PLANT RESPONSE TO SULFUR APPLICATIONS
ON A SULFUR DEFICIENT SOIL

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Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
DOCTOR OF PHILOSOPHY
May, 1975

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ACKNOWLEDGMENTS

I am indebted to Dr. John M. Baker, Jr. for suggesting this thesis problem and giving advice during the early investigative period.

To Dr. Billy B. Tucker, my major advisor, I extend my sincere thanks for his leadership and guidance throughout the research and academic studies.

The author is grateful to the members of his graduate committee, Dr. Eddie Basler, Dr. Lavoy Croy, and Dr. Loren Rommann, for their very helpful suggestions and advice during the course of study and graduate program.

Appreciation is extended to Mr. James Baker, Mr. Joe Scannell, and Mr. Paul Nightengale for providing land and other help for the studies. Also, appreciation is extended to the Agronomy Department, Agricultural Experiment Station, and Oklahoma State University for use of their facilities and financial support which made these studies possible.

A sincere thanks to my father and mother, Alvin and Hilda, as well as other family members and friends who with their sacrifices, understanding and encouragement have made my education possible.

Finally, my wife, Patsy, has helped me in many ways. For her valuable moral support, deep understanding and patience, I owe my most special thanks and unending gratitude. I am also indebted to my four children for their patience and understanding during this period of study.

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CHAPTER I

INTRODUCTION

Numerous soil sulfur deficiencies affecting plant growth have been observed throughout the United States as well as other areas of the world. The severity of the problem seems to be increasing. Deficiencies of sulfur generally appear first on sandy soils which are heavily cropped, characteristically low in organic matter, and are generally acidic. Probable causes for the increase in deficiencies include today's use of higher grade fertilizer materials, a cleaner environment, and a higher demand for sulfur from the soil through increased crop yields. Recently, beneficial plant responses to additions of sulfur have been reported in Texas, Arkansas, and Louisiana. The sulfur status of Oklahoma soils are not clearly defined.

With the clearing of timber land and establishment of improved pastures, as well as the increased production on existing crop land, the soils of Oklahoma are nearing conditions which may be conducive to sulfur deficiencies. This is especially true since high rates of nitrogen fertilizers have been applied to soils in an attempt to increase per acre yields.

Sulfur deficiencies can be easily overcome by the application of various sulfur containing materials to the soil. There are, however, several inherent problems in diagnosing potentially deficient soils. Until recently, analytical determinations for sulfur were time consuming and tedious. Today, however, with the use of an auto-analyzer, analysis for total sulfur has been simplified. The second problem lies in the fact that sulfur is found in soil in organic as well as inorganic forms. This total quantity of sulfur in soils is extremely variable being a function of both location and climate as well as past soil management practices. Total soil sulfur is not a true indication of plant available sulfur during the growing season. Sulfur transformations in soils are continuous and highly variable. Although the sulfate form is considered to be the "available" form, the measurement of sulfates in the soil at a given date is of little value in predicting amounts available during the growing season. An alternative to establishing the available sulfur status of soils is to measure the sulfur content of the growing plant.

The objectives of this study were designed to determine the effect on forage crops, if any, to sulfur additions from various sources added to the soil. The residual effects of a single application of sulfur was also determined. In addition, plant sulfur contents and nitrogen:sulfur ratios were measured and their relationships to yields and responses to added sulfur were determined. These findings will be useful in developing diagnostic techniques for ascertaining needs for sulfur fertilization.

CHAPTER II

LITERATURE REVIEW

Sulfur, one of the elements essential for plant growth, ranks second in importance for consideration in fertility programs only to nitrogen, phosphorus, and potassium, the primary fertilizer elements (39). Over the years numerous sulfur deficiencies have been observed throughout the United States as well as in many regions of the world (6, 7, 24, 42). The severity of the problem seems to be increasing from year to year. Many of these deficiencies are being found in areas where shortages of this element were heretofore unsuspected.

Deficiencies of Sulfur

Distribution of Deficiencies

Today sulfur deficiencies have been reported in 31 of the 50 states (48). In addition, Coleman (15) lists several countries throughout the world which have reported crop deficiencies in this element. Sulfur deficiencies generally occur on sandy, well drained soils, with a low organic matter content, low pH, and which receive high rainfall. The problem is generally localized within a given section of a particular country. They are not restricted, however, to these areas. No doubt these areas will continue to increase both in size and number.

Causes of Deficiencies

There are several reasons for the increase in sulfur deficient areas over the world today. The most probable causes include: the increased use of sulfur-free fertilizers; the decreased use of sulfur as a fungicide and insecticide; the increased crop yields, which result in larger amounts of sulfur being removed from the soil by plants; and the recent emphasis placed on air pollution control (15).

General Appearance of Deficiencies

Although the appearance of a sulfur deficiency may differ slightly from crop to crop, the general rule is a stunted chlorotic growth. Plants usually are shorter, spindly and develop a much reduced leaf area (21). The symptoms may be confused with those of nitrogen deficiency (16). In the case of sulfur, however, the plants do not develop characteristic leaf yellowing patterns. With a nitrogen deficiency, the older leaves turn yellow first and the younger leaves remain green. With a deficiency of sulfur the opposite yellowing pattern is true, the younger leaves, including the veins, yellow first (20, 48). Under severe conditions, however, all the leaves undergo some loss of green color (24). It should be noted, however, that even under a severe deficiency of sulfur, visual symptoms are seldom, if ever, as striking as deficiencies of nitrogen, boron, potassium, zinc or magnesium (48).

Functions of Sulfur

Although there are marked differences in the metabolic pathways of sulfur in plants and animals, the vital functions of this element appear to be similar in both (2). Animals, however, must be supplied with the amino acid methionine and the sulfur bearing vitamins biotin and thiamine (17). Plants, on the other hand, are able to synthesize sulfur-containing amino acids and proteins from inorganic sulfate salts.

Plants take up sulfur primarily as the sulfate ion (SO_4^{-2}) through their roots and reduce it to an active state in two distinct steps (16). In addition, sulfur dioxide (SO_2), a gas, may also be used by plants (15). It is taken in through leaf stomata and then oxidized to sulfate. The activated sulfate is eventually reduced and incorporated into cystine, cysteine and methionine and finally into the protein structure.

The function of sulfur in plants in general, can be classified as structural or metabolic (2, 16). Sulfur compounds which play an important role in protein structure include catalysts (enzymes) and electron carriers (cytochromes) (14). Its most obvious function, however, lies in the participation of sulfur in forming of the various structures of proteins, i.e. primary, secondary, and tertiary. Each structure is affected by its sulfur composition. It is essential that a particular protein conformation be present in order for an enzyme to function properly. Boyer (13), for example, found that 90 percent of a group of enzymes studied were inhibited to some extent by reagents that destroyed sulfhydryl groups.

Other uses of sulfur by plants include two growth regulators, thiamine, and biotin as well as glutathione and coenzyme A (8, 30). Sulfur applications, for example, have been shown to increase the amounts of six of the B vitamins in alfalfa, *Medicago sativa* (41). Vitamin A content was also greatly increased in alfalfa when phosphorus and sulfur were used in combination (22). Still other functions of sulfur include formation of certain glucoside oils and activation of certain proteolytic enzymes. Convincing evidence of proteolysis in many plant types, however, as is found by nitrogen, was lacking with sulfur, although it does occur to a certain extent (20).

Although sulfur is not a constituent of chlorophyll, a sulfur deficient plant, as mentioned earlier, tends to become chlorotic. Ergle (20) reported a 40 percent reduction in chlorophyll content of sulfur-deficient cotton plants as compared to controls. Tisdale further shows this effect for red clover (48). This seems to imply that under conditions of sulfur starvation the chloroplasts have priority on available sulfur.

Levels of Sulfur Content

Plant

In general, crops have been grouped into three catagories according to amounts of sulfur they absorb (30). The first group includes some of the brassica species of plants which take up fairly large amounts of sulfur ranging from 18 to 38 pounds per acre. The intermediate group includes the legumes which require 12 to 24 pounds of sulfur per acre. Corn, grasses, and grain crops usually require a smaller amount of only 8 to 12 pounds per acre when grown at moderate nitrogen levels (31).

Reports can be found in the literature which suggest sulfur additions to the soil increase plant sulfur content (29, 34, 43). Generally, these increases are most notable when adequate to plentiful amounts of other plant nutrients are present. Sulfur generally occurs in plants in either proteins, volatile compounds, such as mustard in plants in either proteins, volatile compounds, such as mustard oil and mercaptans, or sulfates (24). In leguminous crops, much of the increase in total sulfur is synthesized into protein sulfur (3). In nonlegumes, sulfates may be increased considerably with increased sulfur additions. If nonlegumes are well supplied with nitrogen, however, protein formation may proceed as in legumes (30). As a general rule, only a small proportion of the total plant sulfur is in compounds other than the amino acids. It has been reported, for example, that 90 percent of all sulfur and nitrogen present in the plant are found in the protein structure (8). However, under conditions of sulfur deficiencies, excess nitrate and soluble organic nitrogen accumulate in the leaves of plants (20). Under conditions where excessive sulfur is taken up by the plant, it may accumulate within the plant as the sulfate ion and act as a reserve supply of inorganic sulfur. Presence of appreciable amounts of this form of sulfur may be evidenced as adequate sulfur nutrition.

There is not an abundance of information on critical levels of sulfur in grass type plants. Certain ranges have nonetheless been tentatively listed for selected crops (40). As an example, a range for Coastal bermuda grass, of 0.14 to 0.15 percent total sulfur has been suggested (34, 38). As might be expected, the minimum level for alfalfa and cotton is slightly higher at approximately 0.20 percent (30). The critical level, as mentioned above, is intended to represent the minimum concentration of sulfur in the plant tissue necessary for maximum growth of that plant.

Coastal bermuda grass has shown response to applications of gypsum when applied to soils of the southeastern United States as rates of 4, 8, 16, and 32 pounds of sulfur per acre with plant sulfur contents of 0.14, 0.15, 0.19, and 0.21 percent respectively (29). Where no sulfur was applied the plant sulfur content was 0.14 percent. Landua et al. (34) also reported an increase in plant sulfur content of plants growing in soil to which sulfur was applied as $CaSO_4$.

Soil

Soil sulfur content varies greatly. Eaton reviewed the early work on the sulfur content of various soils in the United States (18). He reported on two soil samples collected from cultivated fields near Miami, Oklahoma and found an average value of 0.0240 and 0.0211 percent sulfur for surface and subsoils respectively. Eaton concluded from the analysis of the above samples that Oklahoma soils were low in sulfur, phosphorus, and organic matter. Other data that were collected by several workers and reported by Jordan and Ensminger (30), show the soil sulfur contents were not high, ranging from only 0.012 to 0.156 percent. Robinson reported a range of 0.008 to 0.136 percent sulfur content for certain top soils. Byers et al., on 18 representative soils of agricultural importance, found a range with a mean of about 0.045 percent for the A and B horizons. Of this amount, organic sulfur varied greatly from about 73 to 45 percent of the total sulfur content in surface layers. Subsurface layers, as expected, contain a much smaller amount of about 16 percent organic sulfur (30).

Organic matter comprises an important reserve form of plant usable sulfur. In humid regions it may account for as much as 90 percent of the total sulfur in surface soils (50). Transformations of sulfur from organic forms to sulfate ions will be discussed in another section.

Generally speaking, organic sulfur can be divided into two fractions: carbon-bonded sulfur, as in the sulfur containing amino acids, and non-carbon bonded sulfur, as HI-reducible sulfur (50).

Inorganic sulfate in soils can be divided into two components: a water-soluble fraction usually extracted with neutral solutions and an adsorbed fraction extractable with monophosphate ions. Both of the above are readily available to plants although sulfate is taken up more slowly from soils with a high adsorbing capacity.

The effect of the drying of soil on sulfur availability to plants has been measured (50). Where soil samples were air-dried before potting in the greenhouse, dry matter yields of ryegrass were increased for two harvests at all levels of added sulfur.

Soil Sulfur

Removals of Sulfur from Soil

Losses of sulfur from the soil occur continually (30). The losses may occur as a result of erosion, leaching, crop removal, burning of crop residues, and release from organic matter in the soil through decomposition (30, 39). Early work by Lipman and Conybeare (35) estimate an average of six pounds of sulfur per acre are lost each year in the United States through erosion. Other workers suggest that as much as 35 pounds of sulfur per acre could be lost from bare soils which are well supplied with native sulfur.

The movement of sulfur in soils occurs predominately as sulfate

(26). The behavior of sulfate salts in soils has received a great deal of attention (12, 26, 47). To a large extent, movement of sulfate and nitrate ions are similar in nature. The movement of sulfate is determined primarily by the magnitude of the ion present, the distribution of the ion within the soil profile, soil texture, pH, and the amount and velocity of water movement within the soil. Various lysimeter studies have shown amounts of sulfur lost ranging from very small quantities to as much as 285 pounds per acre per year (26). Lipman and Conybeare(35) estimate 42 pounds per acre losses for non-irrigated cropland.

