THE EFFECT OF SULFUR AND MICRONUTRIENTS ON COMPOSITION AND YIELD OF MIDLAND BERMUDAGRASS

By

RICHARD L. LARGE

Bachelor of Science

Purdue University

West Lafayette, Indiana

1962

Submitted to the Faculty of the Graduate School of
the Oklahoma State University
in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE
July, 1966

THE EFFECT OF SULFUR AND MICRONUTRIENTS
ON COMPOSITION AND YIELD OF
MIDLAND BERMUDAGRASS

Thesis Approved:

Lester W. Reed

Thesis Adviser

Glenn W. Todd

J H Boggs

Dean of the Graduate School

ACKNOWLEDGMENTS

The author is grateful to the Agronomy Department of Oklahoma State University for the facilities and assistance provided for this study, and to the many persons involved who have provided guidance and inspiration.

Special thanks and appreciation is due Dr. Lester W. Reed, my adviser, for his consideration and valuable counsel in the assembling and reviewing of this thesis. An expression of gratitude is also extended to the other members of the committee, Mr. Cliff Elder, Dr. G. W. Todd, and Dr. B. B. Tucker.

Sincere appreciation also goes to Mrs. Paul Brackelsberg for typing this manuscript.

TABLE OF CONTENTS

Chapter Page

I. INTRODUCTION 1

II. LITERATURE REVIEW 2

III. MATERIALS AND METHODS 7

IV. RESULTS AND DISCUSSION 13

V. SUMMARY AND CONCLUSIONS 20

LITERATURE CITED 21

APPENDIX 26

LIST OF TABLES

Table Page

I. Soil Characteristics Determined by Laboratory Analyses . 8

II. Basic Greenhouse Fertilizer Treatments 9

III. Sulfur and Micronutrient Fertility Treatments 10

IV. Influence of Boron, Sulfur, Zinc, Copper, Cobalt, and Molybdenum on Cobalt Composition of Midland Bermudagrass 27

V. Influence of Boron, Sulfur, Zinc, Copper, Cobalt, and Molybdenum on Molybdenum Composition of Midland Bermudagrass 28

VI. Influence of Boron, Sulfur, Zinc, Copper, Cobalt, and Molybdenum on Sulfur Composition of Midland Bermudagrass 29

VII. Influence of Boron, Sulfur, Zinc, Copper, Cobalt, and Molybdenum on Zinc Composition of Midland Bermudagrass 30

VIII. Effect of Boron, Sulfur, Zinc, Copper, Cobalt, and Molybdenum on Yield of Midland Bermudagrass 31

LIST OF FIGURES

Figure Page

1. Change in Composition of Bermudagrass Compared to Yield with Addition of Cobalt, Copper, Molybdenum, Sulfur, and Zinc 14

2. Change in Cobalt Uptake of Bermudagrass with Addition of Cobalt, Boron, Sulfur, Zinc, Copper, and Molybdenum . . . 15

3. Change in Molybdenum Uptake of Bermudagrass with Addition of Molybdenum, Boron, Sulfur, Zinc, Copper, and Cobalt . 17

4. Change in Sulfur Uptake of Bermudagrass with Addition of Sulfur, Boron, Zinc, Copper, Cobalt, and Molybdenum . . . 18

5. Change in Zinc Uptake of Bermudagrass with Addition of Zinc, Boron, Sulfur, Copper, Cobalt, and Molybdenum . . . 19

CHAPTER I

INTRODUCTION

Forage crop production is one of Oklahoma's most important agricultural enterprises. In the state there are an estimated 4.5 million acres devoted to introduced species which respond to commercial fertilizers. Bermudagrass comprises approximately 2 million of the 4.5 million acres of forages and is being planted at the rate of 200,000 acres per year. As a result, there has been a tremendous increase in the amount of fertilizer applied to bermudagrass in order to achieve higher yields.

The higher yields and higher fertilizer rates have resulted in concern about proper rates, forage quality, and depletion of the micronutrients in the soil. Work has been conducted on proper rates of N, P, and K for maximum yields (23)[1], but no work has been initiated on the effects of micronutrients on the yield of bermudagrass.

This study was designed to determine whether sulfur and various micronutrients can increase bermudagrass production and increase the uptake of the various elements at levels of N, P, and K designed to give maximum production.

---

[1] Figures in parenthesis refer to Literature Cited.

CHAPTER II

LITERATURE REVIEW

The yield of bermudagrass has been increased by the use of N, P, and K fertilization (19, 26, 31, 49) in the United States. Various researchers have also attempted to increase the yield of bermudagrass and other forages with micronutrient and sulfur fertilization. Literature relating to the various elements used in this study is presented.

Boron. Murphy and Lynd (47) increased average hay yields of alfalfa by 1,000 pounds per acre with an application of 40 pounds of borax on plots receiving P and K fertilization. Killinger et al. (40) found a boron growth response in grasses grown on well limed soil fertilized with N, P, and K. Mulvehill and MacGregor (46) found that applications of boron produced no increases in yield on alfalfa and oats in Minnesota. Deal and Engel (22), working with Merion Kentucky Bluegrass, found that boron applications had no appreciable effect on regrowth between mowings.

The level of boron in the soil may affect the boron content of the plants growing on the soil. Increases of boron content of red clover, grown under greenhouse conditions, due to boron applications were observed by Tucker and Smith (56). However, McIlrath et al (43) observed that non-toxic levels of boron showed no influence on the uptake of boron, copper, iron, maganese, and molybdenum by Setaria when grown in nutrient solution.

Bingham et al. (10, 11, 13) found interactions of phosphorus and boron on citrus trees. In all cases excessive amounts of P caused reduction of boron content in the citrus tree. When they grew beans, corn, tomatoes, and sour orange seedlings in sand culture they observed variable responses. Harper and Reed (33) analyzed 100 native grasses, 14 bermudagrasses, 23 other grasses, and 20 legume samples from Oklahoma and found the boron content of the soil was probably adequate for plant growth. They also found that most boron deficient soils were collected in central and eastern Oklahoma.

Cobalt. The cobalt content of grasses is normally lower than the cobalt content of legumes (35, 41, 44) irrespective of the cobalt content of the soil.

Beeson et al. (8) found that additions of cobalt to soybeans grown in soil cultures resulted in increased concentrations of cobalt in the plant tissue. They also observed that high rates of phosphorus reduced the cobalt content of the leaf. An increase in pH has also been found to reduce the cobalt content of a plant (8, 45). Ahmed and Evans (2, 3) found that cobalt was an essential element, for symbiotic nitrogen fixation, for soybeans and alfalfa when dependent on atmospheric nitrogen. Smith et al. (55) demonstrated that cobalt is essential for the production of vitamin B-12 in the rumen by microbial synthesis and that the appetites, body weights, and hemoglobin levels of lambs exhibiting a cobalt deficiency were increased by an intravenous injection of Vitamin B-12.

