MANGANESE IN RELATION TO PLANT NUTRITION

by

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DOCTOR OF PHILOSOPHY

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APPROVED:

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ACKNOWLEDGMENTS

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MANGANESE IN RELATION TO PLANT NUTRITION

INTRODUCTION

There are in the United States certain areas in which marked increases in crop growth have been obtained in recent years by the application of fertilizers containing the "minor elements," mainly boron, copper, manganese, and zinc in low concentrations. These areas of response include the light soils of the Atlantic Coastal Plains, the alkaline peats and mucks of the Great Lakes States and Florida, and portions of the Pacific Northwest.

Wherever a response has been obtained with one of the minor elements, further tests have usually shown that some or all of the other minor elements will also give beneficial results. Preliminary trials in western Oregon have indicated that boron, copper, manganese, or zinc in small applications may give increased yield and quality of small fruits, vegetables and seed crops. It was for the purpose of further investigating the extent of need and effects of manganese in relation to plant nutrition and the extent of its need in Oregon soils that this study was undertaken.
Manganese was discovered in pyrolusite by a Swedish chemist, Scheele, in the year 1774 and many observations on its reactions are recorded in his essays on manganese. It is a fairly brittle metal, superficially oxidized by air, which reacts with electronegative elements readily and liberates hydrogen from dilute acids. Manganese is an active reducing agent; manganous compounds are moderately good reducing agents while permanganates are strong oxidizing agents. In order of occurrence in the earth's crust, manganese is twelfth, constituting 0.10 per cent.

Sheele (1774) was also the first to detect manganese in plants grown in the soil. In 1864, Sachs showed that manganese could not replace iron in the plant, but did not decide if manganese was necessary. Bertrand (1897) observed the action of manganese on the enzyme laccase and proposed that manganese may have an importance in physiological systems hitherto unsuspected because it occurs in such small amounts.

As Stimulant

That small additions of a manganous salt will give increased yields and quality of crops was shown by
Bertrand (1905) with oats, by Garola (1909) with sugar beets and flax, by Salomone (1905) with beans, by Aso (1904) and Nagaoka (1904) on rice paddy fields, by Skinner and Sullivan (1914) with wheat on a poor soil, by Namba (1906) with onions, by Voelcker (1904) with wheat and barley and by Bertrand (1912) with pea, barley, radish, rape, lupine, and alfalfa. It was mainly assumed by these workers that manganese in minute quantities acted as a stimulant to catalyze, or influence, microbial activities.

As Poison

That manganese in anything but small quantities may be toxic was the belief of many investigators. Brenchley (1910) working with barley noted that manganese in weak culture solutions was depressing or toxic at concentrations above 1:1,000,000, but in normal nutrient solutions was toxic only at concentrations greater than 1:100,000. She concluded that stronger nutrient solutions mask the toxic effect of moderate concentrations of plant poisons, but admitted that minute traces of manganese are stimulative. Kelley (1912) discussed the toxic effect of certain highly manganiferous soils in Hawaii on the growth of pineapples. He pointed out that excess manganese tends to become deposited as the
brown oxide in the cells, attacking the chloroplastids and causing a fading of chlorophyll. Since there was no correlation between the activity of oxidizing enzymes and the manganese content, Kelley did not subscribe to the "excess auto-oxidation" theory. Rather he considered its effect to be an increase in the ratio of calcium to magnesium absorbed by the plant. 'The decreased magnesium may be related to the decomposition of chlorophyll.' Skinner and Sullivan (1914) found that yearly applications of manganous sulfate to field plots gave a stimulation the first year followed by continually decreasing yields of small grains. Jacobson and Swanbach (1929) observed that tobacco grown on a soil high in manganese showed abnormal physiological symptoms which could be duplicated in the greenhouse by watering with a 0.5 percent manganous sulfate solution.

**As Essential Element**

It remained for McHargue (1923) to prove what Bertrand had suggested in 1897 and Brenchley had admitted as a possibility in 1914, that traces of manganese are absolutely essential to the plant's economy. By careful work with water cultures using purified chemical solutions he showed that wheat seedlings and Alaska peas would grow normally for four or five weeks without manganese, but after that time began to show definite
symptoms of disorder. New buds were yellowish and then became flecked with brown spots, later the top branches died back. The lack of manganese seemed to retard the formation of chlorophyll. Further work by McHargue (1926) showed that manganese is necessary for the normal growth and reproduction of corn, wheat, oats, soy beans, cow peas, garden peas, garden beans, tomatoes, onions, cucumbers, spinach and lettuce and that greatly increased yields result from its use. The lack of manganese results in the failure to synthesize chlorophyll in new leaves and shoots, also in a lower starch and sugar content of the leaves. Thus he considers that manganese is an important and necessary factor in the synthesis of chlorophyll and in carbon assimilation.

Bishop (1928) in Australia found that plants grown in sand cultures needed small amounts of manganese, without which they ceased to grow after a few weeks. He observed that 5.0 p.p.m. was the optimum concentration, that manganese did not affect the iron assimilation but did increase the phosphorous and calcium absorption. His conclusions were that manganese was necessary for chlorophyll formation and possibly to increase the calcium and phosphorous intake.
Deficiency Symptoms

When plants are grown in soil or solution cultures that are lacking or deficient in manganese, characteristic deficiency symptoms appear. Parker, Chapman, and Southwick (1940) state that lemon leaves show the usual pale green or yellow interveinal areas with green midribs and veins, occasionally terminal leaves are devoid of color. Willis (1928) noted with soybeans that early growth is normal, but new leaves become more and more yellow, the chlorosis appearing first between the veins but finally the leaves at the tip may become enlarged and the tissue between the veins very thin. Samuel and Piper (1928) and Sherman and Harmer (1941) describe gray speck disease of oats caused by a manganese deficiency. Small gray necrotic spots appear on the leaves which may enlarge to the full width of the leaf allowing it to topple over in a sharp kink. The grayish shade gives way to a bright yellow with a reddish fringe, while the gray extends outward into fresh tissue. Death of the basal portion of the leaf may follow with the tip remaining green for some time. Eventually the whole leaf dies.

Treatment

Where symptoms of manganese deficiency have been observed, they can usually be corrected by applying soluble
manganese compounds to the plant or soil. Gilbert, McLean and Hardin (1926) corrected the chlorosis of spinach by the application of manganous sulfate to the soil. The application of iron gave no beneficial results. McLean (1927) cured chlorosis of spinach leaves by feeding a weak solution of manganous sulfate through the stomata by means of a modified porometer. No manganese touched the soil. Where one of several plants in a pot was so treated, it alone derived any benefit from the treatment, there being no transfer through the soil to the other plants. With field and truck crops, Gilbert (1934) has found that a spray application of eight pounds of manganous sulfate per acre or 30 pounds mixed with a complete fertilizer will correct any deficiency if applied each year. Such soil treatments as will maintain the reaction between pH 5.5 and 6.5 or a heavy application of manure will prevent the deficiency symptoms from occurring.

Citrus trees in California showing manganese deficiency disease did not respond to soil applications of manganous sulfate according to Parker, Chapman, and Southwick (1940). However, the injection of manganous chloride solutions or crystals into the limbs as well as sprays with a 1.5 per cent solution of the salt resulted in greening up the leaves in 15 days.
Functions

The exact role of manganese in plant nutrition is as yet unknown. C. B. Lipman (1940) asserts that the most difficult and important problems are to ascertain the function of the essential elements. He admits that most investigations have thrown little light on this subject.

Among the many functions that have been assigned to manganese by various workers are the following to the effect that manganese:

1. Is necessary for chlorophyll formation. McHargue (1922). Haas (1932) restated this, adding that he believed its importance to be indirectly due to its action on the iron of the cells, and that it

2. Is an oxidizing agent in the cell.

3. Acts to maintain the proper ferrous-ferric iron balance in the cell. Shive (1941) based this on two considerations: (a) that active functional iron in tissues is in the reduced or ferrous state, (b) that manganese has a higher oxidizing potential than iron.


8. Aids nitrogen fixation and nitrification. Shreiner and Dawson (1927)

9. Acts with oxidases to liberate active or atomic oxygen. Bertrand quoted by Bishop (1928).

EXPERIMENTAL

Methods

Manganese was determined colorimetrically in plant material and soil extracts by the potassium periodate method of Willard and Greathouse (1917), and the resulting color read in a Klett-Summerson photoelectric colorimeter. Plant material was ashed in the electric furnace for 12 hours at 600°F., the ash dissolved in 1:1 nitric acid and evaporated to dryness to dehydrate the silica. The residue was taken up with 1:4 nitric acid, filtered and the filtrate diluted to about 200 ml. after adding 15 ml. of concentrated nitric acid and one ml. of phosphoric acid. Approximately 0.3 gm. of potassium periodate was then added and the solution boiled until the maximum color had developed, cooled, and diluted to a definite volume so that the solution contained between 0.5 to 10.0 p.p.m. of manganese.

The colored solution was read in the previously calibrated colorimeter using a 540 mu. (green) filter since Mehlig (1939) states that the maximum light transmission for this color occurs between 520 and 540 mu. The colorimeter was calibrated and a calibration curve made using standard manganese solutions containing 1, 3,
5, and 10 p.p.m. The zero reading was set using a solution which contained all the reagents and had been subjected to the same procedure as the unknown samples. It is necessary in all cases to have the blank solution diluted to the same volume as the colored solutions, for a more concentrated blank transmits less light than a dilute blank.

Soil extracts were evaporated to dryness at 110° F., then placed in the furnace for 12 hours at 600° F. After cooling, aqua regia was added and evaporated to dryness on a steam bath. If the residue was still dark, the evaporation with aqua regia was repeated. About one ml. of 1:1 sulfuric acid was added and evaporated to dryness to remove all chlorides. The residue was taken up in 1:4 nitric acid and from there on treated just as outlined for plant material.

Iron was determined colorimetrically in soil extracts by the potassium sulfocyanate method, potassium by the volumetric method of Wilcox (1937), calcium and magnesium by the standard gravimetric methods.

Available manganese in soils was considered as being the sum of the water-soluble, exchangeable, and easily reduced or active manganic oxide. The exchangeable manganese is that extracted in 24 hours by neutral, normal ammonium acetate after removing the water-soluble.
The easily reducible or active manganic oxide (MnO₂) was shown by Leeper (1935) to be slowly available to plant roots when they came in actual contact with it and is that extracted in 24 hours by neutral, normal ammonium acetate containing 0.2 per cent hydroquinone after the water-soluble and exchangeable manganese have been removed. Leeper considers the reducing action of the dilute hydroquinone solution to be equivalent to that of the plant roots. Total manganese was determined by an alkali fusion followed by acid extraction and removal of silica. Then the manganese was determined by either of two methods depending on the amount present. If a large amount of manganese was present the Volhard titration was used, if a smaller amount was present the colorimetric method previously outlined was used.

Soils Studied

1. Klamath peat: A well-decomposed sedge grass peat formed under semi-arid conditions at moderately high elevation (4000 feet). It has a slightly alkaline reaction, pH 7.2 to 7.4, and is well supplied with soluble salts.

2. Sauvie silty clay loam: An alluvial soil of the Columbia River valley, moderately heavy textured brown soil lying over gravel at 18 to 30 inches. It is subject to overflow and has a moderately acid reaction.
2a. Newberg loamy sand: A brown to light brown, open textured alluvial soil deposited in billows and waves by rapidly moving water. It is frequently subject to overflow, has excessive internal drainage, slightly acid reaction, and low organic matter content.

2b. Melbourne clay loam: An upland brown to yellowish brown, moderately heavy residual soil developed on sandstone and shale. It has a moderate supply of organic matter, good moisture retention, and is moderately acid.

2c. Dayton silty clay loam: This is a gray to drab, heavy-textured soil. It is developed on the level portions of the valley floor where drainage is impeded, the subsoil is compact and impenetrable, and because of this is waterlogged during a large portion of the year, producing anaerobic conditions and mottling.

2d. Springdale gravelly loam: This soil is developed under semi-arid conditions from an old, high, gravelly terrace of the Columbia river in northeastern Oregon. It is moderately high in organic matter and has a neutral reaction.
3. Powell silt loam: An upland, gray-brown soil of medium texture developed on the higher terraces along the Columbia River. This is a fertile, well-drained, friable soil of acid reaction.

4. Labish peat: A well-decomposed sedge grass peat of shallow to medium depth with considerable mineral matter mixed with it. This is a moderately acid peat of pH 5.0 to 5.2.

5. Clatskanie peat: This is a partially decomposed peat of rather high mineral content and is frequently termed a medium peat or muck. It is formed in the Columbia River valley above tidewater but subject to periodic overflow and silting in. The peat is somewhat coarser than Labish and has a pH of 4.8.

