatment in the forage from the fourth cutting of the Maury soil in 1960. This is in agreement with the work of Van Itallie (48, 49) who found that lime additions to the soil had little effect on K absorption and concluded that the potassium uptake is dependent mainly upon the potassium concentration in the soil.

Potassium content of the forage of the first cutting of 1960 from the Cumberland soil and the second cutting of 1959 from the Hartsells soil was significantly influenced by a boron-potassium interaction. The potassium content in the forage of the first cutting for 1960 decreased at the low K_2O level and increased at the high K_2O level as borax was added to the Cumberland soil. On the other hand, the percent potassium in the forage from the second cutting for 1959 showed an increase at the low K_2O level and a decrease at the high K_2O level as borax was added to the Hartsells soil.

Boron

The results of the boron analysis for each cutting are summarized in Tables 29 through 33.

The boron content of the alfalfa forage ranged from 10.1 to 45.2 ppm. With the exception of the first cutting from the Hartsells soil in 1959, the average boron content in forage was greatest where higher borax was applied.

With the exception of the first cutting for 1960 on the Cumberland soil, and the first and third cuttings from the Hartsells soil for 1959, borax additions caused a significant increase in boron content of the forage, being highly significant (0.01 level of probability) in many of the cuttings. Almost invariably, the boron content of forage grown on the three soils tended to decrease from the first to the last cutting each year. This may be due in part to the amount and vertical distribution of boron in the soil and also to the soil moisture supply. Stewart and Axley (40) found the applications of borax to the dry top-soil did not increase the supply of available boron as long as the top-soil remained dry. They indicated that boron deficiency in alfalfa may result from a deficiency of soil moisture rather than from a deficient supply of boron. However, the boron contents of the forage of the various cuttings throughout the season in this study were generally greater than the critical values reported by other investigators (26, 32).

The results of this study showed that neither calcium nor potassium treatments had any significant effect on the boron content of alfalfa grown on any of the soils for either year except the second and

third cuttings from the Maury soil in 1960. In these two cases, a slight decrease in boron content of alfalfa occurred with the heavy additions of lime. This would indicate that the boron uptake, under the conditions of this study, was independent of the potassium level but influenced at times by the calcium level.

Boron content was significantly influenced by a boron-lime interaction in the following instances: the second cutting for 1959 and the first cutting for 1960 from the Cumberland soil, the fourth cutting from the Hartsells soil and the second cutting from the Maury soil for the year 1960. In two of these cases, boron content of the forage increased at both the low and high levels of lime as the soils received borax treatments, namely the second cutting of 1959 from the Cumberland soil and the fourth cutting of 1960 from the Hartsells soil. On the other hand, boron content of the forage of the first cutting from the Cumberland soil and the second cutting from the Maury soil for 1960 increased at the lower lime level but decreased at the higher lime level as borax was added to the soil.

A significant boron-potassium interaction in the alfalfa for the second cutting of 1959 from the Cumberland soil was found. In this instance, boron content of the forage increased at both the low and high K_2O levels as borax was applied to the soil.

A significant potassium-lime interaction was found in the boron content of alfalfa in the fourth cutting of 1960 from the Cumberland soil. In this case, boron content increased at the low K_2O level but decreased at the high K_2O as lime was added to the soil.

Magnesium

The results of the magnesium analysis for each cutting are summarized in Tables 34 through 38.

Generally, a slight decrease in magnesium content in the forage occurred with the higher K_2O treatments. Highly significant (0.01 level of probability) decreases in magnesium contents of forage were obtained only where the higher K_2O levels were applied.

In all instances, there were no significant differences in percent magnesium in the forage as a result of the higher borax treatment. However, magnesium content of the forage in the first and third cuttings of 1960 was significantly influenced by a boron-lime interaction in the Cumberland soil. The percent magnesium only slightly increased at the no-borax level for the first cutting with no change in the third cutting as lime was added, but the lime treatment decreased the magnesium content of the forage for both cuttings with the borax treatments.

On the Cumberland soil, magnesium content of forage was significantly affected by a boron-potassium interaction. Potassium additions at both the low and high borax levels decreased the percent magnesium in the forage of the first cutting of 1960 from this soil.

Relationship Among Ions Studied

Potassium at higher rates is known to repress the plant uptake of calcium and magnesium and this has been borne out by the results of this study. When 100 pounds of K_2O per acre were applied to the Cumberland soil, the average calcium contents of the forage for 1959 were 1.61, 1.24,

and 1.05 percent, and the average magnesium contents were 0.49, 0.22, and 0.29 percent for the second, third, and fourth cuttings respectively. The corresponding values for percent calcium at the 300 pound K_2O additions per acre were 1.38, 1.15, and 0.96 percent, while the corresponding values for magnesium were 0.40, 0.15, and 0.21 percent. The same general trend in calcium and magnesium contents of forage for each cutting of 1960 was found. This was also observed in the average calcium and magnesium contents of alfalfa for 1959 and 1960 from the Hartsells soil and in the forage from the Maury soil in 1960. This repressing effect of potassium on the absorption of added calcium is generally attributed to antagonism between the ions.

In contrast with the influence of potassium on calcium and magnesium, calcium application does not distinctly lower the percent potassium and magnesium in the forage. Careful studies with Italian rye grass by Van Itallie (48) have shown that calcium is taken up with greatest difficulty by the plant, does not cause great variations in the composition of the plant and therefore does not play an important part in ion replacement. For the no-lime treatment on the Cumberland soil, the average levels of potassium in the plants for 1959 were 2.31, 1.92, and 1.98 percent, and the average levels of magnesium were 0.45, 0.17, and 0.25 percent for the second, third, and fourth cuttings respectively. The corresponding values for the four ton lime additions per acre were 2.24, 1.82, and 2.03 percent for potassium, while the corresponding values for magnesium were 0.45, 0.20, and 0.24 percent. Similar results were found in composition of forage from the other soils.

The relationship of boron to calcium, as well as the relationship between boron and potassium, has been the subject of much study. There have been many conflicting reports as to the effect of boron on these elements. There have been cases where, because boron was the limiting factor, the content of other elements in the plant have been increased. When boron was adequately supplied, the amounts of the other elements in the plant declined. In other cases if an element such as potassium is limiting, the boron content of the plant was high due to a stunting because of a lack of potassium for normal growth. Reeve and Shive (35) presented evidence that there is a real relationship between calcium and boron. They found that at high boron levels there is a marked decrease in boron content in the plant tissue with increases in the calcium concentrations in the nutrient solution. They also found a relationship between potassium and boron. Increasing the potassium concentrations had the effect of increasing the boron content of the plants especially at the higher boron levels. Furthermore, they found that calcium and potassium were similar in their capacity to accentuate the symptoms of boron deficiency with increasing concentrations of calcium but not with potassium.

The data gathered in this study are not quite illustrative of this hypothesis because the boron content of the forage was found to increase in some cases and decrease in others (most of these cases being insignificant changes) as the exchangeable calcium increased between the two lime levels studied. Also, there was no consistent relationship between boron content of forage and exchangeable potassium levels in

the soil. The lack of consistent calcium-boron or potassium-boron relationships in this study may be attributed to the fact that a narrow range of nutrient levels were studied and the levels of nutrients studied were well within the limits for normal plant growth.

Another interesting observation is that, regardless of the soil treatment used in this experiment, alfalfa absorbed a relatively constant amount of cations (expressed in meq.) within cuttings. Several workers have observed a tendency for the sum of the various cations in plants expressed as milliequivalents per 100 g. of dried plant material to be a constant under a given set of conditions. It is well established that a certain amount of each cation is necessary to carry on plant growth. Once this minimum has been obtained, each additional cation taken up is largely for the purpose of cation balance. Plants can show a great deal of variation between the ratios of different cations and still have normal growth. Hunter, Toth, and Bear (22) found that alfalfa could have a ratio of calcium to potassium anywhere between 1 to 1 and 5 to 1 and still have normal growth. The results of this study show that the sum of Ca, K, and Mg, expressed in average milliequivalents for all cuttings, is remarkably constant for alfalfa grown on the same soil for the same year regardless of the fertilizer treatment. These values were found to range between the following: 138 to 141, and 161 to 169 for the Cumberland soil in 1959 and 1960 respectively; 144 to 154, and 156 to 163 for the Hartsells soil in 1959 and 1960 respectively, and from 232 to 239 for the Maury soil in 1960.

This constancy is maintained by the reciprocal relationship

between calcium and magnesium on the one hand and potassium on the other, as well as by the inverse relationship between calcium and magnesium. In the present study an increased uptake of potassium occurred and a decreased absorption of calcium and magnesium in the presence of a higher level of K_2O, thus maintaining a constant amount of bases when expressed on a chemical equivalent basis.

Furthermore, it was found that the total cation content of alfalfa was approximately constant for the various treatments of each cutting on the same soil for the same year but varied from cutting to cutting which can be attributed to a different set of environmental conditions throughout the season. This has some practical significance in that yield was not significantly affected by any of the fertilizer treatments in this study. Therefore, since the proportion of calcium, potassium, and magnesium was found to vary, it is evident from the yield results that the minimum amount of each of these elements was assured to meet the crop's specific needs.

