12-1965

# Soybean yield response to molybdenum

Thomas Clyde McCutchen

To the Graduate Council:

I am submitting herewith a thesis written by Thomas Clyde McCutchen entitled "Soybean yield response to molybdenum." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Extension.

Lewis H. Dickson, Major Professor

We have read this thesis and recommend its acceptance:

O.H. Long, S.A. Griffin

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

November 22, 1965

To the Graduate Council:

I am submitting herewith a thesis written by Thomas Clyde McCutchen entitled "Soybean Yield Response to Molybdenum." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Extension.

Lewis H. Dickson
Major Professor

We have read this thesis and recommend its acceptance:

O.H. Long

S. A. Griffin

Accepted for the Council:

Hilton A. Smith
Dean of the Graduate School

# SOYBEAN YIELD RESPONSE TO MOLYBDENUM

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A Thesis

Presented to

the Graduate Council of

The University of Tennessee

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In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

Thomas Clyde McCutchen

December 1965

ACKNOWLEDGEMENTS

The author wishes to express appreciation to Dr. Lewis H. Dickson, Head of the Department of Agricultural Extension, Dr. O. H. Long, Professor of Agronomy, and Dr. S. A. Griffin, Professor of Animal Husbandry for their helpful guidance and assistance.

TABLE OF CONTENTS

LIST OF TABLES

# CHAPTER I

## INTRODUCTION

Soybeans have become a valuable cash crop in Tennessee. In 1964 the acreage had grown to 586,000 acres for an income of over thirty-five million dollars (22). By comparison in 1955 only 250,000 acres were produced (21). The acreage in soybeans now exceeds that in cotton by over 100,000 acres.

Soybeans are grown across the state, but more than 90 percent of the state's total acreage is found in West Tennessee.

Research work conducted in Georgia in 1960, 1961 and 1962 indicated that molybdenum, a micronutrient, is very important in increasing the yield of soybeans on acid soils. Among the micronutrients molybdenum is unique in that as the soil pH increases the availability of molybdenum increases. All the other micronutrients are more available under more acid conditions (pH values between 5.0 and 6.0).

A summary of 1964 soil test results from a total of 9270 samples submitted by West Tennessee farmers to the State Soil Testing Laboratory in Nashville reveals that 7 percent of the samples were in the pH of 5.0 or below for soybeans where four tons of limestone per acre is recommended; 29 percent were in the pH range of 5.1 to 5.5 where three tons of limestone is recommended; and 24 percent were in the pH range of 5.6 to 6.0 where two tons of limestone is recommended. This means

that an application of from two to four tons of limestone would have been recommended for 60 percent of these fields had the farmer indicated he was planning to grow soybeans.

Assuming that these were average West Tennessee soils, it might be expected that a yield response from application of molybdenum on soybeans could be forthcoming on 60 percent of the soils. It also is assumed that these same soils that would respond to limestone might respond to molybdenum application.

The Tennessee soybean producer plants his most productive fields to cotton and corn. The remainder of his cultivated land may be planted largely to soybeans. The soybean land is usually lower in fertility and unlimed. In many cases the land is rented and the renter feels that he cannot afford to build up the fertility or invest in limestone under a year-to-year rental agreement.

When these conditions exist, the farmer may treat the soybean land with molybdenum at a cost of 35 cents to 75 cents per acre compared to a cost of $10 to $20 per acre for limestone.

The purpose of this study, then, was to determine soybean response to molybdenum on various soil types and under different soil conditions.

## CHAPTER II

## REVIEW OF LITERATURE

### I. THE FUNCTION OF MOLYBDENUM IN PLANTS

Molybdenum is one of the seven micronutrients essential for the growth and development of plants. Molybdenum performs at least two essential functions in plants. It is required in all crops for the reduction of nitrate to ammonia as the first step in protein synthesis. Plant utilization of nitrate nitrogen is dependent on molybdenum. In legumes it is the element directly associated with nitrogen fixation by the root-nodule microorganisms. Its role is not limited to these two physiological processes, however, for plants grown upon combined nitrogen sources other than nitrate still require molybdenum for normal growth (6).

### II. MOLYBDENUM DEFICIENCIES

#### First Locations and Dates

The first recognition of soil deficiency of molybdenum in the United States was reported in 1935. The deficiency was found in the Monterey Peninsula of California.

In 1942 a response was obtained from application of molybdenum to subterranean clover and alfalfa in South Australia (1).

