

UNIVERSITY OF FLORIDA
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A MANGANESE DEFICIENCY AFFECTING BEANS

G. R. TOWNSEND and H. H. WEDGWORTH

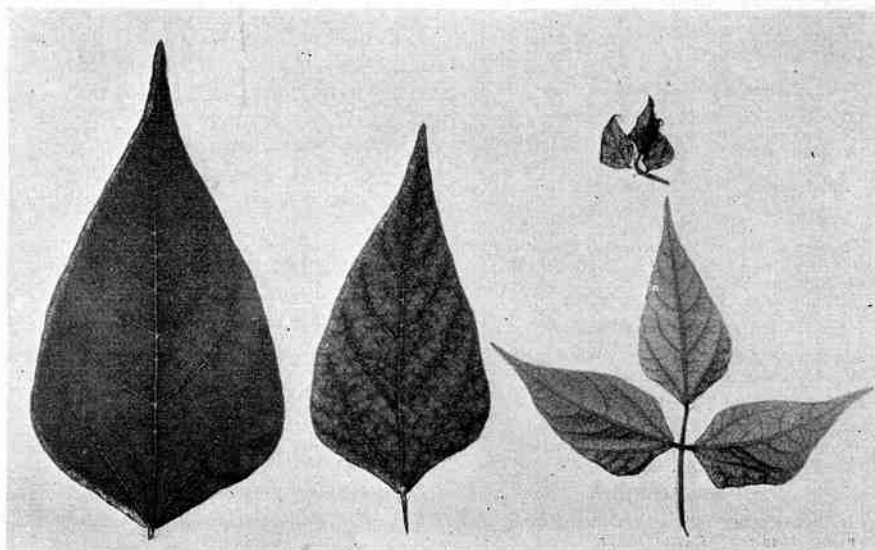


Fig. 1.—Leaf symptoms of manganese deficiency on beans, showing different stages of the disease from normal leaflet on left to severe chlorosis and necrosis of young leaf on upper right.

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A MANGANESE DEFICIENCY AFFECTING BEANS

G. R. TOWNSEND and H. H. WEDGWORTH¹

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INTRODUCTION

The development of large areas of peat soil in the Florida Everglades for agricultural purposes has been attended by the occurrence of problems involving the use of the less common elements. Allison, Bryan and Hunter (2)² reported on the stimulation of plant response on raw saw-grass soils through the use of copper sulfate and other chemicals in 1927. This study of a manganese deficiency disease of beans is an outgrowth of their experiments.

For a number of years prior to 1927 it had been observed that beans growing in certain areas failed to produce good crops. Most of the area involved at that time was made up of the more mineralized custard apple soil near the shores of Lake Okeechobee. The trouble has been found to extend into the saw-grass soil as more of it has been cleared for agricultural use.

It is now known that the failure of beans on these areas is due to a deficiency of available manganese. The soils exhibiting this deficiency are calcareous as the result of burning or through admixtures of marl. Because of the slightly acid to alkaline reactions prevailing in these soils the solubility of manganese is reduced to such an extent that the supply is inadequate for the nutritional requirements of several different kinds of vegetables.

¹Mr. Wedgworth formerly was Assistant Plant Pathologist at the Everglades Experiment Station. The authors wish to acknowledge the assistance given in the conduct of this work by Dr. R. V. Allison, under whose guidance the project was initiated by Dr. J. L. Seal in 1927, and by Mr. R. E. Robertson who has contributed some chemical data.

²Italic figures in parentheses refer to "Literature Cited" in the back of this bulletin.

The disease is not limited to beans, but has been observed on peas, cowpeas, cabbage, potatoes, celery, radishes, beets, carrots, cauliflower, forage crops and sugarcane. On all of these crops the symptoms of yellowing and death of the plant are somewhat similar. In the study of the problem beans were chosen for most of the work because of the economic importance of this crop. What is to be said about manganese deficiency in beans may be applied to almost all crops growing under similar conditions.

In 1927 J. L. Seal, Associate Plant Pathologist, undertook an investigation of the pathological aspects of the problem. R. V. Allison cooperated in this work in his capacity as Soil Technologist.

An examination of the fields clearly showed the relation of crop failure to areas of burned soil, since areas where yellowed plants grew followed very closely the irregularities of the burning of the surface soil. A few areas were found in which the trouble was associated with soils having a high content of shell or marl, or where calcareous waters had flowed over the fields from roadsides or canal banks.

Allison and Seal conducted a series of row tests of several materials for the correction of yellowing in beans during the 1927-28 season on several farms in the vicinity of Lake Okeechobee from Canal Point to Moore Haven. The work was interrupted in 1928 by the hurricane and by the subsequent resignation of Dr. Seal. It was resumed by Dr. Allison in 1929. Field and greenhouse pot experiments were used that year to determine the effects of applications of copper, manganese, sulfur and superphosphate to burned peat soils upon growth of beans and cowpeas.

All of these early experiments showed that yellowing and death of beans and cowpeas could be prevented by the use of manganese sulfate or sulfur or both. The use of superphosphate caused slightly improved growth of beans in some of the experiments. This effect may have been due to impurities in the superphosphate. These trials seemed to be conclusive in showing that copper could not be substituted for manganese, nor manganese for copper.

Dr. Seal isolated fungi and bacteria from roots and stems of bean plants affected with yellowing. Among these organisms were species of *Rhizoctonia*, *Fusarium*, *Rhizopus*, *Penicillium* and *Aspergillus*. All fungi found are common soil inhabitants

and might be expected to occur in the superficial lesions on bean roots and stems.