Copper. The quantity of copper in soil is not as important in plant nutrition as is the relation between copper and other micronutrients.

Brown and Foy (17) found that new barley leaves exhibiting symptoms of copper deficiency contained less calcium and iron, and more phosphorus, than copper sufficient leaves. Therefore, the distribution of certain nutrient elements in the leaves of barley is affected by the copper content of the plant. Seatz et al. (54) found that copper fertilization of snap beans increased calcium content of lower leaves. Younts and Patterson (59) observed that copper applications on wheat up to five pounds per acre increased manganese concentration. They also found that liming the soil resulted in a lower copper concentration in the plants, particularly where the soil pH was increased above 5.1. Brown and Jurinak (16) observed the same reduction of copper content in the plant due to liming.

An increase of grass yields due to copper fertilization on well limed and fertilized soils was observed by Killinger et al. (40). However, Seatz et al. (54) observed no increase in yield of snap beans when fertilized with copper.

Several workers (8, 11, 12, 13) have noted a phosphorus, copper interaction. The copper uptake of the plant is greatly reduced with high rates of phosphorus fertilization.

Molybdenum. An increase in yield of legumes resulting from applications of molybdenum fertilizer have been noted by several researchers (4, 27, 30). Foy and Barber (27) found that molybdenum produced a significant alfalfa yield increase on nine of fifteen Indiana soils studied. Nonleguminous plants do not seem to respond to molybdenum fertilization.

Interactions involving molybdenum have been noted by various researchers. Increased molybdenum uptake by the plant due to the presence of phosphate ions has been observed (5, 6, 42). However, Bingham (10) noted that high levels of phosphorus fertilization on citrus trees may restrict movement of molybdenum. Reisenauer (51) observed that the uptake of molybdenum by peas was reduced by applications of sulfate fertilizer.

The addition of nitrogen has been shown to reduce molybdenum content of pasture grasses (6, 42). Bear and Wallace (7) observed that molybdenum increased the nitrogen content of alfalfa.

Ahlrichs et al. (1) observed that the addition of boron, copper, iron, magnesium, manganese, and zinc repressed the molybdenum uptake of alfalfa on organic soils.

Liming may make the native molybdenum in the soil more available to the plants.

Sulfur. Increases in yields of legumes and grasses have been observed (9, 34, 39, 50, 52, 57) as the result of sulfur fertilization. The concentration of sulfur in the plants decreases as the season advances. Jones (38) observed that where no sulfur was applied on grasses there was little or no uptake of sulfur after the first harvest, but where sulfur was applied it continued to be absorbed up to the third harvest. Pumphrey and Moore (50) state that the rate of decrease in sulfur content of alfalfa during growth is essentially independent of sulfur fertilization.

Nielsen et al. (48) noted that the sulfur content of corn was decreased by increases in phosphorus and potassium fertilization.

Zinc. Ellis et al. (24) increased the yield of corn on a calcareous soil with four pounds of zinc per acre. Fuehring and Soafi (28) increased the stover yields of corn on a calcareous soil, but decreased grain yields. They also found the level of zinc in the plant to be affected to the greatest extent by the level of manganese. Low manganese resulted in low zinc requirements while higher concentrations of manganese in the plant resulted in a high zinc requirement.

Pasture plants grown on well limed and fertilized soil were found to respond to zinc fertilization by Killinger (40). Deal and Engel (22) were not able to find any effect on regrowth of bluegrass turf with zinc fertilization.

Many researchers have found a phosphorus-zinc interaction. High rates of phosphorus were found to reduce the zinc uptake of plants (12, 13, 18) under field conditions. In the greenhouse, Ellis (24) was able to increase the zinc uptake of corn with high levels of phosphorus.

Increase in soil pH or increased rates of lime may reduce the zinc content of plants (15, 16, 53, 58).

CHAPTER III

MATERIALS AND METHODS

The data presented in this thesis were obtained from a greenhouse study. The objective was to determine the relative uptake of sulfur and micronutrients as indicated by plant yields and composition.

Description of the Soil Studied. The soil used in this study was classified as Parsons silt loam (29). The sample site was located on the Eastern Oklahoma Pasture Research Station at Muskogee, Oklahoma. This soil has been under continuous cultivation since 1900. The soil samples were taken in the summer of 1964.

Preparation of Soil for Pot Culture. The soil was mixed thoroughly and sieved through a quarter inch hardware cloth screen and allowed to dry. After the soil had dried, four kilograms of soil were weighed into a plastic bag inside a number 10 (gallon) tin can.

Laboratory Analyses of Soil Sample. A sufficient quantity of the soil was brought to the laboratory for analysis. The sample was air-dried and processed for analysis by crushing the aggregates with a wooden roller, and seiving the sample through an eighteen mesh sieve coated with plastic to avoid zinc or copper contamination. The results of the laboratory tests are included in Table I.

The soil texture determination was made by the hydrometer method (22). The soil reaction value was read with a Beckman, glass electrode

TABLE I

SOIL CHARACTERISTICS DETERMINED BY LABORATORY ANALYSES

Mechanical composition	20	% sand
	68	% silt
	12	% clay
Soil reaction	pH 4.7	
Percent organic matter	1.7	
Percent total nitrogen	0.14	
Cation exchange capacity m.e. per 100 grams	10.1	
Exchangeable calcium ppm	680	
Exchangeable magnesium ppm	372	
Exchangeable sodium ppm	8	
Exchangeable potassium ppm	1	
Bray #1 available phosphorus ppm	13	
Manganese ppm (0.1 N HCl)	1.5	
Cobalt ppm (0.1 N HCl)	0.1	
Copper ppm (0.1 N HCl)	3.5	
Iron ppm (0.1 N HCl)	65	
Zinc ppm (0.1 N HCl)	6.5	
Molybdenum ppm (0.1 N HCl)	0.05	

pH meter. A fifteen gram sample of the soil was mixed with enough water to form a paste and the reading taken after allowing sufficient time for equilibrium. Organic matter content of the soil sample was measured indirectly by the "wet combustion process" (32) of organic carbon oxidation. Total nitrogen in the soil material was determined by the Kjeldahl method of analysis (32). The cation exchange capacity was determined by the ammonium acetate method of Jackson (37). The exchangeable bases were determined from ammonium acetate leachate by the oxy-hydrogen Beckman DU Flame Spectrophotometer.

Acid-soluble phosphorus was determined colorimetrically (32).

Micronutrients were determined by ion-exchange separation by a method reported by Hunter and Coleman (36).

Greenhouse Procedure. The soil was placed in a plastic bag inside a number 10 (gallon) tin can. Lime was added to the soil to raise the pH to 7.0 and the basic fertility treatments applied (Table II).