6. Chehalis silty clay loam: This is a young, moderately heavy, friable, alluvial soil deposited from still water during flood stages. It is a brown earth, very little leached, and is of slightly acid reaction. It possesses good internal drainage.

7. Braillier peat: A coarse, woody, sphagnum peat formed in the marshes of the lower Columbia River valley. This peat is only slightly decomposed, low in minerals and strongly leached. It has a pH of 4.1.

8. Aiken clay loam: A red-hill soil, formed in place from basaltic material which originally weathered
under lateritic conditions. It has an acid reaction, strong to excessive external drainage, is high in iron and manganese.

9. Olympic silty clay loam: A chocolate brown moderately heavy soil underlaid by a reddish-brown heavy subsoil which is deeply weathered. The soil is a hill soil occupying the lower foothills, has strong drainage and an acid reaction. It is high in soluble iron and manganese and tends to have iron-manganese concretions or crusts in the lower subsoil.

Greenhouse Investigation on Four Soils

To initiate studies of the need for manganese in Oregon soils, four soils that had previously been potted and used for fertility studies in the greenhouse were acquired. The original treatments had all been in duplicate so that now each of the treatments was split, one pot receiving MnSO₄ at the rate of 40 pounds per acre, the other pot serving as a check.

The four soils used were Klamath peat, Sauvie silty clay loam, Powell silt loam, and Springdale gravelly loam. The Klamath peat has a neutral to slightly alkaline reaction and was contained in one gallon glazed jars each containing one kilogram of dry soil. There were 28 jars in all, making 14 with and 14 without manganese treatment. The Sauvie silty clay loam has a pH
of 4.8 and was contained in ten-inch red flower pots each containing four kilograms of soil. There were 24 jars making 12 replications. The Powell silt loam has a pH of 5.2 and was contained in two-gallon glazed jars, each containing 4.5 kilograms of dry soil. There were 40 jars, or 20 treatment replications. The Springdale gravelly loam has a pH of 6.3 and was contained in one-gallon glazed jars each containing 2100 grams of dry soil. There were 22 jars, making 11 treatment replications. All soils were fertilized on a weight basis assuming 2,000,000 pounds per acre of mineral soil and 1,000,000 pounds of peat.

Bountiful beans were seeded on October 28, 1940 and after germination thinned to four plants per jar in the small jars and six in the large. On January 25, 1941 the beans were harvested, the total dry matter per jar being obtained. The plant material was then ground and analyzed for manganese.

The yield data and manganese determinations are shown in Table 1. The neutral peat soil alone shows a marked response, while the mineral soils show very little or even a negative response. It is clearly evident that the degree of response varies inversely as the manganese content of the plant parts, and that where the leaves of untreated plants show over 100 p.p.m. we obtain practically
no response.

The Powell silt loam was seeded to a second crop of beans after first being steam sterilized. The increased availability of manganese caused by the steam treatment is clearly evident in the increased manganese content of the crop. Conner (1932) and McCool (1934) have shown that steam heating releases large amounts of soluble manganese, in the first case during a manganese deficient soil and in the second case rendering toxic a soil already high in manganese. This crop, even when it contained over 500 p.p.m. showed no appreciable manganese toxicity.

Table 1. Yield and Manganese Content of Beans Grown on Four Soil Types in the Greenhouse

<table>
<thead>
<tr>
<th>Soil</th>
<th>Treatment and Yield</th>
<th>Mn Content, Leaves</th>
<th>Mn Content, Beans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Klamath peat</td>
<td>65.3</td>
<td>84.6</td>
<td>32 26</td>
</tr>
<tr>
<td>Sauvie silty clay loam</td>
<td>126.0</td>
<td>133.1</td>
<td>50 55</td>
</tr>
<tr>
<td>Powell silt loam, 1st crop</td>
<td>197.6</td>
<td>183.8</td>
<td>134 164</td>
</tr>
<tr>
<td></td>
<td>615.1</td>
<td>606.3</td>
<td>430 524</td>
</tr>
<tr>
<td>Springdale gravelly loam</td>
<td>75.2</td>
<td>77.4</td>
<td>114 110</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Soil</th>
<th>Mn Content, Leaves</th>
<th>Mn Content, Beans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Klamath peat</td>
<td></td>
<td>12 13</td>
</tr>
<tr>
<td>Sauvie silty clay loam</td>
<td></td>
<td>23 24</td>
</tr>
<tr>
<td>Powell silt loam, 1st crop</td>
<td></td>
<td>19 23</td>
</tr>
<tr>
<td></td>
<td></td>
<td>48 51</td>
</tr>
<tr>
<td>Springdale gravelly loam</td>
<td></td>
<td>26 28</td>
</tr>
</tbody>
</table>
Investigations on Klamath and Labish Peats

Since the Klamath peat alone of the four soils studied showed a marked response to manganese, it was decided to investigate peat soils more extensively. Samples of Klamath and Labish peat were potted in two-gallon glazed jars so that there were 28 jars of each soil. The jars respectively contained 2250 grams of Klamath peat of pH 7.1 and 2900 grams of Labish peat of pH 4.95.

The soils were fertilized in blocks of four on a weight basis, assuming 1,000,000 lbs. per acre. The first block received no treatment, the second block received 1,000 pounds per acre of 4-12-8 mixture as did all succeeding blocks. This complete fertilizer was applied as solutions of pure chemicals containing \((NH_4)_2SO_4\), \(KH_2PO_4\), KCl. Also solutions of copper and zinc were added equivalent to 0.1 p.p.m. and boron equivalent to 1.0 p.p.m. Block three also received 10 pounds per acre of MnSO_4, block four 40 pounds, block five 80 pounds, block six 160 pounds, and block seven no manganese.

Sugar beets were seeded in three pots from each treatment, the fourth was left fallow. After germination, the sugar beets were thinned to four per pot and grown all winter in the greenhouse. When harvested they were topped, the roots weighed, and both tops and roots dried for analysis.
Table 2. Yield and Manganese Content of Sugar Beets
Grown in Klamath Peat in the Greenhouse

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Rate per acre lbs.</th>
<th>Yield Average per jar gms.</th>
<th>Relative to NPK per cent</th>
<th>Manganese Content leaves p.p.m.</th>
<th>Manganese Content Roots p.p.m.</th>
</tr>
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<tbody>
<tr>
<td>Check</td>
<td></td>
<td>184.7</td>
<td>91.8</td>
<td>52.7</td>
<td>23.5</td>
</tr>
<tr>
<td>NPK</td>
<td></td>
<td>201.1</td>
<td>100.0</td>
<td>42.5</td>
<td>20.3</td>
</tr>
<tr>
<td>NPK, MnSO₄₅</td>
<td>10</td>
<td>218.9</td>
<td>109.0</td>
<td>56.2</td>
<td>22.5</td>
</tr>
<tr>
<td>NPK, MnSO₄₅</td>
<td>40</td>
<td>224.8</td>
<td>112.0</td>
<td>76.0</td>
<td>30.3</td>
</tr>
<tr>
<td>NPK, MnSO₄₅</td>
<td>80</td>
<td>235.7</td>
<td>117.2</td>
<td>161.5</td>
<td>34.2</td>
</tr>
<tr>
<td>NPK, MnSO₄₅</td>
<td>160</td>
<td>212.0</td>
<td>105.5</td>
<td>109.5</td>
<td>41.7</td>
</tr>
</tbody>
</table>

Table 2 shows the yield and manganese content of the beets from the various treatments on Klamath peat. The yield rises steadily until the 160-pound treatment is reached, at which point it falls off. Again, we find response to manganese when the leaves contain less than 100 p.p.m., and after that point is reached the response becomes erratic.
Fig. 1A.  Sugar Beets in Klamath Peat
Fig. 1B. Sugar Beets in Lathish Peat
Table 3. Yield and Manganese Content of Sugar Beets Grown in Labish Peat in the Greenhouse

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Rate per acre</th>
<th>Average Yield per jar</th>
<th>Relative to NPK</th>
<th>Manganese Content Leaves</th>
<th>Manganese Content Roots</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lbs.</td>
<td>gms.</td>
<td>per cent</td>
<td>p.p.m.</td>
<td>p.p.m.</td>
</tr>
<tr>
<td>Check</td>
<td></td>
<td></td>
<td></td>
<td>538</td>
<td>130</td>
</tr>
<tr>
<td>NPK</td>
<td></td>
<td>74.6</td>
<td>100.0</td>
<td>570</td>
<td>160</td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>10</td>
<td>87.4</td>
<td>117.0</td>
<td>548</td>
<td>91</td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>40</td>
<td>86.1</td>
<td>115.5</td>
<td>553</td>
<td>164</td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>80</td>
<td>61.3</td>
<td>82.2</td>
<td>195</td>
<td>129</td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>160</td>
<td>67.8</td>
<td>90.8</td>
<td>667</td>
<td>172</td>
</tr>
</tbody>
</table>

Table 3 shows the corresponding data for the beets grown in Labish peat. Here a moderate increase resulted from 10- and 40-pound applications, but a decided decrease resulted from the two larger treatments. A glance at the manganese content of the beet leaves immediately tells why the yield dropped on the higher treatments. It should be mentioned that none of the usual toxicity symptoms were evident on leaves of beets from the 80- or 160-pound treatments, only a general reduction in plant size.

The soil in the uncropped pots was maintained at field moisture capacity and in the same environment as the cropped jars. Three months after treatment, samples were taken and 1:5 water extracts made. These were analyzed for the anions nitrate, phosphate, sulfate, and the
cations calcium, magnesium, and potassium. The results are reported in Table 4, in which the effect of the added manganese sulfate on the availability of these ions is shown.

Table 4. Effect of Manganese Treatment on Availability of Other Ions

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Rate per acre</th>
<th>NO₃⁻</th>
<th>P₂O₅</th>
<th>SO₄²⁻</th>
<th>Ca⁺⁺</th>
<th>Mg⁺⁺</th>
<th>K⁺</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lbs. p.p.m.</td>
<td>p.p.m.</td>
<td>p.p.m.</td>
<td>p.p.m.</td>
<td>p.p.m.</td>
<td>p.p.m.</td>
<td>p.p.m.</td>
</tr>
<tr>
<td>Klamath Peat</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPK</td>
<td>80</td>
<td>4.150</td>
<td>80.6</td>
<td>11.17</td>
<td>14.5</td>
<td>293</td>
<td>24.7</td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td></td>
<td>312.4</td>
<td>90.7</td>
<td>11.26</td>
<td>362</td>
<td>294</td>
<td>161</td>
</tr>
<tr>
<td>Labish Peat</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPK</td>
<td>80</td>
<td>24.28</td>
<td>31.2</td>
<td>40.5</td>
<td>712</td>
<td>234</td>
<td>105</td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td></td>
<td>195.6</td>
<td>24.8</td>
<td>42.0</td>
<td>64.8</td>
<td>268</td>
<td>65</td>
</tr>
</tbody>
</table>

The manganese depressed the nitrates, though Schreiner and Dawson (1927) state that it stimulates nitrification. It apparently has little or no effect on phosphate, sulfate, or magnesium, but rather definitely decreases or has displaced calcium. Swanback (1939) shows that calcium strongly antagonizes manganese but shows no antagonism of manganese to calcium. Quite noticeable is its effect on potassium either having repressed it or displaced it. Since there was no leaching of these pots, it apparently conforms to the theory of Swanbeck in which he shows a strong action in the direction Mn → K. In this
phenomenon may possibly lie an answer to some of the potash starvation that occurs on certain soil types.

Ten months after treatment, the soil in all fallow pots was sampled and exchangeable bases determined. These were extracted from 25 grams of soil by 500 ml. of neutral, normal ammonium acetate solution, aliquots being taken for the different determinations. These results are recorded in Table 5.

Table 5. Effect of Manganese Treatment on Exchangeable Bases

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Rate per acre</th>
<th>Ca</th>
<th>Mg</th>
<th>K</th>
<th>Mn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Klamath Peat</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Check</td>
<td>53.1</td>
<td>30.1</td>
<td>3.32</td>
<td></td>
<td>.033</td>
</tr>
<tr>
<td>NPK</td>
<td>53.6</td>
<td>30.0</td>
<td>4.51</td>
<td>.017</td>
<td></td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>10</td>
<td>53.8</td>
<td>30.2</td>
<td>5.85</td>
<td>.020</td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>40</td>
<td>61.3</td>
<td>31.2</td>
<td>4.98</td>
<td>.098</td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>80</td>
<td>54.3</td>
<td>30.3</td>
<td>4.30</td>
<td>.037</td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>160</td>
<td>71.5</td>
<td>32.3</td>
<td>4.27</td>
<td>.033</td>
</tr>
<tr>
<td>Labish Peat</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Check</td>
<td>47.1</td>
<td>9.0</td>
<td></td>
<td>.115</td>
<td>.062</td>
</tr>
<tr>
<td>NPK</td>
<td>46.8</td>
<td>9.7</td>
<td></td>
<td>.110</td>
<td>.077</td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>10</td>
<td>61.0</td>
<td>10.4</td>
<td>.113</td>
<td>.083</td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>40</td>
<td>46.0</td>
<td>9.4</td>
<td>.083</td>
<td>.061</td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>80</td>
<td>46.9</td>
<td>9.5</td>
<td>.076</td>
<td>.066</td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>160</td>
<td>48.2</td>
<td>9.6</td>
<td>.104</td>
<td>.071</td>
</tr>
</tbody>
</table>

*m.e.* expressed as millequivalents per 100 grams of soil.
Again there is very little effect on the magnesium. The calcium seems to have increased a trifle, possibly compensating or accounting for that lost from the water-soluble portion. The exchangeable potassium shows less effect than the water-soluble, though there may be a tendency to decrease as a result of the added manganese in the case of the Labish peat.

