

To the Graduate Office:

I am submitting herewith a thesis written by Dennis B. Seaton entitled "Yield and Chemical Composition of Soybeans as Affected by Molybdenum and Lime." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant and Soil Science.

Gary M. Lessman
Gary M. Lessman, Major Professor

We have read this thesis and
recommend its acceptance:

M.E. Springer
R.J. Lewis

Accepted for the Council:

L. Evans
Vice Chancellor
Graduate Studies and Research

4

Thesis

79

.S44

cop. 2

YIELD AND CHEMICAL COMPOSITION
OF SOYBEANS AS AFFECTED BY
MOLYBDENUM AND LIME

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Dennis B. Seaton

March 1979

1081563

ACKNOWLEDGMENTS

The author wishes to express his gratitude to the following for their encouragement and assistance in completion of my graduate studies:

The University of Tennessee Agricultural Experiment Station for financial assistance in the form of a graduate research assistantship.

The Plant and Soil Science Department, Dr. Lloyd F. Seatz, Head, for providing the necessary materials and equipment.

Dr. Gary M. Lessman for his guidance and assistance throughout the course of this study and in the preparation of this thesis.

Dr. R. J. Lewis and Dr. M. E. Springer for their advice and constructive criticism during the preparation of this manuscript.

My wife Rebecca and all others not previously mentioned.

ABSTRACT

In 1975 and 1976, two experiments involving Molybdenum (Mo) and soybean production were conducted in Tennessee on Collins silt loam. One experiment was a Mo source study which consisted of treatments of a check with no Mo fertilizer or lime, 280 kg/ha of lime banded in the row and no Mo, 35 g/ha of Mo applied as a slurry seed treatment, Mo plus Captan applied to the seed as a powder in the hopper box at planting time, and 6.7 metric tons/ha of lime broadcast. The other experiment was a Mo rate study which consisted of slurry seed treatments of Mo at the rates of 0, 7, 14, 21, 28, and 35 g/ha. In 1977, a separate study of lime and Mo rates was conducted on Loring silt loam using two varieties of soybeans, Essex and Bragg. The lime was applied at three rates to produce three soil pH levels with average pH values near 5.2, 5.9, and 6.5. The Mo rates were 0, 200, and 800 g/ha. The objective of this research was to determine the effects of the selected rates of lime and the selected rates and sources of Mo on the availability of soil Mo and the yield and chemical composition of soybeans.

The data from the two earlier experiments consisted of leaf Mo and N concentrations and soybean yields, while the data of the second consisted of these variables plus leaf Mn concentrations, available soil Mo and exchangeable soil Mn concentrations, and soil pH values. The data from the Mo source study revealed that in both years, only the broadcast lime and the slurry seed treatments produced higher leaf N values than the check, but were not different from each other at the 0.05

probability level. With regard to soybean yield, all of the Mo sources tested, with the exception of the banded lime treatment in 1975, produced higher yields than the check, with the slurry seed treatments being responsible for the highest yields in both years. The Mo rate study revealed that in 1975, only the 21 and 35 g/ha Mo rates resulted in leaf Mo values that were higher than the check. It was also found that all of the rates tested in 1975 produced higher leaf N concentrations than the check, with the 14, 28, and 35 g/ha rates yielding the highest values. In both years, all Mo rates produced higher soybean yields than the check. Both varieties from the 1977 lime and Mo rate study revealed that of the variables tested, only the lime treatments produced differences. With the Essex variety, the highest lime rate produced the largest leaf N, soil Mo, and soil pH values and the lowest leaf and soil Mn values. With regard to the Essex soybean yields, all lime rates produced increases in soybean yields over the no lime rate. With the Bragg variety, the highest lime rate resulted in higher leaf N and soil pH values and lower leaf and soil Mn values than were produced by the zero and medium lime rates. An attempt was also made to correlate plant Mo and N concentrations with soybean yields.

Results of these experiments indicate that the slurry seed application of Mo at any of the rates tested increased soybean yields on some unlimed acid soils in Tennessee. It was concluded that soybean yields responded little to soil applied Mo where lime was also added. In addition, leaf content of Mo was found to be an inaccurate indicator of the Mo needs of soybeans.

TABLE OF CONTENTS

CHAPTER	PAGE
I. INTRODUCTION	1
II. REVIEW OF LITERATURE	2
Molybdenum	2
Manganese	11
III. MATERIALS AND METHODS	14
Collection of Field Data	17
Laboratory Analyses	18
Statistical Analyses	19
IV. RESULTS AND DISCUSSION	20
Molybdenum Source Study	20
Molybdenum Rate Study	23
Lime and Molybdenum Rate Study	27
V. SUMMARY AND CONCLUSIONS	38
LIST OF REFERENCES	42
VITA	48

LIST OF TABLES

TABLE	PAGE
1. Mean Grain Yields and Leaf N and Mo Concentrations as Affected by Lime or Mo Treatments at Milan	21
2. Correlation Coefficients of Leaf N and Mo Concentrations and Grain Yields from the 1975 Mo Source Study at Milan . .	24
3. Correlation Coefficients of Leaf N and Mo Concentrations and Grain Yields from the 1976 Mo Source Study at Milan . .	24
4. Mean Soybean Grain Yields and Leaf N and Mo Concentrations as Affected by Slurry Seed Applications of Six Rates of Mo at Sites A and B at Milan	25
5. Correlation Coefficients of Leaf N and Mo Concentrations and Grain Yields from Site A of the 1975 Mo Rate Study at Milan	28
6. Correlation Coefficients of Leaf N and Mo Concentrations and Grain Yields from Site B of the 1975 Mo Rate Study at Milan	28
7. Correlation Coefficients of Leaf N and Mo Concentrations and Grain Yields from Site A of the 1976 Mo Rate Study at Milan	28
8. Mean Soil pH Values, Soybean Grain Yields, Leaf N Concentrations, Leaf and Soil Mo Concentrations, and Leaf and Soil Mn Concentrations with the Essex Variety, as Influenced by Three Lime and Mo Rates at Ames Plantation	30
9. Mean Soil pH Values, Soybean Grain Yields, Leaf N Concentrations, Leaf and Soil Mo Concentrations, and Leaf and Soil Mn Concentrations with the Bragg Variety as Influenced by Three Lime and Mo Rates at Ames Plantation	31
10. Mean Soil pH Values, Soybean Grain Yields, Leaf N, Leaf and Soil Mo, and Leaf and Soil Mn Concentrations with the Essex Variety as Affected by Three Lime Rates at Ames Plantation	32
11. Mean Soil pH Values, Soybean Grain Yields, Leaf N, Leaf and Soil Mo and Leaf and Soil Mn Concentrations with the Bragg Variety as Affected by Three Lime Rates at Ames Plantation	32

TABLE

PAGE

12.	Correlation Coefficients of All Measured Variables with the Essex Variety at Ames Plantation	35
13.	Correlation Coefficients of All Measured Variables with the Bragg Variety at Ames Plantation	35

CHAPTER I

INTRODUCTION

In recent years, the soybean has become a very important source of protein to feed the ever increasing world population. To meet this demand, large acreages of farm land are now being used for the production of soybeans, making it the predominant cash crop in some regions. This is especially true in the southeastern United States. For example, in Tennessee, the acreage devoted to soybean seed production has increased approximately 200 fold in the last fifty years. Extensive research has accompanied the increasing acreages to improve the yield and quality of the soybean crop. In Tennessee, this research has resulted in approximately a 200% increase in soybean yields per unit area in the last fifty years. Rapid increase in the soybean acreage has resulted in the crop being planted on soils which do not supply adequate quantities of some of the essential plant nutrients. One of these is Molybdenum (Mo), a micronutrient element.

The objectives of this research were: (1) to determine the effect of different Mo sources on the yield and chemical composition of soybeans, (2) to determine the effect of different rates of a Mo fertilizer on the yield and chemical composition of soybeans, and (3) to determine the effect of different rates of lime and Mo applied simultaneously on the availability of soil Mo and the yield and chemical composition of two varieties of soybeans.

CHAPTER II

REVIEW OF LITERATURE

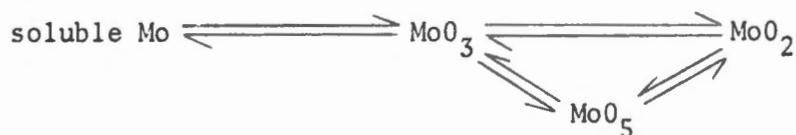
Molybdenum

In the very early days of plant nutrient studies, molybdenum (Mo) was not considered to be essential for the normal growth and development of higher plants. In the 1930's, Arnon and Stout (3) working with tomatoes established that Mo was indeed an essential element for higher plants. They found that the application of 0.05 ppm Mo to the foliage of Mo deficient plants resulted in the disappearance of Mo deficiency symptoms and the resumption of normal growth.