Wedgworth followed up this work and found that beans growing in steam sterilized burned soil remained normal. When bits of non-sterile soil were added to the sterile soil, the beans wilted from fungous attack. A species of *Fusarium* was isolated from the wilted plants. Yellowing of the beans occurred in the non-sterilized burned soil. Reaction studies showed that the soil had increased in acidity when sterilized with steam. It is thought that sterilization of the soil made enough manganese available that the beans did not become chlorotic in the sterile soil. The experiment was repeated with similar results.

The experiments described in the following sections of this paper were conducted by the junior author from 1930 to 1932, and subsequently by the senior author. The earlier experiments conducted by Allison (1) and Seal (11) have been of considerable benefit in the solution of the problems.

REVIEW OF THE LITERATURE

Since the early studies of Richard (10), reported in 1898, on the distribution of manganese in soils, plants, and many animal products, the literature on the relation of this element has become exceedingly voluminous. Thus as early as 1902 Voelcher (13) was demonstrating beneficial effects with the use of certain soluble manganese salts on the development of wheat and barley in pot cultures at Woburn, while Nagaoka (9) was using the element to advantage for stimulation of the rice plant under certain conditions in Japan. Much confusion is to be found in results obtained with this element until the dominating role of soil reaction was clearly established.

The recent paper by Hopkins (4) is a valuable source of information pertaining to the role of manganese in plant nutrition. His review of the literature and well executed experiments leave little doubt that manganese must be considered an essential element for plant growth. Whereas, formerly, much of the evidence pointed to the toxic effects of manganese on plant growth, there is now a considerable body of evidence to show that low concentrations of this element are essential for plant growth. Deficiencies of available manganese occur in several states in this country and in Australia. The condition usually is associated with calcareous soils in which manganese is mostly

insoluble. That the deficiency may arise in strongly acid soils through the leaching of soluble manganese has recently been suggested by Bryan (3).

The need for manganese in plant growth has been demonstrated by the experiments of McHargue (7) with Volusia silt loam and Dunkirk clay loam soils, and with nutrient solution and sand cultures. Additions of small amounts of manganese to the soil increased growth of radishes and cowpeas in neutralized soils but not in acid soils. Cowpeas grown in sand cultures deficient in manganese became chlorotic after a few weeks, and brown specks developed on the chlorotic leaves.

Willis (14) worked with an unproductive soil from the lower coastal plain in North Carolina. Soybeans planted on such soil became chlorotic and this symptom was intensified by liming. When manganese sulfate was applied the chlorosis resulting from applications of lime or calcium phosphate was corrected.

Skinner and Ruprecht (12) found in South Florida that the application of manganese sulfate to marl soils having reactions of pH 7.5 to pH 8.8, prevented severe yellowing of tomatoes, potatoes, beans, cabbage, cauliflower, carrots, beets and corn and induced normal growth.

Mann (6) has shown that in Dunkirk gravelly sandy loam and Dunbar fine sandy loam the solubility of manganese decreases as the hydrogen ion concentration decreases. The addition of a ton of lime to the acre reduced the solubility of manganese by four to 12 times in these soils. Manganese was only slightly soluble in these soils at pH 6.5 and above. Soybeans grown in Dunbar fine sandy loam were chlorotic in proportion to the amount of lime added. Absorption of manganese by these plants was highest in acid soil and decreased constantly with each addition of lime. Chlorosis of leaves disappeared soon after they were dipped in a 1:1,000 solution of manganese sulfate.

McLean (8) appears to have been the first to make applications of manganese to the foliage of diseased plants. He pumped manganese solutions into leaves of chlorotic spinach plants through their stomata. It was observed that leaves of the treated plants became greener and the plants weighed more than non-treated plants.

Lee and McHargue (5) found that Pahala blight of sugarcane is a manganese deficiency disease. By dusting the foliage with sulfur and manganese they found that affected leaves became greener and made better growth than non-treated plants.

The earliest indication that manganese might be needed for

normal growth of crops in Florida Everglades peat soils was obtained by Allison, Bryan and Hunter (2). Their studies showed that response from manganese sulfate was sometimes as great as that obtained from an application of copper sulfate. Photographic records of their experiments show remarkable growth responses where these salts were applied to raw saw-grass peat.

Bryan³ in 1929 reported stimulatory effects of copper and manganese solutions applied to chlorotic foliage of beans and cowpeas growing in Everglades peat soils. He found that solutions containing 50 p.p.m. of manganese sulfate restored the chlorophyll in chlorotic leaves in a few days after the solutions were applied to the foliage.

SYMPTOMS OF MANGANESE DEFICIENCY

As a rule bean plants grow normally for several days after germination before they begin to show symptoms of manganese deficiency. The

first symptom to appear is a slight loss of the green color in the trifoliate leaves. The yellowing does not spread to the cotyledonary leaves until late in the development of the disease. At first the trifoliate leaves show a faint mottled pattern, the tissue near the veins remaining green longer than the islets of tissue between the

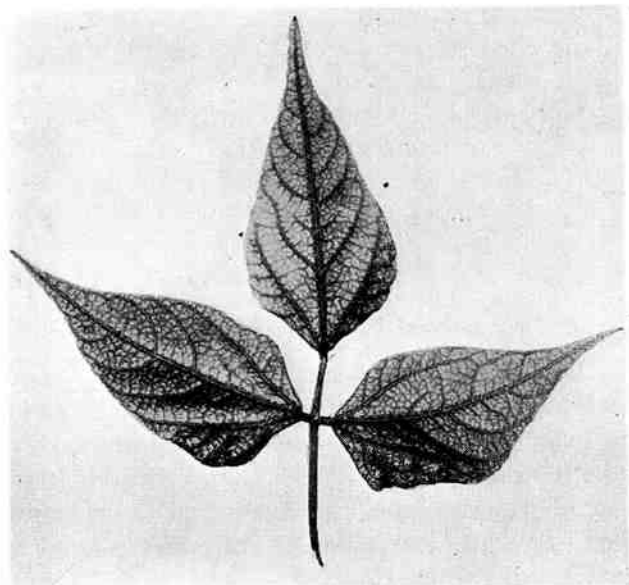


Fig. 2.—Advanced stage of manganese deficiency on bean leaf, showing necrotic spots along mid-rib and veins of chlorotic leaf.