Most early reports of molybdenum deficiencies in the United States came from along the Atlantic and Gulf Coasts. Deficiencies were also found in northeastern Washington and southern Texas (18). Recently deficiencies have been reported in North Carolina, South Carolina, Florida, Georgia, Louisiana, Mississippi, Arkansas and Tennessee.

<u>Conditions Where Most Often Found</u>

Molybdenum is often associated with acid soils because it becomes less available or soluble as the pH declines. Limed or neutral soils may also be deficient in available molybdenum by cropping or by leaching. Many soils derived from calcareous parent materials in the humid regions are acid and crops on some of these soils have been found to respond to molybdenum. Soils high in manganese or iron have been found to be deficient in molybdenum in some areas (18).

<u>Plants Affected and Symptoms</u>

The crops most commonly involved have been alfalfa, cauliflower, soybeans and citrus, but other crops are affected.

Alfalfa deficient in molybdenum has dull, pale green foliage. Leaf margins appear gray, limp, and curled. Leaves wither completely, and petioles wilt and collapse. Symptoms develop mainly in "midstem" or in younger leaves (10). Large pink nodules appear to be present when there is vigorous nitrogen fixation within the nodule. A deficiency of molybdenum results in a decrease in the size of the nodule and a reduction in its pink coloration (1).

Caulifower deficient in molybdenum is affected by a condition known as "whiptail." Leaves of such plants are abnormal in shape and color. It is one of the so-called indicator crops for molybdenum deficiency. In severe cases of whiptail, heads are often unmarketable or fail to develop altogether. Usually only the younger leaves are whiptailed. Older leaves appear normal in mature plants, but are chlorotic between the veins during the earlier stages of growth (19).

Yellow spot of citrus, an indication of molybdenum deficiency, has been found on acid soils throughout the citrus area of Florida. Chlorotic areas appear in the leaf as clearly defined spots. Affected areas of the leaf become brown and gummy and eventually die. Trees gradually lose their leaves and produce little fruit.

Soybeans deficient in molybdenum are characterized by a chlorotic condition caused by poor nitrogen fixation. The chlorosis is nearly always localized between the veins. When leaves have fallen preceding harvest, deficient plants appear smaller with fewer well-developed pods than those supplied with molybdenum. Nodules are more numerous and smaller in the deficient plants; the color of the nodules is paler compared to the pink color of normal plants.

## Related Animal Toxicity

Molybdenum has been shown to be a co-factor of the flavoprotein enzyme, xanthine oxidase in animals. The element has a marked antagonistic effect upon copper metabolism. Animals grazing on pastures low

in molybendum may develop copper toxicity if liberal amounts of copper are present. On the other hand, animals consuming forage with high molybdenum content (grown on high molybdenum soils) may develop copper deficiency. The feeding of sulphate decreases the molybdenum stored in the animal's body. Cattle grazing forages with a high molybdenum content develop a disease known as "teart" which is characterized by severe diarrhea and emaciation. Toxic molybdenum content of forages has been found in Florida, Oregon and California. Levels of molybdenum that are toxic to animals vary with the animal and the feedstuff, especially the levels of copper and sulphate (5).

## III. FACTORS AFFECTING AVAILABILITY OF MOLYBDENUM TO PLANTS

### Forms of Molybdenum in Soils

Molybdenum occurs in the soil in the following forms: (a) water soluble, (b) conditionally available, (c) insoluble, and (d) in organic matter. Water-soluble molybdenum would normally be very low. Under alkaline conditions more of the element would be soluble. The association between soil reaction and molybdenum availability has been known for some time. It appears that molybdenum is held as an exchangeable ion, $MoO_4$. This ion does not leach through the soil. The $MoO_4$ ion can be released by moderately alkaline solutions. It has been found that molybdenum fixation will increase with acidity down to pH 2.2 and all such molybdenum fixed by exchange could be released by alkaline solutions of pH 9 (4).

Most soil molybdenum is in the form of insoluble or available fractions, held in the crystal lattice of primary and secondary minerals.

Molybdenum in organic matter is a variable factor since breakdown by microorganisms is a continual process. Plants tend to act as accumulators of the element.