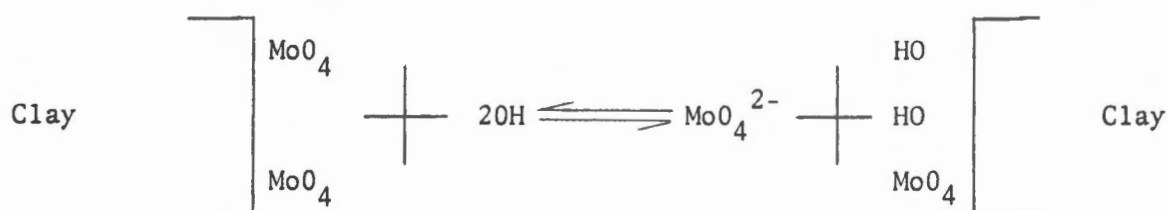
Molybdenum exists on the earth in very small amounts. It has been reported that the Mo content of the lithosphere of the earth averages between 1.5 and 2.3 ppm (14, 36, 54). The predominant mineral ore of the element found on the earth is molybdenite (MoS_2) (21). Molybdenum is found most abundantly in granite and basalt, both of which are igneous rocks. Considerably lower concentrations are found in sedimentary rocks (36).

Soils also tend to contain very small quantities of Mo. Robinson et al. (48) analyzed 400 U.S. soils and found that 95% of these soils had Mo concentrations between 0.6 and 3.5 ppm. The highest concentration of any of the 400 soils analyzed was 31.5 ppm. Others have reported the Mo content of soils to range from less than 1 ppm to as much as 10 ppm (36). The Mo concentration of soils seems to be controlled by the Mo content of the parent materials of that soil.

Molybdenum is found in several forms, some more available to plants than others. According to Tisdale and Nelson (54), the four forms are: (1) unavailable Mo which is held within the crystal lattice of primary and secondary minerals, (2) conditionally available Mo which is retained as the $\text{MoO}_4^{=}$ ion by clay minerals and available to a greater or less degree depending on the soil pH, (3) Mo held in the organic matter of the soil, and (4) Mo which is water soluble. The most abundant form of available Mo present in the soil is $\text{MoO}_4^{=}$ (36). Amin and Joham (2) divided the soil Mo into three categories: (1) water soluble Mo which is available to plants, (2) ammonium hydroxide soluble Mo which is available to plants after reacting with the cations in the soil, and (3) oxidizable Mo which must be oxidized before being converted into a form which is available to plants. This categorization may be explained by the fact that oxides of Mo are amphoteric. Molybdenum trioxide (MoO_3) acts as an acidic oxide and combines with Na, K, and Mg to form soluble $\text{MoO}_4^{=}$. Molybdenum dioxide (MoO_2) and molybdenum hemipentoxide (MoO_5), which have lower metal valences than MoO_3 , are basic in reaction and are insoluble in alkaline solutions. A Mo cycle in soils has been proposed which consists of two steps: (1) the interactions of Mo oxides, and (2) reactions between MoO_3 and the soluble salt forms. The cycle is illustrated as follows:



The availability of the soil Mo depends to a great extent on the pH of the soil. Numerous researchers (14, 20, 28, 29, 44) have shown that unlike most of the other micronutrient elements, Mo is more available at high soil pH levels than at low soil pH levels. The $\text{MoO}_4^{=}$ ion concentration in the soil is said to increase 100 times with each unit increase in pH (36). Tisdale and Nelson (54) explained this as follows:



Beeson (6) suggested that plant uptake of Mo is actually enhanced at pH values between 4.5 and 5.5. However, at these pH levels the Mo is fixed on the soil colloids and higher pH levels are required for its release. This was substantiated by Evans et al. (20), who reported that the concentrations of soluble Mo in a soil at pH 6.1 and 6.5 were 0.7 and 1.1 ppm, respectively.

Molybdenum is rendered unavailable to plants due to its adsorption by clay minerals and sesquioxides of Fe and Al, which are insoluble in strongly acidic soils. Iron oxides seem to be mostly responsible for fixing Mo into unavailable forms (22, 36). Thus, removing the Fe_2O_3 from a soil reduces the amount of $\text{MoO}_4^{=}$ adsorbed by the soil (25). The order of adsorption reported by Jones (26) was: $\text{Fe}_2\text{O}_3 > \text{Al}_2\text{O}_3 > \text{halloysite} > \text{nontronite} > \text{kaolinite}$. Since sorption of molybdates is enhanced at low pH levels and inhibited at high pH levels, it was suggested that liming an acid soil may cause Mo to be more available to plants by exchanging the molybdate adsorbed by the Fe_2O_3 with the hydroxyl ions (25, 26).

Since the availability of Mo is very pH dependent, Mo deficiencies usually occur in acid soils where the Mo is tightly bound (18, 32, 33). Deficiencies of Mo may occur on highly weathered soils, soils with high anion-exchange capacity, ironstone soils, and soils depleted of Mo by heavy cropping (14). Molybdenum deficiencies can also be induced by a heavy application of fertilizers containing S. It seems that in addition to the acidifying characteristics of such fertilizers, the $\text{MoO}_4^{=}$ ion and the $\text{SO}_4^{=}$ ion are similar in size and charge allowing the $\text{SO}_4^{=}$ ion to compete with the $\text{MoO}_4^{=}$ ion for uptake by the root (14, 54).

Molybdenum deficiencies may also result from the leaching of Mo from calcareous and neutral soils (14, 18, 36). However, Mo toxicity is more common on these types of soils. Excesses of Mo may also occur on organic soils and some less weathered soils (14, 36). Although yield reductions from excesses may result, Mo is not commonly known to be toxic to plants. However, excesses of Mo have been known to cause molybdenosis, an imbalance of Cu and Mo, in animals that eat plants containing excessive concentrations of Mo (36).

The rate of uptake of the $\text{MoO}_4^{=}$ ion by plant roots is controlled by the soil temperature and the time of contact between the plant and the soil. Research conducted by Barrow and Shaw (5) suggested that the rate of uptake decreased with time. They also stated that the higher the soil temperature, the faster the rate of uptake decreased. This theory is based on the premise that time and increasing temperature speed up the fixation of available Mo into unavailable forms.

For Mo or any element to be adsorbed by a plant root, contact must be made between root and the element. The element may move through the

soil solution to the root by mass flow or diffusion. The plant root may also contact the element as it grows through the soil. Through the research of Lavy and Barber (31) it was discovered that when the Mo concentration of the soil extract was greater than 4 ppb Mo accumulated in or around the roots by mass flow. However, when the Mo concentration of the soil extract was less than 4 ppb, diffusion usually accounted for the movement of Mo to the root. Mass flow would be most important in nutrient uptake if the soil moisture was high, while the significance of diffusion would increase as the soil moisture decreased.

Movement of Mo in the soil by leaching is limited except under specific conditions. Smith and Leeper (51) reported that added Mo is not leached from acid soils to any great extent. They explained that the added Mo is quickly adsorbed onto sesquioxides and slowly becomes less soluble. On the other hand, leaching of Mo is quite common in naturally occurring neutral to alkaline soils. Many of these soils have lost much of their native Mo through leaching (6).

There are several commercial Mo fertilizers currently on the market. They may be applied to the soil, seed, and foliage. A few of the more popular Mo fertilizer materials and their Mo percentages are: Na_2MoO_4 , 39%; $(\text{NH}_4)_2\text{MoO}_4$, 54%; MoO_3 , 66%; and Mo fritts, 2-3% (36, 54). The most commonly used materials are Na_2MoO_4 and $(\text{NH}_4)_2\text{MoO}_4$. However, it has been reported that the fritted materials are equally as effective as Mo sources (36).

Small quantities of Mo are also present in other fertilizer and liming materials. For example, Evans (18) found that most N and K

fertilizers contained from 0.05 to 0.2 ppm water soluble Mo. The liming materials that were analyzed contained between 1.6 and 3.8 ppm non water soluble Mo. Evans et al. (20) reported similar results from their analyses of several fertilizer and liming materials. However, due to the varying contents of Mo in these materials, they should not be relied on to supply the Mo required by plants.

In all higher plants, the role of Mo in the process of protein synthesis is to activate the enzyme nitrate reductase (9, 16, 19, 38, 3, 54). Nitrate-N is the most common naturally occurring soil N form taken up by plants. Since N cannot be used in the NO_3^- form by the plant, it must be reduced to NH_3 or the NH_4^+ ion before it can be synthesized into protein. According to deMooy (16), the concentration of plant Mo required to convert NO_3^- to NH_4^+ is about 0.2 ppm. If Mo is deficient, NO_3^- tends to accumulate in the plant, and protein synthesis is decreased.

In leguminous plants, Mo has a second role in the fixation of atmospheric N (7, 23, 28, 29, 33, 37, 52). In N fixation, Mo is required by the enzyme nitrogenase to convert atmospheric nitrogen (N_2) to NH_3 which is used by the plant to form amino acids, proteins, chlorophyll and other compounds. More Mo is required by the N fixing organisms than by the host plant for growth or NO_3^- reduction (16, 23).