Leaching losses of sulfates tend to vary with soil texture (49). A sandy soil was compared to a silt loam using cotton as a test crop. Varying rates of sulfur were applied as gypsum. Deficiencies of sulfur began to appear first on the sandy soil. Soil analysis of the two soils showed sulfates had leached beyond the plow layer in the sandy soil while little movement was noted in the silt loam, thus accounting for the differences in plant deficiencies on the two types of soil.

In another study sulfate movement during winter months was measured on sand and clay textured soils (44). Sulfur was applied as gypsum and elemental sulfur. All sulfate added as gypsum and that resulting from the oxidation of the elemental sulfur had been leached from the top 45 cm of sand 180 days after application. Essentially no movement of sulfate occurred in the clay during the same period.

Other work suggests that the loss of sulfates is affected by the kinds and amounts of cations present in the soil solution. Leaching losses were found greatest when monovalent ions such as potassium and sodium predominate, followed by divalent ions such as calcium and magnesium. The least loss occurs when soils are acid and there are appreciable amounts of exchangeable aluminum and iron present (49).

Adsorption of the sulfate ion decreases with increasing pH. At a pH greater than 6.0 very little sulfate is held by anion adsorption. As acidity increases below this level, the adsorption of sulfate tends to increase. MacIntire (37), for example has shown that liming has increased the loss of sulfate.

It has been suggested that the possible mechanisms by which Cl, SO_4, and PO_4 ions are held are similar (30). There are marked differences in the retention of these anions however, being in the order of $PO_4 > SO_4 > Cl = NO_3$ (26). The amount of sulfate ion held by the soil is affected by the amount of phosphate present. Chloride or nitrate ions have little effect, however, on sulfate adsorption.

Oxidation and reduction reactions of sulfur and its compounds in soils are mainly brought about by bacteria (32). Most common genera involved in the oxidation process belong to the genus Thiobacillus (46). The degree of aeration of the soil dictates whether oxidizing or reducing bacteria predominate and hence determines the amount of sulfate present in the soil. Under aerobic conditions sulfur is completely oxidized to the sulfate form. The importance of the above lies in the fact that a major portion of a soil's sulfur is bound into organic matter and held against leaching losses. Only as this organic sulfur is transformed to sulfate does it become susceptible to leaching losses. Microbial transformations, however, are essential before sulfur in the organic fraction becomes useable by plants as the sulfate ion.

Under anaerobic conditions reduced forms of sulfur such as sulfides predominate. Only under special waterlogged conditions, however, is sulfur lost through volatilization as hydrogen sulfide gas.

Additions of Sulfur to Soil

Gains in soil sulfur generally result from upward leaching, from precipitation and from the application of sulfate-containing fertilizers. The first two sources, although minimal, nonetheless do occur.

Additions of sulfur from precipation normally are insignificant. Near industrialized areas, however, the amount of sulfur added through rainwater may be quite large. In Oklahoma, the sulfur content of rainfall was measured during the 1930's at various locations. In this work, Harper (25) found a range of 5.6 to 17.0 pounds of sulfur per acre per year in rainwater. This figure fits well with 5.4 pounds per acre reported by Jordan and Bardsley for rural areas of the southeastern United States (29). In addition to rainwater, considerable amounts of sulfur may also be added from irrigation waters depending on the source of water being used.

The most significant source of sulfur is that of the sulfur-containing fertilizers. Elemental sulfur, of course, is the most concentrated sulfur carrier. Consequently, it is the obvious way of getting the most sulfur into a fertilizer with the least weight increase. The primary consideration in applying elemental sulfur is particle size. Sulfur particles of 80 to 100 mesh and smaller are as effective during the first growing season as sulfur applied in the sulfate form (8). This is true especially when additions of sulfur are large. Under severe deficiencies, however, a portion of the sulfur should be applied as sulfate in order to get a good initial response. As mentioned earlier, a certain time is required to oxidize elemental sulfur to sulfate. A table of oxidation rates is given by Tisdale and Nelson (49).

Another advantage of elemental sulfur other than its concentrated form is the fact that it has a much longer residual effect in subsequent seasons than sulfate applied sulfur (8). It should be pointed out, however, that in other work residual effects of various sources of sulfur have been shown to be equal (4). Yield of corn was increased by single sulfur additions the second year after application when applied as sulfate or elemental sulfur at rates of 100 pounds per acre. No production increase over the check the second year was noted where 25 pounds of sulfur per acre were applied, however. In other work, elemental sulfur was found more effective than $CaSO_4$ after the first year in supplying sulfur to clover and grass plants (1).

Various forms of elemental sulfur are being used today. Some of the more common ones include the so-called "controlled release" or sulfur-coated materials. One such material is sulfur-coated urea, hereafter referred to as SCU. There appears to be a potential for SCU as a sulfur source in addition to its potential for use on coarse-textured soils as a slow release nitrogen source (4).

Other forms of elemental sulfur include prilled, granulated, or flaked sulfur, all of which can be included in bulk blends. These alleviate the problems encountered with finely divided elemental sulfur powder yet contain additives which speed disintegration at a reasonably rapid rate after application.

Mehring and Bennett (39) have given a complete list of fertilizers and their sulfur content. Other information on sulfur fertilizers and their application can be found in various sources (9, 10, 11, 49).

Significant differences in crop yields with different forms of sulfur can be found on certain crops. Clover yields were significantly different where elemental, K_2SO_4 and $CaSO_4$ were added at low rates (1). Grass yields failed to show significant response to the different sources of sulfur, however. In other work, differences in sources were shown only when applied at a low rate. Rates of 100 pounds of sulfur per acre showed all sources equally responsive (4).

Choice of a particular sulfur-containing fertilizer will depend on a number of factors including: 1) cost; 2) ease of application; 3) local supply conditions; 4) need for other nutrients present in the fertilizers; and 5) agronomic effectiveness of product (8). Considering the above factors, a number of possibilities exist which could fulfill sulfur requirements other than the above mentioned elemental sulfur.

Tests for Sulfur

Soil

Sulfur, as previously mentioned, is found in the soil in many forms. Because of this great variability, it has been difficult to estimate the plant-available sulfur content of soil. This, in part, is due to analytical difficulties. For these reasons there is a paucity of data on plant available levels of soil sulfur. The percentages of soil sulfur for various soils were given earlier. Total soil sulfur tends to be a poor indicator of plant available sulfur. Therefore, work has generally been concentrated on estimating sulfate-sulfur. Even though plants absorb sulfur almost exclusively as the sulfate ion, determination of sulfate alone is of little value in measuring the plant useable sulfur. Also, because of the mobility of the sulfate ion, as mentioned earlier, determination can vary greatly depending on time of sampling and other conditions. For those and other reasons, several kinds of sulfur determinations are given by Hesse (27) including a direct method which is dependent on the growth rate of *Aspergillus niger*.

Hoeft et al. listed recommended extraction procedures for soil sulfur (28). Of those listed, the best extractant was found to be 2N acetic acid (HOAc) containing 500 ppm P as $Ca(H_2PO_4)_2 \cdot H_2O$ $[Ca(H_2PO_4)_2-HOAc]$. With this procedure, soil sulfur contents of greater than 10 ppm sulfur would not be expected to show significant response to additions of soil applied sulfur.

Fox et al. (23) measured the effectiveness of various soil sulfur extractants by comparing values of sulfur extracted with plant response. From limited data he suggested that calcium phosphate was the best extractant. Responses for corn and alfalfa were obtained whenever extracted sulfur was in the range of 0-4 and 0-6 ppm respectively. Within a range of 4-8 to 6-10 ppm sulfur responses for corn and alfalfa were possible while responses above these levels were unlikely.

Plant

Several methods for determination of total plant sulfur content have been employed (5, 33, 36, 45). Most are tedious, requiring a considerable amount of time. A recent improvement for measuring total plant sulfur is the Leco 532 auto-analyzer (33).

In analyzing plants for sulfur content, as is true with the other elements, several factors must be considered if results are to be meaningful (19). First, it is necessary to standardize the part of the plant to be analyzed. Secondly, the stage of plant growth must be considered. Even at best, however, often a plant analysis does not reveal a deficiency until late in the growing season. Usually, this is too late for maximum effectiveness of a fertilizer application to correct the problem during that growing season. Ideally, a combination of both soil and plant tests would be employed. The soil test could be performed before initiation of plant growth. If necessary, applications could be made at that time. Then during the plant growth period, plant samples could be analyzed and monitored to check the effectiveness of that application.

CHAPTER III

METHODS AND MATERIALS

This study included both greenhouse and field experiments with two different soils and forages. Field sites were chosen on the basis of soil type as well as past cropping and fertility history. In general, the soils used were sandy and had had heavy applications of a commercial nitrogen fertilizer in recent years. Consequently, large amounts of forage had been removed annually from each.

The objectives of this study were: 1) to determine the effect(s) on forage crops, if any, of sulfur additions to the soil; 2) to determine the nature of various sources of sulfur to the above forage; and 3) to determine the residual effects of a single application of soil applied sulfur.

Location and Classification of Field Sites

Two field sites were used for testing purposes. The first, chosen in 1973, was located in McCurtain County, Oklahoma, near Tom, in the extreme southeastern corner of the state. The other, selected in 1974, was situated in Major County in the central section of the state. Soil for the greenhouse study was collected from the site located near Tom, Oklahoma.

Before applying treatments, a sufficient amount of soil was collected to perform the following soil test: mechanical analysis, cation exchange capacity, pH, N, P, K, and S. The soils had previously been mapped by the Soil Conservation Service; the first, being classified as a Felker sandy loam (Aquic Paleudults, fine-silty, siliceous, thermic), the other as a Pratt loamy fine sand (Psammentic Haplustalfs, sandy, mixed, thermic).

Greenhouse Study - 1973

Experimental Pot Preparation

Soil for this experiment was collected from the top 15 inch layer of the field site near Tom, Oklahoma. After collection, the soil was brought to the agronomy greenhouse on the Oklahoma State University campus at Stillwater, Oklahoma where it was allowed to air dry. Upon drying, the soil was seived through a one-quarter inch mesh sieve and placed into one-gallon plastic-lined metal cans, hereafter referred to as experimental pots. Five uniform sprigs of Midland bermuda grass (*Cynodon dactylon* (L.) Pers.) were carefully placed in each experimental pot containing 3200 gms of the air dry soil. Treatments were uniformly spread over the top of the soil after which sufficient water was applied to bring the net weight of each pot to 3700 gms. Thereafter and throughout the remainder of the experiment, each pot was maintained at a net weight of 3450 gms by weighing each day and applying enough distilled water to bring it to the desired weight. Top watering was necessary since the bottom of each pot was sealed to prevent loss of nutrients.

Experimental Treatments

All treatments were set up in a completely randomized design with six observations per treatment. Each pot initially received equal, adequate amounts of N, P, and K based on soil tests. Originally, a rate of 200 pounds of nitrogen per acre as NH_4NO_3 was applied to all pots except the ones which received SCU. An equal rate of nitrogen was applied in the form of urea to these pots. Treatments included a KCl check and three sulfur sources. Rates of 100 pounds of elemental sulfur per acre were applied either as K_2SO_4, $CaSO_4 \cdot 2H_2O$, or SCU-30. SCU-30 refers to an experimental sulfur-coated nitrogen compound with a nitrogen dissolution rate of 30 percent per week when kept in water at a temperature of 100^{o}F (37^{o}C). Nitrogen at a rate of 400 pounds per acre was applied as NH_4NO_3 to all pots after the second, third and fourth harvests. Following the fourth harvest, in addition to the nitrogen, all pots including the check received a treatment of K_2SO_4 at the same rate as the original K_2SO_4 sulfur treatment mentioned earlier.

Harvesting Techniques

All pots were harvested at monthly intervals beginning six weeks after the sprigging date. Plant material was clipped two inches above the soil with a pair of stainless steel shears and placed into paper bags for later experimental determinations. Before clipping, however, pictures were taken and runner length recorded. Plant material was immediately weighed and then placed in an oven to be dried at 70^{o}F (21^{o}C).

Experimental Measurements and Determinations

After drying, the above samples were reweighed and the percent moisture determined. A small Wiley mill plant grinder equipped with a one-mm screen was used to prepare all plant samples for laboratory analysis. The following measurements were taken for each harvest: plot green weight, plot dry weight, percent sulfur in plant material, and plant protein (N x 6.25) content. In addition the following determinations were studied: percent dry matter, and the nitrogen/sulfur ratio.

Plant protein content was determined by the micro-Kjeldahl method. Sulfur determinations were made with a Leco 532 Sulfur-Analyzer. This proved to be a very valuable, time saving tool in analyzing the large number of samples in this study. The percent sulfur in a sample can be read directly from this instrument in approximately seven minutes once it has been warmed up and calibrated. Other methods of sulfur analysis require considerably more time.

With this instrument the sample is heated in an induction field where it is burned in a stream of oxygen. The major portion of the sulfur is converted to SO_2 which is titrated by the iodometric method (33). An automatic sulfur titrator, used in combination with the induction furnace, leaves the operator free to conduct other analyses or weigh samples during the combustion period.