TABLE II

BASIC GREENHOUSE FERTILIZER TREATMENTS

Treatment Number	Treatment	Rate Per Can
All	Nitrogen	25 PPM
All	Phosphorus	88 PPM
All	Potassium	150 PPM
All	$Ca(OH)_2$	625 PPM

On November 11, 1964, selected rhizomes of Midland bermudagrass each having nodes were washed and transplanted into each can. Distilled water was added daily to maintain good moisture conditions. The cans were then arranged in a complete factorial design with three replications.

The first clipping was 12/6/64 at which time 50 PPM of N was applied to all cans. The second clipping was made 1/9/65 followed by a nitrogen application of 100 PPM per can. It was necessary to replant some cans on 1/11/65 due to insect damage. The plants were sprayed with malathion weekly after the first sign of insect damage.

On 1/26/65 the sulfur and micronutrient treatments were added in 100 ml. of solution in a complete factorial arrangement using none or one designated level of each element (Table III).

TABLE III

SULFUR AND MICRONUTRIENT FERTILITY TREATMENTS

Sulfur	50 PPM or none
Copper	5 PPM or none
Cobalt	2.5 PPM or none
Molybdenum	2.5 PPM or none
Zinc	10 PPM or none
Boron	5 PPM or none

The third clipping (first after sulfur and micronutrient addition) was made on February 20, 1965. The grass from each can was washed 30 seconds in 0.1 N HCl and then a total of 30 seconds in three separate distilled water washes. The grass was then wrapped in aluminum foil and placed in a paper bag and dried at 180° for 24 hours. This cutting was then analyzed for sulfur and micronutrient content.

The fourth cutting was made on March 3; the fifth on April 10; and sixth on May 4; and the seventh on May 27, 1965.

On May 3, 1965, a sulfur deficiency had appeared on the cans not receiving additional sulfur, therefore on May 27, 1965, 50 ppm of sulfur was added to each can not previously receiving sulfur. Before the addition of sulfur a 20 gram soil sample was taken from each can for laboratory analysis of sulfur.

On June 23, 1965, the plants had made visible recovery from the sulfur deficiency and the eighth cutting was made and the roots were washed from the soil, dried, and weighed. After each clipping 100 ppm of nitrogen was added to each can.

All of the cuttings were dried at 180° F for 24 hours then weighed for yield.

Chemical Analyses of Plant Material. Calcium, copper, iron, magnesium, manganese, and zinc were determined with a Perkin-Elmer atomic absorption spectrophotometer (Model 303). A one gram sample of the plant forage was digested by nitric-perchloric acid mixture and brought to a final volume of 25 ml. with 0.1 N HCl. Dilutions were made for each element to bring it into the correct concentration range of accurate determination on the atomic absorption spectrophotometer.

Cobalt and molybdenum were determined by ion-exchange separation by the method outlined by Hunter and Coleman (25).

Sulfur was determined by nitric and perchloric acid digestion using the procedure developed by Blanchar et al. (14).

The total nitrogen in the plant material was determined by the micro Kjeldahl method.

Soil Analyses for Sulfur. Acid extractable sulfur in the soil taken from the greenhouse pots was determined by sodium acetate-acetic acid extraction and 500 ppm P extraction method of Ensminger (25). Sulfur was then determined turbidimetrically as barium sulfate using the method of Chesnin and Yien (20).

CHAPTER IV

RESULTS AND DISCUSSION

Sulfur addition gave a significant increase in yield as shown in Table VIII of the Appendix. The addition of boron, cobalt, copper, zinc, and molybdenum did not significantly affect the yield of Midland bermudagrass (Table VIII).

A sulfur deficiency was observed, on the pots not receiving sulfur, before the sixth harvest. Soil samples were taken from all pots for laboratory analyses of available sulfur, however, sulfur could not be detected on any of the plots by using the sodium acetate or 500 ppm phosphorus extraction procedure and turbidity determination method. After the soil samples had been collected 50 ppm of sulfur was added to each pot not initially receiving sulfur and the deficiency symptoms were corrected.

With the exception of sulfur the chemical composition of the bermudagrass compared to yield shows that changes in trace element composition did not result in yield differences (Figure 1).

The uptake of calcium, copper, iron, magnesium, manganese, and nitrogen was not affected by addition of the element or the addition of other elements.

The cobalt composition of the bermudagrass was significantly increased with the addition of cobalt as shown in Table IV of the Appendix. The addition of boron, sulfur, zinc, copper, and molybdenum did not significantly affect the uptake of cobalt (Figure 2).