Growth of the plants is retarded when these symptoms appear and the chlorotic leaves never attain normal size.

³Bryan, O. C. The effects of external applications of copper and manganese on certain chlorotic plants of the Florida Everglades soils. *Jour. Amer. Soc. Agron.* 21: 923-933. 1929.

Usually it is only a few days from the appearance of this first mottling until the entire leaf blade has turned a golden yellow. Before the leaf is fully yellow small necrotic brown spots can be seen closely parallel to each side of the midrib and principal veins between their lateral branches. All of these stages are shown in Fig. 1. By the time the leaf has become yellow these spots appear as rows of stipples extending to the tips and margins of the leaves (Fig. 2). Subsequently, the undersurface of affected leaves appears to be cupped between the veins, while the upper surface of the same areas appears water-soaked, and soon breaks down.

New growth from the apical bud becomes slower as the disease progresses, and the buds eventually die. Each successive leaf which forms is smaller and more chlorotic than the preceding one. By the time the bud dies all leaves have become brown and withered. Frequently there is secondary growth from lateral buds. Defoliation is the final symptom to appear before the death of the stems.

The root systems of affected plants appear to be normal except that they are somewhat less extensive. Lesions occur no more frequently on the primary roots of diseased than on healthy plants. Wet soil may contribute to manganese inavailability and under such conditions the presence of root pathogens is to be expected.

EXPERIMENTAL STUDIES

RELATION OF SOIL REACTION TO DEFICIENCY OF MANGANESE

This relationship has been studied experimentally by the alteration of the reaction of the soil towards both alkalinity and acidity. Burned soil was acidified with sulfur, and non-burned soil was made alkaline by additions of lime. In each instance the soil used for the experiment was screened and mixed. Sixteen kilograms of each soil were placed in each of 21 eight-gallon glazed crocks. The soil to be made acid was treated with sulfur at rates of one-quarter ton to eight tons per acre. The non-burned soil was treated with hydrated lime at rates of five-eighths ton to 20 tons per acre. Three pots of soil were used for each treatment. On December 4, 1930, these pots were planted with beans of the Bountiful variety. Soil samples were taken for pH tests several times during the growth of the crop. The data shown in Table 1 indicate that the soil solution was buffered against both hydrogen and hydroxyl ions as only the

applications of large amounts of lime and sulfur caused much change in the soil reaction.

TABLE 1.—EFFECT OF SULFUR AND LIME ON THE REACTION OF PEAT SOIL AND ON THE GROWTH OF BEAN PLANTS.

Pots	Treatment	Reaction of Soil on Dates Indicated after Treatment				Green weight of plants in 3 pots
		12/9	1/3	1/17	1/31	
Treated 12/3		Burned Soil				
1-3	None	7.5	7.5	7.6	7.4	98 g.
4-6	4 g. sulfur per pot	7.3	7.2	7.3	7.2	368 g.
7-9	8 g. sulfur per pot	7.3	7.3	7.3	7.2	254 g.
10-12	16 g. sulfur per pot	7.2	7.2	7.3	7.1	228 g.
13-15	32 g. sulfur per pot	7.1	7.2	7.2	7.1	249 g.
16-18	64 g. sulfur per pot	7.1	7.1	7.0	6.8	82 g.
19-21	128 g. sulfur per pot	7.1	7.0	6.4	6.0	51 g.
Treated 11/1		Non-burned Soil				
1-3	None	6.1	6.0	6.1	6.3	560 g.
4-6	10 g. Lime per pot	6.2	6.2	6.1	6.2	273 g.
7-9	20 g. Lime per pot	6.3	6.4	6.5	6.2	163 g.
10-12	40 g. Lime per pot	6.6	6.7	6.8	6.5	133 g.
13-15	80 g. Lime per pot	7.0	7.1	7.3	6.8	122 g.
16-18	160 g. Lime per pot	7.2	7.3	7.4	7.2	291 g.
19-21	320 g. Lime per pot	7.5	7.6	7.6	7.5	218 g.

Plants on the non-treated burned soil became yellow and developed necrotic spots by the 18th day. The lightest application of sulfur prevented the development of necrotic spots and improved the color of the foliage. Heavier applications also prevented the symptoms of extreme manganese deficiency but the plants so treated were injured by the high concentration of sulfur, as indicated by the difference in green weights (Table 1). In the series of lime treatments on non-burned soil the check plants were normal. Applications of 10, 20, 40 and 80 grams of hydrated lime per pot caused yellowing and the development of necrotic spots, increasing in severity with the quantities added. However, no necrotic spots occurred on plants with the two heaviest lime treatments; these were not so yellow and grew better than those with less lime.

EFFECT OF MANGANESE AND SULFUR APPLICATIONS

The work of Seal (11) and Allison (1) suggested the practicability of controlling bean yellowing by the application of manganese to the soil in which the deficiency occurred. A preliminary experiment in 1930 showed that the application of maniferous solutions to burned soil at the time beans were planted prevented yellowing. When the treatment was delayed

until the first trifoliate leaves were yellow, partial recovery occurred within 48 hours in the leaves already formed and the new growth remained normal.