Table 1.--Soil pH values before and after liming a Cumberland silt loam.

Tons Lime Per Acre	pH Before Liming	pH 17 months after Liming
None	6.8	6.7
None	6.5	6.8
None	6.6	6.9
None	6.7	6.8
4	6.4	7.1
4	6.6	7.1
4	6.7	7.1
4	6.5	7.1

Table 2.--Soil pH values before and after liming a Hartsells loam.

Tons Lime Per Acre	pH Before Liming	pH 18 months after Liming
3	5.2	6.3
3	5.3	6.3
3	5.3	6.3
3	5.2	6.3
8	5.3	6.4
8	5.3	6.5
8	5.2	6.5
8	5.2	6.5

Table 3.--Soil pH values before and after liming a Maury silt loam.

Tons Lime Per Acre	pH Before Liming	pH 17 months after Liming
None	6.4	6.8
None	6.3	6.6
None	6.4	6.7
None	6.3	6.8
5	6.3	7.3
5	6.4	7.3
5	6.4	7.2
5	6.3	7.2

Table 4.--Exchangeable calcium on Cumberland silt loam prior to and following various annual fertilizer treatments.

Treatment			Exchangeable Ca	
Lime[a]	K_2O	Borax	1959	1960
T./A.	Lbs./A.	Lbs./A.	Lbs./A.	Lbs./A.
0	100	0	3295[b]	3355
0	100	40	3090	3195
0	300	0	3415	3345
0	300	40	3130	3195
4	100	0	3205	3590
4	100	40	3140	3340
4	300	0	2925	3250
4	300	40	3045	3330

Lime effect means at all levels of K and B[c]

Tons lime/A.	Lbs./A.
0	3322
4	3378
L.S.D. (0.05)	N.S.
C.V.	10%

Potassium effect means at all levels of Ca and B[c]

Lbs. K_2O/A.	Lbs./A.
100	3370
300	3280
L.S.D. (0.05)	N.S.
C.V.	6%

Boron effect means at all levels of Ca and K[c]

Lbs. borax/A.	Lbs./A.
0	3385
40	3265
L.S.D. (0.05)	N.S.
C.V.	7%

[a]Average initial soil pH was 6.6.

[b]Values represent an average of four replications before treatment additions.

[c]Effect means and analysis of variance refer to 1960 soil tests.

Table 5.--Exchangeable calcium on Hartsells loam prior to and following various annual fertilizer treatments.

Treatment			Exchangeable Ca	
Lime[a]	K_2O	Borax	1958	1960
T./A.	Lbs./A.	Lbs./A.	Lbs./A.	Lbs./A.
3	100	0	2040[b]	2073
3	100	40	1953	1980
3	300	0	1953	1733
3	300	40	1953	1733
8	100	0	1973	1687
8	100	40	1973	1747
8	300	0	1973	1760
8	300	40	1973	1833

Lime effect means at all levels of K and B[c]

Tons lime/A.	Lbs./A.
3	1880
8	1757
L.S.D. (0.05)	N.S.
C.V.	10%

Potassium effect means at all levels of Ca and B[c]

Lbs. K_2O/A.	Lbs./A.
100	1872
300	1765
L.S.D. (0.05)	N.S.
C.V.	22%

Boron effect means at all levels of Ca and K[c]

Lbs. borax/A.	Lbs./A.
0	1813
40	1823
L.S.D. (0.05)	N.S.
C.V.	13%

[a]Average initial soil pH was 5.2.

[b]Values represent an average of three replications before treatment additions.

[c]Effect means and analysis of variance refer to 1960 soil tests.

Table 6.--Exchangeable calcium on Maury silt loam prior to and following various annual fertilizer treatments.

Treatment			Exchangeable Ca	
Lime[a]	K_2O	Borax	1958	1961
T./A.	Lbs./A.	Lbs./A.	Lbs./A.	Lbs./A.
0	100	0	2320[b]	3360
0	100	40	2320	3100
0	300	0	2320	3053
0	300	40	2320	3013
5	100	0	2767	3887
5	100	40	2767	4073
5	300	0	2767	4140
5	300	40	2767	3860

Lime effect means at all levels of K and B[c]

Tons lime/A.	Lbs./A.
0	3132
5	3990
L.S.D. (0.05)	424
C.V.	11%

Potassium effect means at levels of Ca and B[c]

Lbs. K_2O/A.	Lbs./A.
100	3605
300	3516
L.S.D. (0.05)	N.S.
C.V.	9%

Boron effect means at all levels of Ca and K[c]

Lbs. borax/A.	Lbs./A.
0	3610
40	3512
L.S.D. (0.05)	N.S.
C.V.	4%

[a]Average initial soil pH was 6.4

[b]Values represent an average of three replications before treatment additions.

[c]Effect means and analysis of variance refer to 1961 soil tests.

Table 7.--Exchangeable potassium on Cumberland silt loam prior to and following various annual fertilizer treatments.

Treatment			Exchangeable K	
Lime[a]	K_2O	Borax	1959	1960
T./A.	Lbs./A.	Lbs./A.	Lbs./A.	Lbs./A.
0	100	0	190[b]	205
0	100	40	195	190
0	300	0	220	345
0	300	40	210	360
4	100	0	190	190
4	100	40	185	200
4	300	0	175	290
4	300	40	155	255

Lime effect means at all levels of K and B[c]

Tons lime/A.	Lbs./A.
0	275
4	234
L.S.D. (0.05)	N.S.
C.V.	32%

Potassium effect means at all levels of Ca and B[c]

Lbs. K_2O/A.	Lbs./A.
100	196
300	312
L.S.D. (0.01)	71
C.V.	21%

Boron effect means at all levels of Ca and K[c]

Lbs. borax/A.	Lbs./A.
0	258
40	251
L.S.D. (0.05)	N.S.
C.V.	13%

[a]Average initial soil pH was 6.6.

[b]Values represent an average of four replications before treatment additions.

[c]Effect means and analysis of variance refer to 1960 soil tests.

Table 8.--Exchangeable potassium on Hartsells loam prior to and following various annual fertilizer treatments.

Treatment			Exchangeable K	
Lime[a]	K_2O	Borax	1958	1960
T./A.	Lbs./A.	Lbs./A.	Lbs./A.	Lbs./A.
3	100	0	210[b]	167
3	100	40	200	140
3	300	0	200	207
3	300	40	200	213
8	100	0	213	180
8	100	40	213	147
8	300	0	213	220
8	300	40	213	213

Lime effect means at all levels of K and B[c]

Tons lime/A.	Lbs./A.
3	182
8	190
L.S.D. (0.05)	N.S.
C.V.	16%

Potassium effect means at all levels of Ca and B[c]

Lbs. K_2O/A.	Lbs./A.
100	158
300	213
L.S.D. (0.05)	36
C.V.	17%

Boron effect means at all levels of Ca and K[c]

Lbs. borax/A.	Lbs./A.
0	194
40	178
L.S.D. (0.05)	N.S.
C.V.	22%

[a]Average initial soil pH was 5.2.

[b]Values represent an average of three replications before treatment additions.

[c]Effect means and analysis of variance refer to 1960 soil tests.

Table 9.--Exchangeable potassium on Maury silt loam prior to and following various annual fertilizer treatments.

Treatment			Exchangeable K	
Lime[a]	K_2O	Borax	1958	1961
T./A.	Lbs./A.	Lbs./A.	Lbs./A.	Lbs./A.
0	100	0	133[b]	327
0	100	40	133	387
0	300	0	133	567
0	300	40	133	820
5	100	0	120	307
5	100	40	120	300
5	300	0	120	520
5	300	40	120	487

Lime effect means at all levels of K and B[c]

Tons lime/A.	Lbs./A.
0	525
5	404
L.S.D. (0.05)	108
C.V.	13%

Potassium effect means at all levels of Ca and B[c]

Lbs. K_2O/A.	Lbs./A.
100	330
300	598
L.S.D. (0.05)	100
L.S.D. (0.01)	248
C.V.	19%

Boron effect means at all levels of Ca and K[c]

Lbs. borax/A.	Lbs.A.
0	430
40	498
L.S.D. (0.05)	N.S.
C.V.	21%

[a]Average initial soil pH was 6.4.

[b]Values represent an average of three replications before treatment additions.

[c]Effect means and analysis of variance refer to 1961 soil tests.

Table 10.--Available boron on Cumberland silt loam prior to and following various annual fertilizer treatments.

Treatment			Available B	
Lime[a]	K_2O	Borax	1959	1960
T./A.	Lbs./A.	Lbs./A.	ppm.	ppm.
0	100	0	1.2[b]	1.3
0	100	40	1.3	1.9
0	300	0	1.3	1.3
0	300	40	1.2	1.8
4	100	0	1.4	1.2
4	100	40	1.2	1.8
4	300	0	1.2	1.2
4	300	40	1.2	1.7

Lime effect means at all levels of K and B[c]

Tons lime/A.	ppm.
0	1.6
4	1.5
L.S.D. (0.05)	N.S.
C.V.	20%

Potassium effect means at all levels of Ca and B[c]

Lbs. K_2O/A.	ppm.
100	1.6
300	1.5
L.S.D. (0.05)	N.S.
C.V.	9%

Boron effect means at all levels of Ca and K[c]

Lbs. borax/A.	ppm.
0	1.2
40	1.8
L.S.D. (0.05)	0.1
L.S.D. (0.01)	0.2
C.V.	13%

[a]Average initial soil pH was 6.6.