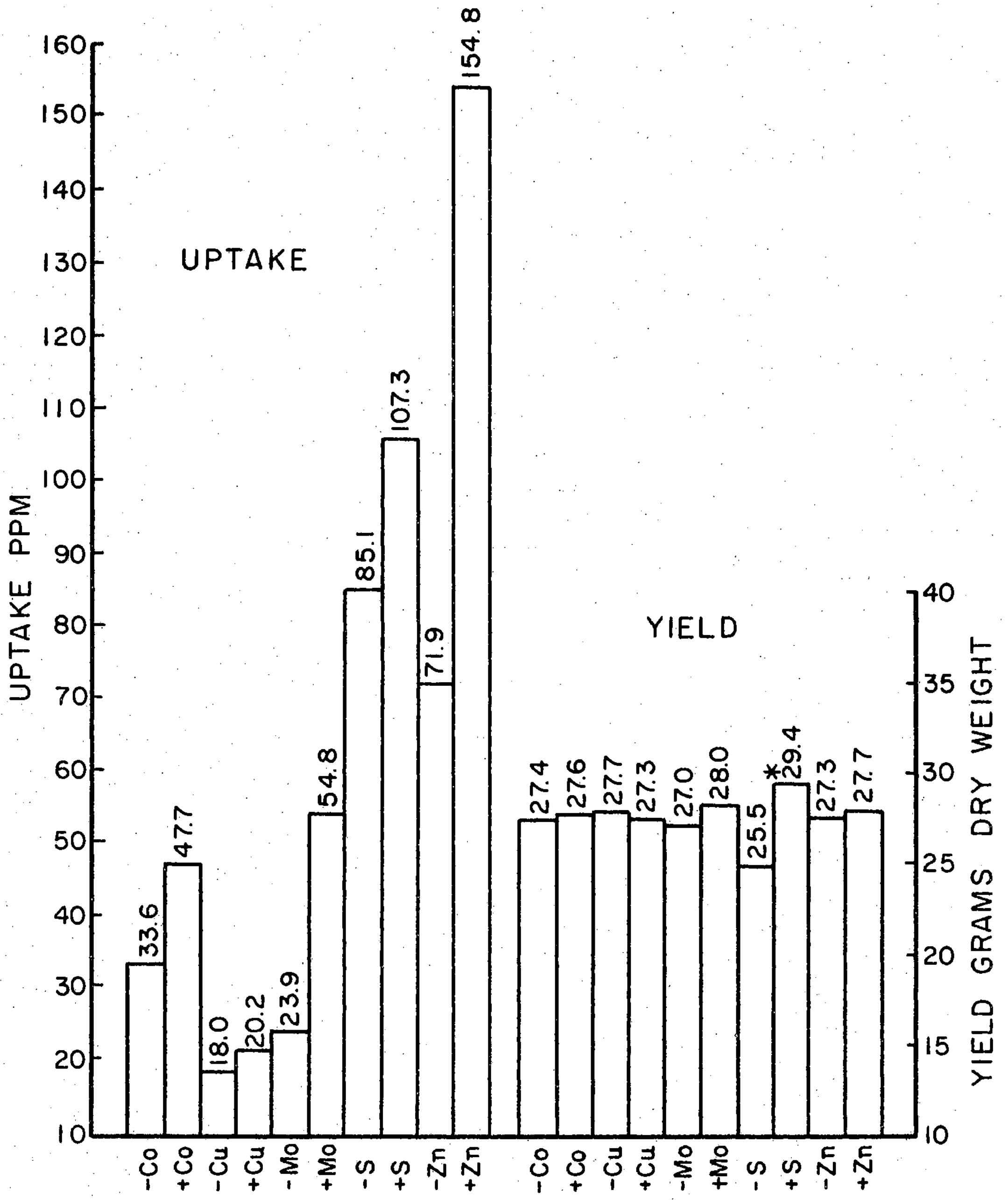

Figure 1. Change in composition of bermudagrass compared to yield with addition of cobalt, copper, molybdenum, sulfur, and zinc.

*Denotes significant difference at the 5 percent level.

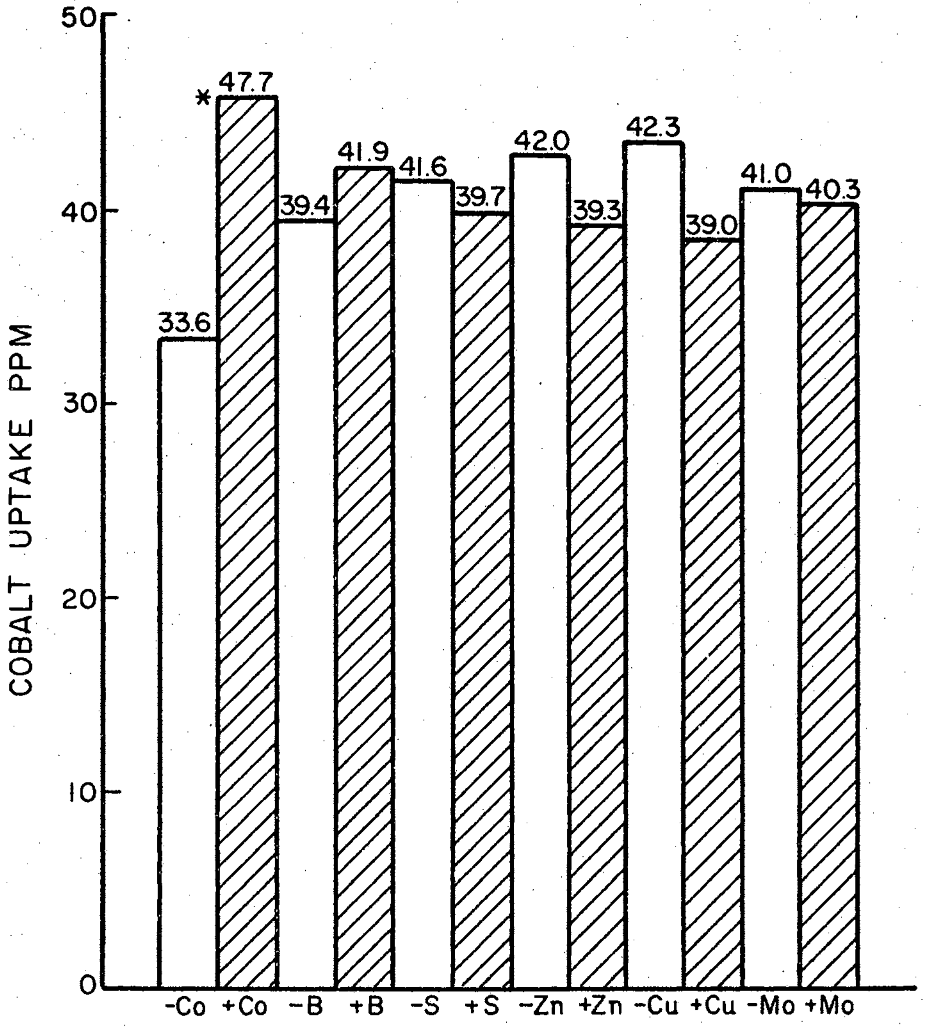

Figure 2. Change in cobalt uptake of bermudagrass with addition of cobalt, boron, sulfur, zinc, copper, and molybdenum.

*Denotes significant difference at the 5 percent level.

The molybdenum composition of the bermudagrass was significantly changed with the addition of molybdenum, sulfur, and copper (Table V). The high rates of sulfur and copper appear to cause a reduction in molybdenum uptake (Figure 3). The addition of boron, zinc, and cobalt did not significantly affect the molybdenum uptake of bermudagrass.

Figure 4 shows the sulfur composition of the bermudagrass was significantly increased with the addition of sulfur. The significance of cobalt may be due to experimental error.

Zinc content was significantly increased with the addition of zinc (Figure 5). Copper at the high level significantly reduced the zinc uptake of bermudagrass. Table VII of the Appendix gives the analysis of variance for the zinc treatment.

The boron concentration in the plant was not high enough to detect with the atomic absorption spectrophotometer. Therefore, no results of the affect of cobalt, copper, molybdenum, sulfur, or zinc on boron composition of bermudagrass were obtained.