Application to the Soil.—With the knowledge that bean yellowing could be controlled by supplying soluble manganese or by acidifying the burned soil with sulfur, an experiment was designed to test the value of manganese and sulfur as fertilizer supplements. A series of field plots in four replications was laid out on an area of burned peat soil. Each plot was 12½ feet by 20 feet, or 1/174th acre in size. Ash was present in the soil and the reaction was approximately pH 6.5. All plots received a uniform application of potash, superphosphate, and copper sulfate. Manganese sulfate and sulfur were applied in varying amounts according to a schedule. These materials were applied in the row and worked into the soil.

Following the treatments in the spring of 1932 Bountiful beans were grown on the plots. This crop showed that complete control of bean yellowing could be obtained through the use of sulfur and manganese, particularly in combination. During the summer the plots were planted to cowpeas which gave evidence of some residual effects of the heaviest treatments. In the fall the plots were retreated and planted to another crop of Bountiful beans. In this crop the treated plots produced an entirely normal growth of beans, whereas the non-treated plots produced no crop (Fig. 3). Cabbage plants were transplanted to the plots after the beans had been harvested. Without further treatment cabbage growth was normal on the plots which had previously received heavy applications of sulfur and manganese. On the check plots the cabbage became very chlorotic and failed to grow.

The data presented in Table 2 were obtained from the two crops of beans grown on these plots. The figures represent the average number of hampers of beans per acre picked from the four replications of each treatment. Only the data for the first picking in each crop are presented, because a flood destroyed the second crop one day after the first picking had been made. If all pickings had been obtained the yields would have been much higher, but relative values would be the same. This was observed in the first crop where four pickings were made.

The data in Table 2 show that failure of beans on burned peat soil can be prevented by supplementing the usual fertilizer with sulfur or manganese. Yields on all plots treated with man-

ganese or sulfur, or both, were greatly in excess of those from non-treated plots. In fact, beans from check plots were of such poor quality that it may be said there was a crop failure. Beans from treated plots were of good quality.

TABLE 2.—YIELDS OF BEANS ON BURNED PEAT SOIL WITH SUPPLEMENTARY TREATMENTS.

Treatment*	Hampers of Beans per Acre		Average
	1st Crop	2nd Crop	
None	8.9	0.2	4.6
Mn	71.5	63.8	67.6
Mn-S	83.3	101.9	92.6
Mn-2S	85.2	109.7	97.4
Mn-4S	91.0	128.6	109.8
Mn-8S	92.0	134.5	113.2
2 Mn-2S	87.2	111.0	99.1
2 Mn-4S	96.5	112.8	104.6
5 Mn	119.5	98.5	109.0
5 Mn-S	110.6	119.8	115.2
5 Mn-2S	113.2	125.7	119.4
5 Mn-4S	118.5	118.5	118.5
5 Mn-8S	114.7	117.4	116.0
10 Mn	138.4	106.7	122.5
10 Mn-2S	127.9	136.8	132.3
20 Mn	115.6	119.9	117.7
S	19.1	75.7	47.4
2S	21.1	95.1	58.1
4S	32.3	115.8	74.0
8S	24.4	104.7	64.5

*Mn = 5 pounds manganese sulfate per acre.

S = 25 pounds sulfur per acre.

It is to be noted in the data (Table 2) that the increment in yields due to the application of more than 25 pounds of manganese sulfate is small. Fifty pounds of this material to the acre was the most that gave a response measurable in yields. Sulfur applied with manganese gave somewhat higher yields than could be obtained with manganese alone. The effect of 25 pounds of sulfur alone was not so great as that due to 25 pounds of manganese sulfate alone. Two hundred pounds of sulfur per acre in the row depressed yields slightly.

Samples of leaves were collected from representative plants on several of these plots. The leaves were carefully washed in distilled water, dried in the oven at 100°C., ashed and analyzed for manganese. The analyses showed that little manganese had been absorbed by plants growing without manganese in the fertilizer. The use of only five pounds of manganese sulfate per acre did not increase the absorption of manganese in meas-

urable amounts. When the same amount of manganese was used with 50 pounds of sulfur the absorption was greatly increased. Higher quantities of manganese alone and with sulfur also increased the absorption of manganese. Two hundred pounds of sulfur used alone doubled the absorption of manganese.