Soil Reaction

Heavy liming and molybdenum application may accomplish the same objective. Liming increases the availability of soil molybdenum. The disease "whiptail" of cauliflower, a molybdenum deficiency, was controlled by liming long before the cause was determined. The extend to which lime application corrects molybdenum deficiency varies considerably, and depends on the amount of unavailable molybdenum present in the soil (4). It has been found that an acid reaction (pH 4.5 - 5.5) favors the actual absorption of molybdenum by the plant and that the real increases at higher pH levels are the result of the release of molybdenum fixed by soil colloids (3). Some soils do not release sufficient molybdenum for optimum plant growth even when they are adequately limed. In Georgia in 1958 it was found that 8 ounces of sodium molybdate plus 500 pounds of lime per acre was equivalent to two tons of lime in alfalfa yield responses (8). Also in Georgia, the soybean yield increase obtained from 0.2 pound per acre of molybdenum alone was equivalent to the increase obtained from two tons of lime (15).

Interactions of Other Elements

Phosphate has been shown to increase the uptake of native and added molybdenum by subterranean clover. It is thought that on molybdenum deficient soils, the need for phosphate could be reduced by applications of molybdenum.

The sulfate ion has been found to exert a depressing action on molybdenum uptake. The influence of phosphate and sulfate on molybdenum availability would tend to offset each other (4).

Movement in Soils

Available molybdenum in the soil may move to the root of the plant by the processes of mass-flow and diffusion. The root may grow to some of the molybdenum present in the soil. The amount of the element available in the soil determines the significance of each of these processes (12).

Content of Soils

Most farm soils contain two to three parts per million or about five pounds per acre of molybdenum in the plow layer. Some soils contain as little as 0.2 ppm. and others as much as 12 ppm. (16).

## IV. RESPONSE OF SOYBEANS TO MOLYBDENUM

Effect on Yields

Experiments were conducted during 1960 and 1961 on two moderately acid soils in northeast Georgia. It was concluded that moly-

bdenum increased soybean yields thirty percent in 1960 and fifty-five percent in 1961. The increase was greatest on the plots that were unlimed and diminished as the lime rate was increased. Seed treatment was more effective than foliar application (15).

Mississippi experiments conducted in 1963 and 1964 on eight strongly-acid to slightly-acid soils showed that molybdenum increased soybean yields significantly where no lime was added and where low rates of lime were drilled or broadcast. The yield increase was greatest on the unlimed plots and decreased as the lime rate was increased. Seed treatment rate was ¼ ounce of molybdenum per acre (2).

Arkansas research in 1964 showed yield increases from molybdenum to be two to five bushels per acre on responsive soils. The application of 0.5 ounce of molybdenum per acre to the seed was more efficient than the same quantity dissolved in water and sprayed in a 10-inch band as a pre-emerge treatment on the soybean row. It was found that seed treatment was easier, faster and cheaper than either foliage or soil spray application (20).

Tennessee research has shown that the average increase from additions of lime to be about 6 bushels per acre per year. Assuming that these soils respond to molybdenum, about the same increase in yield would be expected with molybdenum (14). Over a long period of time, however, liming is preferred over molybdenum fertilization (13).

## Effect on Content of Seed

Early experiments pointed out that soybeans may contain sufficient molybdenum for two generations of normal growth without added molybdenum. In the third generation severe deficiency symptoms may develop (10). Indiana work in 1960 and 1961 showed molybdenum seed treatment on soybeans to give yield increases from 0.7 to 7.6 bushels per acre. The yield increases occurred where the soybean seed produced on the untreated plots contained 1.6 or less ppm. molybdenum (11).

Georgia tests in 1963 using seed obtained from six states showed the molybdenum content to vary from 0.6 to 22.4 ppm. Seed from all sources except Texas contained less than 2.6 ppm. and the progenies responded to molybdenum. The average yield increase due to molybdenum was 32.5 percent for all seed except those from Texas, which contained 22.4 ppm. (9).

## Effect on Protein Content

Georgia work in 1960 and 1961 showed that soybean seed protein was highly correlated with seed yield. Each unit (1 percent) increase in protein was associated with a yield increase of 1.05 bushels per acre in 1960 and 2.08 bushels in 1961 (15).

## Effect on Oil Content

A negative relationship was found between seed protein and oil in the Georgia experiments (15). The relationship was expected since a decrease in percent oil is usually associated with an increase in per-

cent protein in soybean production. Even though the percent oil decreased at the higher yields the total production of oil per acre was greater.

Effect on Nitrogen Content of Leaves

The nitrogen content of the leaves is very closely related to seed yield responses obtained from applications of molybdenum or limestone. In the Georgia experiments the color difference was noticeable as early as two weeks after foliar treatment and remained evident throughout the growing season. Seed treatment with molybdenum required approximately fifty-eight days before a visual response was noted. Highly significant correlations existed between bean yield and leaf nitrogen content. For each one percent increase in leaf nitrogen an increase of 4.5 and 24.5 bushels per acre was obtained in 1960 and 1961 (15).