In soybeans, a deficiency of Mo may appear as a N deficiency due to the reduction in the fixation of N. The foliage of the deficient plants may appear pale green or yellowish in color due to the lack of N needed to form chlorophyll. The plants may also exhibit interveinal chlorosis, twisted stems and stunted growth (15, 43, 49, 52, 54). Molybdenum

deficient soybean plants may also produce seed pods later and produce less dry weight at harvest than nondeficient plants (43).

In addition to the observation of visible symptoms, Mo deficiencies can also be detected by the comparison of Mo contents of soils and plants to critical concentrations previously determined. For example, deMooy (16) reported that a Mo concentration of 0.5 ppm or less in the leaves of soybeans constituted a deficiency. By extracting soil Mo with a mixture of oxalic acid and its ammonium salt, deMooy suggested that a concentration of 0.14 ppm or less available Mo in soils indicated a need for added Mo. Others have suggested that plant concentrations between 1 and 10 ppm Mo are sufficient for maximum growth and yield of soybeans (36). Sedberry et al. (50) reported that soybean yield responses were obtained on soils which had an ammonium oxalate-oxalic acid extractable Mo content between 0.04 and 0.22 ppm. He also stated that significant yield responses were obtained only when the Mo content of the leaves was 0.14 ppm or less.

When Mo is added to strongly acidic soils, there is often a positive response with regard to soybean grain yield. From research conducted in Louisiana by Sedberry et al. (50), a formula for predicting the response to applied Mo has been proposed. They obtained a positive response only when the soil $\text{pH} + (10 \times \text{ppm extractable Mo content of soil})$ was less than 7.5.

When dealing with Mo deficient acid soils, soybean yields may possibly be increased by adding Mo, lime, or both Mo and lime. By applying Mo without lime, Parker and Harris (42) obtained soybean yield increases of 31% and 55% in two years of experiments. Hashimoto and

Yamasaki (23) reported a 15.7% average increase in soybean yields from the application of Mo on unlimed acid soils. Other researchers have substantiated these results (9, 15, 30, 32, 33, 50, 52). One of the possible drawbacks to Mo application without lime is that this practice may result in Mn or Al toxicity on strongly acidic soils with high levels of Mn or Al (28, 50, 57).

The liming of acid soils, which have an adequate supply of unavailable Mo, may also increase soybean yields. Parker and Harris (42), with lime applications of 4.48 metric tons/ha, obtained approximately the same yields as from the application of Mo alone. This rate of lime had the same effect on yields as Mo at the rate of 0.22 kg/ha, which was the highest rate that produced a significant yield response. Other experiments with lime and Mo in soybean production have produced similar results (16, 28, 29, 33, 50, 52, 57).

A positive soybean yield response does not always occur when both lime and Mo are applied. Several researchers have reported no significant yield increases over those resulting from either treatment separately (28, 32, 42, 29, 50). This lack of response is likely due to an excess of available Mo resulting from either liming or the addition of fertilizer Mo. An exception to this is an experiment by deMooy (16) which resulted in a 134 kg/ha increase over either of the treatments separately.

The positive yield response of soybeans to applications of lime or Mo or both are most likely due to an increase in the N content of the plant. This supposition is based on the fact that the level of N in the plant during the bloom stage determines the number of pods not aborted by

the plant, which in turn influences the grain yield (39). Increased plant N concentrations have been reported by several researchers with the application of lime or Mo (9, 20, 42, 52). Smith (52) suggested that lime and Mo applications together would increase soybean leaf N concentrations over either of the treatments separately. Parker and Harris (42), however, did not agree, reporting that lime did not increase leaf N when Mo was also applied.

The fixation of atmospheric N by Rhizobia can supply from 20 to 75% of the total N required by soybeans for maximum yields (16, 39). When Mo is deficient, the activity of the N fixing nodules is lowered, resulting in low N levels in the plant tissue (14). Under these conditions, nodules are numerous, small, and appear white to green in color (23, 29, 52). The increase in nodulation is thought to be caused by an increase in the susceptibility of the Mo deficient plant to infection by the Rhizobium bacteria (29). A sufficient supply of Mo results in fewer nodules which are larger and have a pink to reddish color (23, 29, 42, 56). The red color is from leghemoglobin, a red pigment which indicates an increase in the activity of the bacteria in the nodule (52).

A much smaller portion of the increase in the plant N concentration is due to the increased reduction of NO_3^- . In plants with an adequate supply of Mo, the enzyme nitrate reductase has been shown to be more active than in Mo deficient plants (19). As the activity of the enzyme increases, the rate of NO_3^- uptake by the plant is thought to increase (43). In Mo deficient plants, NO_3^- is believed to accumulate due to the decreased activity of the nitrate reductase enzyme.

Manganese

Manganese, (Mn), one of the essential elements required by all higher plants for optimum growth and development, is fairly abundant on the earth. Concentrations in the earth's crust are about 950 ppm, with limestone rock having the highest concentrations (36). The Mn concentrations of soils vary greatly from a low of 20 ppm to as much as 3000 ppm (36).

Three forms, or valence states, of Mn are thought to exist in the soil. These forms, which are thought to exist in equilibrium with each other, are: (1) Mn^{2+} , a divalent ion; (2) Mn_2O_3 , a trivalent ion with regard to Mn which forms unstable oxides; and (3) Mn^{4+} , a form which occurs at abnormally low soil pH levels (36, 54).

The divalent manganous ion (Mn^{2+}) is the form which is adsorbed by plants (10, 17, 54). The availability of this ion depends on the soil pH. Like most other micronutrient elements, the availability increases as the pH of the soil decreases (12, 34, 44, 46, 47, 57). With each unit increase in the soil pH, the Mn^{2+} ion concentration in the soil decreases 100 times (36). Manganese becomes unavailable at higher pH levels because the Mn^{2+} ion complexes with the soil organic matter (10). The availability of Mn is also increased under reducing conditions in the soil, such as a waterlogged soil. This is due to the increased solubility of the ion (6, 12).

Manganese deficiencies usually occur in soils that have pH values which approach neutrality or higher (36, 47). Deficiencies of Mn can be corrected by the application of Mn fertilizers or in some cases by

lowering the pH of the soil. The symptom most often associated with Mn deficiency in plants is interveinal chlorosis (54).

Toxicities of Mn usually occur in acid soils and soils which are in a state of reduction (41, 54). This is especially true under conditions of high soil moisture (6, 41). Liming the soil to a pH greater than 5.5 will usually correct the toxicity problem (41, 44, 54). The major symptom of Mn toxicity in plants is a condition known as "crinkle leaf," which is often accompanied by a reduction in yields (41, 54). Toxic levels of soil Mn may also inhibit soybean response to Mo fertilization (50).

To aid in the detection of Mn toxicities or deficiencies, critical values in plants and soils have been established. For soybeans, Ohlrogge and Kamprath (40), suggest that a Mn leaf concentration of 14 ppm or less could be considered deficient, while 15 to 20 ppm is low and 21 to 100 ppm is adequate. Using a soil which released 12 ppm Mn by double acid extraction, Robertson et al. (47), obtained the highest soybean yield when leaf and seed Mn concentrations were 72 and 22 ppm respectively. By analysis of the top most recently matured soybean leaves, several researchers have suggested that Mn concentrations of 20 ppm or less may indicate a Mn deficiency (13, 36, 38, 45). A toxicity of Mn may occur in soybeans which have leaf Mn concentrations that are greater than the concentrations needed for optimum growth and development. Ohki (38) reported Mn toxicity when leaf concentrations were greater than 160 ppm while others reported toxicity above 250 ppm (36). Parker et al. (41) found that in soybeans, crinkle leaf, a symptom of Mn toxicity, occurred when water soluble Mn in the soil was 2.5 ppm and leaf concentrations were 495 ppm.

There are several good Mn fertilizer materials on the market. The most common are: MnSO_4 , 26-28% Mn; MnO , 41-68% Mn; MnCO_3 , 31% Mn; and Mn fritts, 10-25% Mn (36, 54).

The role of Mn in the plant is not completely understood. It is thought that Mn activates several enzymatic reactions in plants (6, 54). It has also been shown to promote the uptake of NO_3^- by some plants (6).

CHAPTER III

MATERIALS AND METHODS

During the growing seasons of 1975 and 1976, two preliminary Mo experiments with soybeans were conducted on the Milan Field Station located near Milan, Tennessee. One of the experiments was classified as a Mo source study, while the other was a Mo rate study.

The soil used for both of these experiments was Collins silt loam, which is classified as a coarse-silty, mixed, acid, thermic, Aquic Udifluent. This moderately well drained alluvial soil is naturally strongly acid or very strongly acid. The Collins soil, which may be frequently flooded, has good tilth, high available water holding capacity, and good permeability. This soil is naturally low or medium in available P and K.

The surface layer or plow layer of the Collins soil is about 20 cm in thickness and consists of brown (10YR 3/3) very friable silt loam. The upper subsurface layers (20 to 70 cm) consist of brown (10YR 4/3) friable silt loam with common grayish brown (10YR 5/2) mottles. The lower subsoil layers (70 to 182 cm) consist of grayish brown (10YR 5/2) and gray (10YR 5/1) friable silt loam with common mottles in various shades of brown.