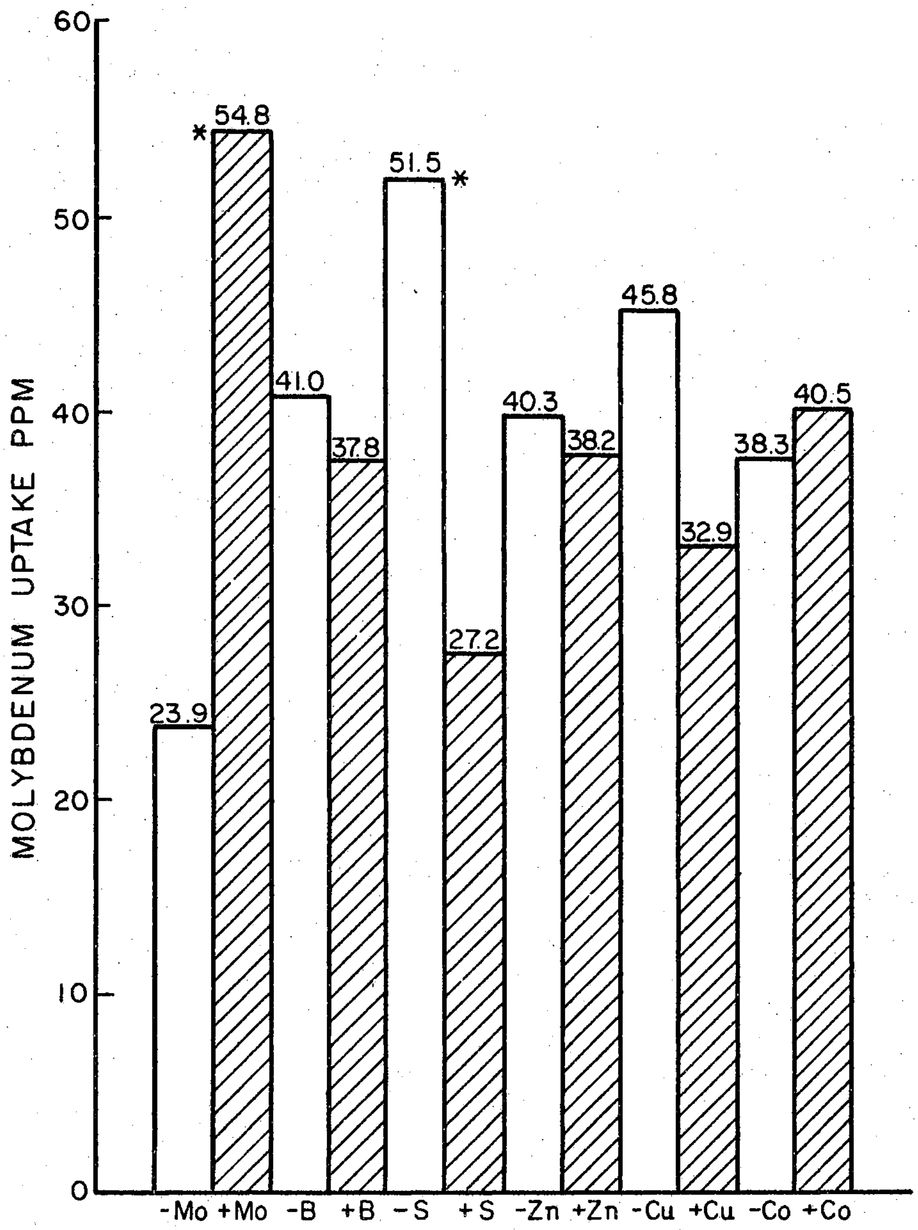

Figure 3. Change in molybdenum uptake of bermudagrass with addition of molybdenum, boron, sulfur, zinc, copper, and cobalt.

*Denotes significant difference at the 5 percent level.

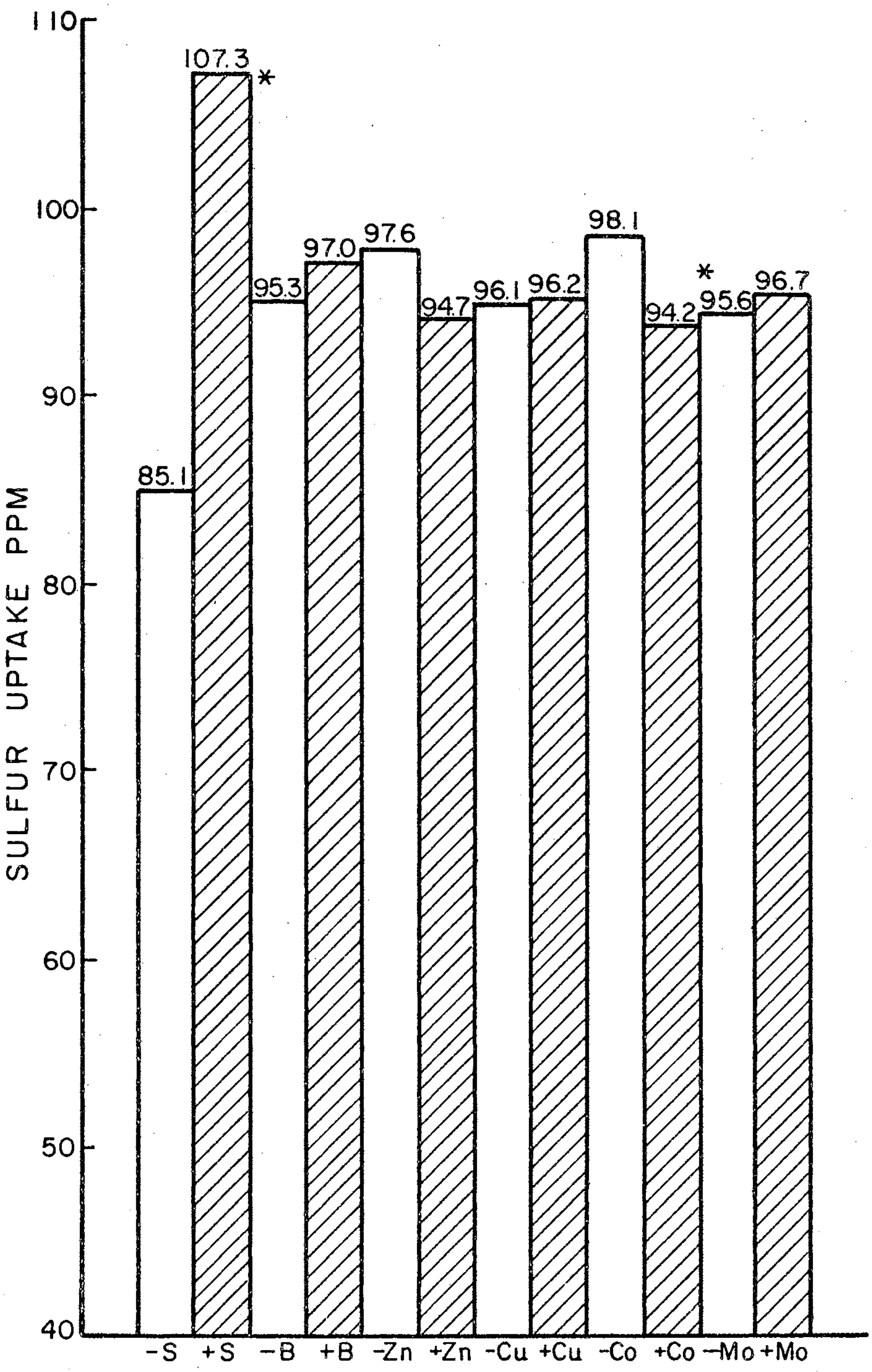

Figure 4. Change in sulfur uptake of bermudagrass with addition of sulfur, boron, zinc, copper, cobalt, and molybdenum.