Field Study - 1973

This study was conducted in the field at the site of Tom, Oklahoma, on an established Midland bermuda grass (*Cynodon dactylon* (L.) Pers.)

stand. Original treatments were exactly as described for the greenhouse study. Treatments were broadcast on each 8x25' plot during the first part of May, just before the grass began to green for spring growth. An additional application of 500 pounds of nitrogen as NH_4NO_3 was applied to all plots after completing the second harvest only.

Harvesting Techniques

The center three feet of each plot was clipped the entire length at a height of three inches above ground level with a mower having a three-foot cutter bar. Alleys and borders were clipped first and plant material raked away so it would not be confused with the experimental matter. Harvests one and two were made at approximately one-month intervals, beginning one month after treatment application. A third harvest was not possible until two months following harvest two due to adverse weather conditions.

The clippings were raked together and piled for weighing purposes. Greenweight was recorded and a 200-500 gm sub-sample taken from each plot and dried in a forced air oven at 70°F (21°C). Drying time varied with each harvest depending on sample size, but in all cases was at least 72 hours.

Experimental Measurements and Determinations

All plant material collected in the field was processed and analyzed in the same manner as described earlier for the greenhouse study. In addition to the above, in this study the forage green and dry weight per acre were determined.

Field Study - 1974

This, the second field study, employed the field study site of 1973. One-half of each original plot had an application of $CaSO_4 \cdot 2H_2O$ applied at a rate of 100 pounds of elemental sulfur per acre applied during the first week of May. A blanket application of N, P, and K was applied at that time at equal rates to all plots. All other facets of this experiment including harvesting techniques were as described earlier for the 1973 field study. In this experiment, however, it was possible to complete four harvests at monthly intervals.

Field Forage Study - 1974

Experimental Treatments

All treatments, replicated four times, were applied to 25x16' plots in a completely randomized design. Treatments included in KCl check and rates of 100 pounds per acre of elemental sulfur applied to each plot as either $CaSO_4 \cdot 2H_2O$, K_2SO_4, or a granular wettable 90 percent sulfur. Treatments were applied to a clean tilled field. Shortly thereafter, a hybrid type sorghum, Pioneer 933 (*Sorghum bicolor* (L.) Moench), was seeded in 38-inch rows at a rate of approximately four pounds per acre. This site was sprinkler irrigated as needed throughout the growing season.

Harvesting Techniques

Representative samples were taken from every plot at one month intervals. Plants were cut at ground level, placed in paper bags, and oven dried at 70°F (21°C). in a forced air dryer. Plant material was separated into leaf and stem fractions for the third harvest and leaf, stem, and head portions for harvest four.

Visual ratings were made of differences in plant color, size, and overall condition before each sampling period. Four months after planting, the center two rows of each plot were harvested. The weight of the harvested plants was recorded. A sub-sample of leaves, stems, and heads were individually, randomly selected and placed in bags and returned to Oklahoma State University for drying. Soil samples of each plot were also taken at one foot intervals to a depth of three feet during the fourth harvest period. Pictures of the plot were taken before harvesting any plants.

<u>Experimental Measurements and Determinations</u>

The entire plant, for harvests one and two, and individual plant fractions, for remaining harvests, were prepared and analyzed according to the procedure explained earlier for the other experiments.

Description of Plant and Soil Analysis

All soil and plant analyses were performed according to procedures employed by the Oklahoma State University Soil and Water Testing Laboratory. A brief description of these procedures is given in Table I.

TABLE I

ANALYTICAL PROCEDURES USED FOR CHEMICAL ANALYSIS OF PLANT AND SOIL SAMPLES

Type Sample	Element	Procedure
Soil	pH	1:1 Soil:H_2O solution, measured by Ion electrode
	NO_3-N	$CaSO_4$ extractant, measured by Orion specific Ion Electrode
	P	Bray I (1:20 soil solution), measured colorimetrically
	K	1N ammonium acetate extractant, measured by Flame Emmission
	SO_4-S	HOAc extraction, $BaCl_2$ turbidimetric
Plant	N	Micro-Kjeldahl analysis
	K, Ca	Nitroperchloric acid digestion, measured colorimetrically
	S	Induction furnace, titrimetric

Description of Statistical Analysis

All variables were analyzed statistically to aid in the interpretation of the results. An analysis of variance was made for each experiment. In addition, the percent coefficient of variation was calculated for each variable. The least significant difference (LSD) was calculated wherever F ratios were found to be significant.

CHAPTER IV

RESULTS AND DISCUSSION

For clarity and ease of comprehension, results of all experiments will be reported in the same order as listed in Chapter III. Soil test values for each experiment will be given separately immediately following the Field Forage Study - 1974.

Greenhouse Study - 1973

Both K_2SO_4 and $CaSO_4 \cdot 2H_2O$ increased yields in the Tom, Oklahoma soil beginning with the first harvest. Visual differences in stand density and runner lengths were observed for the first four harvests (Figure 1). However, after the addition of the blanket sulfur treatment following harvest four, few, if any, differences between treatments could be seen (Figure 1; Table XVIII, Appendix). Oven dry weights of the first four harvests are plotted in Figure 2. The F values for yields were significant at the one percent level for the four harvests (Tables XIV through XVII, Appendix). For the first harvest only, pots treated with KCl yielded more than those treated with SCU. This is probably due to the lack of nitrogen being available from the SCU during this early time period. In all other harvests, however, the SCU treatment yielded more than KCl. The difference in yield between K_2SO_4 and $CaSO_4 \cdot 2H_2O$, as shown in Figure 2, could be due, in part, to the slightly higher soil potassium level for pots receiving

Harvest I

Harvest II

Harvest III

Harvest IV

Harvest V

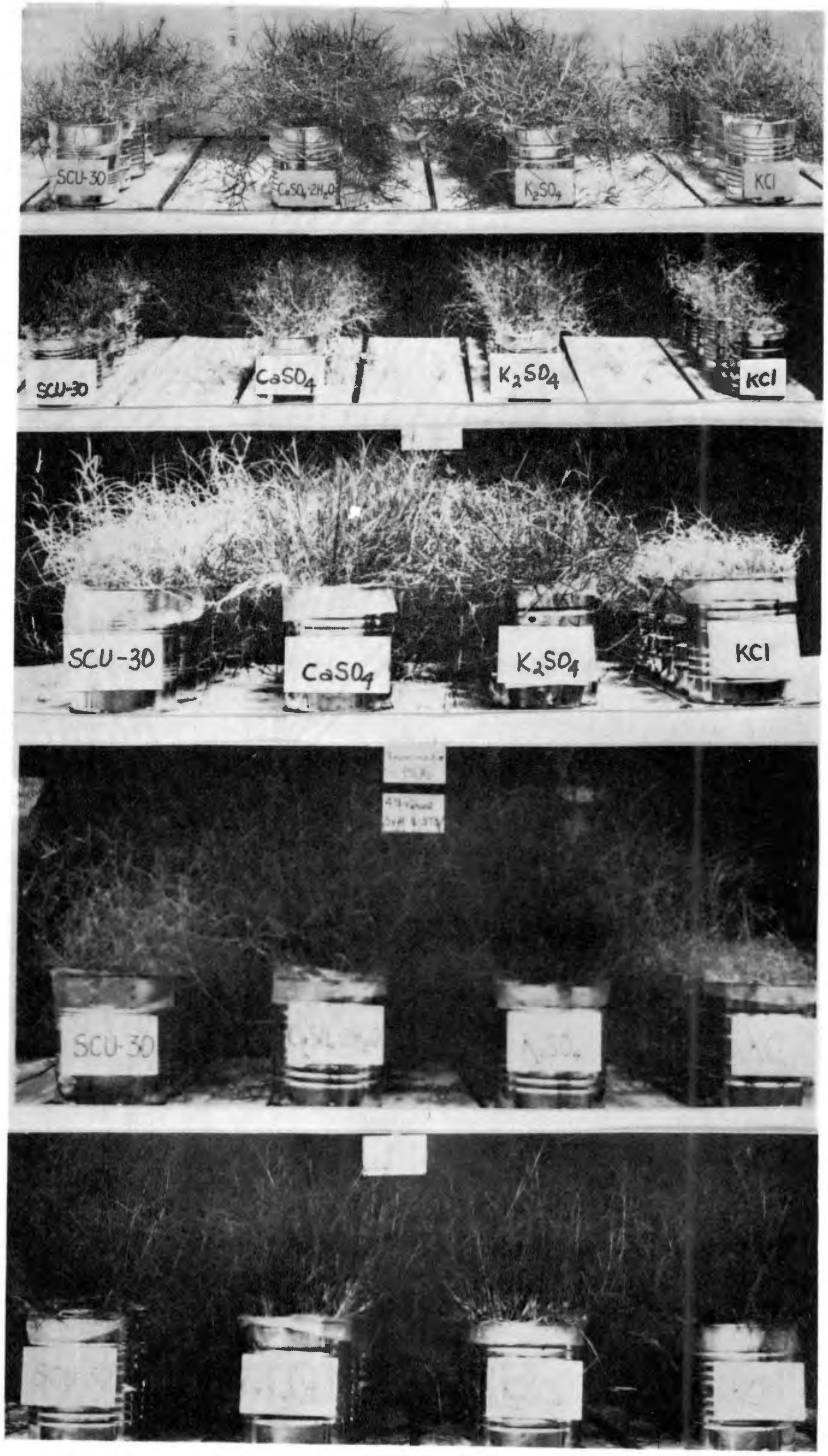

Figure 1. Midland Bermuda Grass (<u>Cynodon</u> <u>dactylon</u> (L.) Pers.) Grown in the Greenhouse as it Appeared Each Harvest.

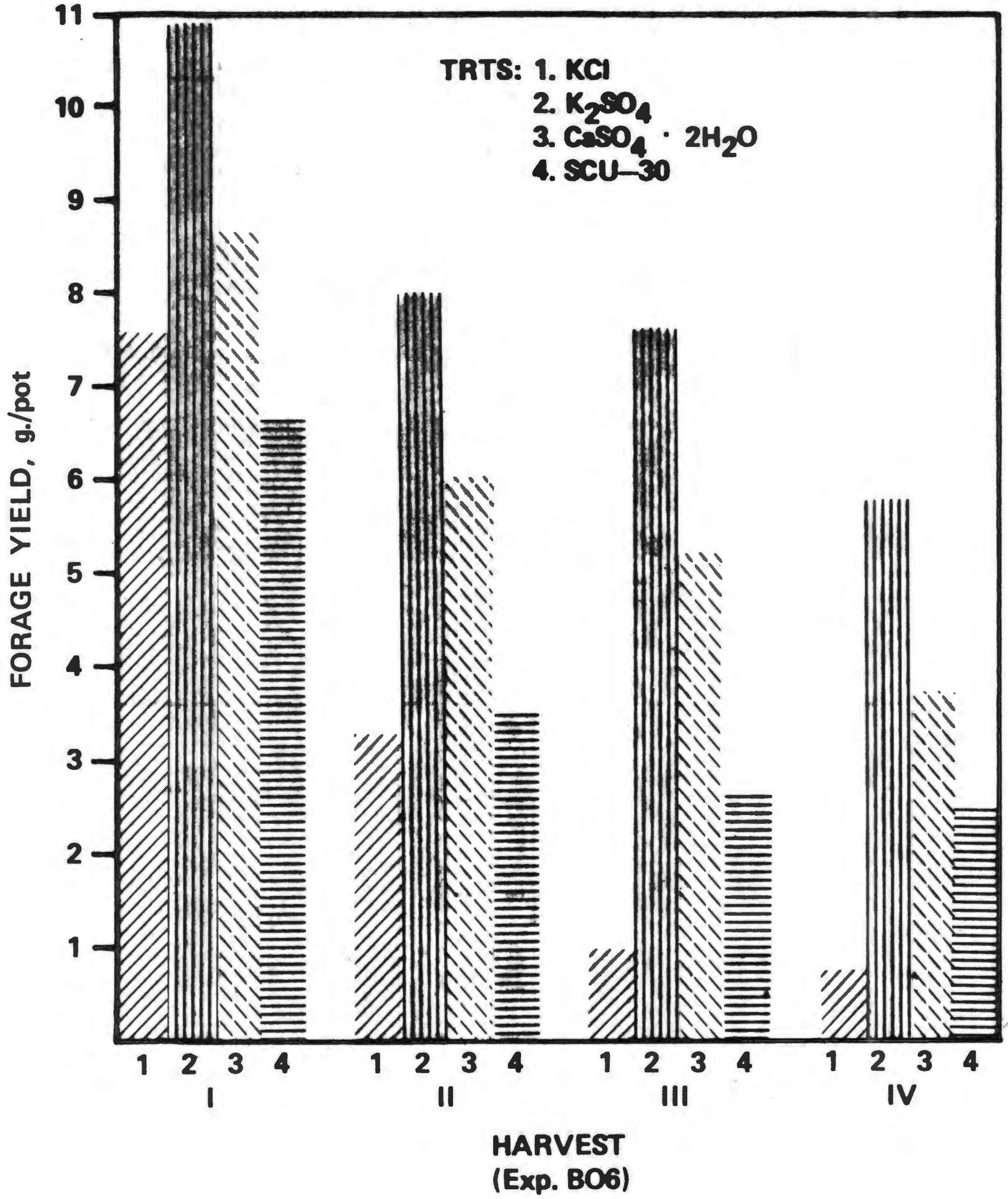

Figure 2. Dry Matter Yields of Bermuda Grass as Influenced by Sulfur Applications. (Greenhouse Study - 1973)

the K_2SO_4 treatment. Note the soil test results in Table VII.

