Partially Annotated Bibliography of Manganese with Special Attention to the Tropics

by

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This bibliography is prefaced by a summary under the following headings:

- Manganese Transformations in Soil
- Effects of Soil and Crop Treatments on Manganese
- Manganese in the Tropics
  - Manganese in Soils
  - Manganese Disorder Symptoms in Tropical Crops
  - Factors Affecting Manganese Availability
  - Controlling Manganese Toxicity

The bibliography includes both references that apply specifically to soils of the tropics and others that contribute to general understanding of the role of manganese in plant nutrition and transformations of manganese in soils. Some of the annotations are by the author; others have been taken from abstracting journals, review articles, or annotated bibliographies. Some articles which were not reviewed are cited without annotation if their titles suggested that they might be of interest. Particularly valuable references include the review article by Mulder and Gerretson in Advances in Agronomy, Volume 14; the Bibliography of the Literature on the Minor Elements by the Chilean Nitrate Education Bureau; and Review Number 962 in Soils and Fertilizers. References that refer specifically to soils of the tropics are marked with "(T)" following the citation.

Manganese Transformations in Soil

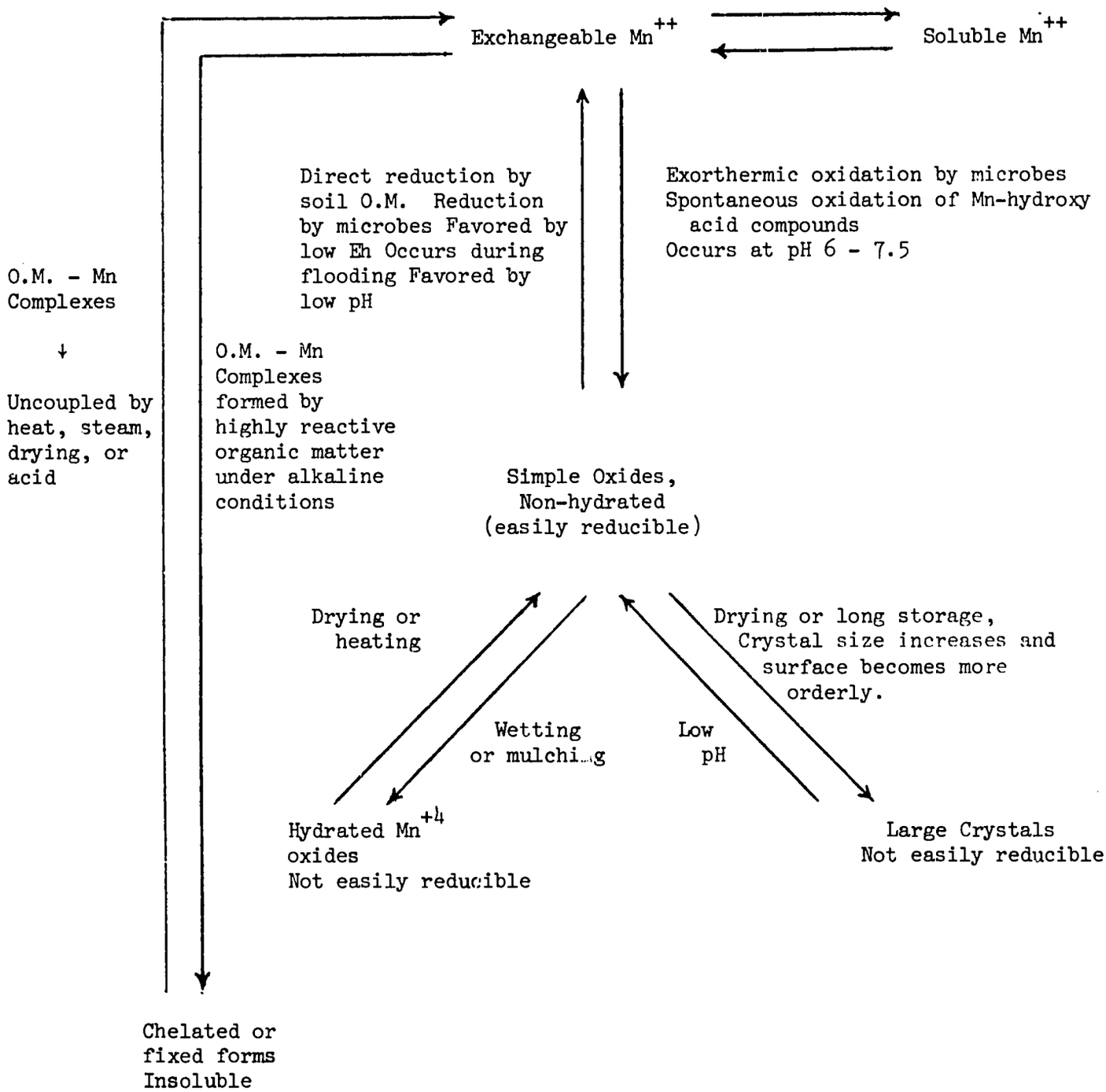
Manganese toxicity in tropical soils has been reported for many soils and crops. Methods for reducing Mn toxicity include the application of materials to increase pH or add Ca, Fe, Mo, N, or phosphate. Manuring and mulching have also been used. There are conflicting reports on the effectiveness of these.

To provide a general framework for discussing toxicities a scheme for the transformations of manganese in soil is presented in the diagram on Page 2.

Plants use divalent Mn. The availability of water-soluble Mn is related to the amount of exchangeable divalent Mn. Complex mineral forms of higher oxidation states of iron and manganese in hydrated and unhydrated forms of varying ages and degrees of crystallinity have different availabilities. More than 30 specific compounds of mangan se in soils have been described, and this diversity makes rigorous chemical thermodynamic equilibrium analyses difficult. Availability of Mn in higher oxidation states has been arbitrarily estimated by various extractants containing reducing agents of different strengths.

The oxidation and reduction of Mn occurs with or without microbiological activity in response to changing conditions of pH, Eh, temperature, and moisture. Divalent Mn can be reduced in availability either by chelating with insoluble organic matter of the soil or by forming insoluble complexes with soluble organic matter fractions. Operations such as drying or manuring can induce changes in forms of manganese. Prediction of Mn availability is difficult.

Transformations of Manganese in Soil



At neutrality, Mn^{++} tends to oxidize to Mn^{4+} perhaps via dismutation of an intermediate Mn^{3+} form (Mann and Quastel, 1946). This reaction occurs spontaneously in atmospheric oxygen at pH 8 or higher, and it is thought that microorganisms play a role in its observed occurence in soil systems at pH greater than 5.5. Hydroxy acids, when combined with divalent manganese, form salts that oxidize at the lower pH values, and this may explain the reaction.

The reverse reaction can also occur. Reduction of higher oxidation states of manganese, either by microbial action or by direct action of organic matter, occurs at neutral pH, but is much more rapid at low pH.

Because of the strong influence of pH on the manganous-manganic ion equilibrium, liming is an obvious practice for reducing Mn toxicities. This has been used extensively in both temperate and tropical areas (Bonnet, 1946; Abruña et al., 1964; Abruña, Rodriguez, et al., 1970; Abruña et al., 1965). Often problems of Mn toxicity have arisen from the use of acidifying nitrogen fertilizers (Abruña and Pearson, 1958). Gupta (1970) reported an interesting case where manganese content was lower in carrot leaves growing on sphagnum at pH 4 to 5 than at higher pH, but this is quite unusual.