The experimental design used in these preliminary experiments was a randomized, complete block with four replications. The five treatments for the Mo source study in 1975 and 1976 were no lime, 280 kg/ha of lime banded in the row, 35 g/ha of Mo applied as a slurry seed treatment, Mo

plus Captan applied to the seed as a powder in the hopper box at planting time, and 6.7 metric tons/ha of lime broadcast. The Mo rate study, which was conducted on two sites in 1975, consisted of six seed treatments. The Mo rates were 0, 7, 14, 21, 28, and 35 g/ha.

Before planting in 1975, 448 kg/ha of a fertilizer supplying 39 kg/ha of P and 73 kg/ha of K were broadcast and incorporated on the experimental areas of both studies. The pH values of the soils used in the Mo rate study were 5.5 at one site and 6.0 at the other. The pH of the soil used in the Mo source study was 5.4. In 1976, 336 kg/ha of a fertilizer supplying 29 kg/ha of P and 56 kg/ha of K were broadcast and incorporated on both experimental areas. Weeds were controlled by preemergence applications of recommended chemical herbicides and mechanical cultivation.

Pickett 71 was the soybean variety used in both of these experiments. Pickett 71 is in maturity group VI and is resistant to race three cyst nematodes. This variety has purple flowers, tan pods, yellow seed with an imperfect black hilum, and gray, normal pubescence. Each plot consisted of four rows spaced 1.1 m apart and 9.2 m in length. The seeding rate was 12 seeds per 30.5 cm of row.

In 1977, a separate experiment involving lime, soil applied Mo and soybean varieties was conducted on the Ames Plantation Agricultural Experiment Station located near Grand Junction, Tennessee. The soil used for this experiment was Loring silt loam, a fine silty, mixed, thermic, Typic Fragiudalf. This medium to strongly acid, well to moderately well drained soil was formed in thick loess. The surface layer, which ranges in thickness from 10 to 20 cm, is brown to dark brown (10YR 4/3) with

silt loam texture. The upper subsurface layers, for the most part, are brown (7.5YR 4/4) with a silty clay loam texture. The lower subsoil (71-94 cm) forms a weak fragipan which is mottled pale brown (10YR 6/3), dark brown (7.5YR 4/4) and yellowish-brown (10YR 5/6) silt loam with light gray (2.5YR 7/2) mottles often present. Runoff from these soils is moderate to slow with rapid permeability except where the fragipan restricts the movement of water, air, and roots. The available water holding capacity is high. The Loring soils usually have low organic matter contents and medium contents of naturally available P and K. However, due to previous fertilization, surface soils from the experimental plots tested high for both P and K.

The experimental designs for the 1977 study were two split-plot designs. One of the split-plot designs was planted with the Essex variety of soybeans, while the Bragg variety was planted in the other split-plot design. The three lime rates were the main-plot treatments and the three Mo rates, 0, 200, and 800 g/ha were the split-plot treatments. The main-plot treatments were arranged in a randomized, complete block design with four replications. The lime was applied so that each of the four replications contained a low, a medium, and a high pH value. The average pH values were 5.2, 5.9 and 6.5 respectively. Each of the 72 plots contained six rows which were six m in length.

Before planting, 336 kg/ha of a fertilizer which supplied 29 kg/ha of P and 56 kg/ha of K were broadcast over the entire experimental area and incorporated. The 200 and 800 g/ha rates of Mo were applied by spraying the appropriate quantity of Na_2MoO_4 dissolved in water. Each

of the experimental areas was planted at the recommended seeding rate with inoculated seed. Weeds were controlled by herbicides recommended for soybean production.

Bragg, one of the two soybean varieties used in the 1977 experiment, is in maturity group VII. It has white flowers, brown pods, yellow seeds with a black hilum, and tawny, normal pubescence. Essex, the other variety used is in maturity group V and has purple flowers, tan pods, yellow seeds with a buff hilum, and gray, normal pubescence.

Collection of Field Data

When the soybeans reached the pod-filling stage (late August to early September), plant tissue samples were collected. These samples consisted of the upper, most recently matured trifoliates taken at random from each plot. The plant samples were dried in a forced-air oven at 70°C. After drying, the leaves were ground in a Wiley mill to pass a 20 mesh screen and stored in sealed plastic bags until analyzed.

Soil samples were also taken later in the 1977 growing season with a soil probe to a depth of 15 cm. The soil samples, taken from several randomly selected sites within each plot, were placed in labeled containers and allowed to air-dry. The dried soil samples were then ground by hand to pass a 10 mesh sieve and stored in paper bags inside cardboard containers until analyzed.

When the soybeans reached maturity, the plots were harvested mechanically. Reported yields were based on plot weights at 13% moisture.

Laboratory Analyses

Each of the plant tissue samples were analyzed for N content. A 0.2 g sample was digested with H_2SO_4 and H_2O_2 as outlined by Thomas et al. (55). The extract was then diluted to a final volume of 250 ml and analyzed by a Technicon AutoAnalyzer, an automated colorimeter.

Plant tissue samples from each plot were also analyzed for Mo. The samples were prepared for Mo analysis by dry-ashing a quantity of plant tissue in a muffle furnace at 500°C for five hours and dissolving the ash in 5% volume per volume HCl as described by Henning and Jackson (24). The Mo concentration of the extract was determined by a Perkin-Elmer HGA-76B graphite furnace connected to a Perkin-Elmer model 372 atomic absorption spectrophotometer.

The plant samples from the 1977 experiment were also analyzed for Mn content. They were prepared for Mn analysis by similarly dry-ashing a quantity of plant tissue and dissolving the ash in 20% volume per volume HCl as outlined by Walsh (58). Concentrations of Mn in the extracts were determined by using an acetylene flame with an atomic absorption spectrophotometer.

The pH of the soil samples was determined in a 1:1 soil to water suspension. The soil samples were also analyzed for available Mo and Mn. A procedure outlined by Bhella and Dawson (8) which used anion-exchange resin to extract the available Mo from the soil was used to prepare the samples for Mo analysis. Ten grams of anion exchange resin were shaken with 25 g of soil and 100 ml of water. The resin was then leached with 50 ml of NH_4NO_3 . The leachate was analyzed for Mo by the graphite

furnace mentioned previously. Exchangeable Mn in the soil was extracted by a 1:10 (soil to extractant) solution of NH_4OAc as outlined by Adams (1). Manganese in the extract was determined by using the acetylene flame with the atomic absorption spectrophotometer.

Composite soil samples representing each of the treatment combinations were also analyzed for free Fe and amorphous Fe. The free Fe was extracted with a 1:20 (soil to extractant) solution of $\text{Na}_2\text{S}_2\text{O}_4$ and a citrate buffer as outlined by Coffin (11). The amorphous Fe was extracted by a 1:40 (soil to extractant) solution of acidified $(\text{NH}_4)_2\text{C}_2\text{O}_4 \cdot \text{H}_2\text{O}$ as described by McKeague and Day (35). The extracts were analyzed for Fe by using an atomic absorption spectrophotometer with an acetylene flame. These values were used in the calculation of the active Fe ratio of the soil as described by Karimian and Cox (27). They contend that the active Fe ratio of a soil may be used to predict the relative yield increases from applied Mo as well as plant Mo concentrations.

Statistical Analyses

The data from these experiments were analyzed on an IBM 360/65 computer. Analyses of variance, Pearson's correlations, and Duncan's New Multiple Range Tests (DNMRT) were conducted using the Statistical Analysis System (SAS) developed by Barr et al. (4).

"F" tests were conducted to determine significance among the various treatments. Separation of the variable means of the significant treatments was accomplished by using the (DNMRT). Dependent variable pairs in each experiment were subjected to Pearson's test of correlation to determine if significant correlations existed.

CHAPTER IV

RESULTS AND DISCUSSION

Molybdenum Source Study

The data from this study consisted of leaf Mo concentrations, leaf N concentrations, and soybean yields. All data were subjected to statistical analysis as described in the previous chapter.

The mean values of the plant tissue analyses for Mo are in Table 1. The results revealed no differences in the leaf Mo concentrations at the 5% level of significance, in either year. The 35 g/ha Mo slurry seed treatment, however, did produce a tenfold increase in leaf Mo concentrations over the check plot in 1975. The broadcast lime treatment was expected to produce increases in the leaf Mo concentrations, since increases in soil pH are known to increase the availability of soil Mo (20). The lack of a significant increase in leaf Mo concentrations may be explained by the assumption that the majority of the soil Mo taken up by the plant was probably used by the Rhizobia bacteria in the root nodules. The bacteria probably used this additional Mo for the increased fixation of atmospheric N instead of it being translocated to other parts of the plant.

The mean leaf N concentrations for each treatment from both years of the study are given in Table 1. The results show that the leaf N concentrations produced by the banded lime treatment and the Mo plus Captan, hereafter referred to as the hopperbox treatment, were not different from the check plots in either year. In both years, the

TABLE 1. Mean Grain Yields and Leaf N and Mo Concentrations as Affected by Lime or Mo Treatments at Milan.