[b]Values represent an average of four replications before treatment additions.

[c]Effect means and analysis of variance refer to 1960 soil tests.

Table 11.--Available boron on Hartsells loam prior to and following various annual fertilizer treatments.

Treatment			Available B	
Lime[a]	K_2O	Borax	1958	1960
T./A.	Lbs./A	Lbs./A.	ppm.	ppm.
3	100	0	1.5[b]	1.9
3	100	40	1.5	2.3
3	300	0	1.5	1.9
3	300	40	1.5	2.2
8	100	0	1.6	1.8
8	100	40	1.6	2.3
8	300	0	1.6	1.8
8	300	40	1.6	3.1

Lime effect means at all levels of K and B[c]

Tons lime/A.	ppm.
3	2.1
8	2.2
L.S.D. (0.05)	N.S.
C.V.	9%

Potassium effect means at all levels of Ca and B[c]

Lbs. K_2O/A.	ppm.
100	2.1
300	2.2
L.S.D. (0.05)	N.S.
C.V.	23%

Boron effect means at all level of Ca and K[c]

Lbs. borax/A.	ppm.
0	1.8
40	2.5
L.S.D. (0.05)	0.4
L.S.D. (0.01)	0.6
C.V.	18%

[a]Average initial soil pH was 5.2.

[b]Values represent an average of three replications before treatment additions.

[c]Effect means and analysis of variance refer to 1960 soil tests.

Table 12.--Available boron on Maury silt loam prior to and following various annual fertilizer treatments.

Treatment			Available B	
Lime[a]	K_2O	Borax	1958	1961
T./A.	Lbs./A.	Lbs./A.	ppm.	ppm.
0	100	0	1.8[b]	1.3
0	100	40	1.8	1.7
0	300	0	1.8	1.4
0	300	40	1.8	2.4
5	100	0	1.7	1.3
5	100	40	1.7	2.5
5	300	0	1.8	1.5
5	300	40	1.8	2.4

Lime effect means at all levels of K and B[c]

Lbs. lime/A.	ppm.
0	1.7
5	1.9
L.S.D. (0.05)	N.S.
C.V.	6%

Potassium effect means at all levels of Ca and B[c]

Lbs. K_2O/A.	ppm.
100	1.7
300	1.9
L.S.D. (0.05)	N.S.
C.V.	6%

Boron effect means at all levels of Ca and K[c]

Lbs. borax/A.	ppm.
0	1.4
40	2.2
L.S.D. (0.05)	0.4
L.S.D. (0.01)	0.6
C.V.	23%

[a]Average initial soil pH was 6.4.

[b]Values represent an average of three replications before treatment additions.

[c]Effect means and analysis of variance refer to 1961 soil tests.

Table 13.--Exchangeable magnesium on Cumberland silt loam prior to and following various annual fertilizer treatments.

Treatment			Exchangeable Mg	
Lime[a]	K_2O	Borax	1959	1960
T./A.	Lbs./A.	Lbs./A.	Lbs./A.	Lbs./A.
0	100	0	100[b]	100
0	100	40	115	114
0	300	0	100	99
0	300	40	115	114
4	100	0	120	115
4	100	40	125	116
4	300	0	120	119
4	300	40	125	124

Lime effect means at all levels of K and B

Tons lime/A.	1959 Lbs./A.	1960 Lbs./A
0	108	107
4	122	118
L.S.D. (0.05)		N.S.
C.V.		13%

Potassium effect means at all levels of Ca and B

Lbs. K_2O/A.		
100	115	111
300	115	114
L.S.D. (0.05)		N.S.
C.V.		26%

Boron effect means at all levels of Ca and K

Lbs. borax/A.		
0	110	108
40	120	117
L.S.D. (0.05)		N.S.
C.V.		12%

[a]Average initial soil pH was 6.6.

[b]Values represent an average of four replications before treatment additions.

Table 14.--Exchangeable magnesium on Hartsells loam prior to and following various annual fertilizer treatments.

Treatments			Exchangeable Mg	
Lime[a]	K_2O	Borax	1958	1960
T./A.	Lbs./A.	Lbs./A.	Lbs./A.	Lbs./A.
3	100	0	140[b]	157
3	100	40	143	137
3	300	0	143	150
3	300	40	143	130
8	100	0	143	177
8	100	40	143	163
8	300	0	143	137
8	300	40	143	150

Lime effect means at all levels of K and B

Tons lime/A.	1958 Lbs./A.	1960 Lbs./A.
3	142	144
8	143	157
L.S.D. (0.05)		N.S.
C.V.		9%

Potassium effect means at all levels of Ca and B

Lbs. K_2O/A.		
100	142	158
300	143	142
L.S.D. (0.05)		N.S.
C.V.		29%

Boron effect means at all levels of Ca and K

Lbs. borax/A.		
0	142	155
40	143	145
L.S.D. (0.05)		N.S.
C.V.		20%

[a]Average initial soil pH was 5.2.

[b]Values represent an average of three replications before treatment additions.

Table 15.--Exchangeable magnesium on Maury silt loam prior to and following various annual fertilizer treatments.

Treatment			Exchangeable Mg	
Lime[a]	K_2O	Borax	1958	1961
T./A.	Lbs./A	Lbs./A	Lbs./A	Lbs./A
0	100	0	85[b]	123
0	100	40	85	123
0	300	0	90	130
0	300	40	90	97
5	100	0	90	103
5	100	40	95	110
5	300	0	90	97
5	300	40	105	90

Lime effect means at all levels of K and B

Tons lime/A.	1958 Lbs./A	1961 Lbs./A
0	88	118
5	95	100
L.S.D. (0.05)		N.S.
C.V.		4%

Potassium effect means at all levels of Ca and B

Lbs. K_2O/A.		
100	89	115
300	94	104
L.S.D. (0.05)		N.S.
C.V.		4%

Boron effect means at all levels of Ca and K

Lbs. borax/A.		
0	89	113
40	94	105
L.S.D. (0.05)		N.S.
C.V.		12%

[a]Average initial soil pH was 6.4.

[b]Values represent an average of three replications before treatment additions.

Table 16.--Average yield of alfalfa forage on Cumberland silt loam grown at two lime levels, two potassium levels, and two boron levels.

Treatment			Average yield air dry forage		
Lime[a]	K_2O	Borax	1959	1960	2-year ave.
T./A.	Lbs./A.	Lbs./A.	T./A.	T./A.	T./A.
0	100	0	2.60[b]	4.13	3.37
0	100	40	3.01	4.49	3.75
0	300	0	2.95	4.34	3.65
0	300	40	3.23	4.30	3.77
4	100	0	2.95	4.17	3.56
4	100	40	2.64	3.73	3.19
4	300	0	3.17	4.44	3.81
4	300	40	2.87	4.37	3.62

Lime effect means at all levels of K and B

Lime (T./A.)	1959 T./A.	1960 T./A.
0	2.95	4.32
4	2.91	4.18
L.S.D. (0.05)	N.S.	N.S.
C.V.	12%	14%

Potassium effect means at all levels of Ca and B

K_2O (Lbs./A.)	1959 T./A.	1960 T./A.
100	2.80	4.13
300	3.06	4.36
L.S.D. (0.05)	N.S.	N.S.
C.V.	19%	28%

Boron effect means at all levels of Ca and K

Borax (Lbs./A.)	1959 T./A.	1960 T./A.
0	2.92	4.27
40	2.94	4.22
L.S.D. (0.05)	N.S.	N.S.
C.V.	14%	13%

[a]Average initial soil pH was 6.6.

[b]Values represent an average of four replications.

Table 17.--Average yield of alfalfa forage on Hartsells loam grown at two lime levels, two potassium levels, and two boron levels.

Treatment			Average yield air dry forage		
Lime[a]	K_2O	Borax	1959	1960	2-year ave.
T./A.	Lbs./A.	Lbs./A.	T./A.	T./A.	T./A.
3	100	0	4.28[b]	4.75	4.52
3	100	40	4.31	4.84	4.58
3	300	0	3.97	4.75	5.36
3	300	40	4.10	5.03	4.56
8	100	0	4.23	4.66	4.44
8	100	40	4.01	4.84	4.42
8	300	0	4.01	5.31	4.66
8	300	40	4.37	4.99	4.68

Lime effect means at all levels of K and B

Lime (T./A.)	1959 T./A.	1960 T./A.
3 ----------	4.16	4.84
8 ----------	4.16	4.95
L.S.D. (0.05)-	N.S.	N.S.
C.V. ---------	11%	10%

Potassium effect means at all levels of Ca and B

K_2O (Lbs./A.)	1959 T./A.	1960 T./A.
100 ----------	4.21	4.77
300 ----------	4.11	5.02
L.S.D. (0.05)-	N.S.	N.S.
C.V. ---------	15%	5%

Boron effect means at all levels of Ca and K

Borax (Lbs./A.)	1959 T./A.	1960 T./A.
0 ----------	4.12	4.87
40 ----------	4.20	4.92
L.S.D. (0.05) ---	N.S.	N.S.
C.V. ----------	7%	7%

[a]Average initial soil pH was 5.5.