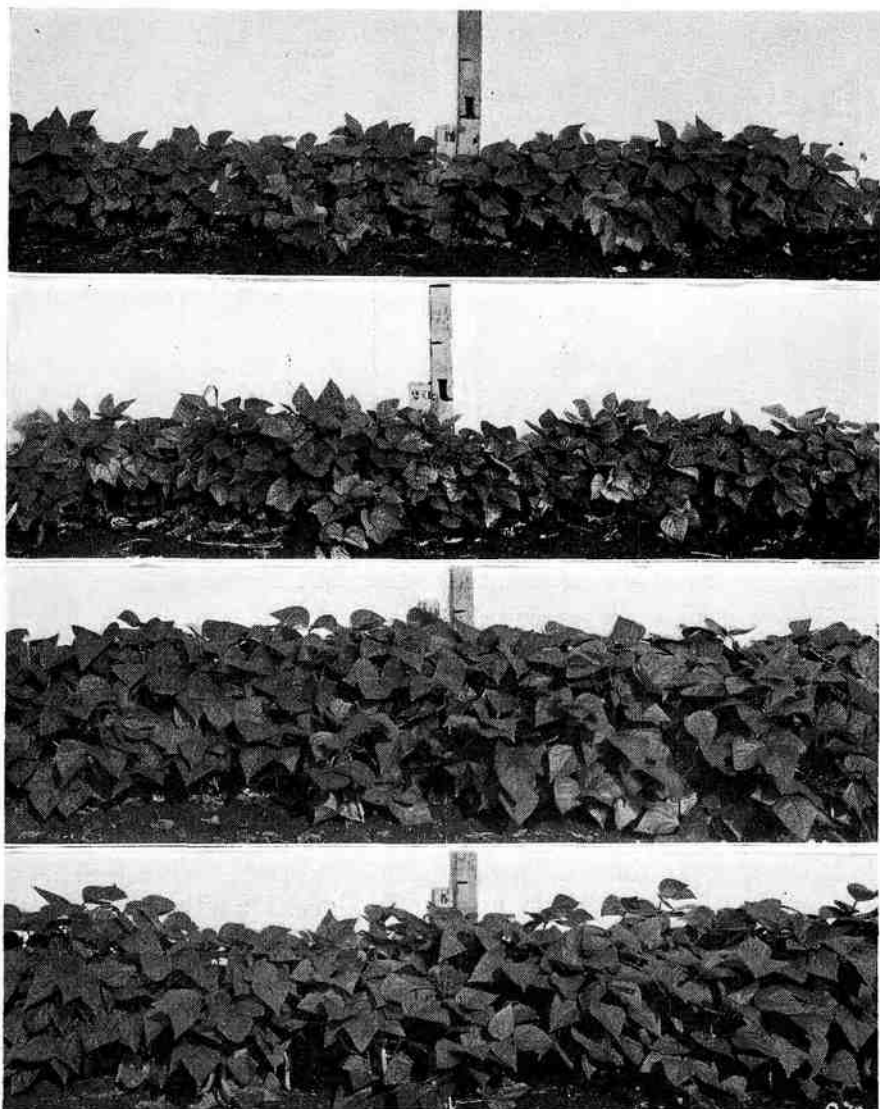


Fig. 3.—Control of bean yellowing by the use of manganese and sulfur in the fertilizer. From top to bottom the treatments are: None; 50 pounds sulfur per acre; 25 pounds manganese sulfate and 50 pounds sulfur per acre; and 100 pounds manganese sulfate per acre.

TABLE 3.—AMOUNTS OF MANGANESE FOUND IN BEAN LEAVES FROM PLOTS TREATED WITH MANGANESE AND SULFUR.*

Treatment Pounds per Acre	Manganese P. P. M.
None	9.9
5 lbs. manganese sulfate	9.5
5 lbs. manganese sulfate plus 50 lbs. sulfur	35.5
50 lbs. manganese sulfate	24.4
50 lbs. manganese sulfate plus 50 lbs. sulfur	113.3
100 lbs. manganese sulfate	84.1
200 lbs. sulfur	18.0

*Analyses by R. E. Robertson.

Application to the Plants.—A preliminary experiment in the fall of 1931 showed that yellowed beans quickly recovered when sprayed with a 1 percent manganese sulfate solution. This was a row test in a field which had become severely yellowed at the time of the application. Two applications appeared to be better than one.

Beans growing in pots of burned soil in the greenhouse were used to check the effect of manganese solutions sprayed on the foliage. The soil was uniformly mixed and had a reaction of pH 7.9. Beans exhibited typical manganese deficiency symptoms when grown in this soil without treatment.

TABLE 4.—DATA RELATIVE TO YELLOWED BEANS SPRAYED WITH MANGANESE SULFATE.

Treatment	Applications	Appearance	Total green weights per 3 pots in grams
	1. Beans 11 days old 2. Beans 23 days old 3. Beans 33 days old		
None		Severe yellowing	195
100 lbs. per acre applied in soil on previous crop		Severe yellowing	183
$\frac{1}{16}$ of 1 percent sol.	1, 2, 3,	Moderate yellowing	346
$\frac{1}{8}$ of 1 percent sol.	1, 2, 3,	Green	560
$\frac{1}{4}$ of 1 percent sol.	1, 2, —,	Green	513
$\frac{1}{2}$ of 1 percent sol.	1, —, —,	Slight yellowing	368
$\frac{3}{4}$ of 1 percent sol.	1, —, 3,	Slight yellowing	438
$\frac{1}{4}$ of 1 percent sol.	—, 2, —,	Moderate yellowing	342
$\frac{1}{2}$ of 1 percent sol.	—, —, 3,	Moderate yellowing	324
1 percent sol.	1, 2, 3,	Green	546
5 percent sol.	1, 2, 3,	Green	491

After the first symptoms of manganese deficiency were evident three applications of solutions of manganese sulfate (C. P.) were atomized on the leaves. Care was exercised to keep the spray from reaching the soil. One soil treatment at the rate

of 100 pounds of manganese sulfate per acre for a previous crop was used for comparison. There was some foliage injury from the 5 percent manganese solution. Two applications of one-fourth of 1 percent solution were enough to cause yellowed plants to recover permanently. The effects were noticeable within 30 hours. The beans grew for 55 days before the final notes and weights were taken.

To be certain that results obtained with manganese sulfate sprays were not due to impurities, a series of treatments was set up similar to those of the previous experiment, except that only one concentration of manganese sulfate was used and several other chemicals were included. All of the chemicals were of the C. P. grade. The evidence obtained here indicates quite clearly that the results obtained in previous experiments have been due to manganese. Iron in three forms and zinc sulfate failed to have any effect upon the chlorotic condition of bean leaves associated with weakly acid to alkaline soils. It was interesting to note also that manganese carbonate, which is relatively insoluble in cold water, had no corrective effects. Manganese chloride caused some burning but was effective in restoring the green color to the foliage. Responses obtained with several of these treatments are shown in Fig. 4.