Harvest number three showed the first visual indications of a sulfur deficiency. This was noted by a darker green color for both K_2SO_4 and $CaSO_4 \cdot 2H_2O$. These two treatments also gave a large increase in dry weight (Figure 2). This was the first time a considerable difference between the KCl and SCU could be seen. Harvest four, again showed color and growth differences with the check (KCl) becoming even more deficient in sulfur.

The percent sulfur in the plant material is given in Figure 3. There were decreasing amounts of sulfur present with each harvest for each treatment except KCl in the third harvest. Sulfur ranged from 0.250 percent for K_2SO_4 in harvest one to extremely low levels for treatments one and four at the last harvest.

Percent nitrogen is shown in Figure 4. It is interesting to note the inverse relationship in the amount of plant sulfur and nitrogen (Figures 3 and 4). As nitrogen increased, sulfur decreased in most cases.

The nitrogen/sulfur (N/S) ratios are shown in Table II. It has been suggested that the ideal N/S ratio should be between 10/1 and 20/1 (40). When a figure of over 20/1 is reached, sulfur deficiencies generally begin to appear. The ratio for the KCl treatment as shown is extremely high. The blanks, as shown, were obtained because the analytical procedure was not sensitive enough to measure the small amount of sulfur extracted from the plant samples, therefore, N/S ratios could not be calculated.

As evidenced by nitrogen-sulfur ratios, it appears the most immediate plant response to sulfur was obtained by the sulfate

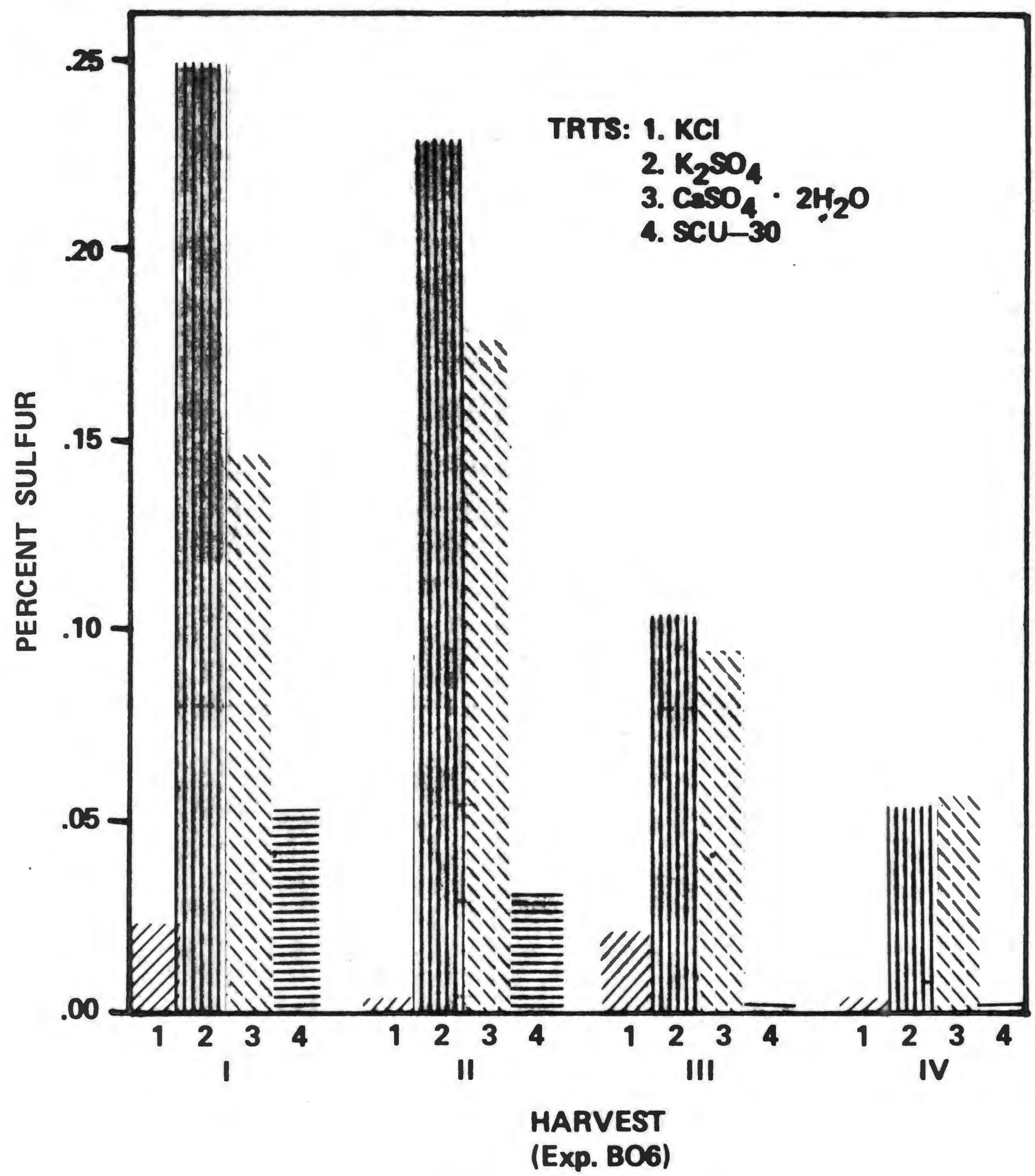

Figure 3. Sulfur Content of Bermuda Grass as Influenced by Sulfur Applications. (Greenhouse Study - 1973)

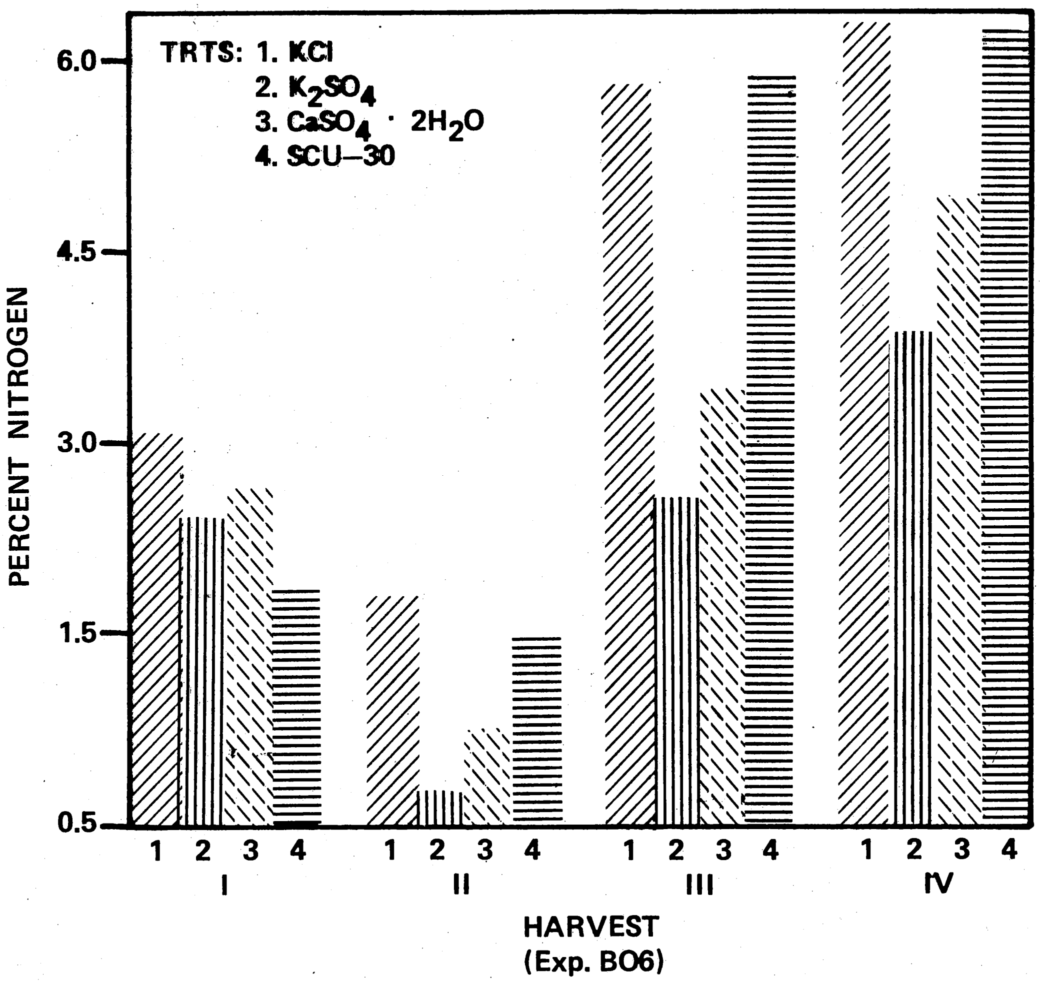

Figure 4. Nitrogen Content of Bermuda Grass as Influenced by Sulfur Applications. (Greenhouse Study - 1973)

TABLE II

NITROGEN/SULFUR RATIOS FOR GREENHOUSE STUDY - 1973

Treatment	Harvest I	Harvest II	Harvest III	Harvest IV
KCl	147.2	217.5	87.9	-*-
K_2SO_4	9.7	3.1	43.0	148.9
$CaSO_4 \cdot 2H_2O$	18.2	7.4	43.9	107.3
SCU-30	33.5	53.2	-*-	810.0

*Insufficient sulfur in plant material to obtain reading.

containing materials. SCU, although superior to the check, failed to provide enough plant available sulfur to lower the N/S ratios to an accepted level during the growing period. It is interesting to note how the ratios widened as the season progressed and additional nitrogen applications were made. This fits well with yield data from corresponding harvests in that as the N/S ratio widened, yields decreased.

Statistical data for all variables are given in the appendix (Tables XIV through XVII, Appendix).

Field Study - 1973

The dry weights of forage from the Tom, Oklahoma field study are reported in Figure 5. A significant F value at the five percent level was obtained only for the first harvest. A significant weight difference at the five percent level was not obtained for harvests two and three. The first two harvests were made one and two months respectively after treatment application. Harvest three, due to adverse weather conditions, was made four months after treatment application. This, along with the 500 pound per acre rate of nitrogen as NH_4NO_3, is probably the cause for the greater yield in forage at harvest three.

As was found in the greenhouse experiment, those treatments containing sulfate gave slightly higher yields for all harvests. Likewise, the check yielded more than the SCU treatment for the first harvest only. This occurred probably for the same reason as mentioned earlier for the greenhouse experiment, i.e. lack of available nitrogen from the SCU. In addition, it is important to keep in mind that the

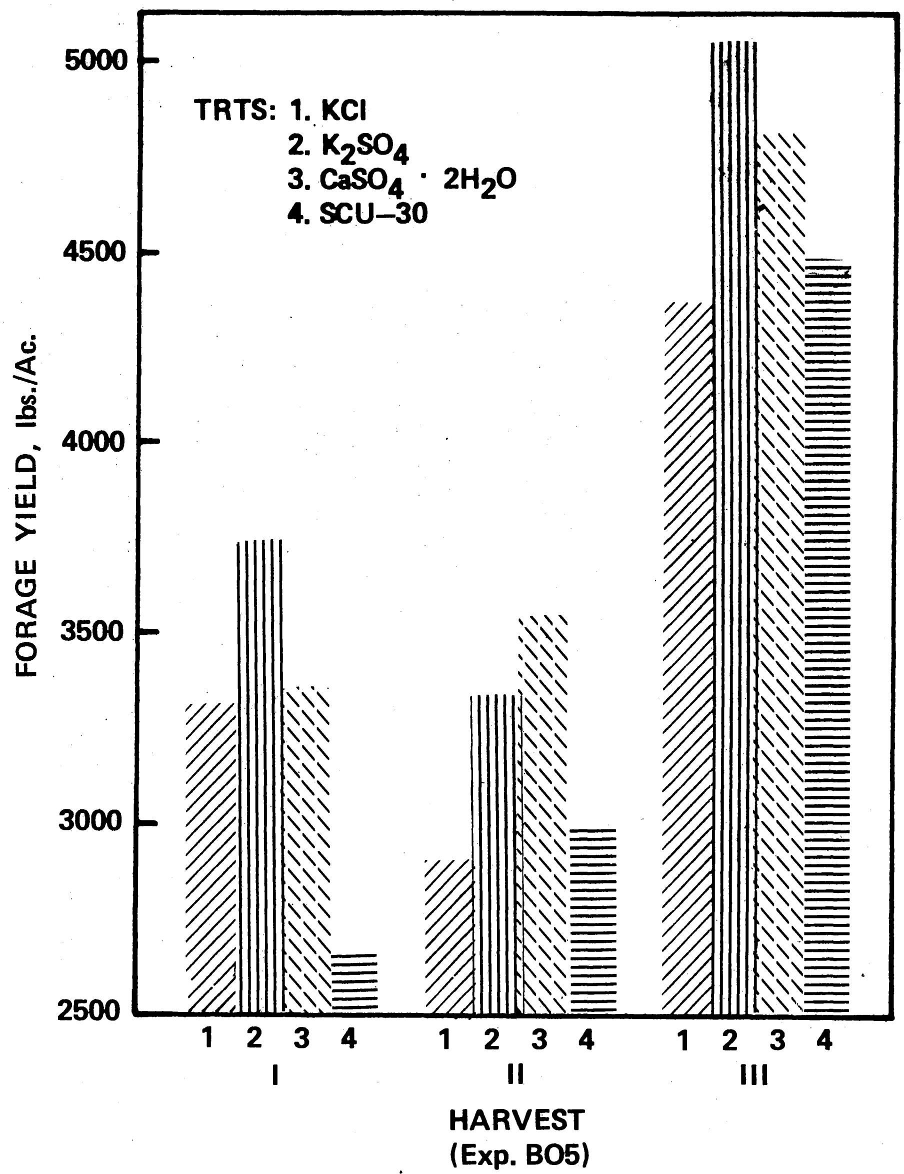

Figure 5. Dry Matter Yields of Bermuda Grass as Influenced by Sulfur Applications. (Field Study - 1973)

elemental sulfur had probably not had sufficient time to oxidize to sulfate.