The effect of moisture regime is complicated. In conditions where flooding excludes atmospheric oxygen, microbial action (which depends on temperature, nutrients, degree of sterilization and presence of organic matter) causes Eh to fall and manganese dioxide to be reduced (Obordo, 1969). Flooding does not always produce this effect. Takkar (1969) found that for the first 55 days solubility of Mn was decreased in waterlogged soils. To make valid comparisons of data, it is necessary to know pH, the amount of organic and mineral nutrients present, temperature, and particularly the time involved. Initially there are rapid decreases and increases in Eh after flooding.

(Ponnamperuma has carried out extensive research on soils used for paddy rice, and his papers are quite helpful because of their precise chemical approach. There are in addition many other papers on the chemistry of rice soils.)

Several studies have been made on changes in available Mn under moist conditions. Cotter (1968) reported that for the first week there was more soluble Mn in soil stored dry than in soil stored at field capacity. McCool (1934) reported that soluble Mn was higher in moist soil stored at high temperature than in that stored at low temperature. Fujimoto and Sherman (1945) reported that daily wetting caused Mn concentration in stored soil to decrease. Presumably several processes are proceeding. It has been observed many times that drying a moist soil usually increases soluble Mn (Fujimoto et al., 1945; McCool, 1934; Zende, 1954; and others). This is presumably due to the dehydration of manganic oxides to more soluble forms. If the soil initially was saturated with high concentrations of reduced Mn, the soluble Mn may decrease on drying (Fujimoto et al., 1945). One must consider microbiological activity, and the effect of water on it, as well as the pH of the soil.

Mulches are used to prevent drying and heating of soils prone to toxicity, and they have been effective in tropical areas, such as Brazil and Hawaii (Medcalf, 1956; Sherman and Fujimoto, 1946).

Extreme heat from ovens or steam sterilization causes very large increases in soluble Mn. These processes may also increase pH (Forsee, 1954). Black (1968) has suggested that steaming may involve reduction of Mn by organic matter. McCool (1934) noted that steam heating the subsoils of several soils caused no increase in Mn, while a large increase was observed when surface soils higher in organic matter were steamed.

Adding easily oxidizible organic matter can be expected to have an effect on state of Mn by either reacting directly, (Grasmanis and Leeper, 1966), or by providing a substrate for microbiological activity and lowering Eh. Christensen et al. (1950) reported that sugar added to soil of pH 4.6 caused a fourfold increase in soluble Mn, which continued to increase with time; while the addition of sugar at pH 6.5 gave a 6 to 13-fold increase, which quickly disappeared after the sugar had been decomposed.

A question of practical importance is the effect of incorporation of crop residues in soils having potential for Mn toxicity. Takkar (1969) studied the effects of various levels of cane trash added to 100 g samples of soil in bottles. He found that in neutral soils there was a decrease in soluble Mn, while in acid soils the long-term result was an increase. Cotter (1968) found that soluble Mn increased when cotton seed hulls were added to a soil from alluvium in Arkansas.

Some kinds of organic matter, however, remove Mn from solution. Bremmer (1946) reported that some kinds of soluble organic matter form insoluble complexes with divalent ions, including Mn^{++}. Rosell and Babcock (1968) showed that organic matter suspensions prepared from mineral soils extracted and chelated 27 percent of the total Mn of newly precipitated manganese. A suspension from an organic soil reacted with 16 percent. In areas where Mn deficiency is a problem (for example peaty mucks in Florida) high organic matter content of the soil correlates with the severity of the problem. Whether added crop residue will function more as stable chelating organic matter to remove soluble Mn or as a substrate for microbial reduction, increasing the amount of divalent manganese, is something difficult to predict.

The availability of various higher oxides of manganese has been studied by Dion and Mann (1947) and by Jones and Leeper (1951). Apparently the fineness, degree of crystallinity and orderliness of ageing surfaces has

a great effect on solubility.

Effects of Soil and Crop Treatments on Manganese

Because reduction can occur more readily at low pH, lime is used commonly to increase pH and reduce solubilization of Mn. It has also been found that the calcium ion without change of pH can decrease the uptake of Mn from soil and decrease its toxic effects on plants (Barton et al., 1927; Rorison et al., 1958; Ouellette and Dessureaux, 1958; Hewitt, 1945; Wallace et al., 1945). Taper and Leach (1957) and Vose and Jones (1963) found similar effects in solution culture. Alfalfa yields were reduced in experiments by Kipps (1947) when the calcium/manganese ratio fell below 66.

For some crops such as pineapple, the use of liming creates problems because the crop needs a relatively low pH. Potato is controlled by low pH, and crops grown in rotation with potatoes may show Mn toxicity. For pineapple in tropical soils, sprays of iron are used to counteract the toxicity of excess Mn.

Iron deficiency and manganese toxicity are reported to be physiologically identical for many crops. A number of researchers have proposed that the Fe/Mn ratio in the plant is more important than absolute amounts of either (Shive, 1941; Somers and Shive, 1942; Somers et al., 1942; Stiles, 1946). This subject has been reviewed by Twyman (1946). At present, iron EDTA is widely used for correcting manganese-induced chlorosis; it is much more effective than the iron salts used previously (Hopkins et al., 1944; Gile, 1916; Sherman and Fujimoto, 1946). On a peculiar soil in Australia (well-drained and neutral, but very slow to oxidize added manganese), Grasmanis and Leeper (1966) reported that injections of iron into orchard

trees was needed to counteract the effects of large amounts of manganese stored in the roots.

The addition of manure, dried blood, cotton seed meal, and the presence of decaying sod have all been reported to increase solubility of Mn on acid soils (Funchess, 1918; McCool, 1934; Perold, 1951), but this may be due to pH changes. Atkinson et al. (1958) reported that addition of a manure that raised the pH one unit caused a decrease in uptake of Mn. Perold (1951) noted a depression of uptake when manure was added to an alkaline soil.

The effects of additions of fertilizer elements reported in the literature are not always the same. pH changes are not reported for many articles. Piszczek (1951) claimed that fertilizing grass with N or P, or including clover in the rotation, increased Mn toxicity. Middelburg (1950) also noted increased mobilization of Mn in waterlogged soil by addition of N, P, or carbohydrate. The effects of carbohydrate were due, presumably, to increased microbiological activity. Gomide et al. (1969), however, reported decreased Mn content in grasses in the tropics where nitrogen had been applied.

The effect of phosphate has been debated for a long time. Lamb (1960), Beeson (1948), and Bortner (1935) have reported that P reduces Mn availability. Larsen (1965) reported, however, that on Mn-deficient soil phosphate-manganese complexes form and increase availability of Mn to plants. Albrecht and Smith (1941) noted increases of Mn in bean leaves but not in leaves of citrus nor tomato from addition of P. Messing (1965) claimed that on steamed soils of pH less than 5 Mn availability was lowered by P addition (pH rising), and that on soils having pH greater than 5 the addition caused pH to drop and Mn availability to increase. Warnock (1970) noted a slight increase in Mn content of plants when P was applied to a zinc-

deficient calcareous soil. The Fe content was very greatly increased, and he suspected these metals might be harming the plants.