Fig. 4.—Bean plants which had been sprayed with several chemicals for the prevention of the chlorosis caused by a deficiency of available manganese. From left to right the applications were: One-half percent zinc sulfate solution; $\frac{1}{2}$ percent ferric chloride solution; $\frac{1}{2}$ percent ferric sulfate solution; $\frac{1}{2}$ percent ferrous sulfate solution; $\frac{1}{2}$ percent manganese carbonate solution; $\frac{1}{2}$ percent manganese chloride solution; and $\frac{1}{2}$ percent manganous sulfate solution.

Field plots were laid out for testing applications of manganese and sulfur to the foliage of yellowed beans for the correction of yellowing. The soil contained ash and had a reaction of about pH 6.9. Four replications of each treatment were made. Ex-

cept for a few minor alterations these plots were used for two crops of beans. A crop of cowpeas grown on the plots after the first crop of beans was not sprayed and gave no evidence of any residual effects of the applications to the foliage. The cowpeas died on all plots except on those treated with manganese in the fertilizer.

The treatments were started two weeks after the seed were planted, and when the young beans had been up for nine days. At this time the earliest symptoms of yellowing were visible in the first trifoliate leaves. Subsequent applications were made at intervals of 10 or 12 days.

The sprays were applied with a barrel pump equipped with a hose and spray rod with three nozzles. One row was sprayed at a time. Such an outfit gave good coverage and used about 100 gallons of the spray solutions to the acre. The dusts were applied with a hand duster at the rate of 35 pounds per acre.

In both crops of beans the results were a striking confirmation of the data obtained in the greenhouse. Yellowed leaves began to turn green within 36 hours after the applications. The yield on the non-sprayed plots was negligible. Where two or more applications of manganese sprays had been made the yields were about normal and in some cases equal to that obtained where manganese was added as a fertilizer supplement (Fig. 5). In

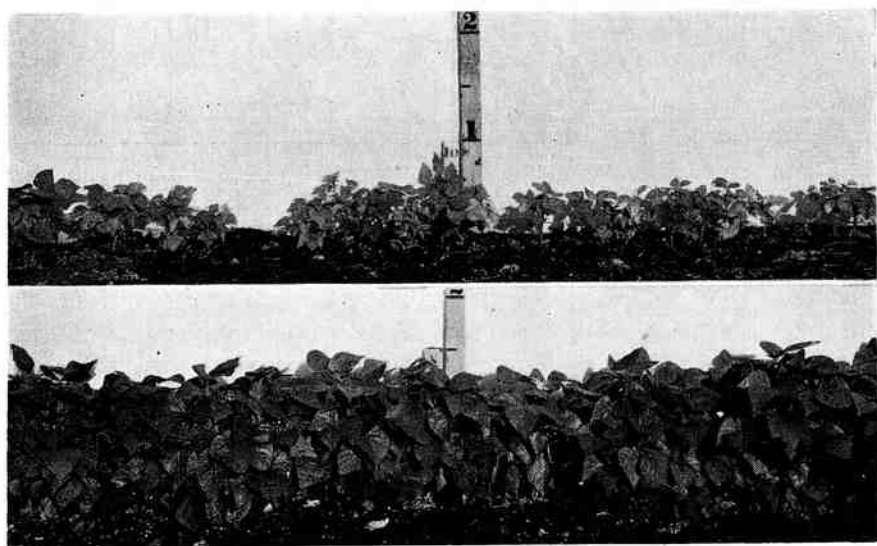


Fig. 5.—Control of bean yellowing by spraying the plants with manganese sulfate solution. Top: No treatment; bottom: Four applications of a 1 percent manganese sulfate solution to plants.

the second crop some burning of the leaves occurred with 1 percent manganese sulfate sprays, but it was observed that this did not occur where 1 percent of hydrated lime had been added to the manganese solution. Mixtures of dusting sulfur and manganese were of some value. The same was true of a sulfur spray (30% sulfur in form of sodium polysulfides) containing 1 percent manganese sulfate. The above sulfur spray used without manganese in the first experiment had a slight effect of itself. The yields from the four replications of each treatment have been averaged and are presented as relative values in Table 5. Plot 4, which was given three applications of a 1 percent manganese solution, has been used as the basis for all comparisons.

TABLE 5.—RELATIVE YIELDS OF BEANS FROM PLOTS SPRAYED AND DUSTED WITH MANGANESE AND SULFUR.

Treatment	Applications	Relative yield	
		1st crop	2nd crop
1. None		5.0	5.1
2. 50 lbs. manganese	In fertilizer	108.1	125.0
3. 1 percent manganese, spray	1, 2, 3, 4, (*)	116.7	117.5
4. 1 percent manganese, spray	1, 2, 3, —	100.0	100.0
5. 1 percent manganese, spray	1, 2, —, —		101.9
6. 1 percent manganese, spray	1, —, 3, —	72.2	96.5
7. 1 percent manganese plus 1 percent lime	1, 2, 3, 4,	87.6	104.2
8. Sulfur (polysulfides)	1, 2, 3, 4,	18.7	
9. Sulfur (polysulfides) plus 1 percent manganese	1, 2, 3, 4,	106.7	85.5
10. Sulfur-manganese (90-10) dust	1, 2, 3, 4,	69.9	111.6
11. Sulfur-manganese (80-20) dust	1, 2, 3, 4,	77.0	110.6

(*) In the second crop none of the plots received the fourth application.

Analyses of leaf samples collected from plots of this series five days after the last application in the second crop show that there were large quantities of manganese in and on the sprayed leaves. Although the leaves were carefully washed with distilled water before the analysis, it is not certain that all manganese adhering to the leaf surface had been washed off. In fact the wide range of values obtained indicate that particularly with the sulfur-manganese dust applications there was manganese adhering to the leaf surface. The analyses given in Table 6 show that where good growth occurred there was more than 20 parts per million of manganese in the dried material.