[b]Values represent an average of three replications.

Table 18.--Average yield of alfalfa forage on Maury silt loam grown at two lime levels, two potassium levels, and two boron levels.

Treatment			Average yield air dry forage
Lime[a]	K_2O	Borax	1960
T./A.	Lbs./A.	Lbs./A.	T./A.
0	100	0	3.29[b]
0	100	40	3.48
0	300	0	3.53
0	300	40	3.56
5	100	0	3.56
5	100	40	3.24
5	300	0	3.74
5	300	40	3.72

Lime effect means at all levels of K and B

Lime (T./A.)	1960 T./A.
0	3.46
5	3.57
L.S.D. (0.05)	N.S.
C.V.	7%

Potassium effect means at all levels of Ca and B

K_2O (Lbs./A.)	1960 T./A.
100	3.39
300	3.64
L.S.D. (0.05)	N.S.
C.V.	18%

Boron effect means at all levels of Ca and K

Borax (Lbs./A.)	1960 T./A.
0	3.53
40	3.50
L.S.D. (0.05)	N.S.
C.V.	10%

[a]Average initial soil pH was 6.4.

[b]Values represent an average of three replications.

Table 19.--Calcium content of alfalfa forage grown on Cumberland silt loam receiving different lime, potassium, and boron treatments, 1959.

Treatment			Calcium content of oven-dry forage by cuttings			
Lime[a]	K_2O	Borax	First	Second	Third	Fourth
T./A.	Lbs./A.	Lbs./A.		%	%	%
0	100	0	No samples obtained	1.60[b]	1.28	1.08
0	100	40		1.83	1.30	1.03
0	300	0		1.39	1.19	.99
0	300	40		1.35	1.13	.93
4	100	0		1.53	1.22	1.05
4	100	40		1.47	1.16	1.03
4	300	0		1.40	1.15	.97
4	300	40		1.36	1.13	.94

[a]Average initial soil pH was 6.6.

[b]Values represent an average of four replications.

Table 19 (continued)

Analysis of Variance

	Cutting			
	First	Second	Third	Fourth
		%	%	%
Lime effect means at all levels of K and B				
Tons lime/A.				
0	No samples obtained	1.54	1.22	1.01
4		1.44	1.16	1.00
L.S.D. (0.05)		N.S.	N.S.	N.S.
C.V.		13%	27%	16%
Potassium effect means at all levels of Ca and B				
Lbs. K_2O/A.				
100		1.61	1.24	1.05
300		1.38	1.15	.96
L.S.D. (0.05)		.17	.05	N.S.
L.S.D. (0.01)		N.S.	.07	N.S.
C.V.		13%	5%	17%
Boron effect means at all levels of Ca and K				
Lbs. borax/A.				
0		1.48	1.21	1.02
40		1.50	1.18	.98
L.S.D. (0.05)		N.S.	N.S.	N.S.
C.V.		9%	7%	13%

Table 20.--Calcium content of alfalfa forage grown on Cumberland silt loam receiving different lime, potassium, and boron treatments, 1960.

Treatment			Calcium content of oven-dry forage by cuttings			
Lime[a]	K_2O	Borax	First	Second	Third	Fourth
T./A.	Lbs./A.	Lbs./A.	%	%	%	%
0	100	0	2.36[b]	1.51	1.21	1.32
0	100	40	2.55	1.50	1.29	1.48
0	300	0	1.80	1.25	1.21	1.24
0	300	40	1.90	1.20	1.27	1.88
4	100	0	2.08	1.47	1.16	1.49
4	100	40	2.33	1.50	1.22	1.40
4	300	0	1.92	1.29	1.14	1.11
4	300	40	1.71	1.14	1.08	1.14

[a]Average initial soil pH was 6.6.

[b]Values represent an average of four replications.

Table 20 (continued)

Analysis of Variance

	Cutting			
	First	Second	Third	Fourth
	%	%	%	%
Lime effect means at all levels of K and B				
Tons lime/A.				
0	2.15	1.36	1.24	1.48
4	2.01	1.35	1.15	1.28
L.S.D. (0.05)	N.S.	N.S.	N.S.	N.S.
C.V.	10%	29%	19%	19%
Potassium effect means at all levels of Ca and B				
Lbs. K_2O/A.				
100	2.33	1.50	1.22	1.42
300	1.83	1.22	1.18	1.34
L.S.D. (0.05)	.20	.11	N.S.	N.S.
L.S.D. (0.01)	.28	.17	N.S.	N.S.
C.V.	13%	10%	21%	8%
Boron effect means at all levels of Ca and K				
Lbs. borax/A.				
0	2.04	1.38	1.18	1.29
40	2.12	1.34	1.22	1.48
L.S.D. (0.05)	N.S.	N.S.	N.S.	N.S.
C.V.	11%	6%	9%	14%

Table 21.--Calcium content of alfalfa forage grown on Hartsells loam receiving different lime, potassium, and boron treatments, 1959.

Treatment			Calcium content of oven-dry forage by cuttings		
Lime[a]	K_2O	Borax	First	Second	Third
T./A.	Lbs./A.	Lbs./A.	%	%	%
3	100	0	1.46[b]	1.24	1.08
3	100	40	1.37	1.18	.97
3	300	0	1.14	1.21	1.01
3	300	40	1.17	1.11	1.10
8	100	0	1.24	1.10	1.03
8	100	40	1.24	1.14	1.16
8	300	0	1.43	.99	.93
8	300	40	1.14	1.03	1.10

[a]Average initial soil pH was 5.5.

[b]Value represents an average of three replications.

Table 21 (continued)

Analysis of Variance

	Cutting		
	First	Second	Third
	%	%	%
Lime effect means at all levels of K and B			
Tons lime/A.			
3	1.28	1.18	1.04
8	1.26	1.06	1.06
L.S.D. (0.05)	N.S.	N.S.	N.S.
C.V.	17%	22%	8%
Potassium effect means at all levels of Ca and B			
Lbs. K_2O/A.			
100	1.33	1.16	1.06
300	1.22	1.08	1.04
L.S.D. (0.05)	N.S.	N.S.	N.S.
C.V.	10%	12%	10%
Boron effect means at all levels of Ca and K			
Lbs. borax/A.			
0	1.32	1.14	1.01
40	1.23	1.12	1.08
L.S.D. (0.05)	N.S.	N.S.	N.S.
C.V.	21%	10%	11%

Table 22.--Calcium content of alfalfa forage grown on Hartsells loam receiving different lime, potassium, and boron treatments, 1960.

Treatment			Calcium content of oven-dry forage by cuttings			
Lime[a]	K_2O	Borax	First	Second	Third	Fourth
T./A.	Lbs./A.	Lbs./A.	%	%	%	%
3	100	0	1.39[b]	1.13	1.24	1.25
3	100	40	1.18	1.07	1.10	1.49
3	300	0	1.18	.79	.94	1.06
3	300	40	1.13	.90	.96	1.17
8	100	0	1.25	1.16	1.00	1.53
8	100	40	1.37	.93	1.15	1.40
8	300	0	1.06	1.00	.97	1.32
8	300	40	1.14	.86	.93	1.17

[a]Average initial soil pH was 5.5.

[b]Values represent an average of three replications.

Table 22 (continued)

Analysis of Variance

	Cutting			
	First	Second	Third	Fourth
	%	%	%	%
Lime effect means at all levels of K and B				
Tons lime/A.				
3	1.22	.97	1.06	1.24
8	1.20	.99	1.01	1.36
L.S.D. (0.05)	N.S.	N.S.	N.S.	N.S.
C.V.	9%	12%	2%	8%
Potassium effect means at all levels of Ca and B				
Lbs. K_2O/A.				
100	1.30	1.07	1.12	1.42
300	1.13	.89	.95	1.18
L.S.D. (0.05)	N.S.	.17	.09	.22
L.S.D. (0.01)	N.S.	N.S.	.15	N.S.
C.V.	14%	15%	7%	15%
Boron effect at all levels of Ca and K				
Lbs. borax/A.				
0	1.22	1.02	1.04	1.29
40	1.20	.94	1.04	1.31
L.S.D. (0.05)	N.S.	N.S.	N.S.	N.S.
C.V.	10%	20%	8%	6%

Table 23.--Calcium content of alfalfa forage grown on Maury silt loam receiving different lime, potassium, and boron treatments, 1960.

Treatment			Calcium content of oven-dry forage by cuttings			
Lime[a]	K_2O	Borax	First	Second	Third	Fourth
T./A.	Lbs./A.	Lbs./A.	%	%	%	%
0	100	0	3.11[b]	2.35	1.74	1.92
0	100	40	3.32	2.10	1.79	1.99
0	300	0	2.88	2.03	1.74	1.89
0	300	40	2.82	2.03	1.55	1.48
5	100	0	3.15	2.13	1.76	1.96
5	100	40	3.72	2.13	1.93	1.75
5	300	0	3.08	2.03	1.69	1.78
5	300	40	3.26	1.94	1.75	1.72

[a]Average initial soil pH was 6.4.