Treatment	Grain Yield		Leaf N		Leaf Mo	
	1975	1976	1975	1976	1975	1976
	----(kg/ha)----		------(%)-----		---(ppm)---	
Check	1895 A*	1161 A	3.16 A	2.85 A	0.03	0.01
280 kg/ha Banded Lime	1989 A	1455 B	3.32 A	2.90 A	0.03	0.02
Mo + Captan (Hopper Box)	2338 B	1572 B	3.25 A	2.75 A	0.07	0.02
6.7 Metric tons/ha (Broadcast)	2735 C	1905 C	4.10 B	4.08 B	0.04	0.04
35 g/ha Mo (Slurry seed trt.)	3050 D	2538 D	4.12 B	3.73 B	0.33	0.05

*Numbers followed by the same letter were not significantly different at the 0.05 level of probability.

6.7 metric tons/ha lime treatment, hereafter referred to as the broadcast treatment, and the 35 g/ha Mo seed treatment, hereafter referred to as the slurry seed treatment, produced leaf N concentrations which were greater than the other treatments, but were not different from each other. These increases were probably due to the greater Mo supply to the Rhizobia bacteria.

The mean soybean yields, which are presented in Table 1, ranged from 1895 to 3050 kg/ha in 1975 and from 1161 to 2538 kg/ha in 1976. The check treatment produced the lowest mean yield in both years. The slurry treatment produced larger yield increases than any of the other treatments in both years. With the exception of the slurry seed treatments, the broadcast lime treatments in both years produced higher yields than the rest of the treatments. In the first year of the study, the hopperbox treatment produced higher yields than the banded lime and the check treatments. In 1976, the hopperbox and the banded lime treatments produced soybean yields which were higher than the yields from the check treatment. Similar results were obtained from a Mo source study conducted at the University of Tennessee in 1970 (H. C. Smith, unpublished data). Average soybean yield increases of 1304 and 1317 kg/ha were obtained by Smith with a slurry seed treatment of Mo at a rate of 35 g/ha and a hopperbox treatment of Mo plus Captan respectively.

Results from both of these studies indicate that as the soil Mo becomes more available to the plant, the supply of N in the plant is also increased. Assuming that the increase in the N content results in fewer pods being aborted, thus increasing the yields, the importance of

increasing the available soil Mo is obvious. The slurry seed treatment was the best of the four sources tested for supplying Mo to the soybean plant with regard to yield. When the leaf N concentrations were considered, however, the slurry seed treatment showed no advantage over the broadcast lime treatment. Therefore, the differences in the yields between these two treatments were probably due to factors other than N content.

Tables 2 and 3 contain the results of correlation tests which were conducted with the dependent variables from both years. In 1975, the leaf N concentrations and leaf Mo concentrations were correlated with yield. The 1976 data produced significant correlations with all possible dependent variable combinations. Since the leaf N concentrations were positively correlated with soybean yield in both years of the study, the theory that plant N contents could influence soybean yields would seem to be supported.

Molybdenum Rate Study

In 1975, a Mo rate study was initiated on two sites which will be referred to as site A and site B. The soils at both sites were identified as Collins silt loam. Due to the high pH (6.0) of the surface soil in site B, no soybean yield responses from added Mo were obtained in 1975. Subsequently, the study on site B was discontinued in 1976.

The mean values of leaf Mo for each treatment from both years are in Table 4. The leaf Mo concentration data revealed differences among treatments in 1975, but not at site A in 1976. From site A in 1975, the

TABLE 2. Correlation Coefficients of Leaf N and Mo Concentrations and Grain Yields from the 1975 Mo Source Study at Milan.

	Leaf N	Leaf Mo	Yield
Leaf N	1.00	.37	.74*
Leaf Mo		1.00	.47*
Yield			1.00

*Coefficients are different from zero at the 0.05 level of probability.

TABLE 3. Correlation Coefficients of Leaf N and Mo Concentrations and Grain Yields from the 1976 Mo Source Study at Milan.

	Leaf N	Leaf Mo	Yield
Leaf N	1.00	.67*	.67*
Leaf Mo		1.00	.50*
Yield			1.00

*Coefficients are different from zero at the 0.05 level of probability.

TABLE 4. Mean Soybean Grain Yields and Leaf N and Mo Concentrations as Affected by Slurry Seed Applications of Six Rates of Mo at Sites A and B at Milan.

Treatment (g Mo/ha)	Grain Yield				Leaf N				Leaf Mo			
	1975		1976		1975		1976		1975		1976	
	Site A	Site B	Site A	Site B	Site A	Site B	Site A	Site B	Site A	Site B	Site A	Site B
	----- (kg/ha) -----				----- (%) -----				----- (ppm) -----			
0	1875 A*	3037	1122 A		3.3 A	5.1	2.8 A		0.03 A	0.04 A	0.01	
7	2480 B	3078	1929 B		3.9 BC	5.1	3.2 AB		0.06 AB	0.04 A	0.02	
14	2769 C	3266	2184 C		4.1 C	5.1	3.5 AB		0.04 A	0.07 A	0.02	
21	2869 C	3185	2115 C		3.8 B	5.1	3.3 AB		0.17 B	0.05 A	0.02	
28	2816 C	3205	2426 C		4.2 C	5.0	3.6 B		0.09 AB	0.09 AB	0.03	
35	3071 D	3105	2439 C		4.2 C	4.8	3.8 B		0.05 A	0.14 B	0.03	

*Numbers followed by the same letter were not significantly different at the 5% level of significance.

21 g/ha treatment produced higher leaf Mo concentrations than the 0, 14, and 35 g/ha treatments. Results from site B in 1975 revealed that the 35 g/ha treatment produced higher leaf Mo concentrations than the other treatments with the exception of the 28 g/ha treatment. Although leaf Mo concentrations at site A in 1976 were increased slightly as the Mo rates increased, none of the differences were significant.

Results of the plant N analyses, which are in Table 4, revealed no differences among treatments from site B in 1975 or site A in 1976. A difference among treatments, however, appeared in the data from site A in 1975. All other treatments from site A in 1975 produced higher leaf N values than the check plot. With the exception of the check and 7 g treatments, all of the Mo rates produced higher leaf N concentrations than did the 21 g/ha treatment.

Soybean yields from this Mo rate study are in Table 4. Results from site A in 1975 and 1976 indicate that yields from all Mo rates were higher than those from the check plots. At site A in 1975, yields from the highest Mo rate, 35 g/ha, were greater than those of all other treatments. Earlier experiments conducted in Tennessee (H. C. Smith, unpublished data) revealed that slurry seed treatments of Mo at the rate of 35 g/ha increase soybean yields by an average of 50% over the check treatment. In another experiment by Smith in 1969, average soybean yield increases of 90% and mean leaf N increases of 45% were obtained with a slurry seed treatment of Mo at the rate of 35 g/ha. The results of Smith's experiments support the results of the current study. From site A in 1975, the 14, 21, and 28 g/ha treatments produced larger yields

than the 7 g/ha and the check treatments. At site A in 1976, the four highest Mo rates produced yields which were not different from each other, but were larger than those from the seven grams per hectare and the check treatments.

The results of this Mo rate study clearly show that the application of Mo to the seed at any of the rates used, did increase yields over the check treatments on unlimed, acid, Collins silt loam soil. However, if the pH of the soil is 6.0 or greater, as was the case with site B in 1975, little or no positive yield response might be expected with added Mo. In site A in 1975, leaf N concentrations were increased over the check by the addition of Mo at any of the rates used. This increase in leaf N was probably the major factor contributing to the yield increases.

Tables 5, 6, and 7 contain the results of the tests for correlation which were conducted with data from all sites and years. From site A in 1975, yield was found to be correlated with leaf N concentrations. Site B in 1975 produced no significant correlations. In 1976, leaf N and Mo concentrations were correlated with yields. These correlations support the theory that increases in the Mo supply in the soil produce increases in the N content of the plant which in turn increases soybean yields.

Lime and Molybdenum Rate Study

This study which was initiated in 1977, included leaf analyses for N, Mo, and Mn, and soil analyses for pH, Mo, Mn, and free and amorphous Fe. Soybean yields were also determined.

TABLE 5. Correlation Coefficients of Leaf N and Mo Concentrations and Grain Yields from Site A of the 1975 Mo Rate Study at Milan.

	Leaf N	Leaf Mo	Yield
Leaf N	1.00	.07	.74*
Leaf Mo		1.00	.18
Yield			1.00

*Coefficients are different from zero at the 0.05 level of probability.

TABLE 6. Correlation Coefficients of Leaf N and Mo Concentrations and Grain Yields from Site B of the 1975 Mo Rate Study at Milan.

	Leaf N	Leaf Mo	Yield
Leaf N	1.00	.02	.07
Leaf Mo		1.00	-.10
Yield			1.00

*Coefficients are different from zero at the 0.05 level of probability.

TABLE 7. Correlation Coefficients of Leaf N and Mo Concentrations and Grain Yields from Site A of the 1976 Mo Rate Study at Milan.

	Leaf N	Leaf Mo	Yield
Leaf N	1.00	.21	.51*
Leaf Mo		1.00	.46*
Yield			1.00

*Coefficients are different from zero at the 0.05 level of probability.