Percent sulfur in the plant material showed significant F values at the one percent level for all harvests (Figure 6). As was found with the greenhouse study, there was a general overall decreasing sulfur content in plant material with each harvest. The check and SCU, however, remained fairly constant and even increased slightly. The larger amounts of sulfur extracted for both K_2SO_4 and $CaSO_4 \cdot 2H_2O$ are especially worthy to note.

A significant F value at the one percent level for percent plant nitrogen concentration was obtained for harvest one only (Figure 7). The nitrogen concentration was essentially the same among treatments in harvests two and three. As with the greenhouse experiment, plant nitrogen content was lower for SCU than the other treatments during harvest one only.

Nitrogen/sulfur ratios for harvests one and three shown in Table III appear to be near ideal for treatments of K_2SO_4 and $CaSO_4 \cdot 2H_2O$. KCl contained the highest ratios throughout the season. SCU was nearing the ideal range at harvest two. After the additional blanket nitrogen application, however, the ratio increased for harvest three.

Field Study - 1974

Forage production results for the Tom, Oklahoma soil during the second year are given in Figure 8. One of the most interesting, yet difficult, results to explain was the greater production levels for those plots which received no additional treatments for the 1974 growing season. Only for harvest one was there a slight increase in

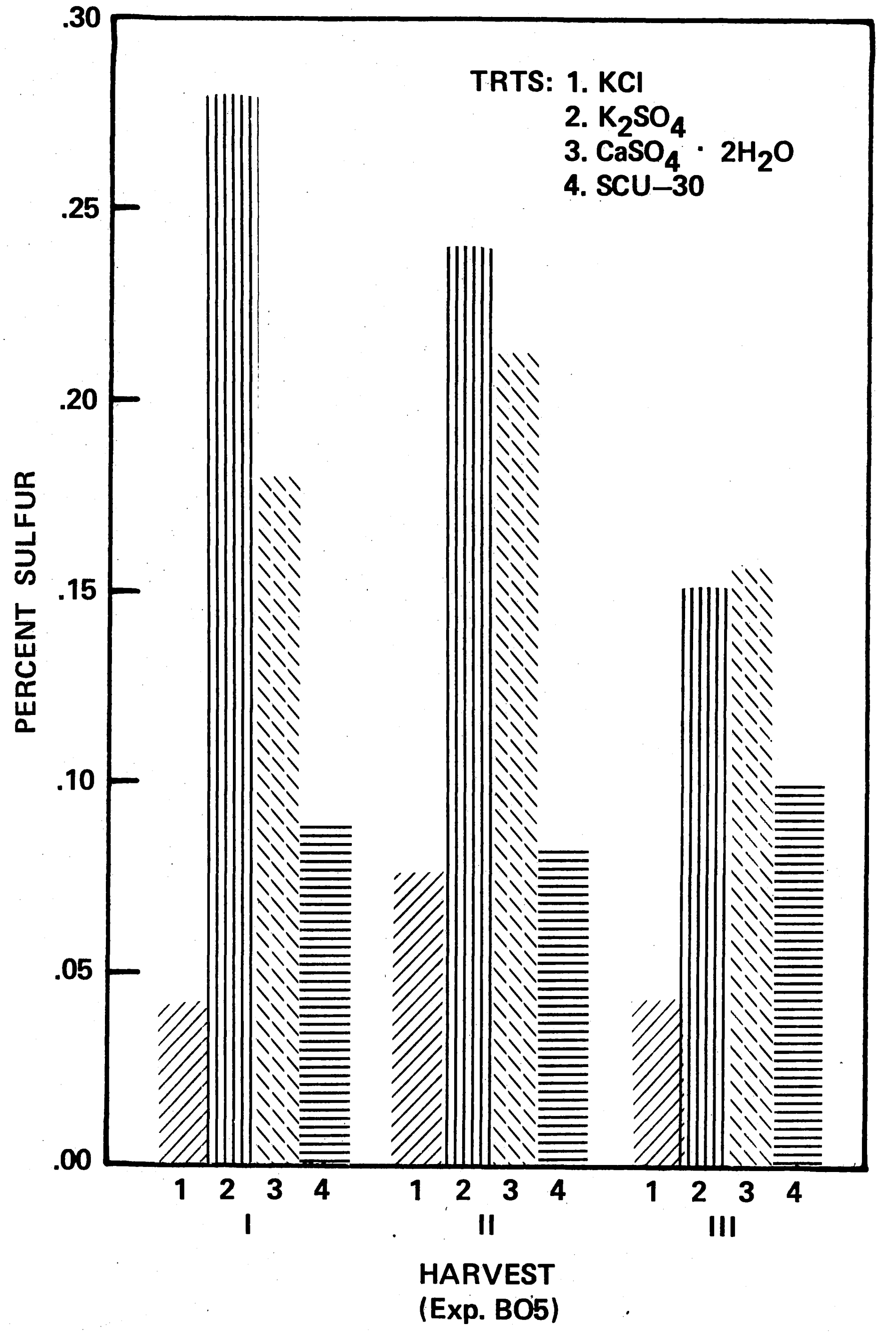

Figure 6. Sulfur Content of Bermuda Grass as Influenced by Sulfur Applications. (Field Study - 1973)

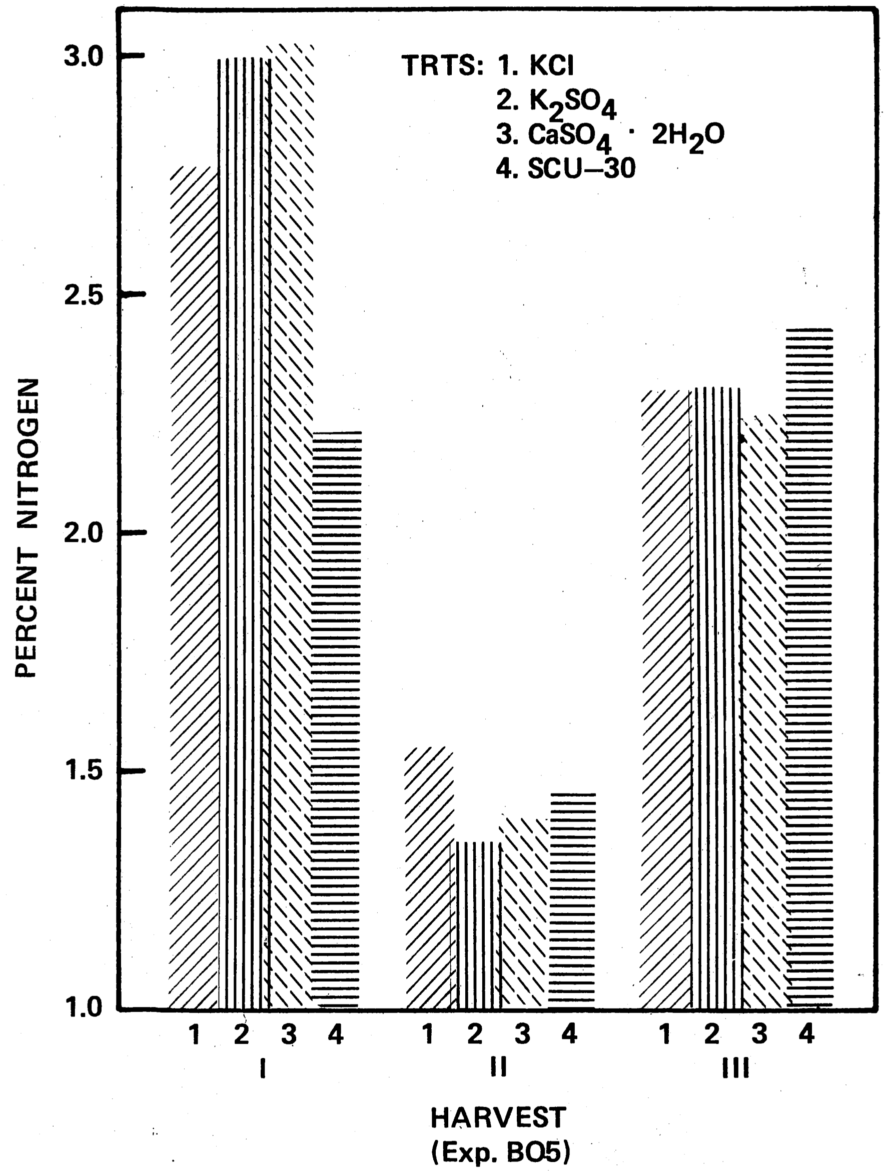

Figure 7. Nitrogen Content of Bermuda Grass as Influenced by Sulfur Applications. (Field Study - 1973)

TABLE III

NITROGEN/SULFUR RATIOS FOR FIELD STUDY - 1973*

Treatment	Harvest I	Harvest II	Harvest III
KCl	84.5	23.8	63.1
K_2SO_4	10.8	5.6	15.5
$CaSO_4 \cdot 2H_2O$	17.3	6.9	15.2
SCU-30	25.1	19.9	25.4

*Conducted at Tom, Oklahoma.

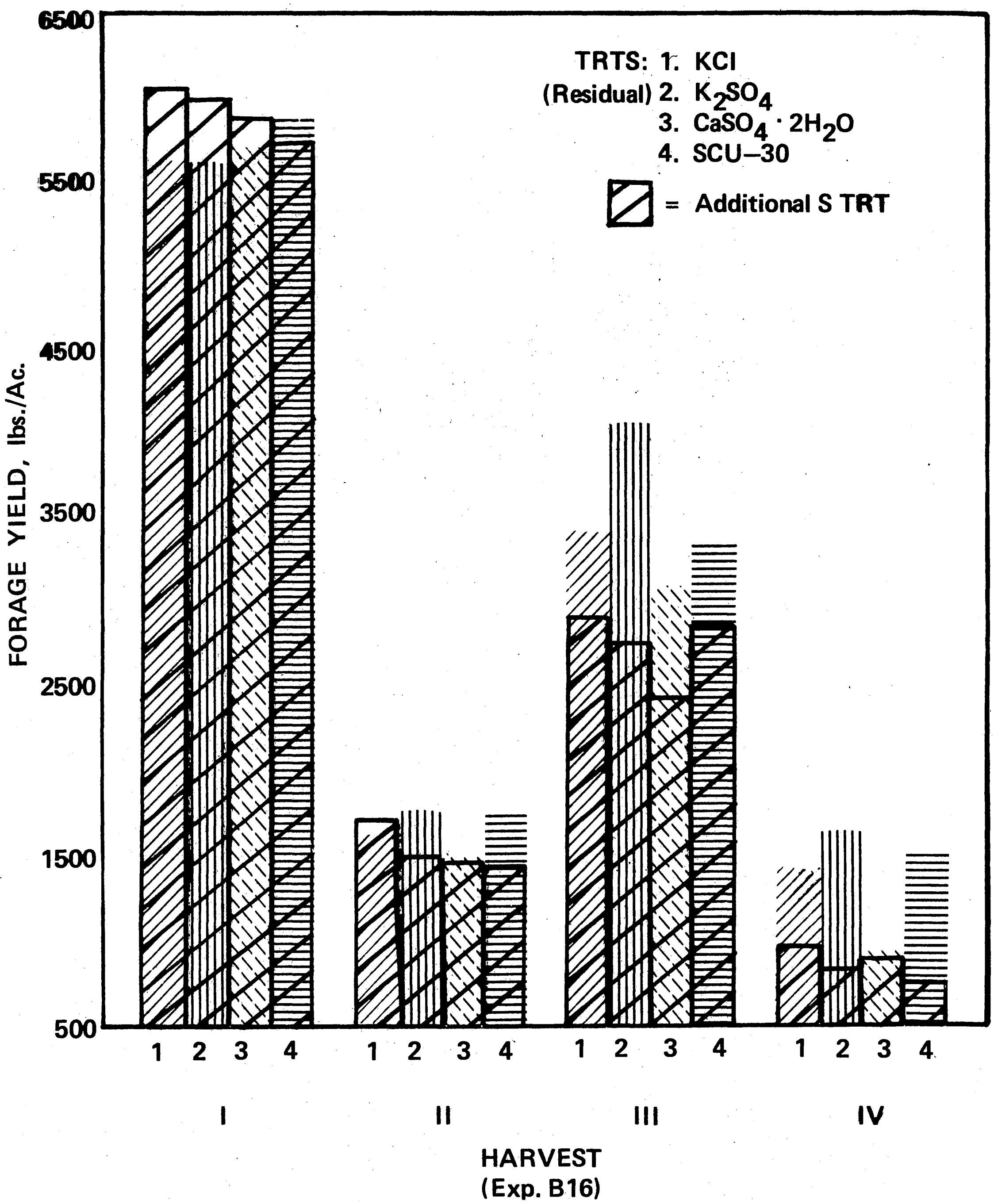

Figure 8. Dry Matter Yields of Bermuda Grass as Influenced by Sulfur Applications. (Field Study - 1974)

forage production for all plots receiving the additional sulfur treatment. This difference was not significant (Table XXII, Appendix). The large variation in amount of production between harvests can be explained in part by the weather conditions which existed over the growing period. Immediately after application of the initial treatment in May and throughout this growing period until the harvest, abundant rains fell. Conversely, little or no rain fell during the second growing period. Although sufficient rainfall occurred over the later portion of the growing season, yields were smaller. This, in part, is probably due to a lack of nitrogen. Statistical information for all harvests is given in the Appendix (Tables XXII through XXV).