*Denotes significant difference at the 5 percent level.

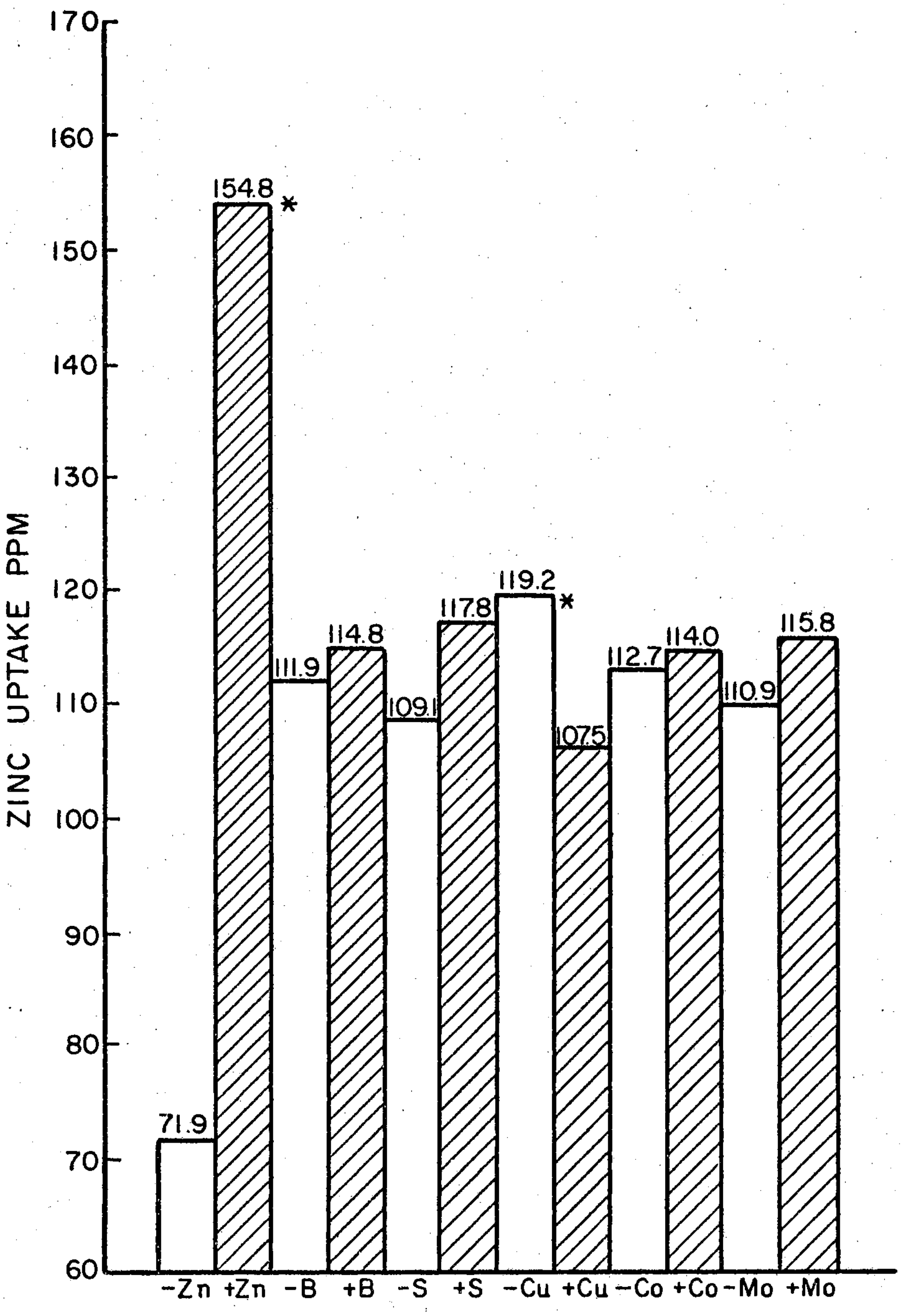

Figure 5. Change in zinc uptake of bermudagrass with addition of zinc, boron, sulfur, copper, cobalt, and molybdenum.

*Denotes significant difference at the 5 percent level.

CHAPTER V

SUMMARY AND CONCLUSIONS

A study of the feasibility of fertilizing Midland bermudagrass with boron, cobalt, copper, molybdenum, sulfur, and zinc was made. The experiment was conducted in the greenhouse using Parsons silt loam soil fertilized at two rates of each element studied.

Plant samples were analyzed for calcium, cobalt, copper, iron, magnesium, manganese, molybdenum, nitrogen, sulfur, and zinc.

The calcium, copper, iron, magnesium, manganese, and nitrogen content of the plant was not affected by addition of any element used in this experiment. The content of cobalt, molybdenum, sulfur, and zinc was increased with the addition of each element respectively. The high rate of copper appeared to cause a reduction in uptake of molybdenum and zinc. The high rate of sulfur also caused a reduction in molybdenum uptake.

The addition of sulfur gave a significant difference in yield, however, the yield was not significantly affected by addition of boron, zinc, copper, cobalt, or molybdenum.

On Parsons silt loam Midland bermudagrass does not respond in yield to boron, cobalt, copper, molybdenum, and zinc. Under intensified cropping a response to sulfur may be observed, therefore, sulfur may become the limiting element after N, P, and K.

The uptake of cobalt, molybdenum, sulfur, and zinc can be increased by including them in the fertilizer.

LITERATURE CITED

1. Ahlrichs, L. E., R. G. Hanson, and J. M. MacGregor. 1963. Molybdenum effect on alfalfa growth on thirteen Minnesota soils in the greenhouse. Agron. J. 55:484-486.

2. Ahmed, S., and H. J. Evans. 1960. A micronutrient element for the growth of soybean plants under symbiotic conditions. Soil Sci. 90:205-210.

3. ______. 1961. The essentiality of cobalt for soybean plants grown under symbiotic conditions. Proc. Natl. Acad. Sci. U. S. 47:24-36.

4. Anderson, A. J. 1946. Molybdenum in relation to pasture improvement in South Australia. Aust. Council Sci. and Indus. Res. J. 19:1-15.

5. ______, and A. C. Oertel. 1946. Factors affecting the response of plants to molybdenum. Aust. Council Sci. and Indus. Res. Bul. 198:25-44.

6. Barshad, I. 1951. Factors affecting the molybdenum content of pasture plants. II. Effect of soluble phosphate, available nitrogen, and soluble sulfates. Soil Sci. 71:387-398.