Hernandez et al. (1958) observed that boron reduced uptake of Mn from nutrient solution. Garretson and Mulder, in their review (1952), cited several authors who claimed that Mo and vanadium reduce Mn uptake.

In general, the addition of fertilizer elements usually does not appear to have a very large effect on toxicity of Mn. The simplest measure is to raise soil pH where this is possible by the use of lime. If pH cannot be raised safely above a level where Mn becomes significantly less soluble, it may be economical for some crops to spray with chelated iron. In some places where acidity arises from use of acidifying fertilizers, as for Puerto Rico coffee, a change in nitrogen source is needed.

In areas where bare ground is exposed to hot dry conditions, toxic amounts of Mn may be released. The use of mulches for coffee in Brazil has proven beneficial. In Hawaii, paper mulches between pineapple rows have decreased the uptake of Mn.

Leaching soils, by rain or other ways, reduces the amount of water-soluble Mn, but this is probably an economic remedy only in very limited situations.

Manganese in the Tropics

Manganese in Soils

Hopkins et al. (1944) reported severe manganese toxicity in pineapple in Puerto Rico. Periodic sprays of iron sulfate controlled the toxicity. The soils did not have excessive amounts of total Mn, but up to 130 ppm were in water-soluble form and almost no water-soluble iron was present. Abruña, Rodriguez, et al. (1970) found manganese toxicity problems with

tobacco on Coto clay in Puerto Rico. The soil had 200 ppm exchangeable and 200 ppm easily reducible Mn. Liming to 60 percent base saturation produced maximum yields. Other Puerto Rican soils studied, Corozal clay subsoil and Humatas clay, did not have excess Mn. Bonnet (1946) reported that unlimed Fajardo clay in Puerto Rico (pH 4.5) had 30 to 40 ppm exchangeable Mn. Liming to pH 6.5 reduced the levels to less than 10 ppm. Manganese contents of grass from the plots were similarly reduced.

Contents of Mn in Argentine soils were studied by Trelles et al. (1951). Contents ranged from 20 to 1150 ppm, but most of the soils contained between 340 and 800 ppm.

Perold (1951) attributed Mn deficiency in the South Coastal Region of South Africa to exhaustion of organic matter and heavy leaching from winter rains.

High levels of manganese in some Hawaiian soils are discussed by Sherman and Fujimoto (1946) and Fujimoto and Sherman (1945). The Wahiawa Series had 10,000 ppm easily-reducible manganese. Pineapple production was affected by the high Mn, necessitating the use of iron sprays.

Bleeker and Austin (1970) found 1900 ppm Mn in the B_2 horizons of some Papua-New Guinea soils.

According to a survey of 65 soils in Formosa by Chiu (1950), typical samples had 3 to 32 ppm exchangeable Mn, 34 to 249 ppm easily-reducible Mn, and no water-soluble Mn. Total Mn content for the 65 samples ranged from 72 to 1028 ppm.

A high manganese-high iron hardpan at Bogor, Java, was reported by Koenigs (1950). The pan develops on soils having high contents of free iron and manganese, a mechanical composition favorable to pan formation, high permeability, and a low water table. The pan disappeared after 40 years

under forest, but the layers of high concentration persisted 80 years. Mixing the Mn-rich layers with the surface soil caused decreases in rice production.

Savant and Kibe (1969) reported extractable Mn contents of soils from Maharashtra State, India. Two laterized basalt soils had 92 and 102 ppm, respectively, and two laterized granite and gneiss soils had 50 and 85 ppm. Misra et al. (1967) found that Black soils from Uttar Pradesh contained 130 to 820 ppm exchangeable plus reducible Mn. Red soils had 160 to 187; and alkali soils, 7 to 623 ppm. Singh and Pathak (1969) reported that in 82 samples of soil, total manganese increased with increasing rainfall. In surface soils, total Mn contents ranged from 556 to 1100; exchangeable Mn, from 1 to 20 ppm; and water-soluble Mn, from 0 to 3 ppm. Total Mn in subsoils ranged from 480 to 1100 ppm; exchangeable and water-soluble main subsoils were essentially the same as in surface soils.

Karin et al. (1960) have reported the Mn contents of four soils of East Pakistan (Bangladesh): An alluvial soil of pH 5.6 had 35 ppm exchangeable Mn; lateritic soil of pH 4.6 had 100 ppm; coastal saline soil having pH of 6.7 to 7.0 had 32 ppm; and hill-tract soil of pH 5.4 had 34 ppm.

Takkar et al. (1969) studied soils from 20 sites in the Punjab and Haryana III. Total Mn ranged from 165 to 382 ppm; free manganese, from 36 to 165 ppm; and active manganese, from 29 to 115 ppm.

Bleeker and Austin (1970) used regression analysis to relate micronutrient contents to profile variables. They found that manganese was concentrated in zones of fluctuating water tables, the main concentration occuring in the B_2 horizons of the soils studied. The contents were lowest in C horizons.

Vinayak et al. (1967) surveyed 80 soils in northeastern India and found that exchangeable, easily-reducible, active, and total Mn were correlated at the 1 percent level with organic matter content. All but exchangeable Mn were also correlated with clay content. Hoon and Dhawan (1943) found Mn content correlated with clay content, as did Randhawa et al. (1961), who also noted that water-soluble, exchangeable, and easily-reducible manganese were concentrated in the surface soil. The concentration of water soluble manganese in the surface soil in Indian soils was also observed by Vinagak et al. (1964). Grewal et al.(1969) found that exchangeable Mn decreased with depth, and Karin et al. (1960), working in East Pakistan, attributed a similar relationship to the decrease of organic matter with depth. These workers found no correlation with mechanical composition of the soil.

Manganese Disorder Symptoms in Tropical Crops

Muller (1964) has discussed "purple leaf tip roll" disease of sisal in Tanganika (Tanzania) and the evidence that it is caused by manganese toxicity. The relation of manganese toxicity to "crinkle leaf" disease of cotton has been discussed by Adams and Ware (1957). Mn toxicity in *Grevillea robusta* has been described by Child and Smith (1960), and Hiatt and Ragland (1963) have discussed manganese toxicity in burley tobacco.

Jordine (1963) has published photographs of manganese and zinc deficient banana plants.

Factors Affecting Manganese Availability

Probably one of the less complicated factors causing differences in Mn availability is the increase that occurs when soil is air-dried or heated.

Fujimoto and Sherman (1945) studied 25 Hawaii soils. A typical result for a soil of pH 4.8 is illustrated by the following: The content of exchangeable Mn in untreated soil was 25.6 ppm; after three weeks air-drying it rose to 27 ppm; when the soil was oven-dried 24 hours at 105°C, the content was 470 ppm and rose to 2100 ppm after three hours autoclaving at 15 pounds pressure. Zende (1954) reported similar effects of air-drying for Indian soils, as did Kelley and McGeorge (1913) for Hawaiian soils. If the soil was flooded when sampled, the changes were different. Fujimoto and Sherman (1945) found that soil from a flooded field being prepared for taro showed exchangeable Mn content of 700 ppm which dropped to 40 ppm on drying. Oven-drying and sterilization increased the concentration again, but not to its original value. They associated the phenomonon with the possible oxidation of reduced soluble Mn^{++} and then, on further heating, dehydration to a more soluble form.