Highly significant differences in plant sulfur content were noted for all plots which received the additional sulfur applications as compared to those plots containing only the residual sulfur (Figure 9). In general, the sulfur content remained fairly constant throughout the growing season for all plots receiving the additional sulfur treatment. For the plots containing only the residual sulfur, the percent sulfur in the plant material increased slightly as the season progressed.

As was found with plant sulfur content, the differences in percent nitrogen found in the plant material between treatments was small (Figure 10). In general, it was found that there was an inverse relationship in nitrogen and sulfur concentrations in the plant material. At low sulfur levels, nitrogen concentration was found to be highest in all cases, except for the first harvest for treatment one (Figures 9 and 10).

Nitrogen/sulfur ratios are given in Table IV. As might be expected from reviewing the percent sulfur and nitrogen contents earlier, there

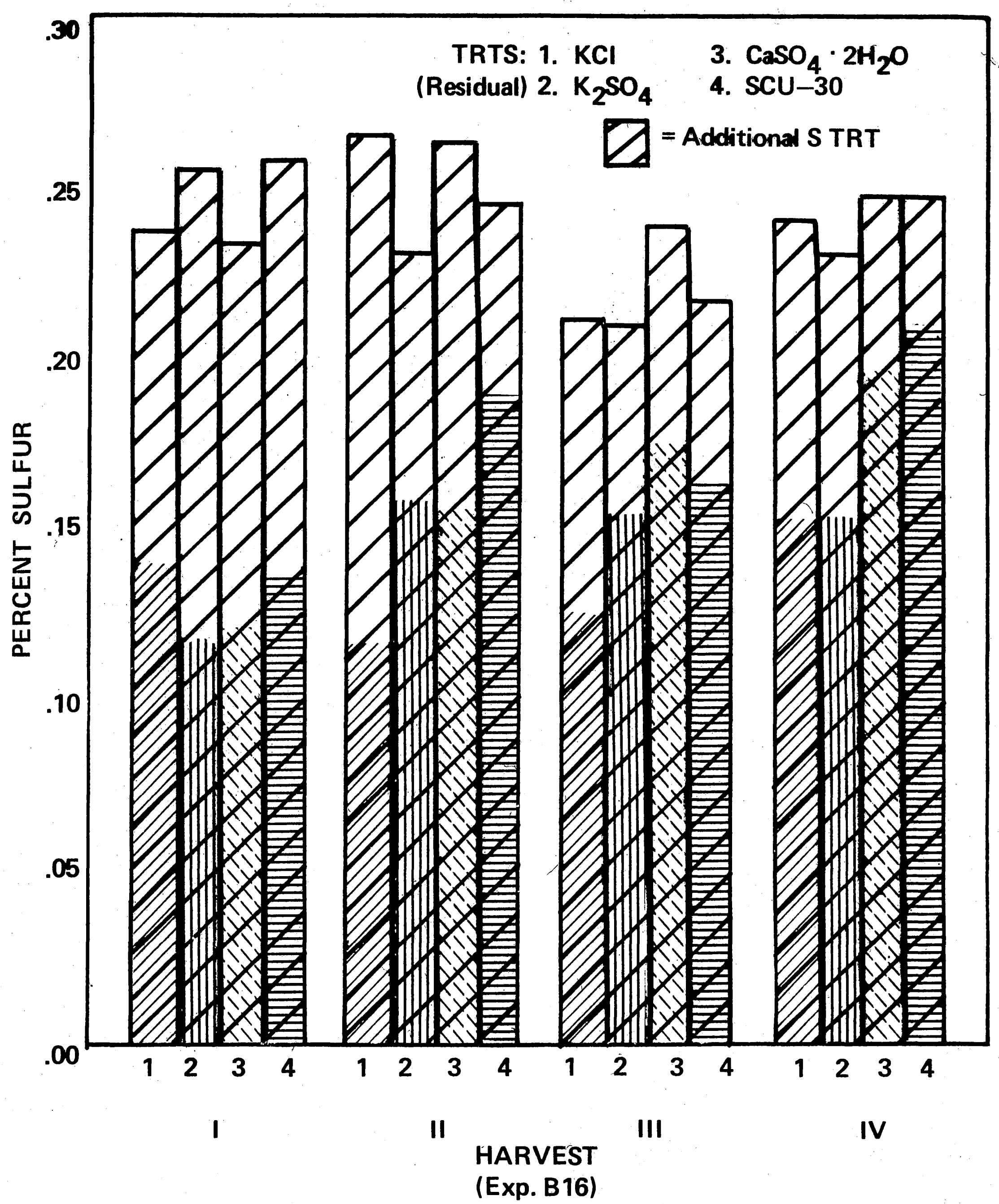

Figure 9. Sulfur Content of Bermuda Grass as Influenced by Sulfur Applications. (Field Study - 1974)

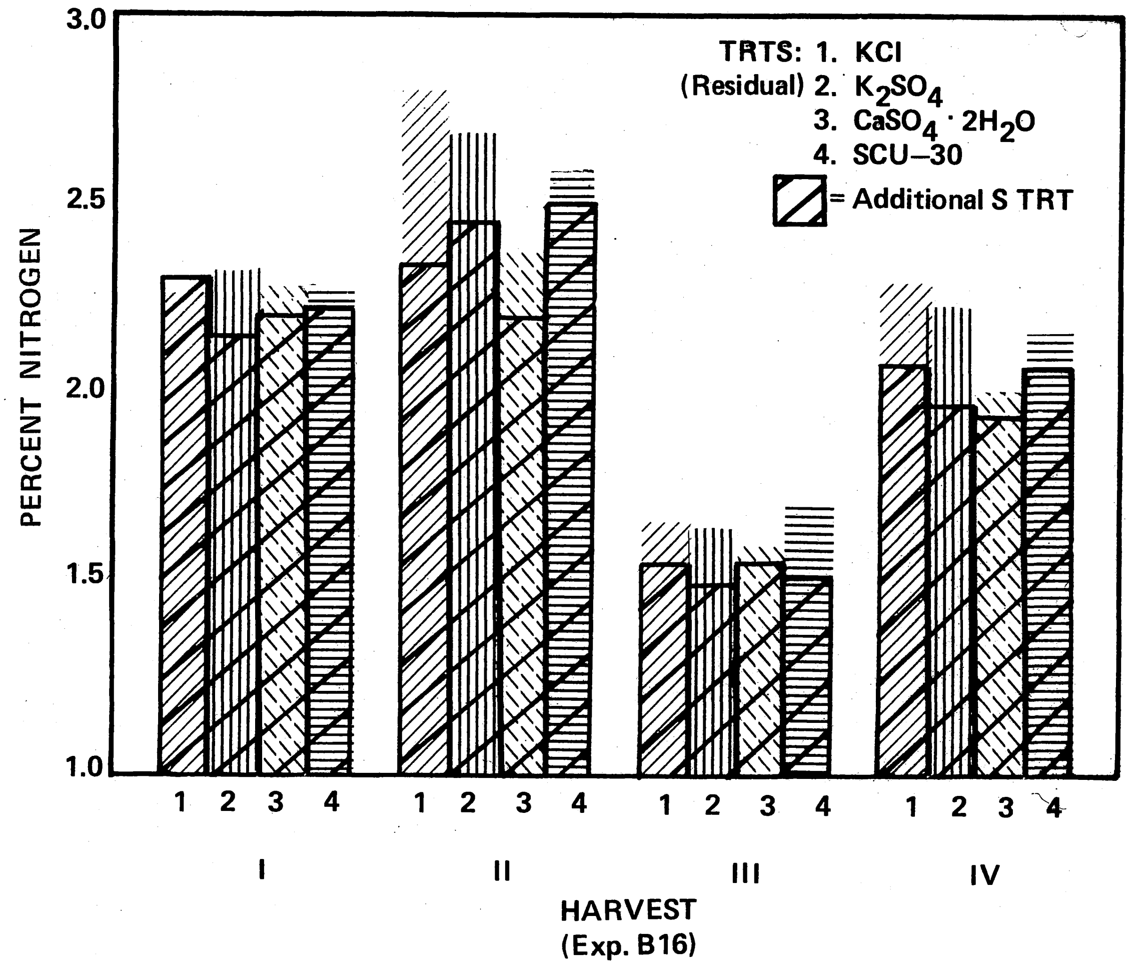

Figure 10. Nitrogen Content of Bermuda Grass as Influenced by Sulfur Applications. (Field Study - 1974)

TABLE IV

NITROGEN/SULFUR RATIOS FOR FIELD STUDY - 1974*

Treatment	Harvest I	II	III	IV
KCl	19.2	26.8	13.6	15.3
K_2SO_4	20.4	17.5	11.6	14.8
$CaSO_4 \cdot 2H_2O$	19.7	15.4	9.2	10.7
SCU-30	18.1	14.3	10.6	10.2
KCl+S**	9.8	9.1	7.6	8.7
K_2SO_4+S**	8.7	10.8	7.4	8.4
$CaSO_4 \cdot 2H_2O$+S**	9.6	8.3	6.7	7.6
SCU-30+S**	8.9	10.8	7.0	8.6

*Conducted at Tom, Oklahoma.

**Added as $CaSO_4 \cdot 2H_2O$.

is a clear distinction in ratios between those plots receiving additional sulfur and those which did not. These differences for all harvests were statistically significant (Tables XXII through XXV, Appendix). All ratios as listed appear to be within the previously suggested desirable range with the exception of the check in harvest two.

Field Forage Study - 1974

Although dry matter yields of forage sorghum grown in Major County Oklahoma appeared to show definite increases over the check (Table V), the differences were not statistically significant at the five percent level. This in part is probably due to the high coefficient of variation (Table XXIX, Appendix). In addition to the weight difference, visual differences in overall plant growth and color were noted throughout the experiment. It is interesting to note the highest yield occurred for treatment four, the granular wettable sulfur compound.

The percent sulfur in the forage is shown for all harvests and plant fractions in Figure 11. There was an overall decrease in plant sulfur content throughout the growing season as the plants matured. Even at the highest concentration in the first harvest the sulfur content was fairly low. The check usually appeared to contain less sulfur than other treatments. On the other hand $CaSO_4 \cdot 2H_2O$ and the granular sulfur in most cases contained the highest sulfur content throughout the experimental period. As was expected, stems contained less sulfur than leaves. The head portion of the plant contained the lowest sulfur content of all plant fractions. There were no significant

TABLE V

SORGHUM FORAGE YIELDS FOR FIELD
FORAGE STUDY - 1974*

Treatment	Dry Matter (lbs/ac)
KCl	3787
$CaSO_4 \cdot 2H_2O$	4693
K_2SO_4	5191
Granular 90% S	5440

*Conducted near Fairview, Oklahoma.