The same samples of Klamath and Labish peats were analyzed for total and available manganese, the available constituting the exchangeable manganese and active manganic oxide (easily reducible). These results, reported in table 6, conform with those obtained by the previous analysis of the sugar beet leaves. This definitely indicates that the neutral or slightly alkaline Klamath peat is low in both available and total manganese, while the more acid Labish peat has an ample supply of available manganese as well as a relatively large total.
Table 6.  Comparison of Exchangeable Manganese and Active Manganic Oxide in Klamath and Lake Labish Peat

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Rate per acre</th>
<th>Exch. Mn lbs.</th>
<th>Active MnO₂ p.p.m.</th>
<th>Available Mn p.p.m.</th>
<th>Total Mn p.p.m.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Klamath Peat</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Check</td>
<td></td>
<td>9.1</td>
<td>6.1</td>
<td>15.2</td>
<td>205</td>
</tr>
<tr>
<td>NPK</td>
<td></td>
<td>4.5</td>
<td>8.0</td>
<td>12.8</td>
<td></td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>10</td>
<td>5.6</td>
<td>7.0</td>
<td>12.6</td>
<td></td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>40</td>
<td>26.9</td>
<td>15.5</td>
<td>42.4</td>
<td></td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>80</td>
<td>10.2</td>
<td>12.5</td>
<td>22.7</td>
<td></td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>160</td>
<td>9.0</td>
<td>13.9</td>
<td>22.8</td>
<td></td>
</tr>
<tr>
<td><strong>Labish Peat</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Check</td>
<td></td>
<td>17.0</td>
<td>14.6</td>
<td>163</td>
<td>1350</td>
</tr>
<tr>
<td>NPK</td>
<td></td>
<td>21.0</td>
<td>152</td>
<td>173</td>
<td></td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>10</td>
<td>22.7</td>
<td>14.4</td>
<td>167</td>
<td></td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>40</td>
<td>16.7</td>
<td>157</td>
<td>174</td>
<td></td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>80</td>
<td>18.2</td>
<td>156</td>
<td>174</td>
<td></td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>160</td>
<td>19.4</td>
<td>158</td>
<td>177</td>
<td></td>
</tr>
</tbody>
</table>

Investigations on Clatskanie Peat

Another peat soil called Clatskanie peat was taken from the George Poyak farm and potted in one-gallon glazed jars, each containing 1640 grams of dry soil. This was fertilized with pure chemicals in solution as indicated in table 7, except the lime, which was applied as pure precipitated chalk at the rate of two tons per acre. The NPK pots received 1,000 pounds per acre of 4-12-8 plus 0.5 p.p.m. of boron.
Table 7. Yield and Manganese Content of Beans Grown on Clatskanie Peat in the Greenhouse

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Average yield per jar</th>
<th>Rate Total dry matter</th>
<th>Rate Relative to NPK</th>
<th>Manganese content</th>
<th>Leaves p.p.m.</th>
<th>Beans p.p.m.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lbs. per acre</td>
<td>gms.</td>
<td>per cent</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPK, Ca</td>
<td>8.3</td>
<td>95.5</td>
<td>166</td>
<td>28.7</td>
<td>29.1</td>
<td></td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>40</td>
<td>9.5</td>
<td>109.2</td>
<td>172</td>
<td>24.4</td>
<td></td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>80</td>
<td>6.2</td>
<td>9.2</td>
<td>288</td>
<td>32.3</td>
<td></td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>160</td>
<td>6.1</td>
<td>69.5</td>
<td>---</td>
<td>36.7</td>
<td></td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>240</td>
<td>6.7</td>
<td>77.0</td>
<td>640</td>
<td>38.3</td>
<td></td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>320</td>
<td>8.8</td>
<td>100.6</td>
<td>577</td>
<td>35.1</td>
<td></td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>320</td>
<td>8.2</td>
<td>9.2</td>
<td>390</td>
<td>40.0</td>
<td></td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>320</td>
<td>8.2</td>
<td>9.2</td>
<td>390</td>
<td>40.0</td>
<td></td>
</tr>
</tbody>
</table>

*First Crop grown December 9, 1940 to February 5, 1941.
Second crop grown February 8, 1941 to April 22, 1941.
The first crop of beans which was grown during the winter months of December and January made a rather small growth and as a result absorbed ample quantities of manganese as can be seen from the third column. There was no increase in yield resulting from manganese applications since the leaves from the control plots contained over 100 p.p.m.

A second crop of beans was grown in February, March, and April, a period which provided considerable clear and warm weather. Because of this a much stronger growth was made with a greater drain on the manganese supply. Retreatment was made at the same rates with manganese only. As shown in table 7, the manganese content of the leaves was below 100 p.p.m. and a definite increase in yield was obtained from the manganese applications.

When comparing plant material from the check with that from the limed control it is evident that the former has taken up more manganese than the latter. This is also the case when comparing the 80-pound MnSO₄ treatments without and with lime. The added calcium has made a portion of the manganese unavailable. This agrees with the findings of Allison et al. (1927) on calcareous Florida peats, with Gilbert and McLean (1928) on overlimed soils in Rhode Island, and with Willis (1932) on overlimed and naturally calcareous soils of North Carolina.
They found that a high lime content was apt to cause an extreme manganese deficiency resulting in chlorotic plants.

Without further fertilization tomatoes were set, one to the pot, and grown all summer. The results are reported in Table 8.

Table 8. Yield and Manganese Content of Tomatoes Grown on Clatskanie Peat in the Greenhouse from May 13 to September 2, 1914

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Rate per acre</th>
<th>Yield</th>
<th>Rela-</th>
<th>Rela-</th>
<th>Manganese Content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lbs.</td>
<td>Tomatoes</td>
<td>to NPK</td>
<td>Vine</td>
<td>NPK</td>
</tr>
<tr>
<td>Check</td>
<td>90.4</td>
<td>87.4</td>
<td>9.8</td>
<td>70.5</td>
<td>163</td>
</tr>
<tr>
<td>NPK, Ca</td>
<td>103.3</td>
<td>100.0</td>
<td>13.9</td>
<td>100.0</td>
<td>82</td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>140</td>
<td>191.6</td>
<td>165.0</td>
<td>16.4</td>
<td>116.0</td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>80</td>
<td>99.6</td>
<td>96.4</td>
<td>18.4</td>
<td>132.3</td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>160</td>
<td>93.4</td>
<td>90.3</td>
<td>16.1</td>
<td>115.8</td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>240</td>
<td>39.2</td>
<td>37.9</td>
<td>16.7</td>
<td>120.0</td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>320</td>
<td>127.6</td>
<td>123.3</td>
<td>11.1</td>
<td>79.8</td>
</tr>
<tr>
<td>NPK, (-Ca) MnSO₄</td>
<td>80</td>
<td>27.5</td>
<td>26.6</td>
<td>17.9</td>
<td>126.8</td>
</tr>
</tbody>
</table>

Certain increases of yield and other decreases as a result of manganese treatments are to be seen, as well as an erratic manganese content of the plant parts, particularly the leaves. Two factors are largely responsible for this behavior.

(1) Having received NPK treatment only once, the peat has become deficient in potash as indicated by
leaf symptoms. This has tended to throw the relation of
the plant with respect to manganese out of balance, in
fact, as pointed out on page 20, additions of manganese
tend to depress the potash and thus aggravate the defi-
ciency. To check this point, potash in solution as KCl
was supplied to the NPK plus 40 pounds per acre of MnSO₄
treatment with remarkable results. The yield was nearly
doubled as was also the manganese content of the leaves.

(2) The other cause was the large amount of
watering necessary because of the high greenhouse tem-
peratures during the summer. In July and August, irri-
gations averaged 0.5 inches daily. Subsequent analyses
showed this tap water to contain an average of 7.5 p.p.b.
of manganese during the fall and winter months, at which
time it would be more dilute than in the summer.

Studies by Samuel and Piper (1928), Steenbjerg
(1935), Leeper (1935), Gerretsen (1936), and Sherman and
Hermer (1941) have shown that oats grown in a manganese
deficient soil are apt to suffer from "gray speck" dis-
ease, and that applications of manganous sulfate will
largely prevent the occurrence of this disease. As a
preliminary trial, oats were sown in Labish and Clats-
kanie peats which had been potted in one-quart cans.
After germination the oat plants were thinned to four
per can. Treatments and results are recorded in Table 9.

Table 9. Effect of Manganese on Yield of Oats Grown on Two Peat Soils in the Greenhouse from July 15 to September 21, 1941

<table>
<thead>
<tr>
<th>Soil and Jar No.</th>
<th>Treatment</th>
<th>Dry Matter</th>
<th>Average</th>
<th>Relative to Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>gms.</td>
<td>gms.</td>
<td>per cent</td>
</tr>
<tr>
<td>Clatskanie Peat</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>51-1</td>
<td>Control</td>
<td>3.0</td>
<td>3.0</td>
<td>100</td>
</tr>
<tr>
<td>51-2</td>
<td>Control</td>
<td>3.0</td>
<td>3.0</td>
<td>100</td>
</tr>
<tr>
<td>52-1</td>
<td>500 lbs. MnSO₄</td>
<td>3.1</td>
<td>3.15</td>
<td>105</td>
</tr>
<tr>
<td>52-2</td>
<td>500 lbs. MnSO₄</td>
<td>3.2</td>
<td>3.15</td>
<td>105</td>
</tr>
<tr>
<td>Labish Peat</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>63-1</td>
<td>Control</td>
<td>1.7</td>
<td>1.9</td>
<td>100</td>
</tr>
<tr>
<td>63-2</td>
<td>Control</td>
<td>2.1</td>
<td>1.9</td>
<td>100</td>
</tr>
<tr>
<td>64-1</td>
<td>500 lbs. MnSO₄</td>
<td>1.8</td>
<td>1.75</td>
<td>92</td>
</tr>
<tr>
<td>64-2</td>
<td>500 lbs. MnSO₄</td>
<td>1.7</td>
<td>1.75</td>
<td>92</td>
</tr>
</tbody>
</table>

As in previous trials, a negative response was obtained with regard to yield from the Labish peat and no sign of gray speck was discernible throughout the growth. A moderate response was obtained from the Clatskanie peat, and during the early stages of growth a very mild development of gray speck was observed on the controls. However, this was overcome later so that no difference could be seen between the controls and the treatments.

Sherman and Harmer (1941) state that with hot dry weather plants may recover from the initial symptoms...
of gray speck disease. Since the trial experiments mentioned above were conducted during the hot dry weather of July and August, it was decided to try a more extensive oats experiment on the Clatskanie peat during the fall.

The Clatskanie peat in one-gallon jars was again used with certain modifications of treatment. All except the minus lime series received hydrated lime equivalent to two tons of calcium carbonate per acre. All jars received 1,000 pounds of 0-3-24 at time of seeding, and applications as needed of Ca(NO₃)₂ in solution during the growth period. The manganese treatments and results are shown in Table 10.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Rate per acre</th>
<th>Dry matter</th>
<th>Manganese Content</th>
<th>Degree of heading</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lbs.</td>
<td>gms.</td>
<td>p.p.m.</td>
<td></td>
</tr>
<tr>
<td>NPK, Ca</td>
<td>120</td>
<td>13.1</td>
<td>140</td>
<td>slight</td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>100</td>
<td>12.0</td>
<td>120</td>
<td>none</td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>250</td>
<td>12.9</td>
<td>261</td>
<td>slight</td>
</tr>
<tr>
<td>NPK, (–Ca), MnSO₄</td>
<td>100</td>
<td>12.4</td>
<td>536</td>
<td>headed</td>
</tr>
</tbody>
</table>
No particular response, positive or negative, is discernible from the yield data. Gray speck disease was not apparent at any stage of growth; however, during November an attack of powdery mildew set in which retarded all plants considerably. When cured by dusting and given supplemental light, all plants recovered and commenced to make a strong vegetative growth but were slow to head.