[b]Values represent an average of three replications.

Table 23 (continued)

Analysis of Variance

	Cutting			
	First	Second	Third	Fourth
	%	%	%	%
Lime effect means at all levels of K and B				
Tons lime/A.				
0	3.03	2.13	1.70	1.82
5	3.30	2.06	1.78	1.80
L.S.D. (0.05)	N.S.	N.S.	N.S.	N.S.
C.V.	9%	19%	12%	7%
Potassium effect means at all levels of Ca and B				
Lbs. K_2O/A.				
100	3.32	2.18	1.80	1.90
300	3.01	2.01	1.68	1.72
L.S.D. (0.05)	.27	N.S.	N.S.	.12
C.V.	13%	7%	8%	6%
Boron effect means at all levels of Ca and K				
Lbs. borax/A.				
0	3.06	2.14	1.73	1.89
40	3.28	2.05	1.76	1.74
L.S.D. (0.05)	N.S.	N.S.	N.S.	N.S.
C.V.	5%	7%	9%	16%

Table 24.--Potassium content of alfalfa forage grown on Cumberland silt loam receiving different lime, potassium, and boron treatments, 1959.

Treatment			Potassium content of oven-dry forage by cuttings			
Lime[a]	K_2O	Borax	First	Second	Third	Fourth
T./A.	Lbs./A.	Lbs./A.	%	%	%	%
0	100	0	No samples obtained	2.02[b]	1.82	1.78
0	100	40		2.27	1.60	1.80
0	300	0		2.43	2.08	2.15
0	300	40		2.53	2.19	2.21
4	100	0		2.09	1.63	1.87
4	100	40		2.12	1.77	1.87
4	300	0		2.37	2.08	2.22
4	300	40		2.37	1.79	2.17

[a]Average initial soil pH was 6.6.

[b]Values represent an average of four replications.

Table 24 (continued)

Analysis of Variance

	Cutting			
	First	Second	Third	Fourth
		%	%	%
Lime effect means at all levels of K and B				
Tons lime/A.				
0	No samples obtained	2.31	1.92	1.98
4		2.24	1.82	2.03
L.S.D. (0.05)		N.S.	N.S.	N.S.
C.V.		16%	22%	21%
Potassium effect means at all levels of Ca and B				
Lbs. K_2O/A.				
100		2.12	1.70	1.83
300		2.42	2.04	2.19
L.S.D. (0.05)		.24	.27	.10
L.S.D. (0.01)		N.S.	N.S.	.14
C.V.		12%	17%	6%
Boron effect means at all levels of Ca and K				
Lbs. borax/A.				
0		2.23	1.90	2.00
40		2.32	1.84	2.01
L.S.D. (0.05)		N.S.	N.S.	N.S.
C.V.		8%	13%	9%

Table 25.--Potassium content of alfalfa forage grown on Cumberland silt loam receiving different lime, potassium, and boron treatments, 1960.

Treatment			Potassium content of oven-dry forage by cuttings			
Lime[a]	K_2O	Borax	First	Second	Third	Fourth
T./A.	Lbs./A.	Lbs./A.	%	%	%	%
0	100	0	1.62[b]	2.16	2.14	1.93
0	100	40	1.61	2.14	2.17	1.86
0	300	0	1.86	2.60	2.67	2.81
0	300	40	2.06	2.59	2.57	2.77
4	100	0	1.63	2.23	1.91	1.88
4	100	40	1.52	2.04	1.98	2.13
4	300	0	1.91	2.61	2.23	2.88
4	300	40	1.97	2.67	2.40	2.86

[a]Average initial soil pH was 6.6.

[b]Values represent an average of four replications.

Table 25 (continued)

Analysis of Variance

	Cutting			
	First	Second	Third	Fourth
	%	%	%	%
Lime effect means at all levels of K and B				
Tons lime/A.				
0	1.79	2.37	2.39	2.34
4	1.76	2.39	2.13	2.44
L.S.D. (0.05)	N.S.	N.S.	N.S.	N.S.
C.V.	17%	21%	25%	14%
Potassium effect means at all levels of Ca and B				
Lbs. K_2O/A.				
100	1.60	2.14	2.05	1.95
300	1.95	2.62	2.47	2.83
L.S.D. (0.05)	.13	.08	.29	.19
L.S.D. (0.01)	.35	.12	N.S.	.29
C.V.	10%	4%	15%	9%
Boron effect means at all levels of Ca and K				
Lbs. borax/A.				
0	1.76	2.40	2.24	2.38
40	1.79	2.36	2.28	2.40
L.S.D. (0.05)	N.S.	N.S.	N.S.	N.S.
C.V.	11%	8%	9%	7%

Table 26.--Potassium content of alfalfa forage grown on Hartsells loam receiving different lime, potassium, and boron treatments, 1959.

Treatment			Potassium content of oven-dry forage by cuttings		
Lime[a]	K_2O	Borax	First	Second	Third
T./A.	Lbs./A.	Lbs./A.	%	%	%
3	100	0	2.08[b]	2.23	1.92
3	100	40	2.22	2.28	2.43
3	300	0	2.58	2.77	2.73
3	300	40	2.61	2.64	2.51
8	100	0	2.58	2.07	1.76
8	100	40	2.28	2.28	1.82
8	300	0	2.44	2.71	2.38
8	300	40	2.61	2.53	2.35

[a]Average initial soil pH was 5.5.

[b]Values represent an average of three replications.

Table 26 (continued)

Analysis of Variance

	Cutting		
	First	Second	Third
	%	%	%
Lime effect means at all levels of K and B			
Tons lime/A.			
3	2.37	2.48	2.40
8	2.48	2.40	2.08
L.S.D. (0.05)	.08	N.S.	N.S.
C.V.	19%	6%	17%
Potassium effect means at all levels of Ca and B			
Lbs. K_2O/A.			
100	2.29	2.22	1.98
300	2.56	2.66	2.49
L.S.D. (0.05)	N.S.	.28	.30
L.S.D. (0.01)	N.S.	N.S.	.50
C.V.	17%	10%	12%
Boron effect means at all levels of Ca and K			
Lbs. borax/A.			
0	2.42	2.44	2.20
40	2.43	2.43	2.28
L.S.D. (0.05)	N.S.	N.S.	N.S.
C.V.	5%	5%	18%

Table 27.--Potassium content of alfalfa forage grown on Hartsells loam receiving different lime, potassium, and boron treatments, 1960.

Treatment			Potassium content of oven-dry forage by cuttings			
Lime[a]	K2O	Borax	First	Second	Third	Fourth
T./A.	Lbs./A.	Lbs./A.	%	%	%	%
3	100	0	2.20[b]	1.84	1.69	1.54
3	100	40	2.35	2.42	1.61	1.78
3	300	0	2.92	3.25	2.76	2.71
3	300	40	2.89	3.07	2.55	2.80
8	100	0	2.07	2.34	2.22	2.06
8	100	40	2.05	2.23	1.71	1.48
8	300	0	3.10	3.68	2.86	3.02
8	300	40	2.84	3.42	2.39	2.87

[a]Average initial soil pH was 5.5.

[b]Values represent an average of three replications.

Table 27 (continued)

Analysis of Variance

	Cutting			
	First	Second	Third	Fourth
	%	%	%	%
Lime effect means at all levels of K and B				
Tons lime/A.				
3	2.59	2.64	2.15	2.21
8	2.52	2.92	2.30	2.36
L.S.D. (0.05)	N.S.	N.S.	N.S.	N.S.
C.V.	16%	13%	10%	10%
Potassium effect means at all levels of Ca and B				
Lbs. K_2O/A.				
100	2.17	2.21	1.81	1.72
300	2.94	3.36	2.64	2.85
L.S.D. (0.01)	.59	.82	.52	.74
C.V.	12%	16%	12%	17%
Boron effect means at all levels of Ca and K				
Lbs. borax/A.				
0	2.57	2.78	2.38	2.33
40	2.53	2.79	2.06	2.23
L.S.D. (0.05)	N.S.	N.S.	.25	N.S.
C.V.	6%	22%	12%	28%

Table 28.--Potassium content of alfalfa forage grown on Maury silt loam receiving different lime, potassium, and boron treatments, 1960.

Treatment			Potassium content of oven-dry forage by cuttings			
Lime[a]	K_2O	Borax	First	Second	Third	Fourth
T./A.	Lbs./A.	Lbs./A.	%	%	%	%
0	100	0	1.59[b]	1.82	2.21	2.45
0	100	40	1.49	2.07	2.06	2.46
0	300	0	1.77	2.22	2.43	2.81
0	300	40	1.86	1.99	2.29	2.84
5	100	0	1.48	2.06	2.52	2.43
5	100	40	1.55	1.76	1.96	2.56
5	300	0	1.75	2.08	2.54	2.82
5	300	40	1.99	2.19	2.49	3.00

[a]Average initial soil pH was 6.4.

[b]Values represent an average of three replications.

