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A. B. CONNER, DIRECTOR
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DIVISION OF CHEMISTRY

MANGANESE IN TEXAS SOILS AND ITS RELATION TO CROPS

AGRICULTURAL AND MECHANICAL COLLEGE OF TEXAS
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Manganese is an essential plant food and a few calcareous soils in the eastern part of the United States have responded to applications of manganese sulfate.

Twenty-one Texas soils have been tested for their response to manganese sulfate by means of pot experiments. No marked increase in the growth of crops was produced by manganese sulfate. On six of the soils manganese sulfate was apparently toxic. Out of the thirteen soils reported to have produced chlorotic crops in the field, only two produced chlorotic crops in the greenhouse.

The coefficient of correlation is low between the amount of manganese removed by corn and the percentage of manganese in the soil, being $.437 \pm .04$. The addition of fertilizer containing nitrogen, phosphoric acid, and potash, but no manganese to soils tends to increase the percentage of manganese in the crop. Crops grown on quartz sand tend to take up increasing amounts of manganese when increasing amounts are applied, corn taking up about 10 per cent of the amount applied, cotton much less.

A crop of corn, cotton, or kafir is estimated to require about half a pound of manganese to the acre, and a crop of wheat about one pound. Although some Texas soils are low in manganese, they contain enough for 320 crops of cotton and are better supplied with manganese than with nitrogen, phosphoric acid, or potash.

The manganese content of the soils of the Central Texas Black Prairie is higher than in the soils of East Texas or South Texas. The manganese content of the soils of the Edwards Plateau is the lowest of any section studied.

Manganese sulfate is not recommended for application to Texas soils, as no soils were found to need it.

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BULLETIN NO. 432 AUGUST, 1931

MANGANESE IN TEXAS SOILS AND ITS RELATION TO CROPS*

By E. C. CARLYLE

It has long been recognized that certain elements (carbon, nitrogen, oxygen, hydrogen, phosphorus, potassium, calcium, magnesium, sulfur, and iron) are essential to plant growth. Other elements such as manganese, copper, boron, cobalt, nickle, zinc, and iodine, while known to occur in very small quantities in plants, have not been regarded as essential but have been neglected by investigators until a short time ago. In recent years, however, investigators have found that manganese and perhaps some other of these elements are essential to plant growth. Other workers have found applications of manganese salts of practical advantage to crops on calcareous soils in Florida and on certain limed soils in North Carolina and Rhode Island. Large increases in yields of truck crops on these Florida soils have resulted from the application of relatively small amounts of soluble manganese salts. The deficiency of manganese was shown by a yellowish condition of the leaves of the plants grown on the affected areas.

Texas contains considerable areas of limestone soils, on some of which chlorosis has been reported to occur. While ferrous sulphate seems to be a good remedy for chlorosis in many of these areas, it seemed desirable to ascertain if the chlorosis might be due to a deficiency of manganese. The investigation of possible needs of Texas soils for manganese also seemed desirable on account of need for more knowledge regarding the possible use of manganese salts for application to the soils of the state.

Some reports have been received at this Station of a kind of chlorosis occurring on calcareous soils in southwestern Texas and in the Rio Grande Valley. Kafir has been reported as turning yellow and failing to make a crop, and peach tree leaves have also been reported to turn yellow and fall off.

This investigation has been undertaken partly to determine whether this chlorosis is due to manganese deficiency and whether an application of manganese sulfate would prevent it.

Other soils of a calcareous nature were studied for the purpose of finding out whether they would respond to applications of man-

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ganese sulfate, as manganese as a fertilizer has not been generally used in Texas.

Soils from different sections of Texas were also analyzed for manganese for the purpose of ascertaining the manganese content of typical Texas soil types and comparing them with any soils responding to manganese to determine whether there was any probability of other Texas soil types responding to manganese and whether manganese could be recommended as a fertilizer for any Texas soils.

PREVIOUS WORK

Bertrand (1) in 1897 seems to have first mentioned the possibility that manganese may be an element essential to plant growth. He obtained an enzyme from the sap of the lac tree which he called laccase, which contained considerable manganese. After several years' work on the relation of this element to plant growth, he concluded that it was an essential nutrient and that its functions cannot be performed by any other element.

Brenchley (3) working with plants in water cultures to which the elements then known to be essential were added, found that manganese sulfate at a concentration of one to one million or less, stimulated plant growth; with greater concentrations a toxic effect was obtained. She concluded that in low concentrations manganese may prove to be a nutrient essential to plants.

McHargue (10) found that wheat grown in quartz sand yielded a larger amount of grain and straw when manganese carbonate was added than when manganese was not added, and that wheat without manganese became chlorotic. Grown in water cultures free from manganese, it also became chlorotic and did not grow as large as the wheat grown in cultures containing manganese salts.

McHargue (11) in 1922 obtained practically the same results with a greater variety of plants. With lettuce, spinach, garden peas, cucumbers, oats, and soy beans grown in quartz, McHargue (12) in 1926 obtained good growth when manganese was supplied but poor growth and a chlorotic condition where manganese was not supplied. From the results of these researches, McHargue concluded that plants have enough manganese in the seed to grow normally for four to six weeks, after which manganese deficiency begins to develop if no manganese has been supplied. Failure earlier to recognize manganese as essential was ascribed to the presence of manganese as an impurity in the reagents used. He concluded that manganese is an essential element of plant growth and functions in the synthesis of chlorophyll.

Miller (14) observed chlorotic conditions with tomatoes in sand cultures in the absence of manganese salts. He grew the plants in good greenhouse soil until they were about ten inches high, and then transferred them to pots of quartz sand supplied with Knops nutrient solution containing calcium nitrate, potassium nitrate, potassium phosphate, and magnesium sulfate. About three weeks after the plants were transplanted, they developed chlorosis and stopped growing. The addition of manganese sulfate cured the chlorosis and resulted in normal growth of the plant, but chlorotic spots remained.

Only recently have soils under field conditions been found which supply so little manganese that plants suffer from the lack of it.

Gilbert, McLean and Hardin (7) found that manganese deficiency was the cause of chlorosis in oats, spinach, beans, and wheat, grown on heavily limed soils in Rhode Island. The soils had been limed with limestone high in lime and high in magnesia; so the chlorosis was not caused by a deficiency of magnesium. Applications of iron salts did not cure the chlorotic condition of the plants; so the chlorosis was not caused by iron. Small applications of manganese sulfate cured the chlorosis and enabled the plant to grow in a normal manner. This showed that the heavily limed soils were deficient in available manganese.

Schreiner and Dawson (15) in 1927 published a report on certain soils in Florida deficient in manganese. These are highly calcareous glade soils devoted to truck growing. Inorganic fertilizer, applied heavily, failed to produce a crop; the plants were small and developed typical manganese chlorosis. Barnyard manure or peat used in connection with the fertilizer produced normal growth. Applications of 25 to 50 parts per million of manganese sulfate with the fertilizer also enabled the crop to grow normally. In greenhouse experiments, vigorous growth and fruiting of tomatoes took place on the soil treated with manganese. On the soil with no manganese, the tomatoes grew poorly, did not fruit, and developed chlorosis.

In Rhode Island, Gilbert and McLean (8) found the application of manganese salts on heavily limed soils beneficial to spinach, lettuce, corn, onions, and mangels. On these soils without manganese, crops were chlorotic and showed typical manganese deficiency. With an application of small amounts of manganese sulfate normal growth took placed and an increased yield over the control plots was obtained. An application of as low as eight pounds per acre of manganese sulfate, applied as a spray, was beneficial to lettuce, spinach, and beets.

In North Carolina barren spots occurred on the Lower Coastal Plain where corn and soy beans failed to grow. Willis (21) found that manganese sulfate applied to these areas cured chlorosis in soy beans and corn and produced increased yields. These soils had been so heavily limed as to become unproductive; as in Rhode Island the heavy liming evidently rendered what manganese there was in the soil unavailable to plants.

Skinner and Ruprecht (18) studied glade soils in Florida used for growing winter truck crops for the Northern markets. These soils consist of about six inches of muck underlaid by a calcareous material containing 90 to 95 per cent of calcium carbonate. With an application of 4000 pounds of 4-8-8 fertilizer per acre tomatoes failed to grow unless peat, stable manure or manganese sulfate was applied, the latter at the rate of 50 pounds per acre. The manure and peat evidently furnished the manganese required to produce the crop. A few cars of manganese sulfate are sufficient to do the work of many train loads of manure or peat.

Later work reported in 1930 by Skinner and Ruprecht (19) include tomatoes, potatoes, beans, cabbage, cauliflower, lettuce, carrots, beets, and corn. With tomatoes, 3000 pounds per acre of 4-8-8 fertilizer failed to produce any crop at all, while with 2000 pounds of manure and 150 pounds of manganese sulfate the yield was 492 crates. With 2000 pounds of 5-7-5 fertilizer per acre, plats without manganese yielded 50 bushels of potatoes; with 400 pounds of manganese sulfate added to the fertilizer, 180 bushels were produced. All of the potatoes grown on the plats which received no manganese were unsalable culls, while the potatoes grown on soil treated with manganese were all large. Snap beans fertilized with 1500 pounds per acre of 4-7-5 yielded without manganese 4860 pounds per acre; with 50 pounds per acre of manganese sulfate the yield was 18,400 pounds per acre. Cabbage with 600 pounds per acre of 4-8-5 fertilizer and no manganese yielded 28,215 pounds, and with 100 pounds per acre of manganese sulfate 47,025 pounds. Lettuce with 1600 pounds of 5-7-3 fertilizer and no manganese grew heads of an average weight of 0.5 pound while with the addition of 50 pounds of manganese sulfate the heads weighed 3.0 pounds. Beets were a failure with 1800 pounds of 5-8-6 fertilizer alone, but the addition of manganese sulfate in the fertilizer produced large marketable beets.