The degree of heading was observed at the time of harvest and is recorded in the last column of table 10. The correlation of degree of heading with manganese content of the plant (the entire aerial portion of the plant was ground for analysis) is quite marked, with one exception, and lends support to the theory that manganese aids maturity and reproduction. The point is again strongly brought out that the 100-pound MnSO₄ application where lime is excluded puts far more manganese in the plant than the same application where lime is included.

After harvesting the oats, soil samples were taken from all jars and the like treatments combined and mixed. Water-soluble manganese, exchangeable manganese, and active manganic oxide were run in duplicate on all treatments and the results reported in table 11.
Table 11. Available Manganese in Clatskanie Peat After Three Fertilizations and Four Harvests

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Rate per acre</th>
<th>Water-Soluble Mn</th>
<th>Exchangeable Mn</th>
<th>Active MnO₂</th>
<th>Total Available Mn</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lbs.</td>
<td>p.p.m.</td>
<td>p.p.m.</td>
<td>p.p.m.</td>
<td>p.p.m.</td>
</tr>
<tr>
<td>NPK, Ca</td>
<td>0</td>
<td>17.2</td>
<td>69</td>
<td>117.9</td>
<td></td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>40</td>
<td>13.9</td>
<td>107</td>
<td>110.7</td>
<td></td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>100</td>
<td>20.8</td>
<td>170</td>
<td>190.8</td>
<td></td>
</tr>
<tr>
<td>NPK, MnSO₄</td>
<td>250</td>
<td>24.5</td>
<td>187</td>
<td>211.5</td>
<td></td>
</tr>
<tr>
<td>NPK, (-Ca), MnSO₄</td>
<td>100</td>
<td>51.9</td>
<td>98</td>
<td>149.9</td>
<td></td>
</tr>
</tbody>
</table>

Water soluble manganese is negligible in all treatments. Some insight into the actual effect of lime on the manganese may be obtained from the second and third columns. The exchangeable manganese is highest on the minus lime treatment, more than twice that of the same manganese application when lime had also been added. Conversely, the minus lime soil has less active manganic oxide than any other save the control. The lime, very evidently, displaces a large portion of the manganese from the exchange complex and causes it to be oxidized to the higher oxide from where it is much more difficultly available. The benefits obtained by Sherman and Harmer (1941) from applications of sulfur, sulfuric acid, and hydroquinone are very likely due to a reduction or transfer of manganese from the higher oxide form to the
exchangeable form. Their table on interaction bears this out, particularly with respect to hydroquinone. The values in the total available column vary directly with the rate of manganese application and show that these outside influences merely shift the balance back and forth between exchangeable manganese and active MnO₂.

**Investigations on Chehalis Silty Clay Loam**

During the summer of 1941, manganese plot trials were conducted on the O.S.C. Horticulture Farm, two miles southeast of Corvallis. The soil on this farm is Chehalis silty clay loam on a slightly undulating topography. A range 175' x 25' was laid out in seven plots, 25 feet square, fertilized with manganous sulfate, as indicated in table 12 and seeded to snap beans in 30-inch rows on April 23th. A week later, two rows of tomato seedlings were set along the west half of the entire range. The crops were given irrigation by sprinkling four times during the growth period -- on June 13, July 1, July 18, July 25, -- for a total of eight inches.

As the beans came up among the tomato plants they were pulled and saved for analysis to learn of the movement and distribution of manganese at different stages of growth. At the final harvest on August 11th they were again pulled and dried for analysis. The results
are shown in table 13, page 35.

The manganese content of the leaves remained below 100 p.p.m. on all plots until maturity when it rose to over 100 p.p.m. on all plots except one. This may be a natural phenomenon of maturity or the result of the cessation of irrigation with a subsequent concentration of the soil solution. Discordantly, the check plot furnished plants with the highest manganese content, the sprayed plot running second. At the first sampling, the sprayed plot furnished leaves with the highest manganese content. In contrast to the leaves, the stems contained less manganese as maturity was reached. Apparently manganese is mainly absorbed during the earliest stages of growth, and later it is all transmitted to the leaves.

The yield data as shown in table 12, page 34, does not correspond with the treatments but does correlate fairly well with the manganese content of the plants. In observing the yields for the four broadcast treatments, 20, 40, 80, and 160 pounds of manganous sulfate per acre, respectively, it is seen that the yield rises with the rate of application.
Table 12. Yield of Tomatoes and Beans
From Manganese Trials on College Horticulture Farm
(Chehalis silty clay loam)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Rate per acre</th>
<th>Yield per acre</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lbs.</td>
<td>Beans</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td>1773</td>
</tr>
<tr>
<td>MnSO_4</td>
<td>20</td>
<td>837</td>
</tr>
<tr>
<td>MnSO_4</td>
<td>40</td>
<td>856</td>
</tr>
<tr>
<td>MnSO_4</td>
<td>80</td>
<td>872</td>
</tr>
<tr>
<td>MnSO_4</td>
<td>160</td>
<td>1328</td>
</tr>
<tr>
<td>MnSO_4, sprayed</td>
<td>40</td>
<td>1613</td>
</tr>
<tr>
<td>MnSO_4, drilled</td>
<td>20</td>
<td>1502</td>
</tr>
<tr>
<td>8 adjacent controls,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>average</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

These four plots on which the treatment was broadcast all lie on the slopes and crest of a minor undulation, positions from which nutrients are more readily leached. The check plot, which gave the highest yield and grew plants containing the most manganese, was situated at the base of the undulation in which position it would be more subject to enrichment than to loss of nutrients. The plots receiving MnSO_4 sprayed and drilled, respectively, lay on either side of the check plot in nearly as favorable a position, and consequently yielded nearly as much. Adjacent to these plots on the west was a Latin square arrangement with eight treatments and eight replications growing the same kind of beans, seeded and harvested on the same dates. The average of the eight check plots was only 863 pounds per acre, which
Table 13. Manganese Content of Beans and Tomato Parts at Different Stages of Growth on Manganese Trials (Horticulture Farm, 1941)

<table>
<thead>
<tr>
<th>Date</th>
<th>Part</th>
<th>Manganese Treatment expressed as pounds MnSO₄ per acre</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Broadcast 0  20  40  80  160  40  80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>p.p.m.  p.p.m.  p.p.m.  p.p.m.  p.p.m.  p.p.m.  p.p.m.  p.p.m.  p.p.m.  p.p.m.  p.p.m.</td>
</tr>
<tr>
<td>Bean</td>
<td></td>
<td></td>
</tr>
<tr>
<td>June  6</td>
<td>leaves</td>
<td>78  70  88  90  89  95  75</td>
</tr>
<tr>
<td></td>
<td>stems</td>
<td>69  29  31  50  38  50  42</td>
</tr>
<tr>
<td>July  3</td>
<td>leaves</td>
<td>84  94  66  88  82  72  70</td>
</tr>
<tr>
<td></td>
<td>stems</td>
<td>42  32  40  41  36  38  40</td>
</tr>
<tr>
<td>July 22</td>
<td>leaves</td>
<td>78  66  92  82  82  82  74</td>
</tr>
<tr>
<td></td>
<td>stems</td>
<td>30  26  40  44  32  32  36</td>
</tr>
<tr>
<td>Aug. 11</td>
<td>leaves</td>
<td>152 95 126 132 119 148 124</td>
</tr>
<tr>
<td>Tomato</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aug. 11</td>
<td>leaves</td>
<td>62  94  88  75  80  69  77</td>
</tr>
<tr>
<td>Aug. 22</td>
<td>leaves</td>
<td>129 174 145 159 110 113 118</td>
</tr>
</tbody>
</table>

Irrigation dates: June 13, July 1, July 18, July 25.  
Total water applied: 8 inches.
supports the theory that position was responsible for the high yield from the control.

On August 11th and 22d, tomato leaves were picked and dried for analysis. The results, recorded in table 13, show that the tomato leaves contain less than 100 p.p.m. of manganese while young but increase with maturity, even though irrigation had ceased two weeks prior to the first picking.

The tomatoes were harvested throughout the last half of August and September with the final picking on September 23d. The total yields are shown in table 12, from which it is seen that positional influence was greater than treatment just as with the beans. However, the observation as to rate of maturity first mentioned with the oats was again apparent here. The plots which received manganese applications gave the largest yields of ripe tomatoes during August and early September. This further supports the theory that manganese aids and hastens maturity.

On the same farm and soil type, the soils department conducted a Latin square minor elements trial on table beets. There were eight treatments and eight replications. The yield data for the control and manganese treatments with statistical analysis for significance are shown in table 14.
### Table 14. Yield of Table Beets from the Latin Square Minor Elements Trials on Horticulture Farm, 1941

<table>
<thead>
<tr>
<th>Block</th>
<th>Beets per acre</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Manganese</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1.31</td>
<td>2.39</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2.83</td>
<td>2.83</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2.18</td>
<td>7.19</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>5.15</td>
<td>5.01</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>3.70</td>
<td>7.62</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>6.53</td>
<td>6.32</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>5.15</td>
<td>8.28</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>8.28</td>
<td>8.06</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>4.47</td>
<td>5.96</td>
<td></td>
</tr>
</tbody>
</table>

| Std. deviation | .893 | .887 |
| Std. error of mean | .316 | .310 |
| Std. error of difference | .143 |

The average yield from the manganese plots, which received MnSO₄ at the rate of 40 pounds per acre, was 1.49 - .443 tons per acre better than the average from the control plots. According to Fischer's table of t (1936), this means that the odds are better than 49:1 against this happening merely by chance.

Because of the disagreement in the field trials as to the results from manganese applications, a bulk surface sample from the control plot was taken to the greenhouse and potted in two-gallon lacquered flower pots. Twelve pots were filled with five kilograms of dry soil each and divided into blocks of four. The first block received no treatment, the second and third, respectively, received 40 and 160 pounds per acre of manganese.
sulfate. Bountiful beans were sown and after germination thinned to four per jar. The results, as recorded in table 15, show a slight yield increase from the 160-pound treatment over the control. Statistical analysis shows that this is significant, with odds of 19:1 against its being due to chance. The 40-pound treatment showed a slight decrease which was not significant. Greater increases could not be expected because of the relatively high manganese supplying power of the control plot, as shown by leaf analysis.

Table 15. The Response of Beans
Grown on Chehalis Silty Clay Loam Under Greenhouse Conditions
To Applications of Manganese
Grown from Nov. 30, 1941 to Feb. 20, 1942

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Block 1</th>
<th>Block 2</th>
<th>Block 3</th>
<th>Block 4</th>
<th>Avg.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>gms.</td>
<td>gms.</td>
<td>gms.</td>
<td>gms.</td>
<td>gms.</td>
</tr>
<tr>
<td>Control</td>
<td>5.6</td>
<td>5.1</td>
<td>5.6</td>
<td>5.5</td>
<td>5.45</td>
</tr>
<tr>
<td>40 lbs. MnSO₄</td>
<td>6.1</td>
<td>5.0</td>
<td>4.3</td>
<td>5.2</td>
<td>5.15</td>
</tr>
<tr>
<td>160 lbs. MnSO₄</td>
<td>5.7</td>
<td>7.0</td>
<td>6.3</td>
<td>5.2</td>
<td>6.05</td>
</tr>
</tbody>
</table>

Following the tomato harvest, soil samples were taken for analysis from all plots at two depth, 0 - 6 inches and 6 - 12 inches. Additional depths of 12 - 20 inches and 20 - 30 inches were taken from the control and the 80-pounds per acre of MnSO₄ plots. Extractions
were made in the usual manner to determine the various forms of available manganese. The results are recorded in Table 16.