Table 28 (continued)

Analysis of Variance

	Cutting			
	First	Second	Third	Fourth
	%	%	%	%
Lime effect means at all levels of K and B				
Tons lime/A.				
0	1.68	2.02	2.25	2.64
5	1.69	2.02	2.38	2.70
L.S.D. (0.05)	N.S.	N.S.	N.S.	N.S.
C.V.	12%	13%	12%	4%
Potassium effect means at all levels of Ca and B				
Lbs. K20/A.				
100	1.53	1.93	2.19	2.48
300	1.84	2.12	2.44	2.87
L.S.D. (0.05)	.20	N.S.	N.S.	.06
L.S.D. (0.01)	N.S.	N.S.	N.S.	.10
C.V.	10%	16%	17%	2%
Boron effect means at all levels of Ca and K				
Lbs. borax/A.				
0	1.65	2.04	2.42	2.63
40	1.72	2.00	2.20	2.72
L.S.D. (0.05)	N.S.	N.S.	N.S.	.08
C.V.	9%	13%	12%	3%

Table 29.--Boron content of alfalfa forage grown on Cumberland silt loam receiving different lime, potassium, and boron treatments, 1959.

Treatment			Boron content of oven-dry forage by cuttings			
Lime[a]	K_2O	Borax	First	Second	Third	Fourth
T./A.	Lbs./A.	Lbs./A.		ppm.	ppm.	ppm.
0	100	0	No samples obtained	10.1[b]	17.2	14.9
0	100	40		13.7	24.9	19.2
0	300	0		11.8	18.5	16.1
0	300	40		12.3	19.3	18.6
4	100	0		12.1	20.3	17.2
4	100	40		12.2	20.7	18.3
4	300	0		12.0	18.9	17.4
4	300	40		12.2	21.8	18.1

[a]Average initial soil pH was 6.6.

[b]Values represent an average of four replications.

Table 29 (continued)

Analysis of Variance

	Cutting			
	First	Second	Third	Fourth
	ppm.	ppm.	ppm.	ppm.
Lime effect means at all levels of K and B				
Tons lime/A.				
0	No samples obtained	12.0	20.0	17.2
4		12.1	20.4	17.8
L.S.D. (0.05)		N.S.	N.S.	N.S.
C.V.		17%	23%	8%
Potassium effect means at all levels of Ca and B				
Lbs. K_2O/A.				
100		12.0	20.8	17.4
300		12.1	19.6	17.6
L.S.D. (0.05)		N.S.	N.S.	N.S.
C.V.		12%	22%	14%
Boron effect means at all levels of Ca and K				
Lbs. borax/A.				
0		11.5	18.7	16.4
40		12.6	21.7	18.6
L.S.D. (0.05)		.8	2.2	1.7
L.S.D. (0.01)		1.1	N.S.	N.S.
C.V.		8%	14%	12%

Table 30.--Boron content of alfalfa forage grown on Cumberland silt loam receiving different lime, potassium, and boron treatments, 1960.

Treatment			Boron content of oven-dry forage by cuttings			
Lime[a]	K_2O	Borax	First	Second	Third	Fourth
T./A.	Lbs./A.	Lbs./A.	ppm.	ppm.	ppm.	ppm.
0	100	0	19.6[b]	20.2	12.8	15.0
0	100	40	29.1	26.3	17.1	18.7
0	300	0	19.5	14.4	15.2	15.9
0	300	40	25.4	23.5	18.4	19.3
4	100	0	25.7	19.9	13.7	16.9
4	100	40	23.8	23.9	15.8	19.2
4	300	0	24.5	20.5	13.3	15.7
4	300	40	24.3	24.6	16.5	18.8

[a]Average initial soil pH was 6.6.

[b]Values represent an average of four replications.

Table 30 (continued)

Analysis of Variance

	Cutting			
	First	Second	Third	Fourth
	ppm.	ppm.	ppm.	ppm.
Lime effect means at all levels of K and B				
Tons lime/A.				
0	23.4	21.1	15.9	17.2
4	24.6	22.2	14.8	17.6
L.S.D. (0.05)	N.S.	N.S.	N.S.	N.S.
C.V.	38%	13%	17%	18%
Potassium effect means at all levels of Ca and B				
Lbs. K_2O/A.				
100	24.6	22.6	14.8	17.4
300	23.4	20.8	15.8	17.4
L.S.D. (0.05)	N.S.	N.S.	N.S.	N.S.
C.V.	17%	12%	9%	5%
Boron effect means at all levels of Ca and K				
Lbs. borax/A.				
0	22.3	18.8	13.8	15.9
40	25.6	24.6	17.0	19.0
L.S.D. (0.05)	N.S.	1.9	1.5	1.7
L.S.D. (0.01)	N.S.	2.6	2.2	2.4
C.V.	22%	11%	12%	13%

Table 31.--Boron content of alfalfa forage grown on Hartsells loam receiving different lime, potassium, and boron treatments, 1959.

Treatment			Boron content of oven-dry forage by cuttings		
Lime[a]	K_2O	Borax	First	Second	Third
T./A.	Lbs./A.	Lbs./A.	ppm.	ppm.	ppm.
3	100	0	35.4[b]	31.8	26.1
3	100	40	30.0	35.7	31.4
3	300	0	36.0	39.5	31.4
3	300	40	38.0	41.2	32.7
8	100	0	45.2	27.5	29.4
8	100	40	40.1	37.3	32.2
8	300	0	32.3	33.7	26.9
8	300	40	39.6	39.2	29.5

[a]Average initial soil pH was 5.5.

[b]Values represent an average of three replications.

Table 31 (continued)

Analysis of Variance

	Cutting		
	First	Second	Third
	ppm.	ppm.	ppm.
Lime effect means at all levels of K and B			
Tons lime/A.			
3	34.8	37.0	30.4
8	39.3	34.4	29.5
L.S.D. (0.05)	N.S.	N.S.	N.S.
C.V.	22%	22%	25%
Potassium effect means at all levels of Ca and B			
Lbs. K_2O/A.			
100	37.7	33.1	29.8
300	36.5	38.4	30.1
L.S.D. (0.05)	N.S.	N.S.	N.S.
C.V.	16%	19%	15%
Boron effect means at all levels of Ca and K			
Lbs. borax/A.			
0	37.2	33.1	28.4
40	36.9	38.4	31.5
L.S.D. (0.05)	N.S.	.43	N.S.
C.V.	19%	3%	14%

Table 32.--Boron content of alfalfa forage grown on Hartsells loam receiving different lime, potassium, and boron treatments, 1960.

Treatment			Boron content of oven-dry forage by cuttings			
Lime[a]	K_2O	Borax	First	Second	Third	Fourth
T./A.	Lbs./A.	Lbs./A.	ppm.	ppm.	ppm.	ppm.
3	100	0	23.4[b]	20.6	19.2	21.5
3	100	40	31.6	28.6	25.7	21.6
3	300	0	23.6	19.2	19.2	20.1
3	300	40	37.1	26.3	30.0	21.5
8	100	0	23.9	19.4	17.7	25.7
8	100	40	32.2	24.5	26.9	28.3
8	300	0	21.4	21.9	19.1	21.7
8	300	40	31.7	26.9	24.3	27.4

[a]Average initial soil pH was 5.5.

[b]Values represent an average of three replications.

Table 32 (continued)

Analysis of Variance

	Cutting			
	First	Second	Third	Fourth
	ppm.	ppm.	ppm.	ppm.
Lime effect means at all levels of K and B				
Tons lime/A.				
3	28.9	23.8	23.5	21.2
8	27.3	23.2	22.0	25.8
L.S.D. (0.05)	N.S.	N.S.	N.S.	N.S.
C.V.	4%	28%	17%	10%
Potassium effect means at all levels of Ca and B				
Lbs. K_2O/A.				
100	27.8	23.3	22.4	24.3
300	28.4	23.6	23.2	22.7
L.S.D. (0.05)	N.S.	N.S.	N.S.	N.S.
C.V.	18%	11%	23%	9%
Boron effect means at all levels of Ca and K				
Lbs. borax/A.				
0	23.1	20.3	18.8	22.2
40	33.2	26.6	26.7	24.7
L.S.D. (0.05)	3.2	5.0	1.6	1.6
L.S.D. (0.01)	4.7	N.S.	2.4	2.4
C.V.	12%	23%	8%	7%

Table 33.--Boron content of alfalfa forage grown on Maury silt loam receiving different lime, potassium, and boron treatments, 1960.

Treatment			Boron content of oven-dry forage by cuttings			
Lime[a]	K2O	Borax	First	Second	Third	Fourth
T./A.	Lbs./A.	Lbs./A.	ppm.	ppm.	ppm.	ppm.
0	100	0	25.6[b]	20.7	17.7	19.5
0	100	40	32.1	27.7	22.5	23.9
0	300	0	25.7	20.0	16.6	18.5
0	300	40	32.1	24.1	18.3	21.0
5	100	0	26.8	19.5	15.4	19.4
5	100	40	28.8	21.3	18.7	21.4
5	300	0	27.6	16.9	14.7	18.6
5	300	40	32.7	21.5	19.1	22.7

[a]Average initial soil pH was 6.4.