From the work reported manganese deficiency is confined to calcareous or heavily limed soils and has so far been found to occur naturally only in relatively small areas in Florida. On limed soils it has been found so far only in Rhode Island and South Carolina. On this class of soils any manganese present is rendered insoluble by the alkaline condition of the soil, and therefore unavailable to plants.

Chlorotic conditions of the plants as reported in Florida, North Carolina, and Rhode Island, are characterized by light green areas appearing on the leaves of the plants; these areas spread rapidly until in a few days the entire plant is affected. The leaves affected seem to be deficient in chlorophyll and the plant becomes stunted in growth and finally dies.

Acid soils do not seem to be deficient in manganese.

Skinner and Sullivan (16) applied manganese salts in pot experiments to a productive Hagerstown loam from the plots of the Pennsylvania Experiment Station. The soil was slightly acid, and they obtained no beneficial results with wheat.

Skinner and Reid reported in 1916 (17) a six-year test with wheat, rye, corn, and soy beans, on an acid silty clay loam soil at the Experiment Station farm at Arlington, Virginia. When no manganese sulfate was used, one acre yielded 4192 pounds of wheat straw and grain; with manganese the yield was 3258 pounds. Rye without manganese yielded 3456 pounds per acre; with manganese, 3424 pounds. Corn without manganese yielded 43 bushels per acre; with manganese, 32 bushels. Cowpeas with manganese yielded 5152 pounds per acre; without manganese, 4702 pounds. All yields of crops were depressed when manganese sulfate was applied. The plots were then neutralized with lime: wheat without manganese yielded 2500 pounds, with manganese 3040 pounds for a three-year average; rye without manganese, 4100 pounds, with manganese, 5173 pounds; corn without manganese, 43 bushels, with manganese, 45 bushels; cowpeas without manganese, 4587 pounds, with manganese, 5020 pounds.

Under some conditions manganese may prove toxic to plants.

Elwell (4) found that certain soils which failed to grow leguminous crops contained a large percentage of soluble manganese salts while the adjacent fertile areas contained no such amounts. He concluded that these soluble salts of manganese contributed to the sterility of the soil.

Kelley (22) found the highly manganiferous soils of Hawaii toxic to pineapples. The application of lime only aggravated the trouble. Kelley had the opinion that the addition of lime created conditions favorable for the formation of the higher oxides, which are the most injurious form of manganese.

Lindsay (9) in Massachusetts found that plats which had become infertile after applications of ammonium sulfate contained 175 parts per million of manganese sulfate; the addition of lime prevented injury by the probable formation of calcium sulfate.

McHargue (13) found that manganese sulfate added to an acid soil retarded the growth of radishes and soy beans. When the soil was made neutral or slightly alkaline with calcium carbonate manganese was beneficial to these crops.

METHODS OF PROCEDURE

In this work, pot experiments were used to determine whether the soils would respond to applications of mangansee sulfate and whether manganese would prevent chlorosis in plants. In pot experiments, variations in the amount of water and in the character of the soil can be controlled to a greater extent than in plat experiments. Attacks of birds and insects can be avoided or reduced and the applications of the various additions can be regulated with more exactness than in field work.

Pot experiments were used by McHargue (12) and Miller (14) in ascertaining whether or not manganese is an essential element for plant growth, by McHargue (12) in testing the effect of different concentrations of manganese on the growth of plants in acid and neutral soils, and by Schreiner and Dawson (15) in testing for deficiency of manganese in the glade soils of Florida.

Method for Pot Experiments

Glazed earthenware pots of two gallons capacity were used in this work so as to eliminate any possibility of contamination by manganese that might result from the use of ordinary galvanized iron pots. Pots were used that had the same weight within 20 grams and contained 5000 ± 20 grams of soil. Manganese sulfate (Mn) in the 1929 series was added in solution at the rate of 125 milligrams per pot, or 50 pounds per acre. In the 1930 series it was added as the solid salt. To each pot to be fertilized (KDN) one gram of potassium sulfate (K) and one gram of ammonium nitrate (N) were added in solution and one gram of dicalcium phosphate (D) as the solid salt. The materials were tested and found to be free from manganese. When second crops were grown the same year on the same soil another application of ammonium nitrate was made but no potassium or phosphoric acid was added. When the same pots of soil were used the second year all additions were made again. The various additions were well mixed with the soil and water added to 50 per cent of the water capacity. After the seed were planted the pots were covered until the seed had germinated. The pots were kept in a greenhouse and distilled water added three times weekly to bring them to the original weight. If water was needed at other times, it was added without weighing in amounts thought sufficient. When well grown, the crops were harvested, dried, weighed, and analyzed for manganese.

Determination of Manganese in Crop

Burn one gram of crop over the full heat of a Fisher burner, moisten the ash with a few drops of water, add 10 cc. of hydrochloric acid, and evaporate to dryness. Moisten the residue with a few drops of hydrochloric acid, take up with hot water and filter into a porcelain evaporating dish, washing with hot water. Add 5 cc. of concentrated sulfuric acid to the filtrate and evaporate to slight fumes. Add 30 cc. of 1:3 nitric acid and proceed as in the bismuthate method. (Methods of the A. O. A. C., 1925, page 101, par. 75.) In the beginning of this work, it was noticed that the color of the solution faded rapidly after filtering through asbestos. To avoid this it was found necessary to add potassium permanganate to the water to be used for making up the dilute nitric acid for washing and redistill it, and to clean the vessels used at frequent intervals with chromic acid cleaning solution.

Determination of Acid-Soluble Manganese in Soil

Digest five grams of soil with 50 cc. of hydrochloric acid, Sp. Gr. 1.115, for eight hours in a boiling water bath. Filter and wash with hot water, evaporate to dryness, and heat to 110° C. to dehydrate silica, take up with 5 cc. of hydrochloric acid and hot water, heating on a water bath if necessary to effect complete solution, filter and make up to 250 cc. To 50 cc. (equivalent to one gram of soil) add 5 cc.

of concentrated sulfuric acid and evaporate to slight fumes, add 30 cc. of 1:3 nitric acid after cooling, and proceed with the bismuthate method as for crops.

Determination of Total Manganese in Soil

Fuse one gram of soil with four grams of manganese-free potassium bisulfate, using a low flame at first until danger of frothing is past, increasing the heat slowly until the full heat of the Fisher burner is obtained, and continuing this heat for about 25 minutes or until the flux is in a state of quiet fusion. If the fusion has been made in a quartz crucible, cool gradually by slowly lowering the heat. Unless this is done, there is danger of cracking the crucible.

When cold, place the crucible and cover in a beaker, cover with 50 cc. of 1:1 sulfuric acid, and digest on a steam bath until the melt is disintegrated. Filter through asbestos that has been washed with sulfuric acid, into a beaker contained in a Witte filter flask and wash well with hot water. Evaporate the solution on a hot plate until it can be transferred to a 100 cc. flask and made up to the mark. To 50 cc. of the solution, add .05 gram of potassium periodate and boil until the color is fully developed, cool, make up to 100 cc., and compare with the standard.

The color of the standard is developed in the same way as with the sample by boiling with .05 gram of potassium periodate in 25 cc. of 1:1 sulfuric acid and 25 cc. of water.

Description of the Soils Used in Pot Experiments

6731 Clay loam, Willacy county, surface soil.
9297 Amarillo fine sandy loam, Lubbock county, surface soil.
14844 Rice soil, Jefferson county, surface soil.
29423 Upland black land, surface soil, Bell county, dark-brown loam.
29425 Crockett clay loam, Brazos county, surface, 0-7″.
29429 Miller clay, Burleson county, surface, 0-7″.
29431 Miller fine sandy loam, Brazos county, surface, 0-7″.
29434 Wilson clay, Brazos county, surface, 0-7″.
30964 Subsoil from Val Verde county. Kafir grown in the field turns yellow and dies.
32077 Surface soil from Kinney county, from a spot in a peach orchard where the leaves of the trees turn yellow and fall off.
32078 Subsoil to 32077.
32187 Surface soil from Cameron county where chlorosis was persistent in a citrus grove.
32188 Subsoil to 32187.
32315 Surface soil from Comal county, in which chlorosis is present in spots.
32316 Subsoil to 32315.

28010 Surface soil from Ochiltree county, where sorghum turns yel- and dies.
28011 Subsoil to 28010.
30963 Surface soil, Val Verde county, where kafir turns yellow and dies.
31115 Subsoil from Harris county, from center of an infertile spot.
32561 Surface soil, Reeves county, where chlorosis occurs.
32562 Subsoil to 32561.

RESULTS OF POT EXPERIMENTS

In the pot experiments, the treatments for most of the soils were made in triplicate in order to secure a good average of the results of each treatment. The detailed results of the experiments are given in Tables 1, 2, and 3, together with the averages and the manganese content of the soil.

The dry weight of the crops from the three treatments in most cases agree as closely as could be expected in pot work. Where the weight of one crop grown in one pot varies widely from the other two with the same treatment, the weight of that crop and the percentage of manganese in it have been excluded from the average. The manganese content of the crops in the three crops with the same treatment usually agree fairly well.

Chlorosis occurred on only two of the soils. The addition of manganese did not produce any marked increases in yields of any of the crops.

The crops grown on two of the soils (32077 and 32078) which received nitrogen, phosphoric acid, and potash alone and also those which received the fertilizer with manganese sulfate, were chlorotic while the crops grown on these soils with no addition of manganese were of a normal green color. These particular soils will be discussed later in the work.

EFFECT OF MANGANESE ON THE WEIGHT OF THE CROPS

The average weights of the crops from the different treatments are summarized in Table 4. The effect of the manganese on the weight of the crops can be seen by comparing the weights of the crops grown on the portions of soil which received no addition, with the weights of the crops grown on the portions which received manganese sulfate (Mn) and also the crops that received complete fertilizer (NDK) with those receiving complete fertilizer with manganese (NDKMn). The fertilizer used was tested for manganese and none found.