Effect on Seed Weight

In the 1963 tests in Georgia molybdenum affected the seed weight in about the same manner as it affected leaf nitrogen and bean yield. The increase in seed size resulting from the molybdenum treatment accounted for only about one-fourth of the increased yield. Response to the molybdenum treatment was expressed in both number of seed and also size of seed (9).

## V. EFFECT OF ADDING MOLYBDENUM TO INOCULANT

An experiment was conducted in Georiga in 1963 to determine the compatibility of several molybdenum compounds with a legume inoculant. It was found that molybdenum compounds should not be mixed with the inoculant prior to seed treatment. From the results of this experiment, it was concluded that the inoculant and molybdenum compound should be obtained separately and mixed at the time of seed treatment (7). Molybdenum is no substitute for inoculation (13).

# CHAPTER III

## METHODS AND PROCEDURE

The work conducted in 1963, 1964 and 1965 was carried out following the same general procedure. The Milan Field Station, where the experiments were conducted, is unique in that all harvest work is done mechanically. The plot size is such that large machines can be used to accurately harvest them. In many cases this means that treatments cannot be replicated because of the large areas involved.

Two types of experiments were conducted. One type compared the application of molybdenum to beans grown on both limed and unlimed acid soils and the other type involved only the application of molybdenum to beans grown on unlimed acid soils.

In setting up the experiments, a soil test was the first step. The areas that might be used were accurately sampled, usually in January, and the samples submitted to the University of Tennessee, State Soil Testing Laboratory for analysis. The soils testing in the 5.0 to 5.5 pH range were selected for the experiments in most instances.

The molybdenum was applied as a seed treatment using sodium molydate (technical anhydrous grade, 39 percent molybdenum) at the rate of 0.2 pound of molybdenum per bushel in 1963 and 1964. In 1965, the rate was reduced to ½ ounce of molybdenum (0.03125 pound) per bushel. Four different commercial molybdenum preparations were tested in 1965 in addition to sodium molybdate at two rates.

The seed were treated in the late winter or early spring well ahead of planting time. The proper amount of molybdenum for treating one bushel of seed was accurately weighed to which enough water was added to produce a slurry suspension. One bushel of soybean seed was placed on a plastic sheet, the slurry suspension was added and thoroughly mixed with the seed to insure uniform coverage. The seed were allowed to dry after which they were bagged and labeled.

Seed of certified Hill, Hood, Kent or Lee were used in the three years' tests.

Where limestone was to be applied preceding planting, the areas were accurately measured and staked as to area to make the application. Commercial lime trucks applied the limestone.

The seedbed preparation consisted of discing to level the old rows followed by turning to a seven to eight inch depth. A spike-tooth harrow was used to firm and smooth the seedbed.

Fertilizer was applied in a band two inches to the side and two inches below the seed at the rate of from 150 to 200 pounds per acre of an 0-20-20 analysis.

The seed were inoculated with a commercial inoculant just prior to planting. The inoculant was dampened and poured over the seed in a tub, then stirred until all seed were covered. To prevent killing of the bacteria, precautions were taken to keep the inoculated seed out of the sun until ready for planting.

One bushel of seed per acre was planted in each experiment. The rows were spaced 36 inches apart in 1963 and 1964 and 40 inches apart in 1965. An attempt was made each year to plant the treated rows in the same location as they were the previous year to prevent the check rows from being contaminated from the molybdenum application.

Planting was done with a four-row planter. In a portion of the experiments, treated seed were placed in two hoppers on one side and the untreated seed in the other two hoppers. Planting by this method resulted in 4 rows of molybdenum-treated seed alternating with 4 rows of untreated seed.

When changing from treated to untreated seed the planter hoppers were washed thoroughly to prevent contamination.

A recommended weed control herbicide was applied immediately following planting. Amiben or sodium PCP was used, applied in a 14- or 20-inch band over the row, or broadcast. In addition to the herbicide, usually two or three cultivations were required to control weeds and grasses.

The experiments were observed several times during the growing season and differences in color, height, and other characteristics were recorded.

All yield data were obtained with a combine with a 12-foot header in 1963 and 1964 and a 13-foot header in 1965. A 13-foot header can harvest four 40-inch rows. In each experiment, at least two border rows were planted before the experiment proper was started.