[b]Values represent an average of three replications.

Table 33 (continued)

Analysis of Variance

	Cutting			
	First	Second	Third	Fourth
	ppm.	ppm.	ppm.	ppm.
Lime effect means at all levels of K and B				
Tons lime/A.				
0	28.9	23.1	18.8	20.7
5	29.0	19.8	17.0	20.5
L.S.D. (0.05)	N.S.	1.7	1.7	N.S.
C.V.	8%	5%	6%	10%
Potassium effect means at all levels of Ca and B				
Lbs. K_2O/A.				
100	28.3	22.3	18.6	21.0
300	29.5	20.6	17.2	20.2
L.S.D. (0.05)	N.S.	N.S.	N.S.	N.S.
C.V.	20%	15%	16%	15%
Boron effect means at all levels of Ca and K				
Lbs. borax/A.				
0	26.4	19.3	16.1	19.0
40	31.4	23.6	19.6	22.2
L.S.D. (0.05)	3.3	1.3	2.5	1.6
L.S.D. (0.01)	4.7	N.S.	N.S.	2.4
C.V.	12%	7%	15%	9%

Table 34.--Magnesium content of alfalfa forage grown on Cumberland silt loam receiving different lime, potassium, and boron treatments, 1959.

Treatment			Magnesium content of oven-dry forage by cuttings			
Lime[a]	K_2O	Borax	First	Second	Third	Fourth
T./A.	Lbs./A.	Lbs./A.	%	%	%	%
0	100	0	No samples obtained	.46[b]	.21	.29
0	100	40		.53	.23	.28
0	300	0		.41	.16	.23
0	300	40		.39	.09	.21
4	100	0		.51	.24	.29
4	100	40		.47	.22	.29
4	300	0		.40	.17	.20
4	300	40		.42	.19	.20

[a]Average initial soil pH was 6.6.

[b]Values represent an average of four replications.

Table 34 (continued)

Analysis of Variance

	Cutting			
	First	Second	Third	Fourth
		%	%	%
Lime effect means at all levels of K and B				
Tons lime/A.				
0	No samples obtained	.45	.17	.25
4		.45	.20	.24
L.S.D. (0.05)		N.S.	N.S.	N.S.
C.V.		12%	32%	6%
Potassium effect means at all levels of Ca and B				
Lbs. K_2O/A.				
100		.49	.22	.29
300		.40	.15	.21
L.S.D. (0.01)		.06	.02	.03
C.V.		10%	27%	9%
Boron effect means at all levels of Ca and K				
Lbs. borax/A.				
0		.44	.20	.25
40		.45	.18	.24
L.S.D. (0.05)		N.S.	N.S.	N.S.
C.V.		10%	24%	19%

Table 35.--Magnesium content of alfalfa forage grown on Cumberland silt loam receiving different lime, potassium, and boron treatments, 1960.

Treatment			Magnesium content of oven-dry forage by cuttings			
Lime[a]	K_2O	Borax	First	Second	Third	Fourth
T./A.	Lbs./A.	Lbs./A.	%	%	%	%
0	100	0	.35[b]	.44	.45	.49
0	100	40	.38	.44	.48	.53
0	300	0	.23	.36	.44	.41
0	300	40	.28	.40	.45	.43
4	100	0	.31	.38	.44	.52
4	100	40	.30	.47	.40	.49
4	300	0	.28	.40	.45	.42
4	300	40	.23	.36	.41	.45

[a]Average initial soil pH was 6.6.

[b]Values represent an average of four replications.

Table 35 (continued)

Analysis of Variance

	Cutting			
	First	Second	Third	Fourth
	%	%	%	%
Lime effect means at all levels of K and B				
Tons lime/A.				
0	.31	.41	.46	.46
4	.28	.40	.42	.47
L.S.D. (0.05)	N.S.	N.S.	.03	N.S.
C.V.	27%	18%	6%	14%
Potassium effect means at all levels of Ca and B				
Lbs. K_2O/A.				
100	.34	.43	.44	.51
300	.26	.38	.44	.43
L.S.D. (0.01)	.07	.04	N.S.	.07
C.V.	18%	8%	12%	9%
Boron effect means at all levels of Ca and K				
Lbs. borax/A.				
0	.29	.40	.44	.46
40	.30	.42	.44	.48
L.S.D. (0.05)	N.S.	N.S.	N.S.	N.S.
C.V.	11%	14%	7%	7%

Table 36.--Magnesium content of alfalfa forage grown on Hartsells loam receiving different lime, potassium, and boron treatments, 1959.

Treatment			Magnesium content of oven-dry forage by cuttings		
Lime[a]	K_2O	Borax	First	Second	Third
T./A.	Lbs./A.	Lbs./A.	%	%	%
3	100	0	.35[b]	.33	.35
3	100	40	.31	.35	.35
3	300	0	.33	.32	.35
3	300	40	.33	.33	.35
8	100	0	.35	.38	.42
8	100	40	.33	.36	.37
8	300	0	.33	.30	.39
8	300	40	.32	.29	.39

[a]Average initial soil pH was 5.5.

[b]Values represent an average of three replications.

Table 36 (continued)

Analysis of Variance

	Cutting		
	First	Second	Third
	%	%	%
Lime effect means at all levels of K and B			
Tons lime/A.			
3	.33	.33	.35
8	.33	.33	.39
L.S.D. (0.05)	N.S.	N.S.	N.S.
C.V.	21%	10%	20%
Potassium effect means at all levels of Ca and B			
Lbs. K_2O/A.			
100	.34	.36	.37
300	.33	.31	.37
L.S.D. (0.05)	N.S.	.04	N.S.
C.V.	21%	7%	24%
Boron effect means at all levels of Ca and K			
Lbs. borax/A.			
0	.34	.33	.38
40	.32	.33	.36
L.S.D. (0.05)	N.S.	N.S.	N.S.
C.V.	10%	12%	15%

Table 37.--Magnesium content of alfalfa forage grown on Hartsells loam receiving different lime, potassium, and boron treatments, 1960.

Treatment			Magnesium content of oven-dry forage by cuttings			
Lime[a]	K_2O	Borax	First	Second	Third	Fourth
T./A.	Lbs./A.	Lbs./A.	%	%	%	%
3	100	0	.41[b]	.47	.52	.67
3	100	40	.43	.45	.47	.69
3	300	0	.38	.45	.46	.51
3	300	40	.36	.42	.46	.55
8	100	0	.46	.42	.47	.75
8	100	40	.46	.43	.52	.75
8	300	0	.38	.41	.46	.67
8	300	40	.39	.41	.44	.60

[a]Average initial soil pH was 5.5.

[b]Values represent an average of three replications.

Table 37 (continued)

Analysis of Variance

	Cutting			
	First	Second	Third	Fourth
	%	%	%	%
Lime effect means at all levels of K and B				
Tons lime/A.				
3	.40	.45	.48	.60
8	.42	.42	.47	.69
L.S.D. (0.05)	N.S.	N.S.	N.S.	N.S.
C.V.	8%	8%	15%	5%
Potassium effect means at all levels of Ca and B				
Lbs. K_2O/A.				
100	.44	.44	.50	.72
300	.38	.42	.46	.58
L.S.D. (0.01)	N.S.	N.S.	N.S.	.08
C.V.	14%	6%	9%	7%
Boron effect means at all levels of Ca and K				
Lbs. borax/A.				
0	.41	.44	.48	.65
40	.41	.43	.47	.65
L.S.D. (0.05)	N.S.	N.S.	N.S.	N.S.
C.V.	14%	6%	9%	7%

Table 38.--Magnesium content of alfalfa forage grown on Maury silt loam receiving different lime, potassium, and boron treatments, 1960.

Treatment			Magnesium content of oven-dry forage by cuttings			
Lime[a]	K_2O	Borax	First	Second	Third	Fourth
T./A.	Lbs./A.	Lbs./A.	%	%	%	%
0	100	0	.79[b]	.97	.83	.86
0	100	40	.87	.91	.79	.72
0	300	0	.85	.87	.78	.87
0	300	40	.86	.92	.78	.51
5	100	0	.94	1.03	.78	.82
5	100	40	.96	.92	.80	.85
5	300	0	.86	.92	.80	.82
5	300	40	.85	.88	.76	.65

[a]Average initial soil pH was 6.4.

[b]Values represent an average of three replications.

Table 38 (continued)

Analysis of Variance

	Cutting			
	First	Second	Third	Fourth
	%	%	%	%
Lime effect means at all levels of K and B				
Tons lime/A.				
0	.84	.92	.80	.74
5	.90	.94	.78	.78
L.S.D. (0.05)	N.S.	N.S.	N.S.	N.S.
C.V.	18%	23%	5%	20%
Potassium effect means at all levels of Ca and B				
Lbs. K_2O/A.				
100	.89	.96	.80	.81
300	.86	.90	.78	.71
L.S.D. (0.05)	N.S.	N.S.	N.S.	N.S.
C.V.	20%	22%	6%	6%
Boron effect means at all levels of Ca and K				
Lbs. borax/A.				
0	.86	.95	.80	.84
40	.88	.91	.78	.68
L.S.D. (0.05)	N.S.	N.S.	N.S.	N.S.
C.V.	16%	11%	7%	13%

CHAPTER V

SUMMARY AND CONCLUSIONS

This study was conducted to determine the influence of different fertility levels on the yield and chemical composition of alfalfa forage grown on three soil types in Tennessee in 1959 and 1960. The soil types were Cumberland silt loam, Hartsells loam, and Maury silt loam. Initial soil test values and soil tests following the various treatments were obtained in order to interpret the treatment effects on the yield and composition of the forage.