In general the behavior of available Mn under moist conditions depends on the microbiological situation and the amount of organic matter present. Commonly on submergence, available Mn increases with the reduction of trivalent manganese (Savant and Kibe, 1969). Takkar (1969), however, studied the effects of adding sugar cane trash to acidic, neutral, calcareous, and saline soils from India under 60 percent of field capacity and under waterlogged conditions. Active Mn showed a marked decrease in all soils except in the acid soil at 69 days. Under water-logged conditions the Mn had increased at 55 days. Organic matter tended to increase the active Mn. The data on which these conclusions were based were not entirely consistent, however. Savant and Kibe (1969) studied the effect of alternate cycles of wetting and oven-drying on Indian soils from Mahrastra State.

They found that exchangeable Mn increased during the first cycle. Then the level fell, although after the third cycle it was still not down to the original level. The effect was more pronounced on laterized soils from basalt than from laterized soils from granite or gneiss. Work similar to that of Takkar was done by Cotter and Mishra (1968). They also obtained variable results, but they concluded that, in general, the addition of aged cotton seed hulls caused an initial increase in extractable Mn, which decreased after five days, presumably due to reoxidation of Mn.

Controlling Manganese Toxicity

The most common method of control is probably liming. This may not be practical where low pH is required for disease control, or increased availability of other nutrients. Sherman and Fujimoto (1946) have discussed the problem of attempting to correct Mn toxicity (Fe deficiency) for pineapples in Hawaii by liming. The addition of enough lime to reduce the Mn availability (two tons) causes a reduction in yield of the pineapples. A similar problem was described by Gile (1916). Sideris and Young (1949(reported the use of iron salt sprays for pineapples. In Australia, Eucalyptus trees suffering from excess manganese are sprayed with Fe EDTA (Winterholder, 1963).

Mulching high-manganese soils to prevent heating and drying can also help to control manganese toxicity. A 72 percent increase in the 1956 Brazilian coffee crop is attributed by Medcalf (1956) to mulching. Sherman and Fujimoto (1946) found decreased in Mn availability with mulching. In the South Coastal Region of South Africa (Cape Flats area) organic manure checked the uptake of added Mn by beans on acid soils, and increased it on alkaline soils (Perold, 1951).

Gomide et al. (1969) reported that nitrogen fertilization decreased the Mn content of six tropical grasses.

Bibliography

Abruña, F., R. W. Pearson, and C. B. Elkins. 1958.
Quantitative evaluation of soil reaction and base status changes resulting from field applications of residual acid nitrogen fertilizers. Soil Sci. Soc. Am. Proc. 22:539-542. (T)

Eight hundred ninety-six kg of nitrogen as ammonium sulfate per hectare yearly for two years sharply increased acidity and loss of bases.

Abruña, F., J. Vicente-Chandler, L. Becerra, and R. Bosque-Lugo. 1965.
Effects of liming and fertilization on yields and foliar composition of high-yielding sun-grown coffee in Puerto Rico. J. Agr. Univ. P. R. 49(4). (T)

Coffee under intensive management responded strongly to liming on high-Mn acid soil but not on low-Mn acid soil, although the latter was high in exchangeable Al.

Abruña, F., J. Vicente-Chandler, and R. W. Pearson. 1964.
Effects of liming on yields and composition of heavily fertilized grasses and on soil properties under humid tropical conditions. Soil Sci. Soc. Am. Proc. 28:657-661. (T)

Abruña, F., J. Vicente-Chandler, R. W. Pearson, and Servando-Silva. 1970.
Crop response to soil acidity factors in Ultisols and Oxisols: I. Tobacco. Soil Sci. Soc. Am. Proc. 34:629-635. (T)

A significant relationship was found between yield and exchangeable Al. On Coto clay (Oxisol), however, the typical yield maximum occurred at 60 percent base saturation even though no exchangeable Al was present. Leaf analysis indicated that Mn toxicity was the problem.

The Coto clay at Isabela had 200 ppm exchangeable and 2000 ppm easily reducible Mn. At base saturation of 32 to 40 percent, yield of tobacco was 260 kg compared to 600 at 60 percent. Tobacco grown on Corozal clay subsoil and Humatus clay did not exhibit significant Mn toxicity, Al toxicity and Ca and Mg deficiencies being more important.

Adams, F. 1965.
Manganese. In C. A. Black, ed. Methods of Soil Analysis Part 2. Agronomy Monograph No. 9, pp. 1011-1018. American Society of Agronomy. Madison, Wis.

Most soil Mn occurs as very insoluble oxides of tetravalent and trivalent Mn. Deficiencies usually occur at pH greater than 6 and toxicities at pH less than 5.

Adams, F. (Cont'd)

The best measure of immediately available Mn in soils of high pH is exchangeable Mn; in low soils of low pH, soluble Mn is a better measure.

The amount of soluble Mn is affected by heating, by drying, and by storage. If it is necessary to store soil samples, they should be air-dried as slowly as possible and analyzed as soon as possible.

Adams, F., and J. I. Ware. 1957.
Manganese toxicity and soil acidity in relation to crinkle leaf of cotton. Soil Sci. Soc. Am. Proc. 21:305-308. (T)

Low pH was associated with toxic levels of manganese.

Agarwala, S. C., C. P. Sharman, B. K. Sinha, et al. 1964.
Soil plant relationship with particular reference to trace elements in Usar soils of Uttar Pradesh. J. Indian Soc. Soil Sci. 12:343-354. (T)

Exchangeable Na percentage was correlated negatively with ammonium acetate extractable Mn. Rice on high-Na soil grew poorly and had high contents of Na, Mg, Fe, and B, but low K, Ca, P, N, Mn, and Cu. Plant Mn had little relation to water-soluble Mn.

Albrecht, W. A., and D. Smith. 1941.
Calcium and phosphorus as they influence manganese in forage crops. Bull. Torrey Bot. Club 68:372-376.

Applied P increased Mn in bean leaves, but not in leaves of citrus or tomato.

Atkinson, H. J., G. R. Giles, and J. G. Desjardins. 1954.
Trace elements of farmyard manure. Can. J. Agr. Sci. 34:76-80.

Atkinson, H. J., G. R. Giles, and J. G. Desjardins. 1958.
Effect of farmyard manure on the trace element content of soils and of plants grown thereon. Plant and Soil 10:32-36.

Trace element contents of six soils and of ladino clover grown on the soils were measured after yearly application of 120 tons of fresh manure for two years. (Mn content of manure, dry weight basis, was 123 ppm.) Five pound samples of soil were used in pots. Mn content of clover was decreased by application of manure. For some, but not all soils, this was associated with an increase of pH.

Baars, J. K. 1950.
Manganese deposits in rice fields. Trans. 4th Intern. Congr. Soil Sci. 1:192-195 & 4:97. (T)

Oxidation of divalent to tri- and tetravalent forms of Mn can be accomplished at pH 5 to 5.5 in rice fields by microorganisms; the reverse reduction is also possible. The proportions of these forms vary with depth. High oxidation states of Mn were found in semi-anearobic layers in the subsoil.

Barton, L. V., and S. F. Trelease. 1927.
Stimulation, toxicity, and antagonism of calcium nitrate, and manganese chloride as indicated by growth of wheat roots. Bull. Torrey Bot. Club. 54:559-577.

Addditon of calcium is suggested to decrease the toxic effect of Mn.