7. Bear, F. F., and A. Wallace. 1950. Alfalfa, its mineral requirements and chemical composition. N. J. Agr. Exp. Sta. Bul. 748.

8. Beeson, K. C., L. Gray, and K. C. Hammer. 1948. The absorption of mineral elements by forage plants. II. The effect of fertilizer elements and liming materials on the content of mineral nutrients in soybean leaves. J. Amer. Soc. of Agron. 40:553-562.

9. Bentley, J. R., L. R. Green, and K. A. Wagnon. 1958. Herbage production and grazing capacity on annual-plant range pastures fertilized with sulfur. J. of Range Mgmt. 11:133-140.

10. Bingham, F. T. 1963. Relation between phosphorus and micronutrients in plants. Soil Sci. Soc. Amer. Proc. 27:389-391.

11. ______, and M. J. Garber. 1960. Solubility and availability of micronutrients in relation to phosphorus fertilization. Soil Sci. Soc. Amer. Proc. 24:209-213.

12. ______, and J. P. Martin. 1956. Effects of soil phosphorus on growth and minor element nutrition of citrus. Soil Sci. Soc. Amer. Proc. 20:382-385.

13. _______, _______, and J. A. Chastain. 1958. Effects of phosphorus fertilization of California soils on minor element nutrition of citrus. Soil Sci. 86:24-31.

14. Blanchar, R. W., G. Rehm, and A. C. Caldwell. 1965. Sulfur in plant materials by digestion with nitric and perchloric acid. Soil Sci. Soc. Amer. Proc. 29:71-78.

15. Boawn, L. C., F. G. Viets, C. L. Crawford, and J. L. Nelson. 1960. Effect of nitrogen carrier, nitrogen rate, zinc rate, and soil pH on zinc uptake by sorghum, potatoes and sugar beets. Soil Sci. 90:329-337.

16. Brown, A. L., and J. J. Jurinak. 1964. Effect of liming on the abailability of zinc and copper. Soil Sci. 98:170-173.

17. Brown, J. C., and C. D. Foy. 1964. Effect of Cu on the distribution of P, Ca, and Fe in barley plants. Soil Sci. 98:362-370.

18. Burleson, C. A., A. D. Dacus, and C. J. Gerard. 1961. The effect of phosphorus fertilization on the zinc nutrition of several irrigated crops. Soil Sci. Soc. Amer. Proc. 26:365-368.

19. Burton, G. W., and E. H. DeVane. 1952. Effect of rate and method of applying different sources of nitrogen upon the yield and chemical composition of bermuda grass, Cynodon dactylon (L) Pers., Hay. Agron. J. 44:128-137.

20. Chesin, L., and C. H. Yien. 1951. Turbidimetric determination of available sulfates. Soil Sci. Soc. Amer. Proc. 15:149-151.

21. Day, P. R. 1956. Report of the committee on physical analyses, 1954-55, Soil Science Society of America. Soil Sci. Soc. Amer. Proc. 20:167-169.

22. Deal, E. E., and R. E. Engel. 1965. Iron, manganese, boron and zinc: Effects on growth of Merion Kentucky Bluegrass. Agron. J. 57:553-555.

23. Elder, W. C., and B. B. Tucker. 1964. Grazing studies and forage crop fertility tests. Oklahoma State University Processed Series P-475.

24. Ellis, R., Jr., J. F. Davis, and D. L. Thurlow. 1964. Zinc availability in calcareous Michigan soils as influenced by phosphorus level and temperature. Soil. Sci. Soc. Amer. Proc. 28: 83-86.

25. Ensminger, L. E. 1954. Some factors affecting the adsorption of sulfates by Alabama soils. Soil Sci. Soc. Amer. Proc. 18:259-264.

26. Fisher, F. L., and A. G. Caldwell. 1959. The effects of continued use of heavy rates of fertilizer on forage production and quality of Coastal bermudagrass. Agron. J. 51:99-102.

27. Foy, C. D., and S. A. Barber. 1959. Molybdenum response of alfalfa on Indiana soils in the greenhouse. Soil Sci. Soc. Amer. Proc. 23:36-39.

28. Fuehring, H. D., and G. S. Soafi. 1964. Nutrition of corn on a calcareous soil: II. Effect of zinc on the yields of grain and stover in relation to other micronutrients. Soil Sci. Soc. Amer. Proc. 28:79-82.

29. Gray, F., and C. D. Fanning. 1959. Characterization and genetic study of a Dennis and a Parson soil. Soil Sci. Soc. Amer. Proc. 23:321-324.

30. Hagstrom, G. R., and K. C. Berger. 1963. Molybdenum status of three Wisconsin soils and its effect on four legume crops. Agron. J. 55:399-401.

31. Hallock, D. L., R. H. Brown, and R. E. Blazer. 1965. Relative yield and composition of Ky. 31 Fescue and Coastal bermudagrass at four nitrogen levels. Agron. J. 57:539-542.

32. Harper, H. J. 1948. Methods for analysis of soil and plant material. Soils Laboratory, Oklahoma Agricultural and Mechanical College.

33. _______, and L. W. Reed. 1964. Effect of chemical composition of soil on micronutrients and other elements in Oklahoma forage plants. Oklahoma State University Exp. Sta. Processed Series P-486.

34. Hilder, E. J. 1954. Some aspects of sulphur as a nutrient for pastures in New England soils. Aust. J. of Agr. Res. 5:39-54.

35. Hill, A. C., S. J. Toth, and F. E. Bear. 1953. Cobalt status of New Jersey soils and forage plants and factors affecting the cobalt contents of plants. Soil Sci. 76:273-284.

36. Hunter, A. H., and N. T. Coleman. 1960. Ion-exchange separations in the determination of some polyvalent metal ions in plant tissue. Soil Sci. 90:214-218.

37. Jackson, M. L. 1958. Soil Cheimcal Analysis. Prentice Hall, Englewood Cliffs, N. J.

38. Jones, M. B. 1963. Effect of sulfur applied and data of harvest on yield, sulfate sulfur concentrations, and total sulfur uptake of five annual grassland species. Agron. J. 55:251-254.

39. _______. 1964. Effect of applied sulfur on yield and sulfur uptake of various California dryland pasture species. Agron. J. 56:235-237.

40. Killinger, G. B., R. E. Blaser, E. M. Hodges, and W. E. Stokes. 1943. Minor elements stimulate pasture plants. Florida Agr. Expt. Sta. Bul. 384.

41. Kubota, J. 1964. Cobalt content of New England soils in relation to cobalt levels in forages for ruminant animals. Soil Sci. Soc. Amer. Proc. 28:246-251.

42. Lewis, A. H. 1943. The teart pastures of Somerset. III. Reducing the teartness of pasture herbage. J. Agr. Sci. 33:58-63.