TABLE 6.—AMOUNT OF MANGANESE FOUND IN BEAN LEAVES SPRAYED OR DUSTED WITH MANGANIFEROUS MATERIALS.*

Treatment	Parts per million manganese
3 applications of sulfur-manganese (90-10 dust)	243.0
3 applications 1 percent manganese in polysulfide spray	253.0
3 applications 1 percent manganese spray	175.0
3 applications 1 percent manganese plus 1 percent lime spray	29.7
None	9.3

*Analyses by R. E. Robertson.

RESIDUAL EFFECTS OF MANGANESE AND SULFUR IN SOIL

Burned peat soil was screened and mixed to provide a uniform culture medium. Sixteen kilograms of the soil were placed in each of 21 eight-gallon glazed clay pots. The soil had a reaction of pH 7.4. The soil in three pots was treated on August 14 with 2.04 grams of C. P. manganese sulfate per pot (equal to 250 pounds per acre). The salt was applied with rain water and all water supplied thereafter was of this kind. Subsequently, the same treatment was given other pots in the series at intervals of two weeks, until there were five dates of application. The six pots remaining without treatment were considered checks. Six crops of beans were grown in these pots during a period of nine months. After the first crop all the treatments represented residual effects of previous applications made on five different dates.

The first crop of beans was planted on the date of the third application of manganese. Two weeks later all beans on treated soil were about normal, but those on soil not yet treated were yellowing. Plants that were yellowing at the time of the fourth application recovered after it was made. The checks became more severely yellowed. The fifth application date coincided with date of harvest of the first crop.

Before the second crop was grown the soil in all pots received a uniform application of superphosphate, potash, ammonium sulfate and copper sulfate. Green weights and notes as to color were recorded when the crop was 29 days old. These data are shown in Table 7.

The third crop grew for 31 days. When it was harvested the green weights were in the same proportion as for the previous crop, except that the checks had fallen off even more than before. The plants from the three earliest treatments were

slightly yellow, while the two later treatments produced normal plants.

TABLE 7.—COMPARATIVE EFFECTS OF MANGANESE SULFATE ON BEANS AT DIFFERENT PERIODS AFTER TREATMENT.

Number of days after treatment	Green weight of plants per 3 pots	Color of plants
85	299 g.	Slightly yellow
71	295 g.	Slightly yellow
57	328 g.	Trace of yellow
43	348 g.	Green
29	410 g.	Deep green
No treatment	192 g.	Severe yellowing
No treatment	200 g.	Severe yellowing

The fourth and succeeding crops showed almost no differences in green weights or color between the different dates of application, but all plants on treated soil were distinctly better than the checks. The comparative condition of the fourth crop at maturity is shown in Fig. 6.



Fig. 6.—Fourth crop of beans following the application of manganese sulfate to burned soil. Treatments from left to right were: 2.04 grams of manganese sulfate per pot applied 174, 160, 146, 132 and 118 days previously, respectively; no treatment was given the last two pots on the right.

In 1931, an area of burned soil was set aside for the study of the cumulative and residual effects of sulfur and manganese treatments. Wooden frames of one inch by six-inch material were placed around plots measuring 40 inches by 78 inches. The tops of the frames were placed slightly above the soil level to confine the treatments to the plots and to prevent the movement of other soil on to the plots. Four replications of each treat-

ment were provided. The soil had been exposed to a surface fire in the past and the ash had become incorporated with the soil to a depth of 12 to 14 inches. The reaction of the soil in all plots varied within a narrow range, averaging about pH 7.7. All plots received a uniform application of superphosphate, potash and copper sulfate at the start and in subsequent treatments. The applications of sulfur and manganese were varied according to a schedule of comparisons. In 1932 the treatments used the previous year were duplicated, but in 1933 some omissions were made to study residual effects.

The weights of Bountiful beans and Little Marvel peas harvested in three crops are presented to show the residual effects of sulfur and manganese. These crops exhibited similar symptoms of manganese deficiency and on the check plots of this series the vines had suffered severely, resulting yields being small and of poor quality. Yields were recorded as grams per plot but have been converted to a value relative to treatment number 10 in all cases. The first crop of beans was harvested in 1931 following the original treatments. In 1932 peas were grown and no yield records were taken. The second set of data with beans was obtained in 1933 after the third treatment with certain omissions. The pea data were secured from a second crop in 1933 without retreatment of the plots, and these together with those for two crops of beans are shown in Table 8.

TABLE 8.—RESIDUAL EFFECT OF SULFUR AND MANGANESE ON THE YIELD OF BEANS AND PEAS ON BURNED PEAT SOIL.

Plot No.	Treatment	Number of years applications were made	pH reactions of soils		Relative yields			Average 1933
			Initial	Final	Beans 1931	Beans 1933	Peas 1933	
1	S*	3	7.7	7.0	8.4	67.4	18.0	42.7
2	S	2	7.7	7.4	18.2	24.1	12.6	18.3
3	2 S	3	7.7	6.5	27.3	86.6	31.8	59.2
4	2 S	2	7.6	7.3	35.0	25.7	12.2	18.9
5	4 S	3	7.6	6.6	57.8	84.2	83.7	83.9
6	4 S	2	7.6	7.1	62.9	72.1	14.2	43.1
7	8 S	3	7.7	6.1	66.1	57.4	139.4	98.4
8	8 S	2	7.6	6.8	80.4	102.0	82.0	92.0
9	16 S	2	7.6	6.0	76.5	99.3	123.2	111.2
10	2 S Mn*	3	7.6	6.9	100.0	100.0	100.0	100.0
11	2 S Mn	S-3: Mn-2	7.6	6.9	101.9	104.5	71.4	87.9
12	Mn	3	7.7	7.5	44.6	91.7	50.1	70.9
13	None	None	7.7	7.5	0.0	37.9	18.0	25.4

*S = Sulfur @ 250 pounds per acre.