Beattie, J. M. 1958.
Manganese problems in production of Concord grapes. In C. A. Lamb, O. G. Beverley, and J. M. Beattie, eds. "Trace Elements," pp. 117-123. Academic Press, N.Y.

Mn at deficiency levels was found on a silt loam soil at pH 5.3.

Beeson, K. C., L. Grey, and K. C. Hamner. 1948.
Absorption of mineral elements by forage plants. II. Effect of fertilizer elements and liming materials on the content of mineral nutrients in soybean leaves. J. Am. Soc. Agron. 40:553-562.

Forty pounds of phosphate per acre reduced the plant concentration of Mn.

Berg, A., G. Clulo , and C. R. Orton. 1958.
Internal bark necrosis of apple resulting from manganese toxicity. W. Va. Agr. Exp. Sta. Bull. 414T.

A distinct purplish tint of apple leaves with interveinal chlorosis signified Mn toxicity.

Berger, K. C., and G. C. Gerloff. 1947.
Manganese toxicity of potatoes in relation to strong soil acidity. Soil Soc. Am. Proc. 12:310-314.

Black, C. A. 1968.
Soil plant relationships, 2nd ed., pp. 323-325. John Wiley and Sons. New York.

Among a number of relationships of Mn discussed, steaming releases Mn, perhaps via reduction with hot organic matter, and experiments with displaced soil solutions show that they may contain levels of Mn found to be toxic in nutrient solution.

Bleeker, P., and M. P. Austin. 1970.
Relationships between trace element contents and other soil variables in some Papua-New Guinea soils as shown by regression analyses. Aust. J. Soil Res. 1970, 8:133-143. (T)

Mn and Co levels were mainly related to fluctuating water tables. The highest concentration (1900 ppm) was in B_2 horizons; concentrations were less in A and lowest in C horizons.

Bohn, H. L. 1970.
Comparisons of measured and theoretical manganese^{++} concentration in soil suspensions. Soil Sci. Soc. Am. Proc. 34:195-197.

The author concluded that pH-1/2 pMn predicts the solubility of MnO_2.

Boken, E. 1952.
On the effect of storage and temperature on the exchangeable manganese in soil samples. Plant and Soil. 4:151-163.

Bonnet, Juan A. 1946.
Tracing the calcium, phosphorus, and iron from a limed and unlimed lateritic soil to the grass and to the animal blood. Soil Sci. Soc. Am. Proc. 11:295-297. (T)

Plots of Fajardo clay (pH 4.5) at Rio Piedras were used to see if soil deficiencies were causing malnutrition in animals. The goats used in the study were to ill from lack of protein to show mineral deficiencies well.

Half the plots were limed to pH 6.5 with 8 to 10 tons of lime in July, 1943, with the following effects on Mn and Fe:

	Exchangeable Mn		Fe extracted by Morgans Sol'n.		Mn content of grass		
Months after liming:	15	23	15	23	14	17	32
Unlimed	42 ppm	29	17	45	229	156	243
Limed	8	5	2	12	137	84	181

Bortner, C. E. 1935.
Toxicity of manganese to Turkish tobacco in acid Kentucky soils. Soil Sci. 39:15-33.

Field and laboratory data are presented to support the idea that phosphate reduces Mn injury. The evidence is not conclusive but appears worth rechecking.

Bremmer, J. M. 1946.
Metallo-organic complexes in soil. Nature 158:790.

Certain types of soluble organic matter can absorb divalent Mn, Fe, and Cu to form insoluble complexes.

Browman, M. G., G. Chesters, and H. B. Pionke. 1969.
Evaluation of tests for predicting the availability of soil manganese to plants. J. Agr. Sci. 72:335-340.

A combination of ammonium-acetate-extractable Mn and pH provided the best criteria for predicting uptake of Mn by maize on eight soils.

Burriel-Marti, F., and A. Suarez u Suarez. 1951.
Sobre la influencia del abanado fosfatado en la composicion química de los forrajes. Ann. Edafol. Fisiol. Veg. 10:247-285. (T)

Phosphate fertilizer had no effect on Mn content of forage.

Callbeck, L. C., and D. B. Robinson. 1956.
Stem streak of potato. Can. Phytopathol. Soc. Proc. 23:14.

Stem streak of potato was associated with Mn toxicity.

Child, R., and A. N. Smith. 1960.
Manganese toxicity in Grevillea robusta. Nature 186:1067. (T)

The toxicity occurred on soil of the tropics, but information about soil conditions of the experiment is inadequate.

Childs, F. D., and E. M. Jencks. 1967.
Effect of time and depth of sampling upon soil test results. J. Am. Soc. Agron. 59:537-540.

Manganese determined by soil test methods is included in the study.

Chino, Mitsuo, and S. Mitsui. 1967.
Distribution of ^{59}iron, ^{60}cobalt, and ^{54}manganese in alfalfa. Studies on the occurrence of heavy metal induced iron chlorosis, Part 3. J. Sci. Soil Japan 38:280-286. Abstract in Soil Sci. and Plant Nut. 13:206.

Plants pretreated for one month with high Mn (with "marginal chlorosis") and with high Ni and Co (with "interveinal chlorosis") were harvested after 96 hours in solution with radioactive isotopes of three metals. The authors concluded that Ni and Co caused inhibition of iron absorption, and that Mn did not affect translocation or absorption, but inhibit chlorophyll formation.

Chino, Mitsuo, and M. Shingo. 1967.
Effects of heavy metal excesses on the absorption, translocation, and distribution of ^{59}iron in rice plants. Studies on the occurrence of heavy metal induced Fe chlorosis in plants. Parts I & II. From abstract in Soil Sci. and Plant Nut. 13:163. (T)

Chlorosis was observed when plants were precultured in solutions containing high levels of Co, but not in solutions containing high levels of Cu or Mn. Mn caused a decrease in translocated Fe, but the decrease was less than that caused by Co.

Concentration of Fe in roots was not affected by the metals. Thus it is thought that the Fe content of the tops was decreased by absorption inhibition rather than by inhibition of translocation. Plant growth was inhibited by the following metals, listed in order of decreasing severity: Cu, Ni, Co, Zn, Mn. Iron absorption was inhibited by the following, listed in order of decreasing severity: Cu, Co, Ni, Zn, Mn.

Chiu, T. F. 1950.
The manganese contents of some Formosan soils and various fertilizers Agr. Res. (Ch.) 1, No. 2, 31-47. From abstract in Soils and Fert. 1t:100. (T)

Total Mn in 65 soil samples ranged from 72 to 1028 ppm. Six typical samples had 3 to 32 ppm exchangeable Mn, 34 to 249 ppm easily reducible Mn, and and no water-soluble Mn.

Christensen, P. D., S. J. Toth, and F. E. Bear. 1950.
The status of soil manganese as influenced by moisture, organic matter and pH. Soil Sci. Soc. Am. Proc. 15:279-282.

Decomposition of sugar in Norton silt loam at pH 4.6 increased the exchangeable Mn to four times that in the untreated soil. The addition of organic matter after the soil had been limed to pH 6.5 increased exchangeable Mn to 6 to 13 times its level in the check. Manganese returned to its low value after decomposition was complete. In the unlimed soil, similar addition of organic matter caused an increase in divalent Mn that persisted. pH was not so favorable for its oxidation.