A truck with a 20-foot bed was used to weigh and store the soybeans. At the rear of the 20-foot bed a platform scale was placed on which a metal bin was mounted. The bin has an auger on the bottom. A power takeoff shaft runs from the transmission of the truck to a gear box at the rear which operates the auger in the bin. The bin has a 15-bushel capacity.

The weighing procedure was as follows: The plot was harvested with the combine; the seed were augered into the bin mounted on the scale at the rear of the truck; the soybeans were weighed, then augered to the front of the truck; the scales were balanced and the bin was made ready for the next plot.

The plot row length was measured either before harvest or staked and measured after harvest. A 100-foot steel tape or land wheel was used for measurements. The land wheel was preferred, in that one person can make the measurements, whereas in the case of the 100-foot tape two persons are required.

## CHAPTER IV

## RESULTS AND DISCUSSION

A lime-molybdenum experiment was started at the Milan Field Station in 1963 on Henry silt loam, a poorly-drained upland soil. Agricultural limestone was applied at rates of 0, 1, 2 and 4 tons per acre in April of that year. The pH of the unlimed soil was in the range 4.9 to 5.2. Planting was about one month later. The experiment was repeated in 1964 and 1965 except for the lime applications. The three-year soybean yields are presented in Table I.

Molybdenum had a marked effect on yields in 1963 but was less effective in 1964. An 8.5-bushel increase was obtained from molybdenum in 1963, a 3.0-bushel increase in 1964, and a 2.5-bushel increase in 1965. Lime had little or no influence on yield for the first two years. In the third year, however, lime increased the yield an average of 1.6 bushels where molybdenum was applied and 7.3 bushels where no molybdenum was applied. The 2- and 4-ton rates of lime were more effective in increasing yield than was the 1-ton rate. In December 1963, the pH of the soil was 5.9 on the 4-ton lime treatment; whereas, by January 1965, the pH had risen to 6.8 on this lime treatment. The yields were somewhat higher on all treatments in 1965 than they were in the two previous years.

A similar experiment was conducted on Calloway silt loam at Ames Plantation, Grand Junction, Tennessee in 1963 and 1964. A

TABLE I

LIME-MOLYBDENUM EXPERIMENT ON LEE SOYBEANS, 1963, 1964, AND 1965
(SOIL TYPE: HENRY SILT LOAM; pH (UNLIMED) = 4.9 TO 5.2)

| Year | Unlimed | | 1 Ton Lime/ Acre | | 2 Tons Lime/ Acre | | 4 Tons Lime/ Acre | |
|---|---|---|---|---|---|---|---|---|
| | Mo | No Mo | Mo | No Mo | Mo | No Mo | Mo | No Mo |
| | -Bushels of Soybeans Per Acre[a]- | | | | | | | |
| 1963 | 36.0 | 24.7 | 30.9 | 24.9 | 37.3 | 28.0 | 34.7 | 27.0 |
| 1964 | 35.6 | 29.3 | 29.7 | 27.5 | 31.4 | 29.0 | 31.7 | 30.4 |
| 1965 | 42.5 | 35.5 | 42.2 | 39.7 | 46.0 | 44.5 | 44.1 | 44.7 |
| Average | 38.0 | 29.8 | 34.3 | 30.7 | 38.2 | 33.8 | 36.8 | 34.0 |
| Lime Treatment Average | 33.9 | | 32.5 | | 36.0 | | 35.4 | |

[a]The usual tests for significance are not possible for the years 1963 and 1964 because treatments were not replicated. There were two replications of each treatment in 1965. In this year the L. S. D. (5%) among lime treatment means is 3.7 bushels, and the L. S. D. (5%) between molybdenum treatment means is 2.6 bushels.

striking response was obtained from both molybdenum and lime in 1963. On the unlimed soil the yield was 15.3 bushels per acre without molybdenum compared with 26.8 bushels where the seed was treated with molybdenum. As was the case in the Milan experiment, molybdenum was effective where lime had been applied at the 1-ton rate, but was less effective as the lime rate was increased. The lime treatments resulted in an average yield of 28.0 bushels per acre for the molybdenum-treated seed compared to 21.0 bushels from the untreated seed. The Ames Plantation experiment showed that in the absence of molybdenum soybean yields were almost doubled by liming (from 15.3 to 27.4 bushels), whereas with molybdenum-treated seed the increase from lime was only 2.4 bushels (from 26.8 bushels on the unlimed soil to 29.2 bushels where lime was applied at the 4-ton rate). In 1964 the Ames Plantation results were markedly different from the 1963 results. There was no response to lime or molybdenum although yields of all treatments were higher. No explanation was offered for the lack of response in 1964 (13).