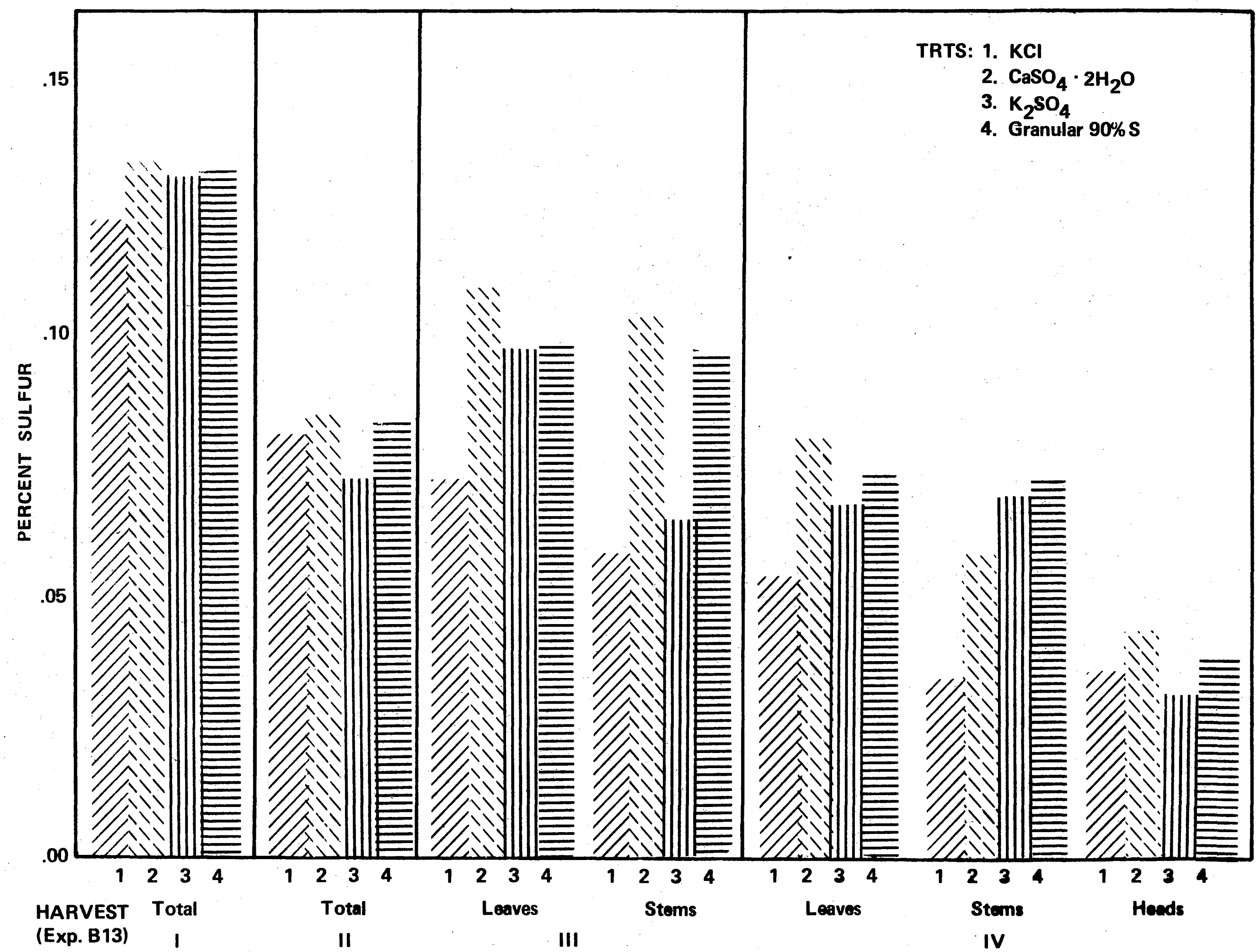

Figure 11. Sulfur Content of Sorghum Forage as Influenced by Sulfur Applications. (Field Forage Study - 1974)

differences found between treatments in plant sulfur content.

The percent nitrogen content of the forage is given in Figure 12. As was expected, the nitrogen level fell throughout the growing season. Plant nitrogen was lowest for the stem plant fraction at the final harvest. As was noted for other experiments, in general, as sulfur content increased for a given treatment the nitrogen content decreased.

Nitrogen/sulfur ratios, in general, were higher than the desired level for all harvests (Table VI). For each harvest, except harvest two, the check plot had the highest ratio, however. It is only fair to mention, however, that K_2SO_4 in all cases had the next to the highest N/S ratio throughout the growing period, yet out-yielded the $CaSO_4 \cdot 2H_2O$ treatment in total dry matter production. This difference might be explained, in part, by considering the soil test values (Table XIII). There is a possibility of a potassium response, thus the differences between K_2SO_4 and $CaSO_4 \cdot 2H_2O$ in forage yield. Statistical information including coefficient of variation and F values are listed in Table XXVI through XXIX in the Appendix.

Soil Tests For All Experiments

Results of all soil tests for each experiment before and after treatment application are given in Tables VII through XIII.

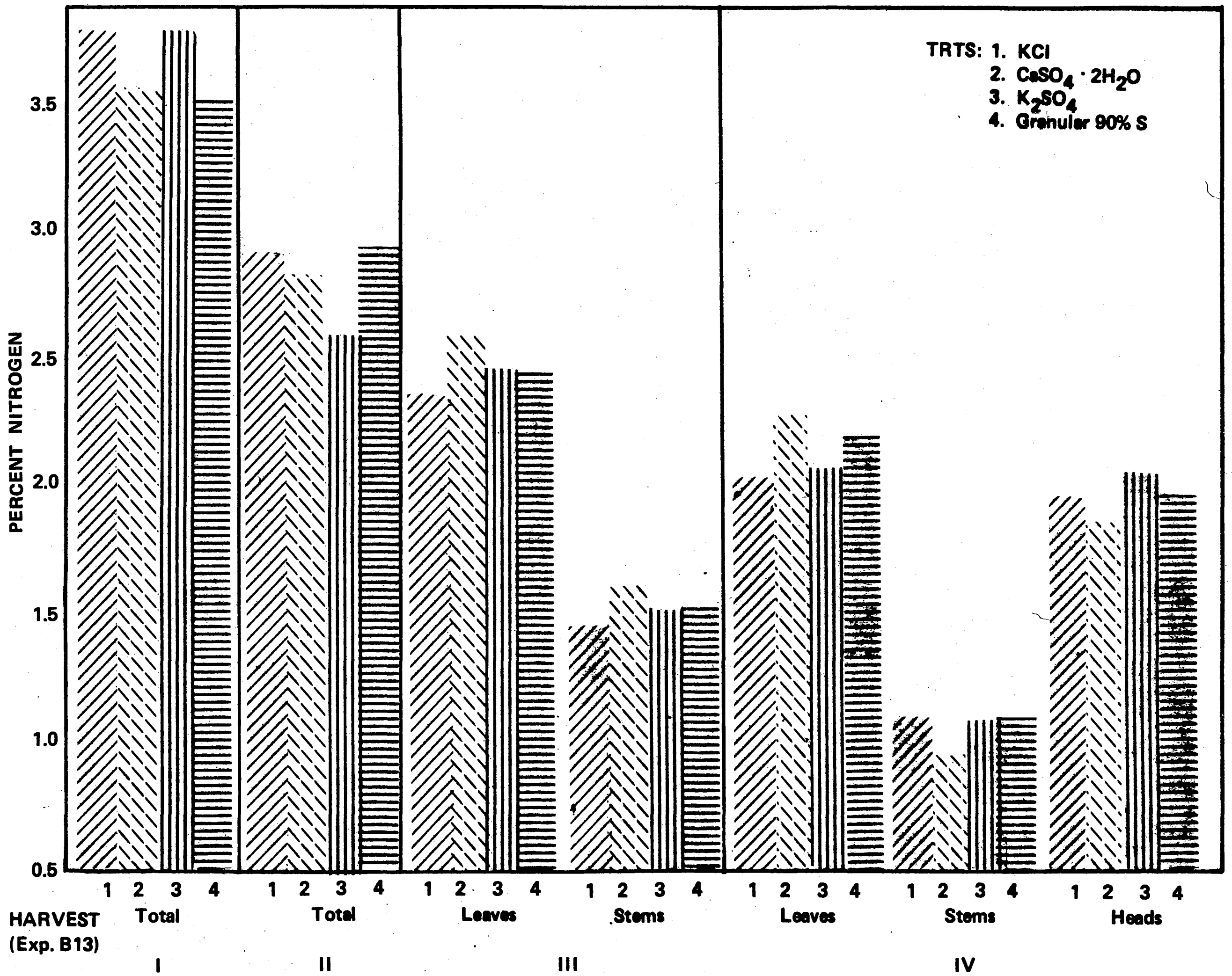

Figure 12. Nitrogen Content of Sorghum Forage as Influenced by Sulfur Applications. (Field Forage Study - 1974)

TABLE VI

NITROGEN/SULFUR RATIOS FOR FIELD FORAGE STUDY - 1974*

Treatment	Harvest I	Harvest II	Harvest III		Harvest IV		
	Total	Total	Leaves	Stems	Leaves	Stems	Heads
KCl	31.6	38.6	33.1	24.8	38.6	37.0	121.5
$CaSO_4 \cdot 2H_2O$	26.2	32.7	25.5	15.2	28.5	15.6	45.4
K_2SO_4	29.1	43.5	25.9	23.5	30.5	28.0	78.0
Granular 90% S	26.0	35.5	25.8	15.3	33.0	25.6	53.2

*Conducted near Fairview, Oklahoma.

TABLE VII

GREENHOUSE STUDY - 1973 SOIL TEST RESULTS
THREE MONTHS AFTER TREATMENT APPLICATION

Treatment	pH	Lbs/Ac NO_3-N	Lbs/Ac P	Lbs/Ac K	ppm SO_4S
KCl	5.9	53	24	152	210
K_2SO_4	6.1	<10	19	38	211
$CaSO_4 \cdot 2H_2O$	6.1	30	21	28	396
SCU-30	6.3	27	22	33	521

All figures represent an average of six samples.

For original soil test values, CEC and Mechanical Analysis, see Table VIII.

TABLE VIII

FIELD STUDY - 1973 SOIL TEST RESULTS BEFORE TREATMENT APPLICATION**

Inches Depth	pH	Lbs/Ac NO_3-N	Lbs/Ac P	Lbs/Ac K	ppm SO_4-S
0-12	7.0	38	11	109	12
12-24	*	*	*	*	*
24-36	*	*	*	*	*

All figures represent an average of two samples.

*Data not available.

**Tom, Oklahoma.

Note: CEC: 3.6 meq/100 gms soil.

Mechanical Analysis: Sand 64%; Silt 30%; Clay 6%.

TABLE IX

FIELD STUDY - 1973 SOIL TEST RESULTS AT FINAL HARVEST*

Treatment	Inches Depth	pH	Lbs/Ac NO_3-N	Lbs/Ac P	Lbs/Ac K	ppm SO_4-S
	0-12	6.2	41	15	105	23
KCl	12-24	6.3	30	9	126	11
	24-36	6.3	130	12	182	3
	0-12	6.5	32	20	67	35
K_2SO_4	12-24	6.5	19	17	63	23
	24-36	5.8	94	6	165	11
	0-12	6.3	<10	15	59	53
$CaSO_4 \cdot 2H_2O$	12-24	6.7	<10	9	90	<7.5
	24-36	5.8	145	12	131	<7.5
	0-12	6.3	33	20	67	15
SCU-30	12-24	6.8	25	20	118	30
	24-36	6.4	110	12	192	<7.5

All figures represent a single sample.

*Tom, Oklahoma.

TABLE X

FIELD STUDY - 1974 SOIL TEST RESULTS BEFORE ADDITIONAL $CaSO_4 \cdot 2H_2O$ TREATMENT*

Treatment	Inches Depth	pH	Lbs/Ac NO_3-N	Lbs/Ac P	Lbs/Ac K	ppm SO_4-S**
	0-12	5.3	<10	7	120	15
KCl	12-24	7.0	<10	7	170	15
	24-36	7.0	<10	7	170	0
	0-12	5.3	68	12	270	53
K_2SO_4	12-24	5.6	33	7	180	9
	24-36	6.3	<10	12	160	9
	0-12	6.1	<10	7	75	39
$CaSO_4 \cdot 2H_2O$	12-24	6.3	<10	5	110	30
	24-36	6.3	<10	5	120	9
	0-12	5.1	<10	7	76	53
SCU-30	12-24	6.0	<10	5	100	15
	24-36	6.5	<10	7	130	0

All figures represent a single sample.

*Tom, Oklahoma.

**Samples taken June 11, 1974.

TABLE XI

FIELD STUDY - 1974 SOIL TEST RESULTS AT FINAL HARVEST †

Treatment	Inches Depth	pH	Lbs/Ac NO_3-N	Lbs/Ac P	Lbs/Ac K	ppm SO_4-S
	0-12	6.2	<10	35	200	31
KCl	12-24	6.1	<10	3	93	18
	24-36	5.7	<10	3	**	10
	0-12	5.4	<10	8	100	25
K_2SO_4	12-24	5.7	<10	3	96	25
	24-36	5.2	<10	3	**	18
	0-12	6.8	<10	23	150	31
$CaSO_4 \cdot 2H_2O$	12-24	6.7	<10	8	**	25
	24-36	6.7	<10	3	150	10
	0-12	6.6	<10	10	85	25
SCU-30	12-24	6.3	<10	3	83	31
	24-36	6.4	<10	3	170	25
	0-12	5.5	<10	5	190	18
KCl+S*	12-24	5.8	<10	5	120	10
	24-36	6.3	<10	3	170	<6
	0-12	6.7	<10	20	130	25
K_2SO_4+S*	12-24	6.3	<10	3	**	18
	24-36	6.8	<10	3	170	31
	0-12	6.0	<10	8	68	25
$CaSO_4 \cdot 2H_2O$+S*	12-24	6.2	<10	3	61	10
	24-36	6.7	<10	3	**	10
	0-12	5.3	<10	18	79	18
SCU-30+S*	12-24	5.5	<10	3	**	10
	24-36	6.2	<10	3	**	10

All figures represent a single sample.