The mean soil pH values for each treatment combination are presented in Table 8 for the Essex variety and Table 9 for the Bragg variety. The results in Tables 10 and 11 show that with each increase in the lime rates, there was an increase in the soil pH values with both varieties.

The mean values of NH_4OAc extractable soil Mn for each treatment combination with each variety are given in Tables 8 and 9. The mean exchangeable soil Mn concentrations for each of the lime treatments for both varieties are in Tables 10 and 11. These results revealed that as the lime rates increased, the exchangeable soil Mn decreased significantly. This was expected since high pH levels are known to decrease the availability of Mn in the soil (12). However, since a concentration of 12 ppm or more of double acid extractable available soil Mn is considered adequate for normal soybean production and since no Mn deficiency symptoms were observed, there was probably sufficient Mn for the normal growth and development of the soybean plants, even at the highest pH level (47).

Analyses of plant Mn for each treatment combination with each variety are in Tables 8 and 9. The data exhibited differences among lime treatments, but not among the Mo treatments. The leaf Mn values for each lime treatment are in Tables 10 and 11. With both varieties, there were no differences in the leaf Mn values between the no and medium lime rates. However, there was a decrease in leaf Mn concentrations with the high lime rate in both varieties.

Tables 8 and 9 contain the anion exchange resin, available soil Mo concentrations for each treatment combination from each variety. As before, the statistical analysis revealed differences among lime

TABLE 8. Mean Soil pH Values, Soybean Grain Yields, Leaf N Concentrations, Leaf and Soil Mo Concentrations, and Leaf and Soil Mn Concentrations with the Essex Variety, as Influenced by Three Lime and Mo Rates at Ames Plantation.

Treatment	Soil pH	Grain Yield (kg/ha)	Leaf N (%)	Leaf Mo	Soil Mo	Leaf Mn	Soil Mn
				----- (ppm) -----			
0 Mo No Lime	5.2	1946	4.0	0.03	1.23	103.8	55.2
200 g/ha Mo No Lime	5.2	2038	4.1	0.02	0.97	108.8	58.6
800 g/ha Mo No Lime	5.2	2312	4.2	0.03	1.35	100.4	52.2
0 Mo Medium Lime	6.0	2259	4.2	0.02	0.83	102.1	39.5
200 g/ha Mo Medium Lime	5.7	2339	4.3	0.02	0.69	100.1	43.0
800 g/ha Mo Medium Lime	5.9	2543	4.5	0.02	1.19	97.5	38.8
0 Mo High Lime	6.3	2444	4.5	0.01	1.13	80.3	23.8
200 g/ha High Lime	6.5	2520	4.7	0.08	2.11	72.6	25.6
800 g/ha High Lime	6.3	2432	4.5	0.02	1.88	78.5	27.0

TABLE 9. Mean Soil pH Values, Soybean Grain Yields, Leaf N Concentrations, Leaf and Soil Mo Concentrations, and Leaf and Soil Mn Concentrations with the Bragg Variety as Influenced by Three Lime and Mo Rates at Ames Plantation.

Treatment	Soil pH	Grain Yield (kg/ha)	Leaf N (%)	Leaf Mo	Soil Mo	Leaf Mn	Soil Mn
				----- (ppm) -----			
0 Mo No Lime	5.4	1577	4.2	0.05	0.64	87.6	50.6
200 g/ha Mo No Lime	5.2	1782	4.4	0.02	0.88	88.8	48.0
800 g/ha Mo No Lime	5.3	1755	4.7	0.03	1.19	100.5	53.8
0 Mo Medium Lime	5.8	1687	4.4	0.02	1.03	95.9	40.2
200 g/ha Mo Medium Lime	6.0	1872	4.7	0.03	0.75	94.8	36.1
800 g/ha Mo Medium Lime	6.0	1856	4.4	0.02	1.00	89.8	42.4
0 Mo High Lime	6.4	1825	4.7	0.02	1.38	72.5	20.9
200 g/ha Mo High Lime	6.6	1778	4.7	0.02	1.55	86.1	21.9
800 g/ha Mo High Lime	6.6	1803	4.7	0.02	3.91	71.9	17.1

TABLE 10. Mean Soil pH Values, Soybean Grain Yields, Leaf N, Leaf and Soil Mo, and Leaf and Soil Mn Concentrations with the Essex Variety as Affected by Three Lime Rates at Ames Plantation.

Treatment	Soil pH	Grain Yield (kg/ha)	Leaf N (%)	Leaf Mo	Soil Mo	Leaf Mn	Soil Mn
No Lime	5.2 A*	2099 A	4.1 A	0.03	1.18 A	104.3 A	55.3 A
Medium Lime	5.9 B	2380 B	4.3 B	0.02	0.90 A	99.9 A	40.4 B
High Lime	6.4 C	2465 B	4.6 C	0.04	1.71 B	77.1 B	25.4 C

*Numbers followed by the same letter were not different at the 0.05 level of probability.

TABLE 11. Mean Soil pH Values, Soybean Grain Yields, Leaf N, Leaf and Soil Mo and Leaf and Soil Mn Concentrations with the Bragg Variety as Affected by Three Lime Rates at Ames Plantation.

Treatment	Soil pH	Grain Yield (kg/ha)	Leaf N (%)	Leaf Mo	Soil Mo	Leaf Mn	Soil Mn
No Lime	5.3 A*	1705	4.4 A	0.03	0.91 A	92.3 A	50.8 A
Medium Lime	5.9 B	1805	4.5 A	0.02	0.93 A	93.5 A	39.6 B
High Lime	6.5 C	1802	4.7 B	0.02	2.28 B	76.8 B	19.9 C

*Numbers followed by the same letter were not different at the 0.05 level of probability.

treatments, but not among Mo treatments. The mean available soil Mo values for each of the lime treatments from each variety are given in Tables 10 and 11. The results show that with both varieites, only the highest lime rate produced increases in the available soil Mo concentrations.

Results of the plant Mo analyses from both varieites are in Tables 8 and 9. No differences were shown among the lime or Mo treatments. The lack of differences suggest that the soybean plants were able to absorb similar concentrations of Mo from the soil with all of the lime and Mo rates.

The mean leaf N concentrations for each treatment combination from each variety are in Tables 8 and 9. Leaf N was the only variable to exhibit a difference among Mo treatments. This difference was observed only in data from the Bragg variety. The no Mo treatment produced a mean leaf N concentration of 4.4% which was less than the mean leaf N value of 4.6% from the 200 and 800 g/ha Mo rates. As with most of the other dependent variables, there were differences in leaf N among lime treatments with both varieties. The mean leaf N values for each lime treatment are in Tables 10 and 11. With the Essex variety, each increase in the lime rate produced an increase in the leaf N values. With the Bragg variety, however, only the highest lime rate produced a difference in leaf N values.

Soybean yields for the Essex and Bragg varieties are in Tables 8 and 9 respectively. As was the case with most of the other dependent variables, there were no differences among Mo treatments. The lime

treatments, however, did produce yield differences with the Essex variety only. The mean yields for each lime rate from both varieties are in Tables 10 and 11. With the Essex variety, the medium and high lime rates produced higher yields than the no lime rate. Yields produced by the medium and high lime rates were not different.

Previous lime and Mo experiments conducted in Tennessee have produced similar results (H. C. Smith, unpublished data). Treatments for this previous study were 0, 4.5, and 9.0 metric tons/ha of lime and Mo slurry seed treatments of 0 and 35 g/ha. Soybean yields and leaf N concentrations were increased by the Mo applications at all lime rates. However, the magnitude of the increases decreased as the lime rates were increased. Earlier experiments indicate that sufficient lime applications might be just as effective as Mo applications for increasing soybean yields, providing that adequate quantities of potentially available Mo are present in the soil.

Correlation tests were also conducted on all dependent variable combinations with both varieties. The correlation coefficients for both varieties are in Tables 12 and 13.

The results revealed that pH was negatively correlated with exchangeable soil Mn with both varieties. Another negative correlation common to both varieties was exchangeable soil Mn with yield. Other negative correlations which occurred only with the Essex variety were pH with leaf Mn and leaf Mn with yield.

Positive correlations that were common to both varieties were leaf Mn concentrations with exchangeable soil Mn and pH with yield. The Bragg

TABLE 12. Correlation Coefficients of All Measured Variables with the Essex Variety at Ames Plantation.

	Leaf N	Soil pH	Leaf Mo	Soil Mo	Leaf Mn	Soil Mn	Yield
Leaf N	1.00	.56*	-.05	.35*	-.38	-.53	.57*
Soil pH		1.00	.12	.29	-.56*	-.77*	.71*
Leaf Mo			1.00	.01	-.03	-.15	-.03
Soil Mo				1.00	-.39	-.19	.36*
Leaf Mn					1.00	.56*	-.43*
Soil Mn						1.00	-.43*
Yield							1.00

*Coefficients are different from zero at the 0.05 level of probability.

TABLE 13. Correlation Coefficients of All Measured Variables with the Bragg Variety at Ames Plantation.