A two-year experiment of a similar nature also was conducted at the Highland Rim Experiment Station at Springfield. It showed a response to lime but no response to molybdenum (13)

In 1964, six additional experiments were started at the Milan Field Station. Two were under limed and unlimed conditions and four on acid unlimed soils. Where lime was applied it was at a rate of 2 tons per acre.

A lime-molybdenum experiment was started on a Memphis silt loam, a well-drained upland soil. The pH before application of lime was 4.9. The soybean yields for 1964 and 1965 are presented in Table II.

Lime increased the yield 4.1 bushels per acre in 1964 and 4.7 bushels in 1965. The application of molybdenum had a slight effect on yield (2.8-bushel increase) in 1964, and a larger increase in 1965 (5.8-bushel increase). The unlimed soil showed a marked increase in yield (8.4 bushels) from an application of molybdenum in 1965 compared to a smaller increase (3.0 bushels) in 1964. Lee was the variety used in 1964 and Hill the variety in 1965. Yields were high both years, averaging about 40 bushels per acre.

A second lime-molybdenum experiment was started in 1964. It was located on Collins silt loam, a well-drained bottom soil with a pH of 5.3. The results for the 2-year period, 1963-1964, are shown in Table III.

There was no response to lime in either year. There was a slight response to molybdenum but the increase from molybdenum averaged only 1.5 bushels for both the limed and unlimed treatments during the 2-year period.

The experiment that showed the most response to molybdenum at the Milan Field Station is presented in Table IV. It was started in 1964 on a Collins silt loam soil with a pH of 5.2. No lime was applied. Four rows treated with molybdenum were alternated with four rows not treated with molybdenum. There were four replications of each treat-

TABLE II

YIELDS OF SOYBEANS WITH AND WITHOUT MOLYBDENUM UNDER LIMED AND UNLIMED CONDITIONS, 1964 AND 1965 (SOIL TYPE: MEMPHIS SILT LOAM; pH (UNLIMED SOIL) = 4.9; VARIETY: LEE 1964, HILL 1965)

| | Limed[a] | | Unlimed | |
|---|---|---|---|---|
| Year | Mo | No Mo | Mo | No Mo |
| | - - - - -Bushels of Soybeans Per Acre[b]- - - - - - | | | |
| 1964 | 42.7 | 40.1 | 38.8 | 35.8 |
| 1965 | 41.7 | 38.8 | 39.8 | 31.4 |
| Average | 42.2 | 39.5 | 39.3 | 33.6 |
| Lime Treatment Average | 40.8 | | 36.5 | |

[a]Agricultural limestone at rate of 2 tons per acre, applied in March 1964.

[b]The usual tests for significance are not possible because the treatments were not replicated.

TABLE III

YIELDS OF SOYBEANS WITH AND WITHOUT MOLYBDENUM UNDER LIMED AND UNLIMED CONDITIONS, 1964 AND 1965 (SOIL TYPE: COLLINS SILT LOAM; pH (UNLIMED SOIL) = 5.3; VARIETY: HILL)

| | Limed[a] | | Unlimed | |
|---|---|---|---|---|
| Year | Mo | No Mo | Mo | No Mo |
| | - - - - -Bushels of Soybeans Per Acre[b]- - - - - - | | | |
| 1964 | 41.7 | 38.6 | 39.9 | 40.2 |
| 1965 | 35.3 | 32.3 | 35.3 | 35.3 |
| Average | 38.5 | 35.5 | 37.6 | 37.8 |
| Lime Treatment Average | 37.0 | | 37,7 | |

[a]Agricultural limestone at rate of 2 tons per acre, applied in April 1964.

[b]The usual tests for significance are not possible because the treatments were not replicated.