The concentration of exchangeable Mn increased with time of incubation at pH 4.6, but decreased with time in the limed soil. Increases in exchangeable Mn were accompanied by decreases in easily reducible Mn. Exchangeable Mn tended to decrease with increases in soil moisture. Liming reduced the concentration of easily reducible Mn in the soil.

Christensen, P. D., S. J. Toth , and F. E. Bear. 1950.
Status of soil manganese as influenced by moisture, organic matter and pH. Soil Sci. Soc. Am. Proc. 15:279.

A good article with good references. It presents data on various manganese forms resulting from the incubation of Norton silt loam with additions of sugar equivalent to 0, 2, and 4 tons per acre under low, medium and high moisture conditions at pH 4.7, 6.5, and 7.2 for 1, 2, and 4 weeks.

The authors suggest that organic matter decomposition in unlimed soil may contribute to the soluble Mn pool from that contained in the organic matter itself, as well as by causing the release of some Mn from the soil. This Mn remains available for some time in acid soil. In limed soil it is rapidly fixed. pH had the primary effect, especially on exchangeable Mn. Organic matter was next; then moisture.

Clark, F., D. C. Nearpass, and A. W. Specht. 1957.
Influence of organic additions and flooding on iron and manganese uptake by rice. J. Am. Soc. Agron. 48:586-589. (T)

The authors suggest that rice needs much Mn and that flooding is helpful in supplying this.

Collins, J. F. 1969.
Eh-pH environment and iron-manganese equilibria in soils. Diss. Abstr. B 29:3575b, Apr. 1969.

A theoretical discussion of experimental results obtained from a sand-column study.

Cotter, D. J., and Mishra, U. N. 1968.
Role of organic matter in soil manganese equilibrium. Plant and Soil 29:439-448.

The manganese equilibrium is affected by organic matter, microbes, temperature and the season. High temperature accelerates the reduction of Mn. Soil drying increases reduced Mn.

Cox, F. R. 1968.
Development of a yield response prediction and manganese soil test interpretation for soybeans. J. Am. Soc. Agron. 60:521-524.

There was a soybean response to Mn when there were less than 20 ppm in the uppermost fully developed leaf. An equation relating to the soil test value is given.

Dion, H. G., P. G. Mann, and S. G. Heintze. 1947.
The "easily reducible" manganese of soils. J. Agr. Sci. 37:17-22.

By use of hydroxylamine hydrochloride the authors attempted to relate reducibility of Mn oxides to their crystalline structures. They found pyrolucite more easily reduced than manganite and hausmanite.

Drosdoff, M., and C. C. Nikiforoff. 1940.
Iron-manganese concretions in Dayton soils. Soil Sci. 49:333-345.

High contents of Fe and Mn were found in concretions in Oregon soils. A possible mechanism for formation is discussed.

Fergus, I. F. 1953.
Manganese toxicity in an acid soil. Queensland J. Agr. Sci. 10:15-27. (T)

A good correlation was found between exchangeable Mn and Mn uptake by beans on a Mn-toxic soil, but the concentration of exchangeable Mn itself was of little value for predicting toxicity. Toxicity should be suspected, however, in soils of low pH where there is a high level of reducible Mn.

Fitts, J. B., et al. 1968.
Availability of manganese from various materials. Proc. Soil and Crop Sci. Soc. Fla. 27:243.

Leaf content of Mn was greatest when Mn was supplied as $MnSO_4$ and decreased for other sources in the following order: MnO (60 percent Mn), MnO (41 percent Mn), $MnCO_3$, MnO_2, check, and MnEDTA.

Follett, Roy H. 1969.
Zinc, iron, manganese and copper in Colorado soils. Colo. State University Ph.D. dissertation. Diss. Abstrs. 3455b, Feb. 1970.

In 37 benchmark soils, the content of Mn was found to be positively correlated with organic matter content, and negatively correlated with pH and lime content. Cu and Mn deficiencies on these soils are rare. Metal concentrations generally decreased with depth.

Forsee, W. T. 1954.
Conditions of affecting the availability of residual and applied manganese in the organic soils of the Florida Everglades. Soil Sci. Soc. Am. Proc. 18:475-478. (T)

Certain Florida soils having pH greater than 6 tend to become Mn deficient. Studies were carried out with sorghum and beans on peaty muck. The soils when at pH 6.5 gave Mn deficiency in the crops, and this was not completely alleviated even with the application of 500 pounds of manganese sulfate per acre. Field deficiencies were satisfactorily corrected by the addition of enough sulfur to lower pH to 5.7. Chemical sterilization with 10 ml chloropicrin per 3-gallon pot increased the level of exchangeable Mn and lowered the pH. Steam sterilization raised the pH 0.3 units and greatly increased the exchangeable Mn.

Fried, M., and M. Peech. 1946.
Comparative effects of lime and gypsum upon plants grown on acid soils. J. Am. Agron. Soc. 38:614-623.

Fujimoto, C. K., and G. D. Sherman. 1945.
The effect of drying, heating, and wetting on the level of exchangeable manganese in Hawaiian soils. Soil Sci. Soc. Am. Proc. 10:107-112. (T)

Exchangeable Mn in a well-aerated soil fell from 25 ppm to 10, or even 1, ppm in two weeks with daily wetting to field capacity. This fixation was not evident in soils which are not well oxidized originally. Drying soil from flooded fields greatly reduced exchangeable Mn. Relationships of Mn chlorosis to seasonal weather were noted in the field.

Fujimoto, C. K., and G. D. Sherman. 1948.
Behavior of manganese in the soil and the manganese cycle. Soil Sci. 66:131-145. (T)

Funchess, M. J. 1918.
Development of soluble manganese in acid soils as influenced by certain nitrogeneous fertilizers. Ala. Agr. Expt. Sta. Bull. 201. 78 pp.

Nitrification of cotton seed meal, dried blood and ammonium sulfate was accompanied by increases in soluble Mn in Georgia soils.

Gerretsen, F. C. 1937.
Manganese deficiency of oats and its relation to soil bacteria. Ann. Bot. New Series 1:207-230.

Gile, D. L. 1916.
Chlorosis of pineapples induced by manganese and carbonate of lime. Science ns 44:855-857. (T)

Gomide, J. A., C. H. Noller, and G. O. Mott. 1969.
Mineral composition of six tropical grasses as influenced by plant age and nitrogen fertilization. J. Am. Soc. Agron. 61:120-123. (T)

As age of grasses advanced from 4 to 36 weeks the content of K, P, Mg, Cu, and Fe dropped. Fertilizing with N caused a decrease in Mn content.

Grasmanis, V. O., and G. W. Leeper. 1966.
Toxic manganese in near neutral soils. Plant and Soil 25:41-48. (T)

The article reviews the theory of Mn toxicity briefly and reports the results of experiments on orchards in which the concentrations of Mn were toxic to trees even at neutral pH.

Graven, E. H., O. J. Attoe, L. K. Smith, and B. G. Ellis. 1965.
Effect of liming and flooding on manganese toxicity in alfalfa. Soil Sci. Proc. Am. 29:702.

Seventy-two hours of flooding increased Mn content of alfalfa on unlimed soil from 426 ppm to more than 6000 ppm, accumulating especially in leaves and growing points. The authors suggest that the sensitivity of alfalfa to poorly aerated soils may be partly due to Mn toxicity.