Mn = 83 percent manganese sulfate @ 80 lbs. per acre.

It will be seen from Table 8 that the yield from these crops was improved most by treatments which caused increases in soil acidity, or which supplied manganese directly. A combination of manganese and sulfur was more effective than either material used separately.

Those plots which were not retreated for beans in 1933 showed considerably lower yields than plots treated with small quantities of sulfur. Where sulfur was applied at the rate of two tons per acre the yields were depressed in crops following the treatments. This injurious effect disappeared after a few months, for when peas were grown following the beans the highest yields were obtained where three heavy applications of sulfur had been made at the rate of one ton per acre per year.

Residual effects of the treatment are best shown by the data for the crop of peas in 1933. These data represent the effects of two and three applications of sulfur and manganese to previous crops during the period 1931-1933. Difference in yields from plots which had received two and three applications indicated that the materials rapidly became less effective. By comparing the yields from treatments 10 and 11 it is found that the omission of manganese from the third application did not affect the first crop (beans, 1933) but that peas suffered considerably following the beans. The omission of sulfur from the manganese-sulfur mixture in the third application caused a reduction in the yield of beans and peas.

DISCUSSION

The yellowing of beans which occurs on weakly acid to alkaline peat soils in the Florida Everglades is a nutritional disorder attributable to lack of available manganese in such soils. The essential nature of manganese as a nutrient element has been shown by the experiments of those whose papers have been reviewed, and by others. Chlorosis and death of the plant due to insufficient manganese have been observed by those who have studied manganese deficiencies.

In the experiments reported here it was demonstrated that pathogenic organisms are not constantly associated with the disease, and that where such are found they produce lesions or wilting as primary symptoms. These organisms do not produce the characteristic symptoms of manganese deficiency.

On the other hand, the particular symptom complex which has been described is always associated with certain soil con-

ditions. Beans grow normally in peat soil more acid than pH 6.2. The severity of the disease increases with the alkalinity of the soil. This is in accordance with the findings of Mann (6) who has shown that manganese becomes insoluble at low hydrogen ion concentrations. There may be some exceptions to this, as there has been observed apparently normal growth in some very alkaline peat, and as in the case of the experiment with additions of lime, the growth of the beans was somewhat better in alkaline soil than in neutral soil.

Manganese deficiency occurs naturally in soils made about neutral or alkaline by burning, or by underlying marl deposits. It may be experimentally produced by adding lime to the soil.

Evidence has been presented to show that the disease can be prevented by acidifying the soil with sulfur, and that when this is done the plants absorb more manganese. The same result is obtained when manganese sulfate is applied with the fertilizer. The effect of such an application is likely to be more temporary when manganese alone is added than when the soil is acidified by the addition of sulfur. The data indicate that small quantities of manganese applied to alkaline soil soon become as non-available as the manganese naturally occurring there. Mixtures of sulfur and manganese have given the best and most lasting results.✓

The effects of both manganese and sulfur pass away so rapidly that economical benefits from a single treatment should not be expected for more than two crops. On the other hand, it is not well to make heavy applications of sulfur continuously. It was found in the pot experiments that sulfur had a decidedly depressing effect upon the growth of beans when used in large quantities. This effect was not in proportion to the effect of the sulfur upon the soil acidity.

It is suggested that the use of 25 pounds of manganese sulfate and 200 pounds of sulfur per acre per year will maintain normal production on badly burned soil. In general practice an entire field may not need to be treated but only those areas which have been made neutral or alkaline by burning.

The results obtained from spraying the plants with manganese sulfate provided further evidence that manganese is essential to the proper functioning of the plant. In these tests it was apparent that effects were obtained by absorption through the leaf, since in the pot experiments only small quantities of the manganese solutions were atomized on the leaves. None

was allowed to reach the soil so that it could not have acted as a catalyzing agent in the soil, nor have been absorbed by the roots. In the field experiments the quantity of manganese sprayed on the foliage with beneficial results was less than a quarter of the amount needed to secure an equal effect in a soil treatment. Had it not been absorbed by the foliage the effect would have been negligible.

The fact that manganese carbonate failed to correct the chlorosis of bean plants indicates that because of its low solubility it could not diffuse to absorbing surfaces, nor be absorbed by them. Results with sulfur-manganese dusts must be explained, it seems, by the solution of manganese in dew and its subsequent diffusion to the substomatal surfaces.

Manganese appears to be essential in controlling the balance between the synthesis and destruction of chlorophyll. When this element is present chlorophyll is formed in sufficient amount to maintain the plant. Iron and zinc do not function in the same manner when applied to beans growing on manganese deficient soils.

CONCLUSIONS

The chlorosis and death of beans growing on slightly acid or alkaline peat soil is due to a deficiency of available manganese.

The availability of manganese in such soils can be increased by acidifying them with sulfur.

✓ Treatments with manganese sulfate prevent the chlorosis and increase the yield of beans.

Manganese sulfate sprays and dusts will also prevent the chlorosis of beans, and greatly increase the yield.

Iron and zinc are not substitutes for manganese in correcting the condition described.

The effects of both manganese and sulfur applied to the soil decrease rapidly.

For a soil treatment 25 pounds of manganese sulfate and 200 pounds of sulfur per acre should be used each year for the prevention of yellowing on badly burned peat soil.

Spraying with a manganese sulfate solution is considered more economical than soil treatment. (Two applications of a solution containing four pounds of manganese sulfate in 50 gallons of water will usually be sufficient.)

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