None of the nine soils gave any greatly increased crop with the application of manganese; only a few of the soils gave slight increases (Table 4). With wheat, only one soil (No. 29425) of the six tested responded. The manganese-treated portion without fertilizer gave an increase of 1.3 grams. With cotton, three soils out of five gave slight increases. Soil No. 29434 gave an increase of 1.6 grams in the fer-

Table 1.—Detailed results of pot experiments

Lab. No.	Soil and additions	Wheat grams	Mn in wheat per cent	Cotton grams	Mn in cotton per cent	Corn grams	Mn in corn per cent	Kafir grams	Mn in kafir per cent
29425	Crockett clay loam, 0–7″								
	No addition (0)...................	11.1	.0416	5.0	.0132	6.5	.0110	14.0	.0220
		12.1	.0460	5.3	.0078	5.0	.0130	12.5	.0234
		9.7	.0456	5.2	....	6.3	.0116	14.0	.0225
	Average........................	10.9	.0444	5.2	.0105	5.9	.0119	13.5	.0226
	Manganese (Mn)....................	11.8	.0464	4.1	.0130	6.3	.0240	11.5	.0227
		11.4	.0468	4.0	.0128	7.0	.0132	11.8	.0222
		13.3	.0464	5.0	.0128	6.0	.0127	11.7	.0228
	Average........................	12.1	.0465	4.3	.0129	6.5	.0134	11.6	.0226
	Nitrogen, phosphoric acid, potash (NDK)	36.4	.0400	15.6	.0118	32.0	.0092	31.3	.0258
		37.0	.0480	16.2	.0080	41.0	.0086	34.5	.0240
		34.4	.0456	15.1	.0090	37.4	.0088	31.8	.0252
	Average........................	36.2	.0445	15.6	.0096	36.7	.0089	32.5	.0250
	Nitrogen, phosphoric acid, potash and manganese (NDKMn)	35.4	.0434	16.6	.0170	33.0	.0079	31.7	.0280
		36.4	.0384	16.4	.0168	37.5	.0101	31.5	.0252
		35.2	.0388	16.6	.0148	42.0	.0104	34.3	.0252
	Average........................	35.6	.0402	16.5	.0162	37.8	.0094	32.5	.0261
29429	Miller clay, 0–7″								
	No addition (0)....................	10.8	.0132	3.2	.0020	5.0	.0021	7.3	.0075
		11.3	.0129	3.4	.0037	5.2	.0018	6.4	.0083
		9.5	.0105	3.0	.0041	5.2	.0015	6.7	.0074
	Average........................	10.5	.0122	3.2	.0033	5.1	.0018	6.8	.0077
	Manganese (Mn)....................	11.8	.0121	3.3	.0031	4.0	.0017	7.8	.0080
		9.5	.0110	3.3	.0038	4.7	.0013	5.7	.0083
		11.2	.0135	3.8	.0077	4.0	.0020	6.7	.0080
	Average........................	10.9	.0122	3.5	.0049	4.3	.0016	6.4	.0081

Table 1.—Detailed results of pot experiments—Continued

Lab. No.	Soil and additions	Wheat grams	Mn in wheat per cent	Cotton grams	Mn in cotton per cent	Corn grams	Mn in corn per cent	Kafir grams	Mn in kafir per cent
	Nitrogen, phosphoric acid, potash (NDK)	33.4	.0070	15.0	.0048	30.5	.0012	30.5	.0045
		31.9	.0061	17.0	.0029	30.9	.0014	33.5	.0053
		30.4	.0060	12.3	.0033	26.5	.0014	30.0	.0059
	Average	31.9	.0067	14.8	.0036	29.3	.0013	31.3	.0052
	Nitrogen, phosphoric acid, potash and manganese (NDKMn)	32.4	.0061	13.5	.0039	28.0	.0019	33.2	.0055
		33.2	.0065	16.0	.0046	29.4	.0016	36.0	.0041
		29.0	.0068	13.6	.0072	27.2	.0016	32.9	.0053
	Average	31.6	.0064	14.3	.0053	28.2	.0017	30.7	.0053
29431	Miller fine sandy loam, 0–7″								
	No addition (0)	5.0	.0144	2.5	.0140	2.5	.0091	3.9	.0168
		5.1	.0148	2.2	.0160	2.7	.0082	3.6	.0168
		4.9	.0135	2.5	.0168	3.7	.0078	3.5	.0153
	Average	5.0	.0141	2.5	.0157	2.9	.0084	3.6	.0163
	Manganese (Mn)	5.0	.0141	3.9	.0312	2.5	.0116	5.0	.0153
		4.8	.0179	3.2	.0164	2.7	.0115	3.5	.0142
		4.5	.0155	2.5	.0152	2.7	.0119	4.9	.0147
	Average	4.8	.0158	3.2	.0209	2.6	.0116	4.1	.0147
	Nitrogen, phosphoric acid, potash (NDK)	26.0	.0216	12.2	.0397	37.0	.0110	33.5	.0540
		27.9	.0240	16.8	.0364	35.2	.0186	30.4	.0612
		26.6	.0268	11.3	.0340	35.0	.0170	25.0	.0612
	Average	27.1	.0241	13.4	.0367	35.7	.0155	29.6	.0588
	Nitrogen, phosphoric acid, potash and manganese (NDKMn)	27.0	.0250	10.1	.0318	34.7	.0222	29.7	.0882
		27.7	.0214	17.5	.0417	37.9	.0204	29.2	.0998
		27.6	.0280	10.7	.0392	32.5	.0246	28.5	.1122
	Average	27.4	.0248	12.8	.0379	35.0	.0224	29.1	.1001

Table 1.—Detailed results of pot experiments—Continued

Lab. No.	Soil and additions	Wheat grams	Mn in wheat per cent	Cotton grams	Mn in cotton per cent	Corn grams	Mn in corn per cent	Kafir grams	Mn in kafir per cent
29434	Wilson clay, 0–7″								
	No addition (0)	9.1	.0117	1.8	.0077	4.5	.0038	4.5	lost
		7.7	.0174	1.6	.0051	4.5	.0057	4.9	.0045
		6.2	.0178	1.3	.0057	5.4	.0068	5.5	.0029
	Average	7.7	.0156	1.5	.0062	4.9	.0054	4.9	.0037
	Manganese (Mn)	5.6	.0220	1.6	.0068	3.5	.0044	3.5	.0031
		6.8	.0162	1.3	.0061	5.9	.0057	5.4	.0031
		2.5	.0220	1.6	.0056	5.0	.0054	4.3	.0033
	Average	6.3	.0191	1.5	.0062	4.9	.0052	4.7	.0031
	Nitrogen, phosphoric acid, potash (NDK)	32.7	.0238	17.0	.0051	25.7	.0109	26.9	.0206
		32.6	.0264	13.2	.0069	24.3	.0094	24.8	.0150
		30.2	.0260	16.1	.0056	29.4	.0068	27.5	.0153
	Average	31.8	.0254	15.4	.0058	26.8	.0090	26.4	.0169
	Nitrogen, phosphoric acid, potash and manganese (NDKMn)	26.4	.0252	16.1	.0073	28.2	.0104	22.7	.0166
		32.7	.0276	18.4	.0066	29.5	.0080	26.7	.0192
		32.6	.0296	16.5	.0057	26.0	.0130	28.0	.0166
	Average	30.6	.0275	17.0	.0065	27.9	.0105	25.8	.0171

Table 2.—Detailed results of pot experiments

Lab. No.	Soil and additions	Corn grams	Mn in corn per cent	Milo grams	Mn in milo per cent	Wheat grams	Mn in wheat per cent	Cotton grams	Mn in cotton per cent
6731	Surface soil, Willacy county								
	No addition (0)	20.0	.0098	17.5	.0082	7.2	.0062	9.3	.0047
		19.5	.0082	24.0	.0052	7.0	.0062	8.2	.0067
	Average	19.5	.0090	20.7	.0067	7.1	.0062	8.7	.0057
	Manganese (Mn)	22.6	.0104	23.1	.0075	6.5	.0093	11.5	.0067
		21.0	.0094	20.5	.0062	6.2	.0076	8.2	.0058
	Average	21.8	.0099	21.8	.0068	6.3	.0084	8.8	.0063
	Nitrogen, phosphoric acid, potash (NDK)	17.6	.0103	28.5	.0063	13.0	.0098	20.0	.0090
		23.2	.0111	24.0	.0062	16.9	.0119	27.5	.0091
	Average	20.4	.0107	26.2	.0061	14.9	.0100	23.7	.0091
	Nitrogen, phosphoric acid, potash and manganese (NDKMn)	19.3	.0137	25.0	.0061	15.9	.0103	27.5	.0090
		11.0	.0117	19.5	.0072	11.5	.0115	21.8	.0126
	Average	15.1	.0127	22.2	.0066	13.7	.0109	24.6	.0108
9297	Amarillo fine sandy loam, 0–7″								
	No addition (0)	4.2	.0134	5.0	.0105	2.3	.0066	9.5	.0042
	Manganese (Mn)	2.0	.0370	4.7	.0165	2.1	.0162	7.0	.0081
		3.8	.0238	5.8	.0142	2.1	.0126	7.5	.0088
	Average	2.9	.0304	5.2	.0153	2.1	.0144	7.3	.0085
	Nitrogen, phosphoric acid, potash (NDK)	14.6	.0360	9.0	.0216	8.0	.0348	18.5	.0117
		10.5	.0360	9.2	.0192	9.0	.0288	24.5	.0125
	Average	12.5	.0360	9.1	.0204	8.5	.0318	21.4	.0122
	Nitrogen, phosphoric acid, potash and and manganese (NDKMn)	15.5	.0342	11.7	.0180	7.0	.0210	25.8	.0156
		7.5	.0296	14.2	.0208	5.2	.0516	25.8	.0213
	Average	11.5	.0319	12.9	.0194	6.6	.0364	25.8	.0184

Table 2.—Detailed results of pot experiments—Continued

Lab. No.	Soil and additions	Corn grams	Mn in corn per cent	Milo grams	Mn in milo per cent	Wheat grams	Mn in wheat per cent	Cotton grams	Mn in cotton per cent
14844	Rice soil, Jefferson county, surface, No addition (0)	5.0	.0076	9.3	.0136	5.9	.0318	....	....
		5.1	.0092	11.9	.0158	5.3	.0312	....	....
	Average	5.1	.0084	10.6	.0147	5.6	.0316	....	....
	Manganese (Mn)	2.5	.0091	3.1	.0142	4.7	.0271	....	....
		2.8	.0071	12.2	.0156	5.7	.0161	....	....
	Average	2.6	.0081	7.6	.0149	5.2	.0216	....	....
	Nitrogen, phosphoric acid, potash (NDK)	15.3	.0118	16.0	.0168	15.5	.0074	....	....
		18.8	.0094	9.2	.0122	12.2	.0147	....	....
	Average	17.5	.0106	12.6	.0145	13.8	.0115	....	....
	Nitrogen, phosphoric acid, potash and manganese (NDKMn)	10.6	.0116	12.2	.0172	13.7	.0166	....	....
		14.0	.0140	18.2	.0163	15.3	.0119	....	....
	Average	12.3	.0126	15.2	.0167	14.5	.0142	....	....