Grewal, J. S., D. R. Bhumbla, and N. S. Randhawa. 1969.
Available micronutrient status of Punjab Haryana and Himachal soils. J. Indian Soc. Soil Sci. 17 27-31. From abstract in Soils and Fert. 33:11(1970). (T)

Exchangeable and active manganese were critical in arid brown soils and marginal in serozem and tropical arid brown soils. Both forms of Mn were signficantly negatively correlated with pH and postively correlated with organic matter. Exchangeable Mn, as well as available An, Cu, Mo, and B, decreased with depth.

Guha, M. M., and R. L. Mitchell. 1966
Trace and major element composition of the leaves of some deciduous trees. II. Seasonal changes. Plant and Soil 24:90-112.

In sycamore, horse chestnut and beech the concentrations and absolute amounts of Mn, B, Si, Ca, Sr, Ba, and Mg increased until late in the season.

Gupta, Umesh C., E. W. Chipman, and D. C. McKay. 1970.
Influence of manganese and pH on chemical composition, bronzing of leaves, and yield of carrots grown on acid sphagnum peat soil. Soil Sci. Soc. Am. Proc. 34:762-764.

Bronz-colored leaves appeared at 2600 ppm Mn in leaves, but yields were reduced only at 7100 ppm. Root contents were 133 to 236 ppm. Mn content of leaves was a maximum at soil pH between 4.4 and 5.0 and lowest at 6.2 to 6.4. Mn in plant tissues was lower at soil pH 4.1 than at 4.4, which is unusual and unexpected. The authors suggest that it may be due to chelation of Mn or direct competition of H^+ at these low pH values since the soil was organic.

Mn toxicity did not appear to be related to deficiency of Fe in tops at pH 4.4 and 5 because the concentration of Fe in the tops was higher than at pH 4.1 or 4.4.

Heintze, S. G. 1957.
Studies on soil manganese. J. Soil Sci. 8:287-300.

The amount of manganese complexed with organic matter may be appreciable in high organic matter soils. This Mn can be extracted with EDTA, but manganese oxides probably are not.

Heintze, S. G., and P. J. G. Mann. 1951.
A study of various fractions of the manganese of neutral and alkaline organic soils. J. Soil Sci. 2:234-242.

Organic matter forms complexes with manganic ions in saline and neutral soils.

Hemstock, G. A., and P. F. Low. 1953.
Mechanisms responsible for retention of manganese in the colloidal fraction of soil. Soil Sci. 76:331-343.

The authors conclude that Mn is chelated by organic matter.

Hernández-Medina, E., and M. A. Lugo-López. 1958.
Boron-manganese relationships in soybeans and corn plants. J. Agric. Univ. Puerto Rico 42:27-34. (T)

Mn at 5 ppm was toxic to soybeans in sand culture. Boron up to 0.5 ppm decreased Mn toxicity, but boron at greater concentration was toxic. Manganese toxicity has been reported in pineapples in Puerto Rico on soils with high soluble Mn and low soluble Fe.

Hewitt, E. J. 1950.
Relation of manganese and some other metals to the iron status of plants. Nature 161:489.

Toxic effects of Mn can readily be distinguished from Fe deficiency in sugar beets.

Hewitt, E. J. 1952.
Biological approach to problems of soil acidity. Transactions of joint meeting of Commissions II and IV, Intern. Soc. Soil Sci. Vol. 1, pp. 107-118.

The order of tolerance of crops to soil acidity can be reproduced when excesses of aluminum and manganese are combined with low calcium supply. Visual responses of many crops are explained by these factors. Foliar symptoms of Mn toxicity are illustrated in black and white.

Hiatt, A. J., and J. L. Ragland. 1963.
Manganese toxicity of Burley tobacco. J. Am. Soc. Agron. 55:47-49.

Hodgson, J. F. 1963.
Chemistry of the micronutrient elements in soils. Advances in Agronomy 15:119-159.

This review article is a comprehensive treatment of micronutrients generally, but it contains much information specifically about manganese. Topics covered include its geochemistry, its forms in soils, its distribution in soils, and factors affecting its availability and toxicity.

Hoon, R. C., and C. L. Dhawan. 1943.
The occurrence and significance of trace elements in relation to soil deterioration. I. Manganese. Indian J. Agr. Sci. 13:601-608. (T)

Manganese content follows silt plus clay content in Indian soil profiles. Analytical data are given for a number of soil and soil-water samples.

Hopkins, E. F., V. Pagán, and F. J. Ramírez-Silva. 1944.
Iron and manganese in relation to plant growth, and its importance in Puerto Rico. J. Agr. Univ. Puerto Rico 28:43-101. (T)

This is an extensive article with 37 references. Tomatoes, pineapple, and beans were studied in pot cultures. Manganese toxic bean plant leaves were observed to turn parallel to the sun's rays to "avoid light injury." A relationship to sun-loving coffee was proposed. The article discusses severe Mn toxicity observed on some unnamed Puerto Rican soils, on which pineapple require periodic iron sulfate sprays. Continuous use of ammonium sulfate fertilizer had lowered the pH to 4 or less in some soils and induced Mn toxicity. Restoring pH to 6.2 cured the Mn toxicity. Common beans were good indicator crops for Mn toxicity. In water and gravel culture, tomatoes were more sensitive than beans, and beans were more sensitive than pineapple to Mn toxicity. The sensitivity of the pineapple varied with the slip chosen. Some variation may be due to differences in the Fe reserves in the slip or seed.

Hurwitz, C. 1948.
Effect of temperature of incubation of amended soil on exchangeable manganese. Soil Sci. 56:267-272.

Mn of some finely divided oxides of higher oxidation states is available.

Imperial Bureau of Soil Science. 1940.
Minor elements of the soil. Imp. Bur. Soil Sci. Tech. Comm. No. 39, 85 pp. (T)

A good early review of micronutrients, including manganese. "Crinkle leaf" of cotton is associated with high acidity, calcium deficiency, and Mn toxicity. Pot tests have indicated that it is caused by Mn toxicity. Mn is reviewed with 99 references.

Iri, H. 1957.
The variation of ferrous iron content in soil profiles under flooded conditions of rice fields. Part I. Soils and Plant Food 3:36-47. (T)

Jackson, T. L., T. D. Westermann, and D. P. Moore. 1966.
Effects of chloride and lime on manganese uptake by bush beans and sweet corn. Soil Sci. Soc. Am. Proc. 30:70-73.

Chloride salts in the absence of lime resulted in Mn contents of leaves greater than 1000 ppm. Lime always decreased Mn content. K_2SO_4 and K_2CO_3 had no effect.

Jones, K. H. P., and G. W. Leeper. 1951.
The availability of various manganese oxides to plants. Plant and Soil 3:141-153.

A large difference was found between oats and peas in their ability to obtain Mn from Mn-deficient soil. Differences in rhizosphere flora, excretions or absorption mechanisms were suggested as explanations. Oats utilized Mn from pyrolucite and manganite, which were not highly crystalline and therefore perhaps more avilable, but not from hausmanite.

Jordine, Clinton G. 1963.
Metal deficiencies in bananas. Agritura Tropical. 19:274-281. (T)

Photographs of Zn and Mn deficient bananas are presented.