TABLE IV

YIELDS OF SOYBEANS WITH AND WITHOUT MOLYBDENUM, 1964 AND 1965 (SOIL TYPE: COLLINS SILT LOAM; pH = 5.2; VARIETY: LEE)[a]

| Year | Mo | No Mo | Increase from Mo | Required for Significance at 5% Level of Probability |
|---|---|---|---|---|
| | - - - - - -Bushels of Soybeans Per Acre- - - - - - - - - | | | |
| 1964 | 38.3 | 21.2 | 17.1 | 2.5 |
| 1965 | 37.8 | 26.2 | 11.6 | 5.3 |
| Average | 38.1 | 23.7 | 14.4 | --- |

[a]Average of four replications in 1964 and of five replications in 1965.

ment in 1964 and five replications in 1965. In 1964 a 17.1-bushel increase was obtained from molybdenum. In 1965 the increase from molybdenum was 11.6 bushels. The increases in yield were both significant. This represents a two-year average increase from molybdenum of 14.4 bushels per acre. Striking color differences were observed in both years especially during the latter part of the growing season. The check plot with no molybdenum exhibited a yellow color in comparison with the treated plots, which were a darker green. Plants on the check plots were more erect than those on the treated plots, which was probably due to less fruiting. At harvest, the check plots were easily distinguished by having fewer pods and those not completely developed.

Three experiments conducted in 1964 on Collins and Vicksburg silt loams are presented in Table V. The pH values were in the range of 5.1 to 5.4. Two of the experiments showed a 5.1- and 5.7-bushel increase, while one showed a negative increase. As an average of the three experiments, the increase was 2.7 bushels in favor of the molybdenum treatment.

An experiment involving rates and sources of molybdenum was started in 1965. The experiment was conducted on a Falaya silt loam soil with a pH of 5.3. Commercial companies supplied the molybdenum products which included the following by trade names: Moly-Gro Foliar Spray, Molynoculant, Moly-B, Red Panther Legume Stimulant, and Pearson's Molybdenum Legume Stimulant.

TABLE V

YIELDS OF SOYBEANS WITH AND WITHOUT MOLYBDENUM ON THREE STRONGLY ACID, UNLIMED SOILS, 1964

| Soil Series | pH | Variety | Bushels Per Acre[a] | | Increase from Mo | L. S. D. (5%) |
|---|---|---|---|---|---|---|
| | | | Mo | No Mo | | |
| Collins | 5.1 | Hood | 39.0 | 33.9 | 5.1 | 1 |
| Collins | 5.1 | Hood | 36.2 | 30.5 | 5.7 | 1 |
| Collins and Vicksburg | 5.4 | Kent | 46.1 | 48.9 | -2.8 | N. S. |
| Average Yield | | | 40.4 | 37.8 | 2.7 | -- |

[a]The usual tests for significance in the first two experiments are not possible because treatments were not replicated.

Moly-Gro Foliar Spray is the trade name of the anhydrous sodium molybdate (39 percent molybdenum) supplied by Climax Molybdenum Company of New York and was the only material used in all of the other molybdenum experiments presented in this report.

Molynoculant and Moly-B are commercial preparations of Kalo Inoculant Company, Quincy, Illinois. Molynoculant is a combination inoculum-molybdenum product with a molybdenum content of 3.63 percent, according to the label on the container. Moly-B is a combination of molybdenum and a carrier; the molybdenum content and the carrier are not specified.

Red Panther Legume Stimulant is manufactured by Coahoma Chemical Company, Inc., Clarksdale, Mississippi. The label on the package reads, in part: "Contains ½ ounce 38 percent minimum molybdenum per 4 ounces." The recommended rate per acre is 4 ounces. The carrier is not named, but the label states that the product contains a highly effective non-oil lubricant.

Pearson's Molybdenum Legume Stimulant is a product of Pearson and Company, Mobile, Alabama. The statement on the package reads, in part: "Contains ½ ounce 38 percent molybdenum per 4 ounces." Four ounces is the recommended rate. The carrier is not specified.

Table VI shows an average increase from molybdenum of 3.1 bushels, which was not significant at the L. S. D. (5 percent). The yield was 42.6 bushels per acre for the molybdenum products compared to 39.5 bushels for the check.

TABLE VI

RATES AND SOURCES OF MOLYBDENUM ON SOYBEANS, 1965 (SOIL TYPE: FALAYA SILT LOAM; pH = 5.3; VARIETY: LEE)[a]

| Source of Molybdenum | Rate Per Acre[b] | Bushels of Soybeans Per Acre |
|---|---|---|
| No Mo (check) | -- | 39.5 |
| Moly-Gro | 0.5 oz. | 41.7 |
| Moly-Gro | 1.0 oz. | 42.8 |
| Molynoculant | 10.0 oz. | 43.1 |
| Moly-B | 3.8 oz. | 42.8 |
| Red Panther | 4.0 oz. | 43.6 |
| Pearson's | 4.0 oz. | 41.5 |
| L. S. D. (5%) | | N. S. |

[a]Average two replications.