Table 3.—Detailed results of pot experiments

Lab. No.	Soil and additions	Corn grams	Mn in corn per cent	Kafir grams	Mn in kafir per cent
30964	Chlorosis present				
	No addition (0)	10.2	.0058	5.5	.0094
	Manganese (Mn)	4.0	.0112	4.7	.0078
	Nitrogen, phosphoric acid, potash (NDK)	29.0	.0068	4.5	.0109
	Nitrogen, phosphoric acid, potash and manganese (NDKMn)	12.2	.0092	7.0	.0093
32077	Surface soil, chlorosis in peach orchard				
	No addition (0) ... Kafir (green)	19.7	.0126	30.5	.0126
	Kafir (green)	13.7	.0138	28.2	.0132
	Average	15.5	.0132	29.3	.0128
	Manganese (Mn) ... Kafir (green)	15.0	.0172	28.5	.0138
	Kafir (green)	18.0	.0182	31.0	.0126
	Average	16.5	.0177	29.7	.0132
	Nitrogen, phosphoric acid, potash (NDK) Kafir (almost white)	26.2	.0154	25.5	.0189
	Kafir (pale green)	25.4	.0155	29.5	.0159
	Average	25.8	.0155	27.5	.0174
	Nitrogen, phosphoric acid, potash, manganese (NDKMn) Kafir (pale green)	22.5	.0162	10.5	.0160
	Kafir (pale green)	16.7	.0204	12.2	.0228
	Average	19.1	.0183	11.3	.0194
32078	Subsoil to 32077				
	No addition (0) ... Kafir (green)	2.7	.0203	10.5	.0105
	Kafir (green)	3.4	.0186	10.5	.0102
	Average	3.0	.0195	10.5	.0103
	Manganese (Mn)	3.7	.0164	13.2	.0106
		2.7	.0137	12.2	.0106
	Average	3.2	.0150	12.7	.0106
	Nitrogen, phosphoric acid, potash (NDK) Kafir (almost white)	13.0	.0164	20.5	.0132
	Kafir (almost white)	10.5	.0134	17.4	.0102
	Average	12.3	.0149	18.9	.0117
	Nitrogen, phosphoric acid, potash, manganese (NDKMn) ... Kafir (almost white)	8.4	.0126	17.5	.0164
32187	Surface soil, chlorosis in citrus grove				
	No addition (0)	19.0	.0129	16.2	.0147
		17.7	.0132	18.8	.0144
		16.2	.0172	16.7	.0156
	Average	17.6	.0144	17.2	.0147
	Manganese (Mn)	13.0	.0145	24.3	.0162
		18.2	.0150	17.5	.0178
		20.2	.0120	16.0	.0120
	Average	17.5	.0138	19.2	.0153
	Nitrogen, phosphoric acid, potash (NDK)	13.5	.0127	25.0	.0159
		24.2	.0164	32.2	.0168
		20.2	.0168	31.4	.0150
	Average	19.3	.0156	29.5	.0159

Table 3.—Detailed results of pot experiments—Continued

Lab. No.	Soil and additions	Corn grams	Mn in corn per cent	Kafir grams	Mn in kafir per cent
	Nitrogen, phosphoric acid, potash, manganese (NDKMn)	22.7 20.0 13.5	.0135 .0129 .0123	29.5 25.0 36.0	.0126 .0144 .0180
	Average	18.7	.0129	27.1	.0150
32188	Subsoil to 32187				
	No addition (0)	4.7 5.2 4.9	.0166 .0111 .0120	15.2 16.0 13.8	.0078 .0075 .0114
	Average	4.9	.0132	15.0	.0089
	Manganese (Mn)	4.4 4.7 4.7	.0123 .0115 .0144	17.7 13.0 14.2	.0090 .0114 .0096
	Average	4.6	.0127	14.9	.0100
	Nitrogen, phosphoric acid, potash (NDK)	20.7 12.7 15.0	.0124 .0126 .0128	20.7 10.7 15.8	.0111 .0102 .0132
	Average	16.1	.0126	15.7	.0115
	Nitrogen, phosphoric acid, potash, manganese (NDKMn)	15.0 7.2 13.2	.0108 .0117 .0103	21.8 17.5 11.8	.0126 .0135 .0099
	Average	14.1	.0112	17.0	.0120
32315	Surface soil, chlorosis present				
	No addition (0)	10.9 9.5 9.7	.0059 .0058 .0065	15.7 11.0 13.5	.0072 .0082 .0078
	Average	10.5	.0061	13.1	.0077
	Manganese (Mn)	9.7 11.7 12.5	.0055 .0055 .0061	16.1 14.1 14.3	.0072 .0078 .0076
	Average	11.3	.0057	14.8	.0075
	Nitrogen, phosphoric acid, potash (NDK)	21.5 20.0 20.5	.0069 .0063 .0084	35.0 16.7 35.2	.0087 .0074 .0078
	Average	20.2	.0072	35.1	.0082
	Nitrogen, phosphoric acid, potash, manganese (NDKMn)	20.0 7.7 19.5	.0087 .0102 .0084	29.7 17.5 24.0	.0096 .0102 .0090
	Average (2)	19.7	.0094	26.8	.0093
32316	Subsoil to 32315				
	No addition (0)	5.5 5.2 12.5	.0069 .0066 .0060	10.3 11.4 20.5	.0072 .0072 .0054
	Average (2)	5.3	.0067	10.8	.0072
	Manganese (Mn)	6.4 5.2 5.0	.0073 .0081 .0078	9.0 8.8 8.5	.0060 .0054 .0065
	Average	5.5	.0077	8.8	.0059

Table 3.—Detailed results of pot experiments—Continued

Lab. No.	Soil and additions	Corn grams	Mn in corn per cent	Kafir grams	Mn in kafir per cent
	Nitrogen, phosphoric acid, potash (NDK)	15.7 17.2 16.9	.0076 .0061 .0058	35.0 32.8 33.3	.0065 .0060 .0057
	Average	16.6	.0065	33.7	.0061
	Nitrogen, phosphoric acid, potash, manganese (NDKMn)	15.4 19.9 18.5	.0076 .0065 .0073	33.5 34.6 39.0	.0063 .0061 .0078
	Average	18.0	.0071	35.7	.0067
29423	Surface soils				
	No addition (0)	8.5 11.0 11.0	.0078 .0074 .0096	6.2 5.8 5.7	.0098 .0098 .0132
	Average	10.2	.0083	5.9	.0107
	Manganese (Mn)	11.3 12.5 12.4	.0069 .0062 .0072	6.8 7.1 7.0	.0096 .0120 .0106
	Average	12.0	.0068	6.9	.0112
	Nitrogen, phosphoric acid, potash (NDK)	21.2 26.2 30.0	.0096 .0078 .0082	37.5 31.5 35.0	.0081 .0075 .0090
	Average	29.1	.0085	34.7	.0082
	Nitrogen, phosphoric acid, potash, manganese (NDKMn)	22.5 18.5 24.4	.0075 .0113 .0072	32.0 34.5 34.5	.0096 .0105 .0096
	Average	21.8	.0087	33.6	.0099

tilized series with manganese; No. 6731 gave an increase of 1.1 gram for the unfertilized portion and 0.9 gram increase for the fertilizer series treated with manganese. Milo responded in all three soils tested. Soil No. 6731 gave increases of 1.1 gram for the unfertilized pots; soil No. 9297 gave increases of 0.2 and 3.1 grams for the fertilized and unfertilized series respectively; soil No. 14844 gave an increase of 3.6 grams for the fertilized crops with manganese. With corn, four soils out of nine gave responses to manganese; soil No. 29434 gave an increase of 1.1 gram in the fertilized series with manganese; soil No. 29425 gave increases in both series with manganese, an increase of 0.7 gram and 1.1 gram with the unfertilized and fertilized series respectively; soil No. 6731 gave an increase of 2.3 grams for the unfertilized series with manganese; soil No. 32316 gave an increase of 1.4 grams in the fertilized series with manganese; with kafir four soils out of nine gave increases with manganese, soil No. 29429 gave an increase of 2.7 grams in the fertilized series; soil No. 30964 gave an increase of 2.5 grams in the fertilized series; soil No. 32187 gave an increase of 2.0 grams in the unfertilized series, and soil No. 32316 gave an increase of 2.0 grams in the fertilized series.