	Leaf N	Soil pH	Leaf Mo	Soil Mo	Leaf Mn	Soil Mn	Yield
Leaf N	1.00	.29	.00	.29	-.29	-.35	.23
Soil pH		1.00	-.19	.37*	-.20	-.82*	.31*
Leaf Mo			1.00	-.05	.06	.10	-.24
Soil Mo				1.00	-.22	-.44	.19
Leaf Mn					1.00	.36*	-.26
Soil Mn						1.00	-.32*
Yield							1.00

*Coefficients are different from zero at the 0.05 level of probability.

variety produced a positive correlation of pH with available soil Mo. This was expected to occur with both varieties since soil Mo availability increases as the pH of the soil is increased. Data from the Essex variety produced positive correlations of pH with leaf N concentrations, leaf N concentrations with available soil Mo, leaf N concentrations with yield, and available soil Mo with yield. These correlations with the Essex variety also support the theory that increasing the available soil Mo supply results in higher soybean yields.

The soil from this experimental area was analyzed for two forms of Fe, free Fe according to Coffin (11) and amorphous Fe as described by McKeague and Day (35). From these soil Fe values, the active Fe ratio was calculated. The active Fe is simply a ratio of the amorphous Fe to the free Fe. According to Karimian and Cox (27), a high active Fe ratio is associated with a low degree of crystallinity and a recent accumulation of Fe oxides. From the soil analysis and plant nutrition studies of twenty different soils, they found that the relative yield and the Mo concentrations of cauliflower increased as the active Fe ratio of one soil increased over the ratio of another soil. They proposed a theory for predicting the responsiveness of an individual soil and content that the active Fe ratio along with the soil pH can be used to predict successfully the relative yield increases and plant Mo concentrations which would result from additions of Mo to the soil. Of course, comparative data from other Tennessee soils would be required to make accurate predictions.

The soil from the present study yielded a free Fe value of 0.77% and an amorphous Fe value of 0.19%. These values produced an active Fe ratio of 0.25, which would be considered low. Therefore, minimal responses with regard to yield and plant Mo concentrations might be expected from additions of Mo to this soil.

CHAPTER V

SUMMARY AND CONCLUSIONS

In 1975 and 1976, two preliminary experiments involving the application of Mo to soybeans were conducted on Collins silt loam soil. One was a Mo source study and the other was a Mo rate study.

The treatments for the Mo source study were no Mo fertilizer or lime, a banded lime treatment of 280 dg/ha, a slurry seed treatment of Mo at a rate of 35 g/ha, a dry hopperbox seed treatment of Mo plus Captan at the recommended rate, and a broadcast lime treatment at the rate of 6.7 metric tons/ha. The treatments were arranged in a randomized, complete block design with four replications. Plant samples were collected and analyzed for N and Mo content. Soybean yields were also determined.

This experiment revealed differences among treatments with regard to leaf N concentrations and soybean yields. Only the broadcast lime and the slurry seed treatments produced leaf N concentrations which were different from the check plot in both years of the study. In 1975 all treatments, with the exception of the banded lime treatment, produced higher soybean yields than the check plots. In both years, the slurry seed treatment produced the highest soybean yields. Correlation tests revealed that all possible variable combinations were significantly correlated with the exception of the combination of leaf N concentrations with leaf Mo concentrations in 1975.

The slurry seed treatment was the best of the Mo sources tested for increasing soybean yields. When leaf N concentrations were considered,

however, the slurry seed treatment showed no advantage over the broadcast lime treatments.

The Mo treatments for the Mo rate study, which was conducted on two sites in 1975 and one site in 1976, were 0, 7, 14, 21, 28, and 35 g/ha. The treatments for this study were also arranged in a randomized, complete block design with four replications. As with the Mo source study, plant samples were analyzed for N and Mo content and soybean yields determined.

Results from site A in 1975 revealed that only the Mo rate of 21 g/ha produced a leaf Mo concentration which was higher than the leaf Mo concentration from the check plot. The Mo rate of 35 g/ha was the only treatment to produce higher leaf Mo concentrations than the check plot from site B in 1975. All Mo rates from site A in 1975 produced higher leaf N concentrations than the check plot, with the 14, 28, and 35 g/ha rates being responsible for the highest leaf N values. All Mo rates produced higher soybean yields than the check plots in site A in 1975 and 1976. The highest soybean yields were produced by the 35 g/ha Mo rate in site A in 1975 and the 14, 21, 28, and 35 g/ha Mo rates at site A in 1976. At site A in 1975, leaf N concentrations were well correlated with yield. At site A in 1976, leaf N and Mo concentrations were correlated with yield.

The results of this Mo rate study indicate that the addition of Mo at any of the rates used increased soybean yields and leaf N concentrations over the check plot on unlimed, moderately acid Collins silt loam.

In 1977, a lime and Mo rate study was initiated on Loring silt loam. The lime and Mo rates were arranged in two split-plot designs with four

replications each. One split-plot design was planted with the Essex variety of soybeans and the Bragg variety was planted in the other. The lime rates, which were the main-plot treatments, were applied so that each replication contained a low, medium, and high pH level with average values near 5.2, 5.9, and 6.5 respectively. The Mo rates, which were the split-plot treatments, were 0, 200, and 800 g/ha. Plant samples were collected and analyzed for Mn, Mo, and N. Soil samples were also collected and analyzed for Mn, Mo, pH, and amorphous and free Fe. Soybean yields were also determined.

Plant and soil analyses of both varieties revealed that only the lime rates produced differences in the values of the variables measured. Plant analyses for Mn showed that with both varieties the highest lime rate was responsible for the lowest leaf Mn concentrations. Also, soils with the highest lime rates had the lowest exchangeable soil Mn concentrations.

With regard to available soil Mo, the highest lime rate was responsible for the highest soil Mo values with both varieties. The data from both varieties revealed that the highest lime rate was responsible for the highest leaf N concentrations. With soybean yields, however, the lime rates produced differences with the Essex variety only. In this case, the medium and highest lime rates were responsible for the higher soybean yields. The pH data from both varieties revealed that pH values increased with the lime rates.

The Fe analysis of the Loring silt loam soil yielded a free Fe value of 0.77% and an amorphous Fe value of 0.19%. Calculating the ratio of

amorphous Fe to the free Fe gave an active Fe value of 0.25. This active Fe ratio, along with the soil pH is used to predict the relative yield response and plant Mo concentrations which might result from soil applications of Mo. Since the calculated active Fe value of 0.25 is considered to be a low value, minimal responses from added Mo might be expected from the soil used in this study.

The data from the Essex variety resulted in the negative correlations of pH with soil Mn, pH with leaf Mn, soil Mn with yield, and leaf Mn with yield. For the Bragg variety negative correlations were pH with soil Mn and soil Mn with yield. Positive correlations for the Essex variety were leaf Mn with soil Mn, pH with leaf N, soil Mo with leaf N, leaf N with yield, and soil Mo with yield. The Bragg variety produced the positive correlations of leaf Mn with soil Mn, pH with soil Mo, and pH with yield.

The lime and Mo rate study revealed that as lime rates were increased, the Essex soybean yields, the soil pH values, the leaf N concentrations, and the soil Mo concentrations were also increased, while the leaf and soil Mn concentrations were decreased. The Mo rates, however had no effect on any of the measured parameters with the exception of leaf N concentrations in the Bragg variety. A high degree of variation was found to exist in all experiments among Mo treatment levels with regard to leaf Mo concentrations. Therefore, the leaf Mo concentrations would not appear to be a valid indicator for predicting the Mo requirements for a soybean crop.

LIST OF REFERENCES

LIST OF REFERENCES

1. Adams, Fred. 1965. Manganese. p. 1011-1018. In C. A. Black, D. D. Evans, J. L. White, L. E. Ensminger, and F. E. Clark (ed.) Methods of soil analysis part 2. Am. Soc. of Agron. Inc., Madison.
2. Amin, J. V. and H. E. Joham. 1958. A molybdenum cycle in the soil. Soil Sci. 85:156-160.
3. Arnon, D. I. and P. R. Stout. 1939. Molybdenum as an essential element for higher plants. Plant Physiol. 14:599-602.
4. Barr, A. J., J. H. Goodnight, J. P. Sall, and J. T. Helwig. 1976. A user's guide to SAS 76. SAS Institute Inc. Raleigh.
5. Barrow, N. J. and T. C. Shaw. 1975. The slow reactions between soil and anions: 4. Effect of time and temperature of contact between soil and molybdate on the uptake of molybdenum by plants and on molybdate concentration in the soil solution. Soil Sci. 119:301-310.
6. Beeson, K. C. 1954. The micronutrient elements. Southern Cooperative Series Bull. (U.S. Plant, Soil, and Nutrition Laboratory, U. S. Dept. of Agri., Ithaca, New York), 36:175-198.
7. Bergersen, F. J. 1971. Biochemistry of symbiotic nitrogen fixation in legumes. Annu. Rev. Plant Physiol. 22:121-140.
8. Bhella, H. S. and M. D. Dawson. 1972. The use of anion exchange resin for determining available soil molybdenum. Soil Sci. Soc. Am. Proc. 36:177-179.
9. Boswell, F. C. and O. E. Anderson. 1969. Effect of time of molybdenum application on soybean yield and on nitrogen, oil, and molybdenum contents. Agron. J. 61:58-60.
10. Browman, M. G., L. A. Peterson, and G. Chesters. 1970. Availability and extractability of soil manganese in a liming experiment. Commun. Soil Sci. Plant Anal. 1:21-26.
11. Coffin, D. E. 1963. A method for the determination of free iron in soils and clays. Can. J. Soil Sci. 43:7-17.
12. Conner, S. D. 1932. Factors affecting manganese availability in soils. Agron. J. 24:726-734.