Table 16. Available Manganese in Chehalis Silty Clay Loam From Manganese Trial Plots, Horticulture Farm, After Crop Removal

<table>
<thead>
<tr>
<th>Treatment and Rate</th>
<th>Water Soluble Mn</th>
<th>Exchangeable Mn</th>
<th>Active MnO₂ Mn</th>
<th>Total Available Mn</th>
</tr>
</thead>
<tbody>
<tr>
<td>lbs. per acre</td>
<td>ins.</td>
<td>p.p.m.</td>
<td>p.p.m.</td>
<td>p.p.m.</td>
</tr>
<tr>
<td>Control</td>
<td>0-6</td>
<td>0</td>
<td>5.3</td>
<td>153</td>
</tr>
<tr>
<td></td>
<td>6-12</td>
<td>0</td>
<td>8.4</td>
<td>129</td>
</tr>
<tr>
<td></td>
<td>12-20</td>
<td>0</td>
<td>4.5</td>
<td>148</td>
</tr>
<tr>
<td></td>
<td>20-30</td>
<td>0</td>
<td>4.4</td>
<td>204</td>
</tr>
<tr>
<td>20 MnSO₄</td>
<td>0-6</td>
<td>0</td>
<td>4.5</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td>6-12</td>
<td>0</td>
<td>3.6</td>
<td>85</td>
</tr>
<tr>
<td>40 MnSO₄</td>
<td>0-6</td>
<td>0</td>
<td>3.6</td>
<td>116</td>
</tr>
<tr>
<td></td>
<td>6-12</td>
<td>0</td>
<td>3.8</td>
<td>123</td>
</tr>
<tr>
<td>80 MnSO₄</td>
<td>0-6</td>
<td>0</td>
<td>2.6</td>
<td>171</td>
</tr>
<tr>
<td></td>
<td>6-12</td>
<td>0</td>
<td>5.2</td>
<td>152</td>
</tr>
<tr>
<td></td>
<td>12-20</td>
<td>0</td>
<td>8.1</td>
<td>190</td>
</tr>
<tr>
<td></td>
<td>20-30</td>
<td>0</td>
<td>5.4</td>
<td>266</td>
</tr>
<tr>
<td>160 MnSO₄</td>
<td>0-6</td>
<td>0</td>
<td>6.1</td>
<td>136</td>
</tr>
<tr>
<td></td>
<td>6-12</td>
<td>0</td>
<td>13.9</td>
<td>150</td>
</tr>
<tr>
<td>40 MnSO₄ sprayed</td>
<td>0-6</td>
<td>0</td>
<td>6.3</td>
<td>149</td>
</tr>
<tr>
<td></td>
<td>6-12</td>
<td>0</td>
<td>7.9</td>
<td>122</td>
</tr>
<tr>
<td>20 MnSO₄ drilled</td>
<td>0-6</td>
<td>0</td>
<td>2.9</td>
<td>173</td>
</tr>
<tr>
<td></td>
<td>6-12</td>
<td>0</td>
<td>2.9</td>
<td>114</td>
</tr>
</tbody>
</table>

As has been expected, the control was higher in exchangeable manganese in the first 12 inches than any of the others except the 160-pound treatment, and the
40 pounds sprayed. There does not appear to be any more exchangeable manganese in the surface of the treated plots at the end of the season except for the 160-pound treatment than before treatment. Either it has been used up by the crop or has reverted to active MnO₂. A glance at the figures for active MnO₂ shows that in most cases the surface is higher than the next layer, indicating that at least that portion of the added manganese which the crop did not use has reverted to active MnO₂. While the exchangeable manganese varies but little with depth, the high value for active MnO₂ in the fourth layer indicates that the lower subsoil is a potential source of manganese which might become available to deep-rooted plants. This would tend to upset manganese experiments with that type of crop and to make manganese applications on such a crop unnecessary.

Investigations on Braillier peat

In a further study of organic soils, a coarse fibrous peat from Braillier marsh of pH 4.05 was obtained from the lower Columbia River valley. This was potted in two-gallon glazed jars, each containing 1360 grams of dry soil and fertilized in duplicate. All jars except the check received fertilizers as pure chemicals in solution equivalent to 500 pounds per acre of 4-10-10, plus two
tons of lime. Minor elements were supplied in solution at the rates of 0.1 p.p.m. of copper and zinc, 0.5 p.p.m. of boron, and 20 pounds per acre of MnSO₄ except where otherwise noted in table 17. Following the check and control, minor elements were omitted one at a time in the next four series, while in the final four series all minor elements were present with the rate of MnSO₄ varying.

Tomatoes, one to the pot, were set in May and allowed to grow until the final harvest on September 2d, 1941. The soil was then refertilized with four tons of lime and 1,500 pounds of 0-16-24 per acre, and minor elements at the same rate as before. Lotus corniculatus was seeded in October, 1941, the soil inoculated, and after germination the plants thinned to eight per jar. These were grown until April, 1942 with the aid of supplemental illumination during the winter months. The yield data for tomatoes and for lotus are presented in table 17.
Table 17. Response of Tomatoes and Lotus to Manganese on Braillier Peat in the Greenhouse

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Rate per acre lbs.</th>
<th>Yield of Tomatoes Average per jar grams</th>
<th>Relation to NPK per cent</th>
<th>Yield of Lotus Average per jar grams</th>
<th>Relation to NPK per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Check</td>
<td></td>
<td>257</td>
<td>88</td>
<td>12.5</td>
<td>68</td>
</tr>
<tr>
<td>NPK</td>
<td></td>
<td>291</td>
<td>100</td>
<td>18.3</td>
<td>100</td>
</tr>
<tr>
<td>NPK (-B)</td>
<td></td>
<td>392</td>
<td>135</td>
<td>19.6</td>
<td>108</td>
</tr>
<tr>
<td>Cu, Sn, Mn</td>
<td></td>
<td>336</td>
<td>115</td>
<td>19.9</td>
<td>109</td>
</tr>
<tr>
<td>NPK (-Cu)</td>
<td></td>
<td>380</td>
<td>121</td>
<td>21.9</td>
<td>120</td>
</tr>
<tr>
<td>B, Mn, Zn</td>
<td></td>
<td>315</td>
<td>108</td>
<td>16.8</td>
<td>92</td>
</tr>
<tr>
<td>NPK (-Zn)</td>
<td></td>
<td>313</td>
<td>107</td>
<td>22.7</td>
<td>121</td>
</tr>
<tr>
<td>E, Mn, Cu</td>
<td></td>
<td>293</td>
<td>101</td>
<td>19.2</td>
<td>105</td>
</tr>
<tr>
<td>NPK (-Mn)</td>
<td></td>
<td>319</td>
<td>110</td>
<td>20.0</td>
<td>109</td>
</tr>
<tr>
<td>B, Cu, Zn</td>
<td></td>
<td>291</td>
<td>100</td>
<td>20.0</td>
<td>109</td>
</tr>
<tr>
<td>NPK, MnSO₄₂₄</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPK, MnSO₄₂₄</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPK, MnSO₄₂₄</td>
<td>80</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPK, MnSO₄₂₄</td>
<td>160</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Of the four minor elements omitted, manganese seemed to be the critical one without which the yield dropped the lowest on both tomatoes and lotus. Boron seemed to be the one without which the best yield was obtained on tomatoes, while zinc occupied that position on lotus and very nearly did on tomatoes. The increasing rates of manganese give very little change in the yield, indicating that on an acid peat of such an open structure as this, a small application yearly would be of more benefit than larger applications at less frequent intervals.
Oxidation-Reduction Investigations

The exact role of manganese in plant nutrition is as yet unknown in spite of the ever-increasing volume of manganese investigation. Kliman (1937) has stated that iron enters the roots, is transported in the phloem and combines as a complex anion with certain proteins all in the ferrous state. Ferric iron is found deposited in the nodes of mature plants. Shive (1941) claims that iron is absorbed in the ferric state but will be reduced to ferrous iron by the powerful reducing systems of the cell unless restrained. He believes that more than a small quantity of ferrous iron would be toxic and that manganese having a higher oxidation potential than iron is the substance necessary to prevent accumulations of ferrous iron. However, he does not state how manganese, which is absorbed as the manganous ion, becomes oxidized within the plant so that it can exert its superior oxidizing potential to prevent excess reduction of iron, unless it is performed by the living system. But according to his previous statement the living cell possesses powerful reducing systems. Willis (1928) when investigating chlorosis of soybeans on overlimed coastal plain soils found that ferric iron had accumulated in the lower nodes of corn plants grown in rotation on the
same plots. This condition was the result of manganese deficiency and was corrected by the application of manganous sulfate. This lends support to the theory that iron normally circulates in the ferrous condition and that oxidation forces within the plant tend to deposit it in the ferric condition resulting in the chlorosis that Willis describes for soy beans. If sufficient manganese is present to keep the iron reduced to the ferrous state the chlorosis is overcome or prevented. Is it possible, then, that the major purpose of manganese is to keep iron in the proper state of oxidation or reduction, that it is functional rather than nutritional? If this is so, would it be possible to replace manganese with some other substances that would serve the same purpose?

In order to study this matter, further additional Klamath peat, previously shown to be low in manganese, was obtained and potted in 36 two-gallon lacquered flower pots, 2200 grams of dry soil per pot. All were supplied with pure chemicals equivalent to 1,000 pounds per acre of 0-8-24 well mixed into the soil. In replications of four they were treated as shown in table 18. This includes a control, four reducing agents, and four oxidizing agents. The reducing agents are manganous chloride, ferrous tartrate, stannous chloride, and
hydroquinone, while the oxidizing agents are cupric acetate, ferric tartrate, potassium chromate and potassium permanganate. The rates of application are in proportion to the molecular weights so that there would be equal numbers of molecules present. Spinach was seeded and after germination thinned to five plants per pot. Table 18 gives the yield and manganese content of the spinach from the different treatments.

Table 18. The Effect of Various Oxidizing and Reducing Agents on the Yield and Manganese Content of Spinach
Grown on Klamath Peat from Sept. 20, 1941 to Feb. 20, 1942

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Rate per acre</th>
<th>Average dry matter per jar</th>
<th>Manganese Content p.p.m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>10</td>
<td>4.0</td>
<td>36.4</td>
</tr>
<tr>
<td>MnCl₂</td>
<td>200</td>
<td>5.35</td>
<td>89.0</td>
</tr>
<tr>
<td>Fe₂(C₃H₆O₆)₃</td>
<td>203</td>
<td>7.9</td>
<td>35.0</td>
</tr>
<tr>
<td>SnCl₂</td>
<td>225</td>
<td>7.72</td>
<td>53.0</td>
</tr>
<tr>
<td>Hydroquinone</td>
<td>110</td>
<td>9.0</td>
<td>51.5</td>
</tr>
<tr>
<td>Cu(C₂H₃O₂)₂</td>
<td>200</td>
<td>8.7</td>
<td>36.7</td>
</tr>
<tr>
<td>Fe₂(S₂H₄O₆)₃</td>
<td>278</td>
<td>7.5</td>
<td>47.0</td>
</tr>
<tr>
<td>K₂Cr₂O₇</td>
<td>194</td>
<td>7.77</td>
<td>40.0</td>
</tr>
<tr>
<td>KMnO₄</td>
<td>158</td>
<td>7.62</td>
<td>76.5</td>
</tr>
</tbody>
</table>

As expected, the manganese content of plants from the MnCl₂ and KMnO₄ treatments is the highest because of the manganese applied. The next two highest were produced by reducers, stannous chloride and hydroquinone,
which probably reduced some of the active MnO₂. Unfortunately the manganous chloride series was injured rather severely by red spider and thrips so that the yield data means little. From the others it was found that the average yield of dry matter per pot from the reducers was 8.2 grams, from the oxidizers, 7.9 grams. This may indicate that the reducers have partly performed the function of the deficient manganese or it may be that they have merely made available some of the oxidized forms of manganese.

To see just what effect these oxidizers and reducers had on the available manganese, samples were taken from all pots after the spinach harvest, like treatments mixed, and extractions for available manganese made in the usual manner. The results of these extractions are shown in table 19.
Table 19. The Effect of Various Oxidizing and Reducing Agents on the Availability of Manganese in Klamath Peat

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Rate per acre</th>
<th>Exchangeable Mn</th>
<th>Active MnO₂</th>
<th>Total Available Mn</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lbs.</td>
<td>p.p.m.</td>
<td>p.p.m.</td>
<td>p.p.m.</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MnCl₂</td>
<td>200</td>
<td>4.0</td>
<td>6.4</td>
<td>10.4</td>
</tr>
<tr>
<td>Fe₃(PO₄)₂</td>
<td>278</td>
<td>2.1</td>
<td>7.9</td>
<td>10.0</td>
</tr>
<tr>
<td>SnCl₂</td>
<td>110</td>
<td>1.2</td>
<td>5.7</td>
<td>6.9</td>
</tr>
<tr>
<td>Hydroquinone</td>
<td>110</td>
<td>1.2</td>
<td>5.7</td>
<td>6.9</td>
</tr>
<tr>
<td>Cu(C₂H₃O₂)₂</td>
<td>200</td>
<td>1.8</td>
<td>6.2</td>
<td>8.0</td>
</tr>
<tr>
<td>KMnO₄</td>
<td>158</td>
<td>2.6</td>
<td>11.3</td>
<td>13.9</td>
</tr>
<tr>
<td>K₂CrO₄</td>
<td>194</td>
<td>1.6</td>
<td>4.9</td>
<td>6.5</td>
</tr>
</tbody>
</table>

The MnCl₂ contributed to the exchangeable manganese (there was no water-soluble), but apparently no other treatment did. Both the MnCl₂ and KMnO₄ contributed to the active MnO₂ with no other treatment showing much effect. From the somewhat lower active MnO₂ figure for hydroquinone, the K₂CrO₄ treatment excepted, and the higher manganese content of the plants from this treatment, it seems reasonable to conclude that some of the oxidized form has been reduced and used by the plants.

The oxidizers and reducers, except for those mentioned in the preceding paragraph, had no effect on any form of manganese, yet the reducers gave a higher
average yield than the oxidizers. While there are many other tests and experiments that should be made, these results indicate the possibility that manganese may be largely functional rather than nutritional, and in this respect replaceable by other substances.