Table 4.—Effect of manganese on the average weights of the crops grown (in grams)

Lab. No.		No addition	Manganese added	Nitrogen, phosphoric acid and potash added	Manganese and nitrogen, phosphoric acid, potash added
	Wheat				
29434	Wilson clay, 0–7″	7.7	6.3	31.8	30.6
29425	Crockett clay loam, 0-7″	10.9	12.2	36.2	35.6
29429	Miller clay, 0–7″	10.5	10.9	31.9	31.6
29431	Miller fine sandy loam, 0–7″	5.0	4.8	27.1	27.4
6731	Clay loam, surface	7.1	6.3	14.9	13.7
9297	Amarillo fine sandy loam, surface	2.1	2.1	7.5	6.6
14844	Rice soil, surface	5.6	5.2	13.8	14.5
	Cotton				
29434	Wilson clay, 0–7″	1.5	1.5	15.4	17.0
29425	Crockett clay loam, 0–7″	5.1	4.3	15.1	16.5
29429	Miller clay, 0–7″	3.2	3.5	14.8	14.3
29431	Miller fine sandy loam, 0–7″	2.5	3.2	13.4	12.8
6731	Clay loam, surface	8.7	9.8	23.7	24.6
9297	Amarillo fine sandy loam, surface	9.5	7.2	21.5	25.8
	Milo				
6731	Clay loam, surface	20.7	21.8	26.2	22.2
9297	Amarillo fine sandy loam, surface	5.0	5.2	9.1	12.2
14844	Rice soil, surface	10.6	7.6	12.6	15.2
	Corn				
29434	Wilson clay, 0–7″	4.9	4.9	26.8	27.9
29425	Crockett clay loam, 0–7″	5.9	6.5	36.7	37.8
29429	Miller clay, 0–7″	5.1	4.3	29.3	28.4
29431	Miller fine sandy loam, 0–7″	2.9	2.6	35.7	35.0
6731	Clay loam	19.5	21.8	20.4	15.1
32187	Surface, citrus chlorosis	17.6	17.5	19.3	18.7
32188	Subsoil to 32187	4.9	4.6	16.1	14.1
32315	Surface soil, chlorosis present	10.5	11.3	20.2	19.7
2316	Subsoil to 32315	5.3	5.5	16.6	18.0
	Kafir				
29434	Wilson clay, 0–7″	4.9	4.4	26.4	25.8
29425	Crockett clay loam, 0–7″	13.5	11.6	32.5	32.5
29429	Miller clay, 0–7″	6.8	6.7	31.3	34.0
29431	Miller fine sandy loam	3.6	4.1	29.6	29.1
30964	Subsoil, surface produces chlorotic kafir	5.5	4.7	4.5	7.0
32187	Surface soil, citrus chlorosis	17.2	19.2	29.5	27.1
32188	Subsoil to 32187	15.0	14.9	18.3	17.0
32316	Subsoil, chlorosis on surface	10.8	8.7	33.7	35.7
29423	Upland black land, surface	5.9	6.9	33.3	33.6

The increases or decreases in the weights of the crops caused by the manganese sulfate are within the experimental error; the weights of the individual crops receiving the same treatments on the same soil varied nearly as much as the average weights of the crops receiving manganese varied from those which did not receive manganese on the same soil.

POSSIBLE TOXICITY OF MANGANESE SULFATE

A few of the soils seemed to show some depression in yield when manganese sulfate was added. These results are not given in Table 2 but are brought together in Table 5.

Corn on Amarillo fine sandy loam, soil No. 9297, produced 1.3 grams less dry matter when manganese sulfate was added than when

Table 5.—Possible toxicity of manganese sulfate. Weight of crops in grams

Lab. No.	Soil	Crop	No addition	Manganese	Nitrogen, phosphoric acid, potash	Nitrogen, phosphoric acid, potash and manganese
9297	Amarillo fine sandy loam	Corn	4.2	2.9	12.5	11.5
14844	Rice soil	Corn	5.1	2.6	17.5	12.3
30964	Subsoil, kafir (chlorotic on soil)	Corn	10.2	4.0	29.0	12.2
32077	Peach leaves turn yellow	Corn	15.5	16.5	25.8	19.1
32078	Subsoil to 32077	Corn	3.0	3.2	12.3	8.4
29423	Upland black land soil, surface, chlorotic crop	Corn	10.2	12.0	29.1	21.8
32077	Surface soil, Kinney county	Kafir	29.3	29.7	27.5	11.3
32078	Subsoil to 32077	Kafir	13.0	12.7	18.9	17.5

Table 6.—Effect of the amounts of manganese on the manganese in crop and quantity removed

Pot No.	Amount of manganese added per pot	Weight of corn, grams	Mn in corn, per cent	Average Mn removed, per cent	Mn removed by corn mg.	Average Mn removed by corn	Weight of cotton, grams	Mn in cotton, per cent	Average Mn per cent	Mn removed by cotton mg.	Average Mn removed mg.
1	No manganese	7.5	Trace	....	Trace	....	13.0	.0025	....	.33	....
2	No manganese	7.0	Trace	Trace	Trace	Trace	3.0	.0029	.0027	.09	.22
3	10 milligrams	18.0	.0104	....	1.87	....	9.2	.0140	....	1.29	....
4	10 milligrams	6.2	.0150	.0125	.93	1.40	4.5	.0114	.0127	.51	.90
5	25 milligrams	8.5	.0234	....	1.99	....	4.8	.0256	....	1.23	....
6	25 milligrams	11.5	.0268	.0251	3.08	2.53	8.0	.0212	.0234	1.69	1.46
7	50 milligrams	8.0	.0612	....	4.89	....	7.8	.0359	....	2.98	....
8	50 milligrams	11.2	.0456	.0534	5.11	5.00	5.5	.0230	.0295	1.27	2.17
9	100 milligrams	9.2	.0595	....	4.57	....	3.1	.0398	....	1.23	....
10	100 milligrams	7.5	.0808	.0701	6.06	5.76	12.5	.0508	.0453	6.32	3.78

it was not added. The crop from the pot with manganese sulfate and fertilizer was also smaller than on the pot with no manganese and fertilizer but the difference of one gram is probably within the experimental error. The yields of wheat, milo, and cotton grown on this soil were not depressed by additions of manganese sulfate.

The corn grown on soil No. 14844, a rice soil from Jefferson county, showed significant depressions in yield when manganese was added, both with the fertilized and the unfertilized pots. This depression amounted to about 50 per cent for the unfertilized pots and about 24 per cent for the fertilized pots. Wheat and milo grown on this soil were not affected, and the cotton grown was too much damaged by insects to allow any comparisons between the treatments. This soil was the lowest in manganese of any of the soils tested, containing only .016 per cent of acid-soluble manganese.

Soil No. 30964 is a subsoil, the surface soil of which produced chlorotic kafir crops in the field. The yields of corn on this soil were materially reduced by the application of manganese, both on the fertilized and unfertilized pots. Unfortunately there was only one pot of each treatment for this soil, but the decrease in yield for both the pots treated with manganese, fertilized and unfertilized, is large enough to be significant, especially for the unfertilized pot. Kafir on this soil showed neither chlorosis nor reduced yields.

Soil No. 32077 is a soil from a peach orchard where the leaves of the trees turn yellow and fall off. There is quite a depression in the yield of both corn and kafir on the pots which received fertilizer and manganese, while the unfertilized pots showed no depression in yield with either crop. The kafir on the fertilized pots with and without manganese were almost white, while on the unfertilized pots with and without manganese the crop was a normal green. The corn was a normal green on all the pots. Kafir on this soil did not respond to a complete fertilizer. The application of manganese not only did not prevent chlorosis but also greatly reduced the yield.

Soil No. 32078 is the subsoil to No. 32077, and it also produced lower yields of corn when manganese was added to the fertilized pots, but the decrease was not as great as on soil No. 32077. The kafir grown on the fertilized pots with and without manganese was a very pale green, almost white, while those on the unfertilized pots were normal in color. The decrease in yield with kafir on pot treated with manganese was not great, probably within experimental error. It is not clear why the application of fertilizer to these two soils caused chlorosis, nor why the application of manganese in addition to fertilizer should cause a reduction in yield on one soil and not on the other.

Soil No. 29423, a black-land soil from Bell county, also showed a slight reduction in yield when manganese was applied to the fertilized pot.

On most of the soils mentioned above, the application of manganese to the pots which were fertilized caused a greater reduction in yield than where the fertilizer was not added. It was found during the course of this work, as will be discussed later, that the addition of fertilizer enabled the crop, in some cases, to take up more manganese than when fertilizer was not applied. It was first thought that the application of fertilizer to these soils enabled the plant to take up enough manganese to be toxic, but on checking back over the analyses it was found that the crops grown on these soils contained no more manganese than the crops that were not affected. It is not clear why the addition of manganese sulfate to the fertilized pots should cause crops grown on these soils to have chlorosis.

EFFECT OF THE QUANTITY OF MANGANESE ON THE WEIGHT AND MANGANESE CONTENT OF THE CROPS

One experiment was carried out with quartz sand to determine the effect of increasing amounts of manganese sulfate on the weight and manganese content of corn and cotton.

Glazed earthenware pots were selected that did not vary more than 20 grams from each other and 5000 grams of quartz sand were weighed into each. The following weights of nutrients in 25 cc. of water were applied to each pot, both for corn and the succeeding crop, cotton:

Potassium chloride	.75 grams
Magnesium sulfate	3.00 grams
Ammonium nitrate	.75 grams
Ferrous ammonium sulfate	.13 grams

In addition each pot received .86 gram of dicalcium phosphate and 1.72 grams of calcium sulfate, both free from manganese. The ferrous ammonium sulfate contained manganese and was purified by recrystallization before it was used. The other materials were tested and found to be free from manganese.

The manganese sulfate was applied to duplicate pots as shown in Table 4, equivalent to 10, 25, 50, and 100 milligrams of manganese (Mn), as found by analysis. The detailed results are given in Table 6.

Corn responded to manganese, though the variations in the weights of the crops grown in the duplicate pots showed that some other factor also influenced the growth of the corn in some of the pots.