13. Cox, F. R. 1968. Development of a yield response prediction and manganese soil test interpretation for soybeans. *Agron. J.* 60:521-524.
14. Davies, E. B. 1956. Factors affecting molybdenum availability in soils. *Soil Sci.* 81:209-221.
15. deMooy, C. J. 1970. Molybdenum response of soybeans (*Glycine max* (L.) Merrill) in Iowa. *Agron. J.* 62:195-197.
16. deMooy, C. J. 1970. For better soybean yields; molybdenum. *Crops and Soils.* 23:11-13.
17. Dolar, S. G. and D. R. Keeney. 1971. Availability of Cu, Zn, and Mn in soils. I. Influence of soil pH, organic matter, and extractable phosphorus. *J. Sci. Food Agri.* 22:273-278.
18. Evans, H. J. 1950. The importance of molybdenum in fertilizer. *Agri. Chem.* 5:31-32, 72-74.
19. Evans, H. J. and N. S. Hall. 1955. Association of molybdenum with nitrate reductase from soybean leaves. *Science* 122:922-923.
20. Evans, H. J., E. R. Purvis, and F. E. Bear. 1951. Effect of soil reaction on availability of molybdenum. *Soil Sci.* 71:117-124.
21. Foster, R. J. 1973. General geology. Charles E. Merrill Co., Columbus.
22. Gurley, W. H. and J. Giddens. 1969. Factors affecting uptake, yield response, and carryover of molybdenum in soybean seed. *Agron. J.* 61:7-9.
23. Hashimoto, K. and S. I. Yamasaki. 1976. Effects of molybdenum application on the yield, nitrogen nutrition and nodule development of soybeans. *Soil Sci. Plant Nutr.* 22:435-443.
24. Henning, S. and T. L. Jackson. 1973. Determination of molybdenum in plant tissue. *At. Absorption Newsletter* 12, 100.
25. Jones, L. H. P. 1956. Interaction of molybdenum and iron in soils. *Science* 123:1116.
26. Jones, L. H. P. 1957. The solubility of molybdenum in simplified systems and aqueous soil suspensions. *J. Soil Sci.* 8:313-327.
27. Karimian, N. and F. R. Cox. 1979. Molybdenum availability as predicted from selected soil chemical properties. *Agron. J.* 71 (in press).

28. Keogh, J. L., R. Maples, G. W. Hardy, and B. Huey. 1971. Limestone and molybdenum studies on soybeans. Ark. Agri. Exp. Sta. Rep. Ser. 193:23p.
29. Kliewer, W. M. and W. K. Kennedy. 1960. Studies on response of legumes to molybdenum and lime fertilization on Mardin silt loam soil. Soil Sci. Soc. Am. Proc. 24:377-380.
30. Lavy, T. L. and S. A. Barber. 1963. A relationship between the yield response of soybeans to molybdenum applications and the molybdenum content of the seed produced. Agron. J. 55:154-155.
31. Lavy, T. L. and S. A. Barber. 1964. Movement of molybdenum in the soil and its effect on availability to the plant. Soil Sci. Soc. Am. Proc. 28:93-97.
32. Long, O. H. and R. J. Lewis. 1966. Molybdenum content of the leaf and seed of soybeans. Tenn. Farm and Home Sci. Prog. Rep. 59:4-5.
33. Long, O. H., J. R. Overton, T. McCutchen, and L. M. Safley. 1965. Molybdenum on soybeans. Tenn. Farm and Home Sci. Prog. Rep. 55:10-13.
34. Maclean, K. S. and W. M. Langille. 1976. The extractable trace element content of acid soils and the influence of pH, organic matter, and clay content. Commun. Soil Sci. Plant Anal. 7:777-785.
35. McKeague, J. A. and J. H. Day. 1966. Dithionite- and oxalate-extractable Fe and Al as aids in differentiating various classes of soils. Can. J. of Soil Sci. 46:13-22.
36. Mortvedt, J. J., P. M. Giordano, and W. L. Lindsay. 1972. Micronutrients in agriculture. Soil Sci. Soc. of Am., Inc., Madison.
37. Norman, A. G. 1963. The soybean: genetics, breeding, physiology, nutrition, management. Academic Press, New York.
38. Ohki, K. 1976. Manganese deficiency and toxicity levels for 'Bragg' soybeans. Agron. J. 68:861-864.
39. Ohlrogge, A. J. 1960. Mineral nutrition of soybeans. Adv. Agron. 12:229-263.
40. Ohlrogge, A. J. and E. J. Kamprath. 1968. Fertilizer use on soybeans. p. 273-293. In L. B. Nelson (ed.) Changing patterns in fertilizer use. Soil Sci. Soc. of Am., Inc., Madison.
41. Parker, M. B., H. B. Harris, H. D. Morris, and H. F. Perkins. 1969. Manganese toxicity of soybeans as related to soil and fertility treatments. Agron. J. 61:515-518.

42. Parker, M. B. and H. B. Harris. 1962. Soybean response to molybdenum and lime and the relationship between yield and chemical composition. *Agron. J.* 54:480-483.
43. Peterson, N. K. and E. R. Purvis. 1961. Development of molybdenum deficiency symptoms in certain crop plants. *Soil Sci. Soc. Am. Proc.* 25:111-117.
44. Price, N. O. and W. W. Moschler. 1965. Effect of residual lime in soil on minor elements in plants. *J. Agri. Food Chem.* 13:163-165.
45. Randall, G. W., E. E. Schulte, and R. B. Corey. 1975. Effect of soil and foliar-applied manganese on the micronutrient content and yield of soybeans. *Agron. J.* 67:502-507.
46. Randall, G. W., E. E. Schulte, and R. B. Corey. 1976. Correlation of plant manganese with extractable soil manganese and soil factors. *Soil Sci. Soc. Am. J.* 40:282-287.
47. Robertson, W. K., L. G. Thompson, and F. G. Martin. 1973. Manganese and copper requirements for soybeans. *Agron. J.* 65:641-644.
48. Robinson, W. O., G. Edington, W. H. Arminger, and A. V. Breen. 1951. Availability of molybdenum as influenced by liming. *Soil Sci.* 72:267-274.
49. Scott, W. D. and S. R. Aldrich. 1970. Modern soybean production. *The Farm Quarterly, Cincinnati.*
50. Sedberry, J. E., Jr., T. S. Dharmaputra, R. H. Brupbacher, S. A. Phillips, J. G. Marshall, L. W. Sloane, D. R. Melville, J. L. Rabb, and J. H. Davis. 1973. Molybdenum investigations with soybeans in Louisiana. *La. Agri. Exp. Sta. Bull.* 670.
51. Smith, B. H. and G. W. Leeper. 1969. The fate of applied molybdate in acidic soils. *J. Soil Sci.* 20:246-254.
52. Smith, H. C. 1973. Lime and molybdenum in soybean production. *Tenn. Farm Home Sci. Prog. Rep.* 85:28-31.
53. Soil Conservation Service. 1978. Soil survey, Madison County, Tennessee. *USDA-SCS and Tenn. Agri. Exp. Sta. Knoxville, TN.*
54. Tisdale, S. L. and W. L. Nelson. 1966. Soil fertility and fertilizers. *The Macmillan Co., New York.*
55. Thomas, R. L., R. W. Sheard, and J. R. Moyer. 1967. Comparison of conventional and automated procedures for nitrogen, phosphorus, and potassium analysis of plant material using a single digestion. *Agron. J.* 59:240-243.

56. Thompson, L. and T. K. Walker. 1972. Soybean response to molybdenum on old rice soils irrigated with reservoir water. Ark. Farm Res. 21:29.
 57. Thompson, W. R., Jr. and W. N. Miley. 1977. Do soybeans need micronutrients? Prog. Farmer 92:28.
 58. Walsh, L. M. 1971. Instrumental methods for analysis of soils and plant tissue. Soil Sci. Soc. Am., Inc., Madison.
- 

VITA

Dennis B. Seaton was born in Hardin County, Tennessee, on March 24, 1954. He attended public school in Savannah, Tennessee, and graduated in 1972 from Hardin County Central High School. In June of 1976, he received a Bachelor of Science degree in Plant and Soil Science from the University of Tennessee in Martin. He attended graduate school at the University of Tennessee in Knoxville and received a Master of Science degree in Plant and Soil Science in March of 1979.