**Effect of pH on Manganese Availability**

Numerous investigators have reported manganese deficiency on calcareous or overlimed soils and frequently recommend sulfur applications or other treatments to increase the acidity as a means of overcoming the deficiency. It was noted in the investigation of Clatskanie peat that the addition of lime drastically reduced the intake of manganese even though the pH never rose above 5.0. Is the manganese availability then entirely related to the calcium supply or is it a function of the pH? Can a manganese-deficient soil be corrected merely by adjusting to a more favorable reaction?

To answer these questions a Klamath peat of pH 7.1 and known to be very low in available manganese and an Aiken clay loam of pH 5.7 thought to be high in manganese were divided into four samples each and adjusted to pH values of 4.5, 5.5, 6.5, 7.5. These adjustments were made with sulfuric acid or sodium hydroxide and checked with the glass electrode. After the initial adjustment the soils were allowed to stand for a week to
attain equilibrium and then adjusted again. After standing another week they were weighed out and extracted in the usual manner to obtain the water-soluble and exchangeable manganese and the easily reducible manganic oxide. The results are reported in Table 20.

Table 20. The Influence of pH on Manganese Availability

<table>
<thead>
<tr>
<th>Soil</th>
<th>pH</th>
<th>Water-Soluble Mn</th>
<th>Exchangeable Mn</th>
<th>Active MnO₂ Mn</th>
<th>Total Available Mn</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>P.p.m.</td>
<td>P.p.m.</td>
<td>P.p.m.</td>
<td>P.p.m.</td>
</tr>
<tr>
<td>Klamath Peat</td>
<td>4.5</td>
<td>6.3</td>
<td>11.2</td>
<td>4.4</td>
<td>24.9</td>
</tr>
<tr>
<td></td>
<td>5.5</td>
<td>2.5</td>
<td>12.2</td>
<td>5.6</td>
<td>20.3</td>
</tr>
<tr>
<td></td>
<td>6.5</td>
<td>1.4</td>
<td>4.3</td>
<td>5.8</td>
<td>11.5</td>
</tr>
<tr>
<td></td>
<td>7.5</td>
<td>0.0</td>
<td>2.8</td>
<td>7.0</td>
<td>9.8</td>
</tr>
<tr>
<td>Aiken Clay Loam</td>
<td>4.5</td>
<td>75.0</td>
<td>320</td>
<td>114.9</td>
<td>1886.0</td>
</tr>
<tr>
<td></td>
<td>5.5</td>
<td>93.5</td>
<td>601</td>
<td>110.7</td>
<td>1801.5</td>
</tr>
<tr>
<td></td>
<td>6.5</td>
<td>7.9</td>
<td>114.5</td>
<td>1261</td>
<td>1733.9</td>
</tr>
<tr>
<td></td>
<td>7.5</td>
<td>0.0</td>
<td>739</td>
<td>984</td>
<td>1723.0</td>
</tr>
</tbody>
</table>

With the Klamath peat a very significant increase has been obtained in the water-soluble and exchangeable portions, with a slight decrease in the active MnO₂ as a result of acidification. This indicates that by rather drastic acidity treatments the deficiency could be overcome temporarily, but the supply released is not large enough to last. The active MnO₂ has been depleted to supply this extra amount leaving less reserve. The sum of all available types indicates that the acid treatment
brought into solution certain amounts from formerly unavailable sources in addition to reducing the active manganic oxide. Thus acidification might make sufficient manganese available to avoid a deficiency for a very few years, but later the condition would probably be aggravated. Light applications of MnSO₄ would be a more feasible method to overcome the deficiency.

A somewhat different result was obtained from the Aiken clay loam. Neutralizing reduced drastically the water-soluble manganese but had no apparent effect on the exchangeable portion and only a moderate effect on the active manganic oxide. The total available manganese was reduced slightly by neutralizing and increased slightly by further acidifying, but the changes were relatively insignificant. Thus where soils are overlimed or naturally calcareous, it is the lime that reduces the availability of manganese, not the pH.

The Effect of Manganese on Availability of Other Elements

In the investigations of Klamath and Labish peat it was pointed out (table 4) that manganese seemed to repress the potassium and possibly the calcium. A further investigation of this effect on potassium and also on iron was conducted using Clatskanie peat and Chehalis silty clay loam. The samples of Clatskanie peat chosen were the control and the 250-pounds per acre of MnSO₄
treatment from the greenhouse trials, while those of the Chehalis silty clay loam were the control and the 160-pound per acre of MnSO₄ from the field trials on the College Horticulture Farm. Aliquots of the water and ammonium acetate extracts were analyzed for iron and potassium by methods previously outlined. The results are presented in table 21.

Table 21. The Effect of Manganese on the Availability of Iron and Potash in Soils

<table>
<thead>
<tr>
<th>Soil</th>
<th>Treatment</th>
<th>Rate per acre</th>
<th>Iron H₂O Soluble</th>
<th>Potassium H₂O Soluble</th>
<th>Exchangeable available</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clatskanie Peat</td>
<td>Control</td>
<td>10.2 lbs.</td>
<td>56.3 p.p.m.</td>
<td>98.5 p.p.m.</td>
<td>154.8 p.p.m.</td>
</tr>
<tr>
<td>Clatskanie Peat</td>
<td>MnSO₄</td>
<td>250 lbs.</td>
<td>7.5 p.p.m.</td>
<td>53.7 p.p.m.</td>
<td>146.5 p.p.m.</td>
</tr>
<tr>
<td>Chehalis Silty Clay Loam</td>
<td>Control</td>
<td>1.67 lbs.</td>
<td>43.6 p.p.m.</td>
<td>291.0 p.p.m.</td>
<td>334.6 p.p.m.</td>
</tr>
<tr>
<td>Chehalis Silty Clay Loam</td>
<td>MnSO₄</td>
<td>160 lbs.</td>
<td>1.36 lbs.</td>
<td>47.3 p.p.m.</td>
<td>255.0 p.p.m.</td>
</tr>
</tbody>
</table>

The water-soluble iron decreased with the application of manganese on both soil types, the effect being slightly greater with the peat. There was no exchangeable iron from either soil. The water-soluble potassium likewise decreased where manganese had been added to the Clatskanie peat, but the reverse took place on the Chehalis soil. However, the exchangeable potassium was consistently lowered by the application of manganese as was
the sum of the water-soluble and exchangeable or the total available. It may be that the increase in the water-soluble portion where manganese was applied to the Chehalis was a result of displacement from the exchangeable complex.

Again, we have confirmation of the theory that manganese depresses potassium. Is it then possible that excess manganese may be the cause of some potash deficiencies? A sample of Olympic silty clay loam was taken from the check plot of the potash trial plots on the Ernest Ede farm, where potash-deficiency symptoms are distinct on the leaves of small fruit. The water-soluble, exchangeable, active MnO₂ manganese were determined by the usual extractions. The following results were obtained:

<table>
<thead>
<tr>
<th></th>
<th>Water-soluble Mn</th>
<th>Exchangeable Mn</th>
<th>Active MnO₂</th>
<th>Total Available Mn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Olympic silty</td>
<td>9.2</td>
<td>115</td>
<td>1202</td>
<td>1326</td>
</tr>
<tr>
<td>clay loam</td>
<td>p.p.m.</td>
<td>p.p.m.</td>
<td>p.p.m.</td>
<td>p.p.m.</td>
</tr>
</tbody>
</table>

The available manganese in this soil is thus found to be very high, being surpassed by only one other soil so far studied, the Aiken clay loam. In this high content of manganese may possibly lie the cause for the potash deficiency. If so, the proper fertilization of this soil should then include lime and possibly copper.
to antagonize or tie up the excess manganese. Willis and Piland (1936) state that copper as generally used in North Carolina is a soil amendment to correct conditions of excess soluble iron and manganese.

A further investigation of the Olympic series reveals that in many cases the subsoil at four to five feet contains iron-manganese concretions or seams of iron hardpan. These are due to excess soluble iron and manganese being carried down into the subsoil by percolation waters and precipitated there. A sample of an Olympic series subsoil containing a distinct iron-pan was taken near Camas Valley. The iron crust was separated from the rest of the sample and the two portions extracted for available manganese in the usual manner. An alkali fusion was made on a separate portion to obtain total manganese. The results are reported in table 22.

Table 22. Total and Available Manganese in Iron Seam and Surrounding Subsoil of an Olympic Series

<table>
<thead>
<tr>
<th></th>
<th>Water-Soluble Mn</th>
<th>Water-Soluble Mn</th>
<th>Exchange-Available Mn</th>
<th>Active MnO₂ Mn</th>
<th>Total Mn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron seam</td>
<td>0.0</td>
<td>tr.</td>
<td>4.5</td>
<td>4000</td>
<td>10770</td>
</tr>
<tr>
<td>Soil mass</td>
<td>2.5</td>
<td>83.0</td>
<td>39.0</td>
<td>1545</td>
<td>9280</td>
</tr>
</tbody>
</table>
The manganese in the iron seam is quite insoluble in the milder solvents, but apparently large quantities exist as active MnO₂ and still larger amounts as higher oxides. The surrounding subsoil does not contain as much total manganese as the iron seam but does have it in a more available form. This indicates that such manganese is still migrating and has not been precipitated or oxidized yet. The importance of this source of manganese may be considerable, existing as it does in the soil of the hillsides where seepage waters may pass down into the soils of the valley below.

**Effect of Manganese on Microflora and Respiration of the Soil**

Some of the beneficial effects resulting from the addition of manganese to soils have been attributed to its stimulation of the soil micro-organisms. These micro-organisms in turn create a better root environment, release additional mineral nutrients and promote increased crop yields. Brown and Minges (1916) state that MnSO₄ at 100 pounds per acre appreciably increased both ammonification and nitrification. Ammonification may be increased at considerably higher rates but not nitrification. They conclude that "if a crop responds to moderate applications of MnSO₄ or is decreased by larger applications, it may be due to the effect of the manganese on
bacterial activity." Leoncini (1914) and Montanari (1914) working in Italy both found that nitrification was increased by small additions of manganese salts. Deatrich (1919) observed that with the addition of manganese, ammonification was stimulated but nitrification reduced.

Since these observations, it has been proved by McHargue (1922) that manganese is essential and that stimulations need not be regarded as entirely indirect through the action on micro-organisms. Nevertheless, a certain amount of stimulation must still come indirectly through the micro-organisms if the findings of Brown, Leoncini, Montanari, and Deatrich are correct. To investigate this phase further some studies were made on the response of soil organisms to added manganese.

Samples of Chehalis silty clay loam, Willamette silty clay loam, Newberg loamy sand, Melbourne clay loam, Dayton silty clay loam, Braillier peat, and Clatskanie peat were carefully taken in sterile bottles and brought into the laboratory. They were screened under sterile conditions, then samples weighed out and placed in sterile jars, six for each soil type. Two served as checks, two received MnSO₄ in solution equivalent to 40 pounds per acre, and two received MnSO₄ at 100 pounds per acre. Sufficient sterile water was added to bring the soil up to 60 per cent of its saturation capacity and the jars placed
in the incubator at $30^\circ$ C.

After five days one jar of each treatment was removed from the incubator and sufficient sterile water added to make a 1:5 extract. This was well shaken and then plated out in duplicate, using appropriate dilutions.

Peptone-glucose-acid agar was used on the lower dilutions for molds and sodium-albuminate agar on the higher dilutions for bacteria and actinomycetes. All plates were incubated at $30^\circ$ and the molds were counted after four days, the bacteria and actinomycetes after ten days. The results are entered in table 23, page 57. The remaining jars were incubated thirty days, then removed and the soil plated out in the same manner. The results from this treatment are entered in table 24, page 58.