Cotton also responded to the applications of manganese sulfate. The weight of the crop in pot 1 was probably exchanged for the weight of pot 9.

There was no chlorosis in any of the plants, regardless of whether or not manganese had been applied.

The percentage of manganese in both the cotton and the corn increased with increasing applications of manganese. The amount of manganese removed also increased with an increase in the amount applied. These results are in general agreement with the work at this Station on the available potash (19) and available phosphoric acid

(20) in the soil. With the corn, the amount of manganese was found to be removed in direct proportion to the amount added. The crops removed from the 25- and 50-milligram applications almost 2.5 and 5.0 times as much manganese as from the 10-milligram application. The crops, however, removed only about 10 per cent of the manganese applied, and less than 10 per cent from the 100-milligram application.

With cotton also the percentage of manganese in the crop and the amount of manganese removed were larger with larger applications of manganese sulfate, but the increases were not directly proportional to the quantities of manganese sulfate added. With the 50- and 100-milligram applications the cotton contained considerably smaller percentages of manganese than the corn, although it had the benefit of the residual manganese applied to the corn besides that added as a second application. With the 10- and 25-milligram applications, the cotton removed only about one-tenth of the manganese applied, but with the 50- and 100-milligram applications the cotton removed much less than the corn.

VARIATIONS IN THE PERCENTAGE OF MANGANESE IN PLANTS

Some plants grown on the different soils showed great variations in their percentage of manganese, as shown in Table 7. This table gives the minimum and maximum percentages of manganese in the crops grown on the soils, with no addition and with complete fertilizer.

With the exception of the wheat there is a greater variation in manganese in the plants grown on the fertilized pots than those from the unfertilized pots. The maximum percentage of manganese in the wheat grown on the unfertilized soil is exceptionally high (.044 per cent), the next highest being only .014 per cent. If this exceptionally high crop is omitted the variation will also be less on the unfertilized than with the fertilized wheat. The maximum is two to five times the minimum in the plants grown on the unfertilized soils, and three to ten times the minimum in soils grown on the fertilized soils.

It will be noticed in Table 7 that a soil which produces a minimum percentage of manganese in one crop does not produce a maximum percentage in another crop. Soil No. 6731 produced three crops containing minimum percentages of manganese, namely, wheat, and milo, unfertilized, and milo, fertilized, and it produced no crop with a maximum percentage of manganese. Soil No. 29429 produced four crops with minimum percentages of manganese, namely, cotton and corn, unfertilized, and wheat and cotton, fertilized, and no crops with a maximum of manganese. Soil No. 29431 produced four crops with maximum percentages of manganese,—cotton and corn, fertilized and unfertilized, and kafir fertilized and unfertilized, and no crops with minimum percentages of manganese.

Table 7.—Variations in manganese content of plants

	No addition per cent manganese	Soil number	Nitrogen, phosphoric acid and potash, per cent manganese	Soil number
Wheat				
Minimum	.0062	6731	.0067	29429
Maximum	.0445	29425	.0445	29425
Cotton				
Minimum	.0033	29429	.0036	29429
Maximum	.0157	29431	.0367	29431
Corn				
Minimum	.0018	29429	.0065	32316
Maximum	.0195	32078	.0360	9297
Milo				
Minimum	.0067	6731	.0061	6731
Maximum	.0147	14844	.0204	9297
Kafir				
Minimum	.0072	32316	.0057	32316
Maximum	.0163	29431	.0588	29431

RELATION OF THE MANGANESE TAKEN UP BY CROPS TO THE MANGANESE CONTENT OF THE SOIL

Previous work at this Station has shown that the percentages of nitrogen, active phosphoric acid (5), and active potash (6), in the soil are related to the quantities of nitrogen, phosphoric acid, and potash that are removed from the soil in pot experiments. It was a question if similar relations exist for manganese.

The results obtained in the pot experiments with manganese are given in Table 8, which is arranged in an ascending order of the percentage of acid-soluble manganese in the different soils. The table gives the average percentages of manganese in the crops grown on the pots receiving no addition and those grown on the pots receiving complete fertilizer.

An inspection of the table shows that there is a small relation between the total manganese in the crop, or the amount removed from the soil, expressed in milligrams, and the percentage of acid-soluble manganese in the soil. The correlation coefficient for corn for the pots receiving no fertilizer is $.437 \pm .04$. The correlation coefficients were not calculated for the other crops, on account of their small number.

From the results presented in Table 8 one is led to the conclusion that the acid-soluble manganese in the soil is not as good a criterion of the availability of manganese, as measured by the amount removed by crops, as is the active phosphoric acid or the active potash. The coefficient of correlation for active phosphoric acid (5) is .57 and for active potash (6), $+.794 \pm .014$.

In this connection mention may be made of the work of Bertrand (2) on the determination of different forms of manganese in the soil. He

Table 8.—Relation of manganese taken up by crop to manganese in the soil

Lab. No.		No addition				Fertilizer		
		Weight of crop, grams	Per cent manganese in crop	Milligrams manganese in crop	Per cent manganese in soil	Weight of crop, grams	Per cent manganese in crop	Milligrams manganese in crop
	Corn							
14844		5.0	.0076	.380	.016	17.5	.0106	1.855
9297		4.2	.0134	.563	.024	12.5	.0360	4.450
29434		4.9	.0054	.265	.032	26.8	.0090	2.412
30964		10.2	.0058	.692	.036	29.0	.0068	1.973
29425		5.9	.0119	.702	.041	36.7	.0089	3.376
29429		5.1	.0018	.103	.042	29.3	.0013	.381
29431		2.9	.0084	.243	.043	35.7	.0155	5.554
32315		10.5	.0061	.641	.048	20.2	.0072	1.454
32078		3.0	.0195	.585	.055	12.3	.0149	1.833
6731		19.5	.0090	1.755	.055	20.4	.0107	2.183
32077		15.5	.0132	2.047	.057	25.8	.0155	3.999
32316		5.3	.0060	.318	.057	16.6	.0065	1.079
32187		17.6	.0144	2.534	.065	19.3	.0156	3.011
32188		4.9	.0120	.588	.067	16.1	.0126	2.029
	Wheat							
14844		5.6	.0316	1.769	.016	13.8	.0115	1.587
9297		2.1	.0162	.341	.024	7.5	.0318	2.385
29434		7.7	.0156	1.201	.032	31.8	.0254	9.697
29425		10.9	.0444	4.840	.041	36.2	.0445	16.109
29429		10.5	.0122	1.281	.042	31.9	.0067	2.137
29431		5.0	.0142	.710	.043	27.1	.0241	6.530
6731		7.1	.0062	.440	.055	15.9	.0103	1.638
	Cotton							
9297		9.5	.0042	.399	.024	21.4	.0122	2.612
29434		1.5	.0062	.093	.032	15.4	.0058	.893
29425		5.2	.0105	.546	.041	15.6	.0096	1.498
29429		3.2	.0033	.106	.042	14.8	.0036	.533
29431		2.5	.0157	.432	.043	13.4	.0367	4.918
6731		8.7	.0057	.496	.055	24.6	.0108	2.654
	Milo							
14844		10.6	.0147	1.558	.016	12.6	.0145	1.827
9297		5.0	.0105	.525	.024	9.1	.0204	1.856
6731		20.7	.0067	1.387	.055	26.2	.0061	1.598
	Kafir							
29423		5.9	.0107	.630	.010	34.7	.0082	1.245
29434		4.9	.0037	.180	.032	26.4	.0171	4.514
30964		5.5	.0094	.517	.036	4.5	.0109	.471
29425		13.5	.0186	2.510	.041	32.5	.0250	9.125
29429		6.7	.0074	.596	.042	31.3	.0054	1.690
29431		3.6	.0163	.585	.043	25.0	.0588	24.700
32315		13.1	.0077	1.008	.048	35.1	.0082	2.878
32078		10.5	.0103	1.082	.055	18.9	.0117	2.211
32077		29.3	.0128	4.750	.057	27.5	.0174	4.785
32316		10.8	.0072	.772	.057	33.7	.0057	1.921
32187		17.2	.0147	2.528	.065	29.5	.0159	4.641
32188		15.0	.0089	1.335	.067	15.7	.0115	1.806
29311					Trace	15.6	.0047	.733
29316					.009	33.5	.0037	1.239
29315					.013	29.0	.0049	1.421
26817					.019	30.0	.0077	2.320
26818					.023	24.0	.0065	1.580
26815					.025	33.2	.0050	1.650
29314					.036	21.0	.0060	1.260
29318					.038	48.8	.0012	.586
29313					.040	21.8	.0107	2.333
29314					.040	16.0	.0046	.736

extracted soils with 1 per cent acetic acid in determining the available manganese. This determination was not carried out in this work. Had it been it might have showed closer relations than the acid-soluble form.

In working with the soils of the Netherlands, Wester (20) found no relation between the manganese content of the crop and that of the soil on which it was grown in field experiments.

EFFECT OF FERTILIZER ON THE MANGANESE CONTENT OF PLANTS

The percentage of manganese in plants tends to increase when fertilizer containing nitrogen, phosphoric acid, and potash is added to the soil, as shown in Table 9. The crops from only two soils and the average for all the crops grown on the soils are given. The unfertilized crop grown on one of the soils contained more manganese than the crop grown on the same soil but fertilized. The crop grown on the other soil which had been fertilized contained more manganese than the crop grown on the portion that had not been fertilized. On an average the crops grown on the fertilized pots contained more manganese than those grown on the portion of the same soil that had not been fertilized. This fertilizer did not contain manganese.

The crops grown on the soils that received complete fertilizer plus manganese contained larger percentages of manganese than those grown on soils which received manganese only. This difference is slight in some cases and large in others. On an average the addition of fertilizer caused an increase of 22 to 68 per cent, while the addition of manganese effected an increase of only 7 to 24 per cent.