All soils received initial fertilization as need was indicated by the standard soil test procedures and enough lime to establish two soil pH levels at each location. Annual fertilization treatments consisted of 100 and 300 pounds of K_2O and 0, and 40 pounds of borax.

The major results were as follows:

Soil analyses show that lime treatments raised the pH in all soils but increased the exchangeable calcium supply only on two of the soils. However, lime treatment on one soil shows a decrease in available calcium with the higher lime treatment. No explanation is given for this except that possibly an error was made in the soil sampling or inadequate application or mixing of the lime.

Soil studies for exchangeable potassium show that potassium was significantly increased as potash application increased. No significant differences in the available supply of potassium were revealed by the increased levels of lime or borax except in the case of the Maury soil

where the lime treatment significantly lowered the exchangeable potassium level.

Soil tests after treatment show that available boron was not significantly influenced by either lime or potassium treatments. However, borax fertilization resulted in significant increases in the available boron supply of all three soils.

The data show that exchangeable magnesium was not significantly influenced by any of the fertilizer treatments. Furthermore, the exchangeable magnesium in the soil changed very little during the period under study.

No significant differences among mean yields were found following the various treatments on each soil. This indicates that the quantity (even at the lower fertilizer levels) of all nutrient elements being studied, was sufficient for the production levels obtained under the conditions grown.

Chemical analyses of alfalfa plant tissue for calcium show no significant changes in calcium content as a result of the higher level of either lime or borax. In fact, a slight increase in calcium content in most cases was found in the alfalfa forage grown on the soils which received the lower lime treatments. In general, the calcium content was significantly decreased by the higher potassium treatments.

Highly significant increases in potassium concentration in the forage at the higher level of potash treatment were generally found, whereas the higher lime or borax levels failed to significantly change the potassium content in most cases. The lowest average potassium

content found in the alfalfa forage was 1.48%. This is above the critical value of 1.0% suggested by Bear, et al. (6, 22).

The addition of borax significantly increased the boron content of the alfalfa plants in almost every cutting. In general, the addition of potassium or calcium did not significantly change the boron content. However, there was a tendency for the boron content of the forage to decrease from the first to the last cutting each year. This may be related to changes in available soil moisture.

In general, the magnesium content of the forage was significantly lower at the higher potassium levels. This may have been caused by a larger supply of available potassium in the soil which affected the plant uptake of magnesium and possibly resulted in luxury consumption of potassium. No consistent relationship was found between magnesium and boron uptake nor magnesium and calcium uptake.

As for the interrelationship among the ions studied, it was found that potassium at the higher rates repressed the plant uptake of calcium and magnesium in practically all instances. This is generally attributed to antagonism between the ions.

In contrast with the influence of potassium on calcium and magnesium, lime application did not distinctly lower the percent potassium and magnesium in the forage.

The data gathered in this study show no consistent relationship between boron and calcium or potassium at the levels of this study.

The results of this study show that the sum of calcium, potassium, and magnesium, expressed in average milliequivalents per 100 g. for all

cuttings, is remarkably constant for alfalfa grown on the same soil for the same year regardless of the fertilizer treatment. It was also found that the total cation content of alfalfa was approximately constant for the various treatments of each cutting on the same soil for the same year but varied from cutting to cutting which can be attributed to a different set of environmental conditions throughout the season. This has some practical significance in that yield was not significantly affected by any of the fertilizer treatments in this study. Therefore, since the proportion of calcium, potassium, and magnesium was found to vary, it is evident from the yield results that the minimum amount of each of these elements was assured to meet the crop's specific needs.

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APPENDIXES

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APPENDIX A

PROCEDURE FOR DETERMINATION OF EXCHANGEABLE CALCIUM, MAGNESIUM, AND POTASSIUM OF SOILS

1. Place 10 grams of air-dry soil (ground to a fineness that will pass a 2 mm. sieve) in a 125 ml. erlenmeyer flask.
2. Add 50 ml. of neutral normal ammonium acetate.
3. Shake for 30 minutes and let set overnight.
4. Shake for 30 minutes the following morning.
5. Filter, using Whatman No. 42 filter paper, with suction flask and wash with an additional 50 ml. of neutral normal ammonium acetate, collecting entire filtrate.
6. Procure a small portion of the filtrate (about 5 ml.) and determine exchangeable calcium and potassium content with a Beckman DU flame spectrophotometer equipped with a photomultiplier attachment. The wavelengths for calcium and potassium are 422.7 and 766.8 Mu respectively.
7. Sample readings are compared with the calibration curves obtained from standard solutions and the calcium and potassium contents of the soil are calculated.
8. Samples for determining magnesium are obtained by procuring a 50 ml. aliquot of the original filtrate and taking to dryness on the hot plate.
9. Destroy organic matter with 30 percent hydrogen peroxide.
10. Add 20 ml. of 0.1 N hydrochloric acid.

11. Procure a small portion of this solution (about 5 ml.) to determine exchangeable magnesium with a Beckman DU flame spectrophotometer equipped with a photomultiplier attachment. A wavelength of 285.2 is used.

12. The sample readings are compared with the calibration curve obtained from standard solutions and magnesium content of the soil calculated.

APPENDIX B

PROCEDURE FOR DETERMINATION OF AVAILABLE BORON IN SOILS

PROCEDURE:

1. Place 12.5 grams of soil in 100 ml. extraction flask (Corning #75160) and 25 ml. boron-free water. Attach a reflux condenser made of corning 728 glass. Heat to boiling and boil for five minutes. It is then allowed to cool, and the condenser is disconnected.
2. A blank is determined by placing 25 ml. of water in the extraction flask and boiling for five minutes as in the soil extraction. This solution is carried through all steps in the subsequent procedure.
3. The soil suspension is transferred to a centrifuge tube, 2 drops of a 1 N solution of $CaCl_2$ is added, and the suspension is centrifuged for five minutes at 2000 rpms. The supernatent solution is used to determine boron.
4. Pipet 2 ml. of the sample (should not exceed 10 ppm. B) into an Erlenmeyer flask (125 ml.).
5. Add 2 drops of conc. hydrochloric acid (prevents NO_2^- and NO_3^- from interfering with color development).
6. Add 10 ml. of conc. sulfuric acid.
7. Mix and cool.
8. Add 10 ml. of 0.05% carmine soln. by weight (0.920 gm. of carmine/ l. sulfuric acid) and allow to stand at least 45 minutes for color development.

9. Determine the percent transmittance using an Evelyn Colorimeter at a 585 Mu wavelength against a reference soln. of 2 ml. of boron-free water carried through the entire process.
10. The sample readings are compared with the calibration curve obtained from standard solutions and available boron content of the soil calculated.

APPENDIX C

CALCIUM, MAGNESIUM, AND POTASSIUM ANALYSIS OF PLANT SAMPLES

1. Weigh out a 1.000 g. sample in a silica evaporating dish and ash in a muffle furnace at 550° C. for four or more hours.
2. Cool and moisten ash with 1 ml. of distilled water and add 3 ml. of 1:1 hydrochloric acid. This is transferred quantitatively to a 25 ml. volumetric flask and made to volume using distilled water.
3. Procure a small portion of this (about 5 ml.) and determine exchangeable calcium, magnesium, and potassium contents with a Beckman Model DU flame spectrophotometer equipped with a photomultiplier attachment. Wavelengths for calcium, magnesium, and potassium are 422.7, 285.2, and 766.8 Mu respectively.
4. Sample readings are compared with the calibration curves obtained from standard solutions and the calcium, magnesium, and potassium contents of the forage are calculated.

APPENDIX D

BORON DETERMINATION OF PLANT SAMPLES

1. Weigh 1.000 g. plant material in a silica evaporating dish and ash in a muffle furnace for four hours at 600° C.
2. Cool and moisten ash with 1 ml. boron-free water. Add 3 ml. 1:1 hydrochloric acid under a soft glass watch glass. Transfer quantitatively to a 25 ml. soft glass volumetric flask being sure to wash watch glass and bring to volume using boron-free distilled water.
3. Pipet 2 ml. of the sample (should not exceed 10 ppm B) into an Erlenmeyer flask (125 ml.).
4. Add 2 drops of conc. hydrochloric acid (prevents NO_3^- and NO_2^- from interfering with color development).
5. Add 10 ml. of conc. sulfuric acid.
6. Mix and cool.
7. Add 10 ml. of 0.05% carmine soln. by weight (0.920 gm. of carmine/ 1. sulfuric acid) and allow to stand at least 45 minutes for color development.
8. Determine the percent transmittance using an Evelyn Colorimeter at 585 Mu against a reference soln. of 2 ml. of distilled water carried through the entire process.