An appreciable increase in total molds from the five-day incubation is noted in the Willamette soil being higher for the 40-pound treatment than for the 100-pound treatment. An increase of both molds and bacteria has occurred in the Braillier peat and of total bacteria in the Chehalis soil. After thirty-day incubation, an increase of both molds and bacteria, especially bacteria, is noted in the Braillier peat. Again the 40-pound treatment is the best. A decrease in molds is observed in the Newberg soil.
<table>
<thead>
<tr>
<th>Soil</th>
<th>Treatment</th>
<th>Rate per acre</th>
<th>Rate</th>
<th>Molds Total per gram soil</th>
<th>Mucor per cent</th>
<th>Aspergillus per cent</th>
<th>Penicilll per cent</th>
<th>Bacteria and Actinomycetes Total per gram soil</th>
<th>Actinomycetes per cent</th>
<th>Bacteria per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chehalis</td>
<td>Check</td>
<td>lbs.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MnSO₄</td>
<td>100</td>
<td>15.0</td>
<td>8.3</td>
<td>5.0</td>
<td>55.0</td>
<td>5500</td>
<td>21.5</td>
<td>75.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>12.0</td>
<td>18.7</td>
<td>12.5</td>
<td>52.1</td>
<td>12350</td>
<td>19.2</td>
<td>80.8</td>
<td></td>
</tr>
<tr>
<td>Willamette</td>
<td>Check</td>
<td>lbs.</td>
<td>16.5</td>
<td>12.1</td>
<td>7.6</td>
<td>45.4</td>
<td>9900</td>
<td>25.5</td>
<td>74.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MnSO₄</td>
<td>100</td>
<td>16.8</td>
<td>9.0</td>
<td>7.5</td>
<td>70.2</td>
<td>8325</td>
<td>27.1</td>
<td>72.9</td>
<td></td>
</tr>
<tr>
<td>Newberg</td>
<td>Check</td>
<td>lbs.</td>
<td>32.0</td>
<td>7.0</td>
<td>1.6</td>
<td>68.7</td>
<td>8925</td>
<td>26.0</td>
<td>74.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MnSO₄</td>
<td>100</td>
<td>24.5</td>
<td>6.1</td>
<td>2.0</td>
<td>70.4</td>
<td>8425</td>
<td>16.9</td>
<td>83.1</td>
<td></td>
</tr>
<tr>
<td>Melbourne</td>
<td>Check</td>
<td>lbs.</td>
<td>177.5</td>
<td>8.5</td>
<td>4.2</td>
<td>77.5</td>
<td>5850</td>
<td>23.1</td>
<td>76.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MnSO₄</td>
<td>100</td>
<td>192.5</td>
<td>2.6</td>
<td>3.9</td>
<td>87.0</td>
<td>5175</td>
<td>20.7</td>
<td>79.3</td>
<td></td>
</tr>
<tr>
<td>Dayton</td>
<td>Check</td>
<td>lbs.</td>
<td>185.0</td>
<td>25.0</td>
<td>4.1</td>
<td>65.0</td>
<td>6375</td>
<td>26.6</td>
<td>71.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MnSO₄</td>
<td>100</td>
<td>360.0</td>
<td>6.2</td>
<td>0.0</td>
<td>89.5</td>
<td>4800</td>
<td>17.2</td>
<td>82.8</td>
<td></td>
</tr>
<tr>
<td>Brailier</td>
<td>Check</td>
<td>lbs.</td>
<td>1350.0</td>
<td>5.9</td>
<td>0.0</td>
<td>91.2</td>
<td>5500</td>
<td>9.1</td>
<td>90.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MnSO₄</td>
<td>100</td>
<td>1550.0</td>
<td>6.5</td>
<td>0.0</td>
<td>89.6</td>
<td>10500</td>
<td>12.4</td>
<td>87.6</td>
<td></td>
</tr>
<tr>
<td>Clatskanie</td>
<td>Check</td>
<td>lbs.</td>
<td>2020.0</td>
<td>5.9</td>
<td>0.0</td>
<td>90.1</td>
<td>8300</td>
<td>13.3</td>
<td>86.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MnSO₄</td>
<td>100</td>
<td>2020.0</td>
<td>5.9</td>
<td>0.0</td>
<td>90.1</td>
<td>8300</td>
<td>13.3</td>
<td>86.7</td>
<td></td>
</tr>
</tbody>
</table>
Table 2L. Influence of Manganese on Bacterial County after Thirty Days of Incubation

<table>
<thead>
<tr>
<th>Soil</th>
<th>Treatment</th>
<th>Rate per acre lbs.</th>
<th>Molds Total per gram soil thousands</th>
<th>Mucor per cent</th>
<th>Aspergillus per cent</th>
<th>Penicillii per cent</th>
<th>Bacteria and Actinomycetes Total per gram soil thousands</th>
<th>Actinomycetes per cent</th>
<th>Bacteria per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chehalis</td>
<td>Check</td>
<td>40</td>
<td>117.5</td>
<td>9.19</td>
<td>1.2</td>
<td>61.7</td>
<td>99250</td>
<td>8.5</td>
<td>91.5</td>
</tr>
<tr>
<td></td>
<td>MnSO₄</td>
<td>140</td>
<td>120.0</td>
<td>9.7</td>
<td>0.7</td>
<td>53.2</td>
<td>100250</td>
<td>6.2</td>
<td>93.8</td>
</tr>
<tr>
<td></td>
<td>MnSO₄</td>
<td>100</td>
<td>115.0</td>
<td>6.2</td>
<td>0.0</td>
<td>75.5</td>
<td>119500</td>
<td>4.6</td>
<td>95.4</td>
</tr>
<tr>
<td>Willamette</td>
<td>Check</td>
<td>400</td>
<td>112.5</td>
<td>7.1</td>
<td>0.0</td>
<td>78.6</td>
<td>112750</td>
<td>8.0</td>
<td>92.0</td>
</tr>
<tr>
<td></td>
<td>MnSO₄</td>
<td>40</td>
<td>129.0</td>
<td>7.9</td>
<td>0.0</td>
<td>60.4</td>
<td>90750</td>
<td>2.5</td>
<td>97.5</td>
</tr>
<tr>
<td></td>
<td>MnSO₄</td>
<td>100</td>
<td>115.0</td>
<td>6.2</td>
<td>0.0</td>
<td>75.5</td>
<td>119500</td>
<td>4.6</td>
<td>95.4</td>
</tr>
<tr>
<td>Newberg</td>
<td>Check</td>
<td>100</td>
<td>105.0</td>
<td>6.3</td>
<td>0.0</td>
<td>70.6</td>
<td>77750</td>
<td>24.8</td>
<td>75.2</td>
</tr>
<tr>
<td></td>
<td>MnSO₄</td>
<td>40</td>
<td>114.0</td>
<td>6.1</td>
<td>0.0</td>
<td>69.1</td>
<td>68500</td>
<td>32.5</td>
<td>67.5</td>
</tr>
<tr>
<td></td>
<td>MnSO₄</td>
<td>100</td>
<td>97.0</td>
<td>3.1</td>
<td>0.0</td>
<td>65.1</td>
<td>70500</td>
<td>32.3</td>
<td>67.7</td>
</tr>
<tr>
<td>Melbourne</td>
<td>Check</td>
<td>100</td>
<td>165.0</td>
<td>5.0</td>
<td>0.7</td>
<td>52.7</td>
<td>4825</td>
<td>28.5</td>
<td>71.5</td>
</tr>
<tr>
<td></td>
<td>MnSO₄</td>
<td>40</td>
<td>177.5</td>
<td>4.2</td>
<td>4.2</td>
<td>53.5</td>
<td>10075</td>
<td>12.9</td>
<td>87.1</td>
</tr>
<tr>
<td></td>
<td>MnSO₄</td>
<td>100</td>
<td>177.5</td>
<td>4.2</td>
<td>4.2</td>
<td>53.5</td>
<td>10075</td>
<td>12.9</td>
<td>87.1</td>
</tr>
<tr>
<td>Dayton</td>
<td>Check</td>
<td>40</td>
<td>252.5</td>
<td>3.0</td>
<td>0.0</td>
<td>71.2</td>
<td>6800</td>
<td>26.8</td>
<td>73.2</td>
</tr>
<tr>
<td></td>
<td>MnSO₄</td>
<td>100</td>
<td>310.0</td>
<td>1.6</td>
<td>0.0</td>
<td>70.2</td>
<td>5075</td>
<td>40.4</td>
<td>59.6</td>
</tr>
<tr>
<td></td>
<td>MnSO₄</td>
<td>100</td>
<td>265.0</td>
<td>1.0</td>
<td>0.0</td>
<td>70.2</td>
<td>5075</td>
<td>40.4</td>
<td>59.6</td>
</tr>
<tr>
<td>Brailler</td>
<td>Check</td>
<td>40</td>
<td>1050.0</td>
<td>3.8</td>
<td>0.0</td>
<td>88.5</td>
<td>4600</td>
<td>21.5</td>
<td>78.5</td>
</tr>
<tr>
<td></td>
<td>MnSO₄</td>
<td>100</td>
<td>1350.0</td>
<td>2.2</td>
<td>0.0</td>
<td>89.6</td>
<td>7600</td>
<td>18.4</td>
<td>81.6</td>
</tr>
<tr>
<td></td>
<td>MnSO₄</td>
<td>100</td>
<td>1220.0</td>
<td>7.4</td>
<td>0.0</td>
<td>81.2</td>
<td>5900</td>
<td>8.5</td>
<td>91.5</td>
</tr>
<tr>
<td>Clatskanie</td>
<td>Check</td>
<td>40</td>
<td>660.0</td>
<td>3.0</td>
<td>0.0</td>
<td>48.5</td>
<td>72000</td>
<td>25.0</td>
<td>75.0</td>
</tr>
<tr>
<td></td>
<td>MnSO₄</td>
<td>100</td>
<td>570.0</td>
<td>3.5</td>
<td>1.7</td>
<td>50.9</td>
<td>3400</td>
<td>55.0</td>
<td>47.0</td>
</tr>
<tr>
<td></td>
<td>MnSO₄</td>
<td>100</td>
<td>640.0</td>
<td>4.7</td>
<td>1.8</td>
<td>53.2</td>
<td>4800</td>
<td>22.9</td>
<td>77.1</td>
</tr>
</tbody>
</table>
The formation of CO₂ as a metabolic waste product is a physiological consequence of the assimilative activities of micro-organisms in the soil according to Bollen (1941), and a measurement of the excreted CO₂ should give a quantitative measure of these activities. Bollen has measured the CO₂ excreted by the following soil series of the Willamette Valley: Newberg, Chehalis, Willamette, Sifton, Dayton, and Aiken. These represent soils with a wide range of texture, organic matter content, and C:N ratio. He observes that the dominant factor in controlling respiration appears to be the C:N ratio.

If manganese exerts an appreciable effect on the micro-organisms of the soil, it should be directly reflected in their assimilative activities as measured by the respiration or CO₂ excreted. Thus a study of the respiration of some soils, with and without manganese, was initiated.

The soils chosen were Klamath peat, Chehalis silty clay loam, and Newberg loamy sand. These were subjected to bacterial count as described in the previous section with the following results given in table 25.
Table 25.  Bacterial Count of Untreated Soils Used in Respiration Experiment

<table>
<thead>
<tr>
<th>Soil</th>
<th>Total per gram soil</th>
<th>Mucor per cent</th>
<th>Aspergilli per cent</th>
<th>Penicilli per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>thousands</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOLDS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Klamath peat</td>
<td>62.5</td>
<td>2.4</td>
<td>1.6</td>
<td>45.6</td>
</tr>
<tr>
<td>Chehalis silty clay loam</td>
<td>21.3</td>
<td>11.8</td>
<td>0.0</td>
<td>23.5</td>
</tr>
<tr>
<td>Newberg loamy sand</td>
<td>21.3</td>
<td>10.6</td>
<td>2.3</td>
<td>36.5</td>
</tr>
<tr>
<td>BACTERIA AND ACTINOMYCES</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Klamath peat</td>
<td>77,000</td>
<td>24.7</td>
<td></td>
<td>75.3</td>
</tr>
<tr>
<td>Chehalis silty clay loam</td>
<td>8,875</td>
<td>15.8</td>
<td></td>
<td>84.2</td>
</tr>
<tr>
<td>Newberg loamy sand</td>
<td>7,900</td>
<td>15.2</td>
<td></td>
<td>84.8</td>
</tr>
</tbody>
</table>

The 1:5 water extract was also analyzed for nitrate by the phenoldisulfonic acid colorimetric method of Harper (1924), sulfate by the turbidity method of Schreiner and Failyer (1906), phosphate by Truog and Meyer's method (1929), a modification of the Deniges method, and pH by the Coleman glass electrode. Total nitrogen was determined by the Kjeldahl method and total carbon by the dry combustion method in an electric furnace. The results are shown in table 26.
Table 26. Chemical Analysis of Soils Studied

<table>
<thead>
<tr>
<th>Soil</th>
<th>pH</th>
<th>NO$_3$-N p.p.m.</th>
<th>SO$_4$ p.p.m.</th>
<th>PO$_4$ p.p.m.</th>
<th>Total N per cent</th>
<th>Total C per cent</th>
<th>C:N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Klamath</td>
<td>7.7</td>
<td>65.3</td>
<td>43.0</td>
<td>1.08</td>
<td>1.13</td>
<td>11.602</td>
<td>10.27</td>
</tr>
<tr>
<td>Chehalis</td>
<td>6.8</td>
<td>1.0</td>
<td>6.1</td>
<td>.46</td>
<td>.209</td>
<td>2.143</td>
<td>10.25</td>
</tr>
<tr>
<td>Newberg</td>
<td>6.4</td>
<td>1.9</td>
<td>1.0</td>
<td>.42</td>
<td>.066</td>
<td>.853</td>
<td>12.92</td>
</tr>
</tbody>
</table>

Respiration measurements were obtained as described by Bollen (1941) using 500 grams of soil in quart milk bottles. Four samples of each soil were placed in the bottles, two serving as checks and two receiving MnSO$_4$ in solution equivalent to 100 pounds per acre. All soils were made up to 60 per cent of saturation capacity. Then one of each treatment placed on the pressure line and measurements of CO$_2$ evolution begun. The others were autoclaved for three and one-half hours, then, after cooling, were also attached to the pressure line.