[b]Rate is of the element Mo in the case of Moly-Gro and the recommended amounts of the mixtures of the other materials.

CHAPTER V

# SUMMARY AND CONCLUSIONS

Thirteen field experiments were conducted during 1963, 1964 and 1965 at the Milan Field Station involving the use of the micronutrient molybdenum on soybeans. Some of these experiments were conducted on acid unlimed soil, others were conducted on limed soils where agricultural limestone was applied at rates of 1, 2 and 4 tons per acre. All experiments contained an unlimed treatment. The range in pH values of the soil before liming was between 4.9 and 5.4.

The molybdenum was applied as a seed treatment using sodium molybdate at a rate of 0.2 pound molybdenum per bushel (or per acre) in 1963 and 1964. The rate was reduced to one-half ounce in 1965 because of the possibility that the higher rate might lead to toxic amounts in the soil. The treatment was accomplished by dissolving the sodium molybdate in water and wetting the seed with this solution, followed by drying. This was done several days before planting. At planting both lots of seed, Mo-treated and untreated, were inoculated with a commercial inoculum.

Averaging all thirteen experiments conducted on the unlimed soil, the soybean yield was 39.1 bushels where molybdenum was used and 33.3 bushels on the untreated check, an increase of 5.8 bushels. Soybean yields were increased in ten out of the thirteen experiments where molybdenum was applied as a seed treatment.

Seven experiments were conducted involving application of limestone at one or more rates to determine the yield response to molybdenum under limed conditions. Averaging these seven experiments, the soybean yield was 38.7 bushels per acre where molybdenum was used and 35.5 bushels on the untreated check, an increase of 3.2 bushels attributable to molybdenum.

Six of the experiments were conducted on Collins silt loam soil, one on a Collins-Vicksburg silt loam, two on Memphis silt loam, three on Henry silt loam, and one on Falaya silt loam. These soils represent a wide range in productivity among the soils of West Tennessee, where 90 percent of the soybeans are grown in the state.

Experiments on the six Collins silt loam soils showed a 5.6-bushel increase per acre from molybdenum (37.8 bushels for the molybdenum-treated compared to 32.2 bushels for the untreated check). Responses were obtained on four out of the six experiments. The greatest response obtained in the three-year period occurred on one of the sites of Collins silt loam where a 17.1-bushel increase was obtained with molybdenum in 1964. The one experiment on the Collins-Vicksburg complex produced an excellent yield (47.5 bushels), but the molybdenum treatment produced a yield slightly less than the yield on the check treatment.

The two experiments conducted on Memphis silt loam showed increases of 3.0 bushels per acre in 1964 and 8.4 bushels in 1965 from the molybdenum application.

The three experiments conducted on Henry silt loam soil resulted in a 9.2-bushel increase from molybdenum over the three-year period.

The experiment on Falaya silt loam soil comparing commercial molybdenum products resulted in a 3.1-bushel increase.

From the results of these experiments it can be concluded that a response can be expected from a molybdenum application on soybeans in a majority of the cases where the crop is grown on strongly- to moderately-acid soil. Soybeans grown on soils testing pH 6.0 or above are less likely to respond to molybdenum. A summary of 1964 soil-test results on samples from West Tennessee reveals that the pH was 6.0 or lower in 60 percent of the fields. These samples were submitted for soil tests and fertilizer recommendations for a variety of crops, probably cotton and corn for the most part. It is unlikely that many of the samples called for a fertilizer-lime recommendation for soybeans, because much of the acreage of this crop is planted without benefit of fertilizer or lime.

Since the thirteen experiments reported in this work resulted in a 5.8-bushel per acre increase from a molybdenum application on strongly to moderately acid soils and since the cost of the treatment is so small (35 cents to 75 cents per acre), the economics are highly in favor of its use. This 5.8-bushel increase would amount to a gross increase of $13.34 per acre on the basis of a price of $2.30 per bushel for the soybeans.

Over the long run, liming of acid soils is preferred over molybdenum fertilization. The reason is that not enough is known about the number of years that molybdenum could be applied before other soil conditions might appear where its use might be ineffective. It is known that manganese toxicity appears on strongly acid soils and molybdenum would not correct that situation.

Under certain conditions, where acid soils exist and where for some reason the farmer or renter cannot apply agricultural limestone, the application of molybdenum might be very beneficial.

The three-year study revealed that additional research was needed, especially the determination of molybdenum content of seed produced from treated and untreated areas. The molybdenum content of plant tissues also need to be studied.

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