The differences in the percentage of manganese for the fertilized crops as compared with those that were not fertilized vary from minus .0055 per cent to plus .0127 for wheat; minus .0030 per cent to plus .0226 per cent for corn; minus .0009 per cent to plus .0210 per cent for cotton; minus .0024 to plus .0425 per cent for kafir.

Attention is called to the exceptionally high effect on the kafir crop grown on soil No. 29431. The crop with no addition contained .0163 per cent of manganese while the fertilized crop contained .0588 per cent, an increase of .0425 per cent, or over three times as much. The difference in the crops grown on the soil treated with manganese is still greater. The crop on the soil with manganese contained only .0147 per cent and that grown on the fertilized soil plus manganese contained .1001 per cent—a difference of .0854 per cent, or nearly seven times as much.

This increased amount of manganese in the fertilized crops may be caused in part by an increased root system, which enables the crop to draw more heavily on the manganese in the soil. However, considering the fact that the increase was much greater on some of the soils than on others, it is possible that the fertilizer increases the availability of manganese in some of the soils. This is a question that will have to be solved by further investigation.

On some of the soils the application of fertilizer increased the amount of manganese in the crop more than did the application of manganese sulfate.

Table 9.—Effect of fertilizer on the percentage of manganese in plants

Lab. No.	Crop	Per cent manganese in crop: No addition	Fertilizer added	Manganese added	Fertilizer and manganese added
29429	Wheat	.0122	.0067	.0122	.0064
9297		.0162	.0318	.0144	.0364
	Average 6 soils	.0181	.0238	.0194	.0227
	Percentage increase		31.5	7.2	25.4
29425	Corn	.0119	.0089	.0134	.0094
9297		.0134	.0560	.0304	.0319
	Average 15 soils	.0095	.0116	.0118	.0126
	Percentage increase		22.1	24.2	32.4
29425	Cotton	.0105	.0096	.0129	.0162
6731		.0057	.0091	.0063	.0108
	Average 6 soils	.0076	.0128	.0086	.0158
	Percentage increase		68.4	10.4	107.9
6731	Milo	.0067	.0061	.0068	.0066
9297		.0105	.0204	.0153	.0194
	Average 3 soils	.0106	.0133	.0127	.0142
	Percentage increase		25.5	20.0	33.9
29429	Kafir	.0077	.0054	.0080	.0051
29431		.0163	.0588	.0147	.1001
	Average 11 soils	.0102	.0170	.0126	.0198
	Percentage increase		66.4	23.5	94.1

EFFECT OF MANGANESE ON CROPS GROWN ON SOILS WHICH PRODUCE CHLOROTIC PLANTS

Several soils which have produced chlorotic crops have been tested with various additions to find the cause of chlorosis. This work has not yet been published, but the results with manganese on seven samples are given in Table 10.

The application of manganese was of decided benefit to only one of the soils, No. 32561, on which sorghum was grown. The sorghum on the pot with no addition was almost white, while the sorghum that received manganese was a pale green. The manganese seemed of only slight benefit in preventing chlorosis, but it had a decided effect on the weight of the sorghum, increasing it from 9.6 to 27 grams.

On the other hand, manganese was injurious to the crop grown on the subsoil, No. 32562. The crops from the pots with no addition was a pale green, while the crop from the pot with the addition of manganese was chlorotic and died.

Kafir on soil No. 28010 seemed to have been benefited slightly from the application of manganese but the crops on both the fertilized pots and on those treated with manganese died; so it is not known whether manganese would have benefited the crops had they grown to the end of the experiment. Kafir on the subsoil, No. 28011, seemed to have received a slight benefit from the application of manganese although

Table 10.—Effect of manganese on growth of crop on soils causing chlorosis: crop in grams

Crop and addition	Soil 28010	Soil 28011	Soil 30963	Soil 30964	Soil 31115	Soil 32561	Soil 32562
Corn with nitrogen, phosphoric acid and potash	27.2	14.5	....	....	....	....	....
Corn with manganese	25.0	11.3	....	....	....	....	....
Kafir with nitrogen, phosphoric acid and potash	1.7	1.7	....	....	....	....	....
Kafir with manganese	3.6	5.2	....	....	....	....	....
Milo with no addition	....	....	0.7	0.9	0.8	....	....
Milo with manganese	....	....	0.4	1.1	0.6	....	....
Sorghum with no addition	....	....	18.7	10.2	4.8	9.6	24.2
Sorghum with manganese	....	....	17.8	7.8	6.0	27.0	6.5

the plants were not chlorotic.

Manganese salts applied to the other soils given in the table had no decided beneficial or toxic effects, nor were the crops in any of these pots chlorotic. From the results given in Table 10, it seems that soils which produce chlorotic crops in the field, as these soils were reported to do, may not produce chlorotic crops in pots in the greenhouse, as crops from only two of these soils were chlorotic. It is also evident, in considering soils No. 32561 and No. 32562, that applications of manganese sulfate may be beneficial to the crop on one soil and injurious on another soil, and if manganese is to be applied as a corrective for chlorosis, it should be at first tried out on a small scale.

APPROXIMATE AMOUNTS OF MANGANESE REQUIRED BY CROPS

The minimum, maximum, and average amounts of manganese required by wheat, cotton, corn and kafir have been calculated from the

Table 11.—Approximate amounts of manganese required by crops (pounds)

Crop		Manganese in pounds per acre
Wheat	Grain, 30 bushels	
	Straw (dry), 2653 pounds	
	Minimum	.26
	Maximum	1.86
	Average	1.06
Cotton	300 pounds lint	
	Stalk, seed, hulls, 2100 pounds	
	Minimum	.08
	Maximum	.38
	Average	.23
Corn	30 bushels	
	Stalks (dry), 1877 pounds	
	Minimum	.07
	Maximum	.74
	Average	.41
Kafir	2000 pounds dry forage	
	Minimum	.14
	Maximum	.33
	Average	.23

amounts of manganese found in the crops grown in pot experiments and are given in Table 11.

The crops require very small amounts of manganese. Cotton, corn, and kafir require less than one-half pound per acre, while wheat requires little more than a pound.

MANGANESE CONTENT OF OTHER PLANT PRODUCTS

A few samples of other plants and plant products were analyzed for manganese and the results are given in Table 12.

The grain of corn contained only a trace of manganese. The other grains also contain low percentages of manganese, with the exception of feterita heads, which are comparatively high.

Table 12.—Manganese content of various plant products

Lab. No.		Per cent manganese in material
30493	Yellow Dent corn (grain)	.0007
30483	Yellow Creole corn	Trace
30491	Yellow Dent corn	Trace
30770	Nicholson Giant Yellow corn	Trace
30481	Ferguson Yellow Dent corn	.0004
30213	Fentress Strawberry corn	Trace
25979	Hegari heads	.0020
26335	Feterita heads	.0108
26187	Hegari grains	.0010
29211	String beans	.0024
26399	California pink beans	.0009
26398	Pinto beans	.0013
	Cotton leaves (2 samples)	.0041
29956	Cowpeas and pods	.0019
30490	Peanut meal	.0060
29782	Cotton roots	.0016
	Guar leaves (3 samples)	.0064
29793	Guar stalk	.0016
29292	Cottonseed cake	.0017
26282	Alfalfa hay	.0070
26050	Guar hay	.0037
26246	Prairie hay	.0049
24368	Johnson grass hay	.0058
29751	Kentucky blue grass	.0108
26233	Hegari stems	.0046
26261	Kafir fodder	.0034
29720	Corn silage (dried)	.0062
30212	Orange peel and pulp (dried)	Trace

The leafy parts of the plants contain the most manganese. Cotton leaves contain .0041 per cent, while the roots contain only .0016 per cent. Guar leaves contain .0064 per cent, while the stalks contain only .0016 per cent. Guar hay, composed of leaves and stalks, contains .0037 per cent. Kentucky blue grass was the highest in manganese, containing .0108 per cent.

MANGANESE CONTENT OF TEXAS SOILS

Representative soils from the different sections of Texas were analyzed for acid-soluble manganese. A few determinations of total man-

Table 13.—Percentage of manganese of Texas soils. Relation to location

Laboratory number		Surface soil acid-soluble	Subsoil acid-soluble
	Soils of East Texas		
21222-3	Bell clay	.078	.080
24029-30	Bibb clay loam	.516	.424
29425	Crockett clay loam	.041	....
23948-9	Luverne fine sandy loam	.008	.006
24049-50	Greenville fine sandy loam	.038	.014
17502-3	Lufkin clay	.122	.015
8314	Lufkin fine sand	.003	
29431	Miller fine sandy loam	.042	....
29429	Miller clay	.041	....
23966-7	Milam fine sandy loam	.009	.006
3653	Norfolk fine sand	....	.008
8314	Norfolk fine sand	.003	....
1224	Norfolk fine sand	.040	....
12594-5	Norfolk fine sand	.041	.005
21224-5	Norfolk sand	.006	.004
2331	Norfolk fine sandy loam	.073	....
7180	Norfolk fine sandy loam	.012	....
1289	Norfolk fine sandy loam	.010	....
14942-3	Ruston fine sandy loam	.036	.020
14946-7	Ruston fine sandy loam	.010	.046
16072-3	Ruston fine sandy loam	.014	.006
6194-5	Susquehanna clay	.010	.022
8389-90	Susquehanna clay	.008	.003
8348	Susquehanna clay	....	.046
6196-7	Susquehanna fine sandy loam	.030	.011
10146-7	Susquehanna fine sandy loam	.008	.003
12586-7	Susquehanna fine sandy loam	.021	.041
14957	Susquehanna fine sandy loam	....	.008
12598-9	Susquehanna gravelly loam	....	.009
29434	Wilson clay	.032	....
	Average	.031	.023
	Central and West Texas Soils		
21594-5	Bastrop clay loam	.050	.034
20995-6	Bell clay	.035	.038
18247	Brackett clay loam	.022	....
21591-2	Calumet silty clay loam	.050	.034
11669-7	Crawford clay	.032	.032
12665-6	Crockett fine sandy loam	.015	.021
12984-5	Crockett fine sandy loam	.011	.007
15948	Denton clay	.051	....
18248	Denton clay loam	.034	....
21568-9	Foard clay loam	.040	.041
21542-3	Foard very fine sandy loam	.066	.072
21564-5	Fowlkes very fine sandy loam	.037	.043
20281	Frio fine sandy loam	.015	....
21073	Houston clay loam	.050	....
21069-70	Houston black clay	.045	.071
12021-22	Houston black clay	.097	.080
12029	Houston clay	.039	....
12568-9	Houston clay	.152	.102
21547-8	Miller silty clay loam	.062	.046
21588-9	Miller clay	.052	.049
20685-6	Miles fine sand	.008	.003
21587-8	Reagan loam	.042	.034
16006	San Saba silty clay loam	.088	....
20980	Trinity clay	.033	....
21067-8	Trinity clay	.046	.057
21576-7	Vernon clay	.040	.051
21549	Vernon clay	.059	....
21560-1	Vernon very fine sandy loam	.040	.063
21582-3	Wichita very fine sandy loom	.050	.024
17534	Wilson clay	.060	....
12014	Wilson clay loam	....	.079
21071-2	Wilson clay loam	.039	.035
20986	Wilson fine sandy loam	.006	....
21555-6	Yahola silty clay loam	.050	.049
21572-3	Yahola loam	.040	.040
21580-1	Yahola fine sand	.051	.051
	Average	.050	.046