The CO$_2$ evolved was bubbled through normal NaOH in 50 ml. test tubes, which were replaced each day at first, later at longer intervals. The absorbed CO$_2$ was determined by double titration, using thymol-blue and brome-phenol-blue. The aeration was carried on for 55 days. The CO$_2$ evolved by each soil is plotted on figure 2, page 62.
FIGURE 2. EFFECT OF MANGANESE ON SOIL RESPIRATION

Klamath Peat

Chehalis Silty Clay Loam

Newberg Loamy Sand

Mg/m^3 CO₂

Days

Sterilized

Unsterilized

Sterilized

Unsterilized

Sterilized

Unsterilized
From the results for Klamath peat and Newberg loamy sand, it is apparent that manganese definitely stimulates microbial activities with a resulting increase in respiration. That there should be no increase from the Chehalis is difficult to explain since it had the same C:N ratio as the Klamath peat, unless it already has an optimum content of available manganese. This is probably the case, since the Chehalis sample came from the check plot on the Horticulture Farm, which was well supplied with available manganese, as shown on page 38.

The fact that manganese gives no increased respiration in the sterilized samples would lead to the conclusion that it plays no part in the non-microbial CO₂ production. However, as pointed out on page 16, steam sterilization makes available relatively large amounts of manganese so that the 100-pounds per acre treatment would have very little additional effect and might even lead to a slight toxicity.

At the close of the 55-day period of respiration the bottles were disassembled and a small sample of soil taken from each of the unsterilized bottles. This was air dried, ground to pass 60-mesh, and 0.1 gram of each treatment sprinkled evenly on the surface of a previously poured nitrogen-free agar medium according to Curie (1931).
Only *Azotobacter* or other bacteria capable of fixing their own nitrogen will develop on this medium.

After a four-day period of incubation at 30° C., the plates were examined. The plates from Klamath peat had several large colonies along with numerous small colonies. The manganese treatment had large, dark brown, pigmented colonies that spread almost over the entire plate. The plates from Chehalis had several hundred small isolated colonies with little apparent difference between the manganese treatment and check. The plates from the Newberg had a similar appearance though somewhat fewer colonies.

After ten days of incubation, the cultures were transferred from the plates to Kjeldahl flasks and total nitrogen determinations made. This gives a quantitative measure of the influence of manganese on the nitrogen fixing power of the bacteria from the soil. The results are shown in table 27. Each figure is the result of duplicate determinations, as are all figures throughout this study.
Table 27. Influence of Manganese Treatment on the Fixation of Nitrogen by Azotobacter

<table>
<thead>
<tr>
<th>Soil</th>
<th>Check</th>
<th>Mn</th>
<th>Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Klamath</td>
<td>0.0</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Chehalis</td>
<td>0.3</td>
<td>0.45</td>
<td>0.15</td>
</tr>
<tr>
<td>Newberg</td>
<td>0.35</td>
<td>0.3</td>
<td>-0.05</td>
</tr>
</tbody>
</table>

Manganese had a stimulative action on the Azotobacter of Klamath and Chehalis soils but a negative action on the Newberg, though it is too slight to be significant.

Though manganese has been proved by McHargue, and verified by others, to be an essential nutrient element, this study supports the earlier theories that at least some of the beneficial results obtained from the application of manganese to soils are due to the stimulative action of the manganese on micro-organisms. It is not intended to discredit the essential nutrient theory but merely to point out that some of the observed and phenomenal responses reported as a result of manganese treatments may be frequently of an indirect nature through the medium of the micro-organisms.
Summary of Field Experiments

It has been the practice of the Oregon State College soils department to carry on cooperative field fertilizer trials with field stations and farmers throughout the state. These trials are supervised by the soils department and materials furnished and applied by them, but field operations are performed by the farmer. The results of MnSO$_4$ applications on several trials carried out in this manner during the last three years are shown in table 23, page 67.

Good response was obtained on Willamette silt loam, Sisters gravelly sandy loam, and Deschutes sandy loam. Slight or moderate response was obtained on Clatskanie peat, Powell silt loam, and one trial on Willamette silt loam. Negative response was obtained as indicated on Newberg sandy loam, Olympic loam, and one trial on Clatskanie peat. These results cover somewhat different soil types than those mainly studied in this paper, but when on the same series they do not differ essentially from the results obtained in the more detailed study.
Table 28. Summary of Field Experiments with Manganese Soils Department, O.S.C. Agricultural Experiment Station.

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Crop</th>
<th>Treatment</th>
<th>Rate per acre</th>
<th>Yield per acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Willamette silt loam</td>
<td>Cover</td>
<td>5-20-5 MnSO₄</td>
<td>500 lbs.</td>
<td>8.47 tons</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10</td>
<td></td>
<td>6.51 tons</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.96 tons</td>
</tr>
<tr>
<td>Deschutes sandy loam</td>
<td>Peas and rye hay</td>
<td>MnSO₄</td>
<td>30</td>
<td>1.26 tons</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.90 tons</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.36 tons</td>
</tr>
<tr>
<td>Clatskanie peat</td>
<td>Hay</td>
<td>MnSO₄</td>
<td>30</td>
<td>4.42 tons</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.41 tons</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.01 tons</td>
</tr>
<tr>
<td>Clatskanie peat</td>
<td>Hay</td>
<td>5-15-15 MnSO₄</td>
<td>500 lbs.</td>
<td>3.12 tons</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30</td>
<td></td>
<td>3.38 tons</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-.26 tons</td>
</tr>
<tr>
<td>Newberg sandy loam</td>
<td>Beets</td>
<td>MnSO₄</td>
<td>30</td>
<td>6.00 tons</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.25 tons</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-1.25 tons</td>
</tr>
<tr>
<td>Olympic loam</td>
<td>Blackcaps</td>
<td>NPK MnSO₄</td>
<td>40</td>
<td>.87 tons</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.96 tons</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-.09 tons</td>
</tr>
<tr>
<td>Willamette silt loam</td>
<td>Boysenberries</td>
<td>NPK MnSO₄</td>
<td>10</td>
<td>6.51 tons</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.21 tons</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-.70 tons</td>
</tr>
<tr>
<td>Powell silt loam</td>
<td>Raspberries</td>
<td>MnSO₄</td>
<td>30</td>
<td>2.74 tons</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.09 tons</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-.35 tons</td>
</tr>
</tbody>
</table>

Sulfur or gypsum plots were used as checks.
The writer is indebted to Dr. W. L. Powers and the soils department for this data.
DISCUSSION

The need for manganese on Oregon soils so far as tested is probably neither widespread nor very acute. The soils studied in this paper that showed a need for manganese occupy a small proportion of the total cultivated land in Oregon. Moreover, they do not show such an acute need for manganese as to have crops grown on them show severe disease or deficiency symptoms. Manganese has induced sufficient increases in yield and quality of crops from some of the more important soil types to make its use highly profitable under intensive cultivation.

The critical limits of soluble manganese in soils will vary widely with the exchange capacity of the soil, its pH, its lime content, and content of other salts. Because of this, no very definite statements can be made. However, it has been observed that deficiency symptoms may be expected where the total available manganese is less than 15 to 30 p.p.m., response may be expected where less than 100 to 150 p.p.m., and some form of excess symptoms may be expected where more than 1,000 p.p.m. Distribution of the three forms of available manganese is a factor that may alter the above figures. Where most of the available manganese is water-soluble
or exchangeable, a lower total available will be sufficient than where it is largely as active manganic oxide.

An easier way of determining the need for manganese is by analysis of plant material taken from the soil in question. Some plants require less than others, but for those that need manganese response may be expected when the content on a dry matter basis is less than 100 p.p.m. and deficiency symptoms may be expected when it falls below 40 to 50 p.p.m. Gilbert et al. (1926) found that the manganese requirement of oats and spinach was 20 to 60 p.p.m.

Definite response can be expected on neutral or alkaline peats, other neutral or alkaline soils of fairly high organic matter content, and acid peats that have been strongly leached. Response may also be obtained on well-drained valley floor or alluvial soils which are slightly acid to nearly neutral in reaction, such as are found in the Willamette and Columbia River valleys. Response should not be expected on acid residual soils imperfectly drained soils, or acid peats except as noted above. Because of the high manganese content of the residual hill soils, local conditions are apt to arise in the valleys where soils otherwise expected to respond will not do so because of inwash from the hills.
Soils suffering from an excess of soluble manganese with all its physico-chemical and physiologic reactions may be found in some of the residual hill soils. These soils can be treated with lime to tie up the manganese, basic fertilizers to render it less soluble, or copper compounds to physiologically antagonize the manganese.

The relations of manganese to plant nutrition are rather complex, and with each subsequent investigation that is published the list of possible functions increases with the specific relationships becoming more rather than less complex. It is the belief of the author that all functions that have so far been assigned to manganese are merely different expressions of the one function which it actually performs and for which it is essential. When it fails to perform this one necessary function, various symptoms of disorder occur which have led investigators to state that the function of manganese is to correct that one symptom which was manifest in their work.

With the exception of the stimulation of bacteria, all the functions listed on pages 8 and 9 may be explained as different manifestations of one main function if we accept the maintaining of the proper oxidation-reduction equilibrium in the cell as the main function.
Maintaining iron in the proper state will allow it to catalyze properly the formation of chlorophyll which is necessary for the manufacture and utilization of starch, and by thus promoting the well-being of the plant will increase the absorption of calcium and properly dispose of organic toxins or peroxides.

This theory, to the present date, has best answered all the questions regarding the performance of manganese in the plant. There is some difference of opinion as to which direction the manganese tends to shift the equilibrium, but there can be little doubt that the fundamental purpose of manganese is to maintain the equilibrium at some definite state. Experiments conducted during this study indicate that manganese may shift the equilibrium toward the reduced state, but they are in no way conclusive. Further work can profitably be expended along this line of investigation.

**Fertilization of Manganese-Deficient Soils**

The economic use of manganese will be determined by the degree of response on the particular soil type concerned, the acre value of the crop being raised, and the current price of the manganese compound to be applied. The rate of application can vary from 10 to 100 pounds of MnSO₄ per acre on soils up to pH 7.0 and up to 250
pounds per acre on alkaline peats without danger of toxicity. However, on the more acid soils the excess is apt to be leached away and on the alkaline soils will become unavailable. A more feasible procedure would be to apply 50 to 100 pounds of MnSO₄ the first year and 20 to 40 pounds yearly thereafter. With row crops it may be drilled alongside the rows at half the above rates.
SUMMARY AND CONCLUSIONS

The need for and response from manganese additions on several soil types of widely varying nature was studied by field, greenhouse, and laboratory methods. Definite response to manganese was shown by alkaline soils of the Klamath, Deschutes, Sisters, and Springdale series. Response of a less definite nature was also obtained on slightly acid to neutral well-drained soils of the Sauvie, Chehalis, Willamette, and Newberg series. No consistent response was obtained on acid soils of the Aiken, Olympic, Labish, Clatskanie, Melbourne, and Dayton series. A definite response was obtained on the acid, strongly leached Braillier peat.

Analysis of plant parts has shown that the minimum manganese content for healthy leaves is about 50 p.p.m., the optimum content about 100 p.p.m. on a dry matter basis. Analysis of soil extracts has shown the minimum, critical content of available manganese to be about 15 to 30 p.p.m., optimum content 100 to 150 p.p.m., and the toxic limit about 1,000 p.p.m.

The availability of manganese depends mainly on the pH and lime content of the soil. At high pH values the manganese is less available than at lower pH values. A high lime content drastically reduces the availability in either an acid or neutral soil. Soils containing toxic
concentrations of manganese may be corrected by the addition of lime.

The oxidation-reduction role of manganese in plant tissues was discussed. Several reducing substances gave a better average yield of spinach on a manganese-deficient soil than a similar number of oxidizing substances, even though no additional manganese was apparently released.

Applications of manganese were found to decrease the availability of potassium, iron, and, to a minor extent, calcium.

Studies of bacterial count and soil respiration showed that the application of manganese, where needed, stimulates bacterial growth and metabolic activities, and also increases the rate of nitrogen fixation by Azotobacter or other nitrogen fixing organisms.

The subsoil of the Olympic series was found to contain large amounts of soluble iron and manganese, some of which had been precipitated in the form of crusts or concretions by oxidation or bacterial activity. The oxidized form was only very slightly soluble.
REFERENCES CITED


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