43. McIlrath, W. J., J. A. deBruyn, and J. Skok. 1960. Influence of boron supply on the micronutrient element content of *Setaria* shoots. Soil Sci. 89:117-121.

44. Mitchell, R. L. 1945. Cobalt and nickel in soils and plants. Soil Sci. 60:63-70.

45. Mokragnatz, M., and Z. Filipovic. 1961. Further evidence of the influence of soil pH on cobalt contents of grasses. Soil Sci. 92:127-128.

46. Mulvehill, J. F., and J. M. MacGregor. 1955. The effect of some trace elements on the yield and composition of alfalfa and oats in Minnesota. Soil Sci. Soc. Amer. Proc. 19:204-207.

47. Murphy, H. F., and J. Q. Lynd. 1956. Effects of various soil fertility treatments in alfalfa. Soil Sci. Soc. Amer. Proc. 20: 385-387.

48. Nielsen, K. F., R. B. Carson, and I. Hoffman. 1963. A study of ion interactions in the uptake of nitrogen, phosphorus, potassium, calcium, chlorine, and sulfur by corn. Soil Sci. 95:315-321.

49. Prine, G. M., and G. W. Burton. 1956. The effect of nitrogen rate and clipping frequency upon the yield, protein content and certain morphological characteristics of Coastal bermudagrass (*Cynodon dactylon*, (L) Pers.) Agron. J. 48:296-301.

50. Pumphrey, F. V., and D. P. Moore. 1965. Sulfur and nitrogen content of alfalfa herbage during growth. Agron. J. 57:237-239.

51. Reisenauer, H. M. 1963. The effect of sulfur on the absorption and utilization of molybdenum by peas. Soil Sci. Soc. Amer. Proc. 27:553-555.

52. Rendig, V. V. 1956. Sulfur and nitrogen composition of fertilized and unfertilized alfalfa grown on a sulfur-deficient soil. Soil Sci. Soc. Amer. Proc. 20:237-240.

53. Rogers, L. G., and C. H. Wu. 1948. Zinc uptake by oats as influenced by applications of lime and phosphate. J. Amer. Soc. Agron. 40:563-566.

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

55. Smith, S. E., B. A. Koch, and K. L. Tuck. 1951. The response of cobalt deficient lambs to liver extract and vitamin B-12. Jour. of Nutrition. 44:455-465.

56. Tucker, T. C., and F. W. Smith. 1952. The influence of applied boron, magnesium, and potassium on the growth and chemical composition of red clover grown under greenhouse conditions. Soil Sci. Soc. Amer. Proc. 16:252-255.

57. Walker, C. F., and W. A. Williams. 1963. Responses of annual type range vegatation to sulfur fertilization. J. of Range Mgmt. 16: 64-69.

58. Wear, J. I. 1956. Effect of soil pH and calcium on uptake of zinc by plants. Soil Sci. 81:311-315.

59. Younts, S. E., and R. P. Patterson. 1964. Copper-lime interaction in field experiments with wheat: yield and chemical composition data. Agron. J. 56:229-232.

APPENDIX

TABLE IV

INFLUENCE OF BORON, SULFUR, ZINC, COPPER, COBALT, AND MOLYBDENUM ON COBALT COMPOSITION OF MIDLAND BERMUDAGRASS

Source	Analysis of Variance d.f.	Mean Square ppm Cobalt
Treatments	63	10.369
Boron	1	3.025
Sulfur	1	1.595
Zinc	1	3.333
Copper	1	5.433
Cobalt	1	94.781*
Molybdenum	1	0.292
Error	126	2.871

*Denotes significant difference at the 5 percent level.

TABLE V

INFLUENCE OF BORON, SULFUR, ZINC, COPPER, COBALT, AND MOLYBDENUM ON MOLYBDENUM COMPOSITION OF MIDLAND BERMUDAGRASS

Analysis of Variance		
Source	d.f.	Mean Square ppm Molybdenum
Treatments	63	34.547
Boron	1	4.940
Sulfur	1	282.269*
Zinc	1	1.613
Copper	1	80.860*
Cobalt	1	2.296
Molybdenum	1	459.421*
Error	126	9.869

*Denotes significant difference at the 5 percent level.

TABLE VI

INFLUENCE OF BORON, SULFUR, ZINC, COPPER, COBALT, AND MOLYBDENUM ON SULFUR COMPOSITION OF MIDLAND BERMUDAGRASS

Analysis of Variance

Source	d.f.	Mean Square ppm Sulfur
Treatments	63	587.308
Boron	1	135.005
Sulfur	1	23651.879*
Zinc	1	411.255
Copper	1	0.046
Cobalt	1	716.880*
Molybdenum	1	64.171
Error	126	134.980

*Denotes significant difference at the 5 percent level.

TABLE VII

INFLUENCE OF BORON, SULFUR, ZINC, COPPER, COBALT, AND MOLYBDENUM ON ZINC COMPOSITION OF MIDLAND BERMUDAGRASS

	Analysis of Variance	
Source	d.f.	Mean Square ppm Zinc
Treatments	63	6773.063
Boron	1	411.255
Sulfur	1	3459.504
Zinc	1	329759.464*
Copper	1	6591.792*
Cobalt	1	89.380
Molybdenum	1	1135.878
Error	126	1141.673

*Denotes significant difference at the 5 percent level.

TABLE VIII

EFFECT OF BORON, SULFUR, ZINC, COPPER, COBALT, AND MOLYBDENUM ON YIELD OF MIDLAND BERMUDAGRASS

Analysis of Variance

Source	d.f.	Mean Square Grams Dry Wt.
Treatments	63	33.502
Boron	1	41.347
Sulfur	1	733.593*
Zinc	1	6.787
Copper	1	6.490
Cobalt	1	2.827
Molybdenum	1	51.979
Error	126	28.152

*Denotes significant difference at the 5 percent level.

VITA

Richard Lee Large

Candidate for the Degree of

Master of Science

Thesis: SULFUR AND MICRONUTRIENT UPTAKE OF MIDLAND BERMUDAGRASS

Major Field: Agronomy

Biographical:

Personal Data: Born June 9, 1940, in Fulton County, Indiana, the son of Alfred and Belva Large.

Education: Graduated from Culver High School, Culver, Indiana, in 1958; received a Bachelor of Science degree, with a major in Agronomy, at Purdue University, Lafayette, Indiana, in 1962; completed requirements for a Master of Science degree in June, 1966.

Experience: Farm reared; worked for Agronomy Department at Purdue University Sand Research Experimental Field during the summer 1959-1962; served in U. S. Army Artillery, fall 1962-1964; served as half-time graduate research assistant while completing requirements for the Master of Science degree during academic years of 1964-65 and 1965-66; full-time employment in Agronomy Department at Oklahoma State University during the summer of 1965.

Organizations: Alpha Zeta, Ceres, American Society of Agronomy, and Soil Science Society of America.