Table 13.—Percentage of manganese of Texas soils. Relation to location—Continued

Laboratory number		Surface soil acid-soluble	Subsoil acid-soluble
	Soils of South Texas		
23353	Tiocano silty clay loam	.010	....
26815	Catalpa clay	.027	....
23339–40	Delfina fine sandy loam	.012	Trace
25893–4	Raymondville clay loam	.038	.035
25891–2	Raymondville fine sandy clay loam	.030	.030
24019–20	Duval fine sandy loam	.022	.014
26731	Guadalupe clay	.048	....
26729–30	Guadalupe silty clay loam	.034	.041
26817–18	Guadalupe silty clay loam	.021	.021
21253–4	Harlingen clay	.029	.034
20725	Hockley fine sandy loam	....	.005
21283	Laredo fine sandy loam	.031	....
21265–6	Laredo silty clay loam	.043	.032
7195	Lake Charles clay	....	.006
7282–3	Lake Charles clay	.007	.014
20928	Lake Charles clay	.044	....
20726–7	Lake Charles clay loam	.051	.052
21286	Lomalta clay	.034	....
25879–80	Nueces fine sand	.007	.008
23349	Nueces fine sandy loam	.010	....
25877–8	Point Isabel clay	.025	.027
21288–9	Point Isabel clay	.046	.027
25897	Point Isabel fine sandy loam	.019	....
21281	Rio Grande clay	.046	....
21257	Rio Grande very fine sandy loam	.030	....
26814	Trinity clay	....	.032
21274–5	Victoria clay loam	.015	.020
17700–1	Victoria fine sandy loam	.020	.017
21277–8	Victoria fine sandy loam	.019	.022
20785	Willacy fine sandy loam	.026	....
25883–4	Willacy fine sandy loam	.027	.025
	Average	.027	.023
	Soils of Western Plains		
10144–5	Amarillo clay loam	.011	.019
29311–2	Amarillo fine sand	Trace	Trace
13737	Amarillo fine sandy loam	.011	....
13760	Amarillo fine sandy loam	.023	....
29315–6	Amarillo fine sandy loam	.012	.009
20605–6	Amarillo fine sandy loam	.005	.004
20705	Amarillo loam	.018	....
20601–2	Arno clay	.028	.032
20622	Arno clay	....	.093
20658	Arno clay	....	.018
29318	Randall clay	....	.038
30964	Randall clay	.033	....
9297	Randall clay	.025	....
29313–4	Reagan silty clay loam	.041	.036
20599	Reeves fine sandy loam	.015	....
11615–16	San Saba clay	.091	.092
20604	Miles clay	.028	....
	Average	.024	.034

ganese were also made. There was little difference between the percentages of total manganese and acid-soluble manganese, there being only a few soils in which the total manganese is higher than the acid-soluble manganese. For this reason these estimations of total manganese are not included in the tables.

Manganese Content of Texas Soils Related to Location

Table 13 gives the percentages of manganese found in various soil types. The soils are arranged according to location; for this purpose the state was divided into East Texas, The Central and West Texas, South Texas, and The Western Plains.

From an inspection of the table it is evident that there is a wide range in the percentages of manganese in the different types of soil; there is also a considerable variation in the manganese content of soils of the same type.

In most cases there is not much difference in the manganese content of the surface and the corresponding subsoil. There are, of course, a few cases in which there is a decided difference, but, generally if the surface soil is high in manganese, the subsoil will also be high, and vice-versa.

The soils of Central and West Texas contain the highest percentages of manganese, although there are a few soils in this section that are low in manganese.

The soils of East Texas and South Texas contain about the same percentages of manganese, while the soils of the Western Plains are decidedly lower.

The average manganese content of the surface soils of all these sections is .033 per cent. Of the soils of East Texas, 40 per cent are above this average; Central Texas has 82 per cent above; South Texas has 32 per cent above; the Western Plains has only 21 per cent above the average.

Some of the soils are very low in manganese. For example, one sample of Susquehanna clay contains only .008 per cent in the surface soil and .003 per cent in the subsoil. This would be equivalent to 160 pounds an acre to the depth of 7 inches in the surface soil and 60 pounds in the subsoil. The surface soil would contain enough for 320 crops of corn, cotton, or kafir, if the estimate of 0.5 pound of manganese to the crop is correct. As the surface soil may contain nitrogen sufficient for only 18 crops, phosphoric acid for 33 crops, and acid-soluble potash sufficient for 50 crops, it is evident that in spite of the low percentage, the amount of manganese is more nearly adequate than is the amount of nitrogen, phosphoric acid, or potash.

MANGANESE CONTENT OF TEXAS SOILS RELATED TO TEXTURE

The soils are regrouped according to texture into clay, clay loam, sandy, and sandy loam and the minimum, maximum, and average percentages of acid-soluble manganese are given in Table 14.

Table 14.—Average percentate of acid-soluble manganese in soils as related to texture

	Clay soils		Clay loam		Sands		Sandy loam	
	Surface	Subsoil	Surface	Subsoil	Surface	Subsoil	Surface	Subsoil
Minimum	.010	.008	.010	.020	Trace	Trace	.005	.004
Maximum	.152	.102	.516	.484	.057	.199	.094	.741
Average	.045	.046	.064	.068	.021	.040	.024	.025
Number averaged	30	18	21	13	9	8	34	26

The clay loams average higher in manganese than the others. There is also one exceptional soil in this group, the Bibbs clay loam, which contains the highest percentage, .516, of any of the soils analyzed.

The sands and sandy loams are generally lower, while the clay soils are on the average close to the clay loams.

The average percentage of manganese for all of the soils is .038 per cent; 57 per cent of the clay soils are above this average; 70 per cent of the clay loams are above; 22 per cent of the sands and 21 per cent of the sandy loams are above the average.

Only one of the sandy loam soils has a manganese content equal to the average of the clay or clay loam soils, and only two of the sandy loam soils are above this average. Only two of the clay soils are lower than the averages of the sands and sandy loams. These two soils are of the same type, Susquehanna clay. The clay loams have four soils lower than the averages for the sands and sandy loams.

The clay loams contain a slightly higher percentage of manganese than the clays, and the sandy and sandy loam soils had decidedly lower percentages.

These results correspond somewhat with work reported by Wester (23) in a study of the soils of the Netherlands. He found that the loam soils contained a higher percentage of manganese than the other types he analyzed, but he does not specify whether a sandy loam or clay loam classification was the highest.

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SUMMARY AND CONCLUSIONS

(1) Manganese sulfate is not appreciably beneficial to the growth of crops on most of the 21 soils tested. On one soil it produced a decided increase in growth.

(2) On six soils manganese sulfate decreased the yields. If manganese sulfate is tried it should be tested on a small scale at first so as to be certain it will be of benefit and to guard against any possibility of toxic action.

(3) Of the thirteen soils which produced chlorotic crops in the field only two produced chlorotic crops when tested in the greenhouse.

(4) Corn and cotton take up amounts of manganese almost in proportion to the quantities added to quartz sand, but only about 10 per cent of that supplied.

(5) A plant grown on one soil may contain two to five times as much manganese as the same kind of plant grown on another soil.

(6) The coefficient of correlation between the acid-soluble man-

ganese in the soil and the amount of manganese taken up by corn was .437 ± .04. This is not as close a correlation as that between the active phosphoric acid and the active potash of the soil and that removed by crops.

(7) The application of a fertilizer containing nitrogen, phosphoric acid, and potash increases the percentage of manganese in the crop 30 to 70 per cent.

(8) Manganese was of benefit to the growth of sorghum on one of the soils which produced chlorotic crops in the field.

(9) On a basis of manganese content, the soils of Texas may be grouped as follows: Black Prairie region highest; East Texas and South Texas intermediate; Edwards Plateau lowest.

(10) Clay loam and clay soils were considerably higher in manganese than the sandy and sandy loam soils.

(11) A crop of corn, cotton, or kafir requires less than one-half pound of manganese per acre, while a crop of wheat requires little more than a pound.

(12) The percentage of manganese in a number of grains of plants is given.

(13) While some Texas soils contain only small percentages of manganese, the requirements of the plant are so small that the soil is much better supplied with manganese than with nitrogen, phosphoric acid, or potash.

(14) Manganese sulfate is not recommended for application on the soils of Texas. There may be some soils on which it is needed, but so far only one has been found with which it is a possibility.

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