*Added as $CaSO_4 \cdot 2H_2O$.

**Data not available.

†Tom, Oklahoma.

TABLE XII

FIELD FORAGE STUDY - 1974 SOIL TEST RESULTS
BEFORE TREATMENT APPLICATION *

Inches Depth	pH	Lbs/Ac			ppm
		NO_3-N	P	K	SO_4-S
0-12	6.5	10	77	65	30
12-24	7.0	10	42	100	30
24-36	7.2	10	40	90	15

All figures represent a single sample.

*Fairview, Oklahoma.

Note: CEC: 3.5 meq/100 gms soil.

Mechanical Analysis: Sand 86%; Silt 9%; Clay 5%.

TABLE XIII

FIELD FORAGE STUDY - 1974 SOIL TEST RESULTS AT FINAL HARVEST *

Treatment	Inches Depth	pH	Lbs/Ac NO_3-N	Lbs/Ac P	Lbs/Ac K	ppm SO_4-S
KCl	0-12	6.2	10	54	90	16
	12-24	6.8	10	42	92	13
	24-36	7.0	10	40	91	15
K_2SO_4	0-12	5.8	10	81	123	18
	12-24	6.6	10	53	106	12
	24-36	6.7	10	42	105	11
$CaSO_4 \cdot 2H_2O$	0-12	5.7	10	70	93	12
	12-24	6.4	10	46	125	12
	24-36	6.6	10	23	97	13
Granular 90%S	0-12	5.6	10	77	95	9
	12-24	6.7	10	46	118	16
	24-36	6.8	10	28	97	9

All figures represent an average of four samples.

*Fairview, Oklahoma.

CHAPTER V

SUMMARY AND CONCLUSIONS

Additions to the soil of various sulfur sources failed in some cases to show significant plant dry matter yield differences. Certain other plant responses, however, were noted.

In both the greenhouse and field studies, sulfur applications showed slight increase in bermuda grass and sorghum forage yields. As intensive cropping continues and environmental controls prevail, significant plant response will no doubt in the near future occur when sulfur is applied to certain soils of Oklahoma. This research indicates that K_2SO_4 and $CaSO_4 \cdot 2H_2O$ promote the greatest immediate plant response. A granular wettable 90 percent sulfur compound also appeared to promote good yield increases during the initial year of application on forage sorghum.

As sulfur became deficient, N/S ratios widened greatly. There was also found to be an inverse relationship between nitrogen and sulfur plant levels. As plant nitrogen increased, the sulfur concentration of these plants decreased. Nitrogen/sulfur ratios appear to be a good tool for assessing sulfur needs.

From the limited data, it is difficult to define a critical level of plant sulfur, however, this level appears to be near the 0.10 to 0.15 percent range for Midland bermuda grass. This level is probably somewhat less for the commercial forage sorghum that was tested.

It is evident from the forage yield data that much additional work needs to be done. Based on the information herein, it appears several sources are satisfactory in correcting sulfur deficiencies. Additional work is needed to determine the most economical rates of sulfur to apply and to predict when it is needed.

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APPENDIXES

TABLE XIV

ANALYSIS OF VARIANCE FOR HARVEST ONE OF GREENHOUSE STUDY - 1973

Variable	C.V.(%)	LSD^{01}	LSD^{05}	F	Prob.>F
% Dry Matter	7	3.93	2.88	14.17	0.0001
Pot Green Wt.	19	8.50	6.23	16.68	0.0001
Pot Dry Wt.	18	2.63	1.93	7.93	0.0014
S	34	0.07	0.05	37.93	0.0001
N	20	0.84	0.62	6.14	0.0042
N/S	-	-	-	-	-

TABLE XV

ANALYSIS OF VARIANCE FOR HARVEST TWO OF GREENHOUSE STUDY - 1973

Variable	C.V.(%)	LSD^{01}	LSD^{05}	F	Prob.>F
% Dry Matter	10	7.93	5.82	0.63	0.6045
Pot Green Wt.	34	6.03	4.42	8.54	0.0010
Pot Dry Wt.	32	2.75	2.01	11.00	0.0003
S	22	0.04	0.03	125.71	0.0001
N	16	0.34	0.25	30.58	0.0001
N/S	95	71.89	52.18	17.29	0.0001

TABLE XVI

ANALYSIS OF VARIANCE FOR HARVEST THREE OF GREENHOUSE STUDY - 1973

Variable	C.V.(%)	LSD^{01}	LSD^{05}	F	Prob.>F
% Dry Matter	19	9.98	7.32	3.15	0.0466
Pot Green Wt.	13	2.63	1.93	163.55	0.0001
Pot Dry Wt.	14	0.98	0.72	150.70	0.0001
S	72	0.07	0.50	10.20	0.0005
N	7	0.50	0.36	187.80	0.0001
N/S	73	70.64	50.06	1.33	0.3019

TABLE XVII

ANALYSIS OF VARIANCE FOR HARVEST FOUR OF GREENHOUSE STUDY - 1973

Variable	C.V.(%)	LSD^{01}	LSD^{05}	F	Prob.>F
% Dry Matter	15	7.87	5.77	2.01	0.1436
Pot Green Wt.	13	2.12	1.55	153.12	0.0001
Pot Dry Wt.	15	0.80	0.59	115.63	0.0001
S	134	0.06	0.04	3.80	0.0257
N	15	1.28	0.94	14.50	0.0001
N/S	96	505.02	355.05	7.75	0.0094

TABLE XVIII

ANALYSIS OF VARIANCE FOR HARVEST FIVE OF
GREENHOUSE STUDY - 1973

Variable	C.V.(%)	LSD^{01}	LSD^{05}	F	Prob.>F
% Dry Matter	6	2.81	2.06	10.67	0.0004
Pot Green Wt.	18	4.95	3.63	0.44	0.7280
Pot Dry Wt.	23	1.67	1.23	0.35	0.7950
S	22	0.07	0.05	2.40	0.0962
N	7	0.41	0.30	5.02	0.0094
N/S	24	7.54	5.53	1.89	0.1620

TABLE XIX

ANALYSIS OF VARIANCE FOR HARVEST ONE OF
FIELD STUDY - 1973

Variable	C.V.(%)	LSD^{01}	LSD^{05}	F	Prob.>F
% Dry Matter	6	2.75	2.02	4.17	0.0188
Green Wt./Ac	12	2213.27	1622.56	13.76	0.0001
Dry Matter/Ac	10	537.30	393.90	10.57	0.0004
S	17	0.04	0.03	110.40	0.0001
N	7	0.03	0.25	20.62	0.0001
N/S	63	35.76	26.21	14.54	0.0001

TABLE XX

ANALYSIS OF VARIANCE FOR HARVEST TWO OF FIELD STUDY - 1973

Variable	C.V.(%)	LSD^{01}	LSD^{05}	F	Prob.>F
% Dry Matter	6	3.92	2.87	7.97	0.0014
Green Wt./Ac	23	2880.82	2111.94	0.71	0.5595
Dry Matter/Ac	23	1216.13	891.55	1.31	0.2979
S	22	0.05	0.04	40.77	0.0001
N	14	0.34	0.25	0.98	0.5757
N/S	50	11.62	8.52	10.06	0.0005

TABLE XXI

ANALYSIS OF VARIANCE FOR HARVEST THREE OF FIELD STUDY - 1973

Variable	C.V.(%)	LSD^{01}	LSD^{05}	F	Prob.>F
% Dry Matter	5	2.60	1.90	1.47	0.2501
Green Wt./Ac	11	2422.14	1775.68	1.08	0.3771
Dry Matter/Ac	11	845.33	619.72	2.09	0.1322
S	25	0.05	0.03	19.09	0.0001
N	5	0.21	0.15	2.00	0.1453
N/S	54	26.64	19.53	11.75	0.0002

TABLE XXII

ANALYSIS OF VARIANCE FOR HARVEST ONE OF
FIELD STUDY - 1974

Variable	C.V.(%)	LSD^{01}	LSD^{05}	F	Prob.>F
% Dry Matter	2	0.97	0.72	1.26	0.2924
Green Wt./Ac	9	2512.38	1877.52	0.46	0.8584
Dry Matter/Ac	9	809.95	605.27	0.62	0.7416
S	24	0.07	0.05	12.15	0.0001
N	10	0.35	0.26	0.46	0.8559
N/S	32	7.21	5.38	8.29	0.0001

TABLE XXIII

ANALYSIS OF VARIANCE FOR HARVEST TWO OF
FIELD STUDY - 1974

Variable	C.V.(%)	LSD^{01}	LSD^{05}	F	Prob.>F
% Dry Matter	6	2.74	2.05	5.10	0.0005
Green Wt./Ac	14	1170.35	874.60	4.52	0.0011
Dry Matter/Ac	12	292.45	218.55	2.43	0.0355
S	19	0.06	0.05	12.12	0.0001
N	11	0.41	0.31	3.21	0.0085
N/S	38	8.37	6.25	7.61	0.0001

TABLE XXIV

ANALYSIS OF VARIANCE FOR HARVEST THREE OF FIELD STUDY - 1974

Variable	C.V.(%)	LSD^{01}	LSD^{05}	F	Prob.>F
% Dry Matter	5	2.49	1.86	1.23	0.3050
Green Wt./Ac	19	2951.25	2205.48	4.99	0.0006
Dry Matter/Ac	18	877.49	655.76	4.72	0.0008
S	16	0.05	0.03	10.10	0.0001
N	15	0.38	0.29	0.67	0.6978
N/S	23	3.26	2.44	8.63	0.0001

TABLE XXV

ANALYSIS OF VARIANCE FOR HARVEST FOUR OF FIELD STUDY - 1974

Variable	C.V.(%)	LSD^{01}	LSD^{05}	F	Prob.>F
% Dry Matter	11	5.33	3.98	1.92	0.0912
Green Wt./Ac	42	2433.00	1818.20	4.21	0.0017
Dry Matter/Ac	34	608.03	454.38	4.94	0.0006
S	12	0.04	0.03	13.84	0.0001
N	12	0.41	0.30	1.88	0.0981
N/S	18	2.97	2.22	14.59	0.0001

TABLE XXVI

ANALYSIS OF VARIANCE FOR HARVEST ONE OF FIELD FORAGE STUDY - 1974

Variable	C.V.(%)	LSD^{01}	LSD^{05}	F	Prob.>F
S	11	0.03	0.02	0.69	0.5765
N	6	0.46	0.33	2.81	0.0838
N/S	14	8.44	6.02	1.81	0.1988

TABLE XXVII

ANALYSIS OF VARIANCE FOR HARVEST TWO OF FIELD FORAGE STUDY - 1974

Variable	C.V.(%)	LSD^{01}	LSD^{05}	F	Prob.>F
S	23	0.04	0.03	0.54	0.6687
N	4	0.22	0.16	6.46	0.0077
N/S	37	29.73	21.21	0.45	0.7238

TABLE XXVIII

ANALYSIS OF VARIANCE FOR HARVEST THREE OF FIELD FORAGE STUDY - 1974

Variable	C.V.(%)	LSD^{01}	LSD^{05}	F	Prob.>F
Leaf S	22	0.04	0.03	2.19	0.1418
Leaf N	8	0.40	0.28	2.50	0.1083
Stem S	29	0.05	0.04	3.98	0.0347
Stem N	14	0.44	0.31	0.53	0.6763
Total S	19	0.07	0.05	4.81	0.0199
Total N	8	0.64	0.46	2.16	0.1447
Total N/S	24	14.22	10.15	1.27	0.3278

TABLE XXIX

ANALYSIS OF VARIANCE FOR HARVEST FOUR OF FIELD FORAGE STUDY - 1974

Variable	C.V.(%)	LSD^{01}	LSD^{05}	F	Prob.>F
% Dry Matter	6	3.99	2.85	1.04	0.4101
Green Wt./Ac	21	7080.02	5050.21	1.36	0.2996
Dry Matter/Ac	23	2378.73	1696.75	1.76	0.2080
Leaf S	27	0.04	0.03	1.27	0.3277
Leaf N	15	0.68	0.49	0.91	0.5318
Stem S	29	0.03	0.02	2.98	0.0733
Stem N	14	0.32	0.23	1.70	0.2197
Head S	44	0.03	0.02	0.52	0.6815
Head N	8	0.33	0.24	0.52	0.6840
Total S	22	0.07	0.05	2.31	0.1279
Total N	7	0.77	0.55	0.17	0.9115
Leaf N/S	21	14.75	10.52	1.66	0.2281
Stem N/S	38	21.62	15.43	3.08	0.0678
Head N/S	110	177.33	126.49	0.70	0.5740
Total N/S	24	18.52	13.22	2.78	0.0862

VITA

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