Karin, A. Q. M. B., M. Hussain, and S. Choudhury. 1960.
Studies on the manganese content and its distribution in some East Pakistan soils. Soil Sci. 90:129-132. (T)

Exceptionally low rice yields (1000 lbs/acre) were obtained in new paddies on alluvial soil. Manganese deficiency was thought to be a possible cause. This study eliminated that possibility. Data on exchangeable Mn in different kinds of soil are presented.

Kelley, W. P., and W. McGeorge. 1913.
Effect of heat on Hawaiian soils. Hawaii Agr. Expt. Sta. Bull. 30. 58 pp. (T)

Water-soluble Mn was increased by air-drying and by heating at 100° and 250°C.

Kipps, E. H. 1947.
The calcium/manganese ratio in relation to growth of lucerne at Canberra. Jour. Council Sci. and Ind. Res. 20:176-189. (T)

Plants were chlorotic and alfalfa yields were reduced when the plant Ca/Mn ratio was less than 66.

Koenigs, F. F. R. 1950.
A "sawah" profile near Bogor, Java. Trans. 4th Intern. Congr. Soil Sci. I:297-300. (T)

In "sawah" profiles of irrigated rice fields, a "hardpan" rich in iron hydroxides and manganese oxides occurs under a plowpan. Oxidation of reduced compounds coming from the soil above is thought to explain this "inverted gley" process.

Mixing the Mn-rich layer with the surface soil caused decreases in rice production. Few groundnut roots penetrated the Mn layer and droughts lasting more than a week checked growth unless irrigation was practiced.

In a 40-year old forest on former "sawahs," the pan had disappeared, but layers rich in Fe and Mn remained even after 80 years in forest.

The soil develops on material high in free Fe and Mn, a mechanical composition favorable to pan formation, high permeability, and a low water-table.

Labanskas, C. K. 1958.
Soil applications of nitrogen, phosphate, potassium, dolomite, and manure and their effects on micronutrient content of avocado leaves. Proc. Am. Soc. Hort. Sci. 71:285-291. (T)

Lakshmikanta, S. R., and S. V. Govindarajan. 1950.
Sensitivity of Patchouli to manganese deficiency in soils. Current Sci. (India) 19:280-281. (T)

Chlorosis was exhibited in spinach and patchouli grown in Mn-deficient soil and was cured by the application of 5 to 10 pounds of manganese sulfate per acre as solutions.

Lamb, J. G. D. 1960.
Manganese toxicity in a cold house tomato crop. Irish J. of Agr. Res. 1:17-20. 1960.

Phosphorus reduced the available of Mn.

Larsen, S. 1965.
Relationships between phosphorus and manganese. Bull. Doc. Int. Superphos. Man. Assoc. No. 20, pp. 96-99.

Yield increases were reported to result not from pH changes, but due to soluble Mn-P complexes arising from the application of super-phosphate.

Leeper, G. W. 1935.
Manganese deficiency of cereals: Plot experiments and a new hypothesis. Proc. Roy. Soc. Victoria. 47:225-261. (Reported by Sherman & Harmer, 1942. Soil Sci. Soc. Am. Proc. 7:398-405.)

Manganous ions are reported to be in equilibrium with collodial hydrated manganese dioxide which is easily reducible and is in equilibrium with inert manganese dioxide. The precipitation of the dioxide goes spontaneously in neutral or alkaline soils, especially in the presence of salts.

Leeper, G. W. 1947.
Forms and reactions of manganese in the soil. Soil Sci. 63:79-94.

The author has reviewed the chemistry of manganese in soil in some detail and has related it mainly to manganese deficiency.

Leeper, G. W., and R. J. Swaby. 1940.
Oxidation of manganous compounds by microbes in the soil. Soil Sci. 49:163-168.

The article reports studies of microbial oxidation of manganous ions to manganic oxide over a range of final pH values from 4.8 to 8.9.

Lingle, J. C., et al. 1961.
The effect of soil liming and fumigation on the manganese content of Brussels sprouts leaves. Proc. Am. Soc. Hort. Sci. 78:310-318.

Löhnis, M. P. 1951.
Manganese toxicity in field and market garden crops. Plant and Soil 3:193-222.

In addition to a comprehensive discussion of Mn toxicity in these crops, the article contains colored photographs of Mn toxicity symptoms.

Löhnis, Marie P. 1960.
Effect of magnesium and calcium supply on uptake of manganese by various crop plants. Plant and Soil 12:339-375.

Thirteen kinds of crop plants had been studied in experimental plots over a period of 18 years, with supplementary work in solution culture. The article reports the effects of magnesium and calcium additions on manganese toxicities in acid soils and in solution cultures. Results varied among crops and, in some instances, between field plots and solution cultures.

Lunin, Jesse. 1949.
Factors affecting the solubility of aluminum, iron, and manganese in soils and clays. Ph.D. Thesis, Cornell University.

Effects of incubation (after acid washing) and of liming Mardin soil on solubility of manganese are reported.

Mandal, L. N. 1961.
Transformation of iron and manganese in water-logged soils. Soil Sci. 91:121-126. (T)

Manganese entered into the exchange complex and also appeared in soluble form much more quickly than iron when rice was grown in water-logged soil in pots. Iron and manganese in organic complexes appeared not to be affected by water-logging, with or without addition of organic matter.

Mandal, L. N. 1962.
Levels of iron and manganese in soil solution and the growth of rice in waterlogged soils in relation to the oxygen status of soil solution. Soil Science 94:387-391. (T)

Rice was grown in water-logged soil under controlled concentrations of oxygen in the atmosphere above the water surface. Rice grew best, drainage water contained the most Mn, and plants absorbed the most Mn under a 10 percent oxygen atmosphere.

Mann, P. J. G., and J. H. Quastel. 1946.
Manganese metabolism in soils. Nature 158:154-156.

It is known that Mn^{+++} ions dismutate spontaneously to manganous and manganic ions. Therefore, it is thought that biological oxidation can change manganous ions to Mn^{+++} and these will dismutate to manganous and manganic forms, the manganic state being capable of reduction directly either biologically or in the absence of micro-organisms. Under conditions of the experiments, oxidation of Mn in neutral soil was attributed almost entirely to biological means.

McCool, M. M. 1934.
Effect of various factors on the soluble manganese in soils. Contr. Boyce Thompson Inst. 6:147-164.

This article reports a series of studies of soluble and exchangeable Mn involving CO_2 concentration, water movement, salt displacement, storage of soil at different temperatures and moisture contents, steam heating, and acidity.

McGregor, A. J., and G. C. S. Wilson. 1966.
Influence of manganese on the development of potato scab. Plant and Soil 25:3-16.

As little as 24 pounds of manganese sulfate per acre decreased the incidence of scab. The mechanism is unknown.

McHargue, J. S. 1945.
Role of manganese in agriculture. Soil Sci. 60:115-118.

Iron and Mn are reported as antagonistic, and their functions are related to redox reactions in the plant.

Medcalf, J. C. 1956.
Preliminary study on mulching young coffee in Brazil. IBEC Research Institute Bull. No. 12, cited in Wrigley, G. Tropical Agriculture. Longmans. London. 1968. (T)

Mulching is reported to have increased the 1956 Brazil coffee crop by 72 percent. P and K levels increased, while N and Mn availability was reduced.

Mehta, B. V., and M. K. Patel. 1969.
Evaluation of different chemical methods for determining available manganese from soils of Kaira district in Gujarat. J. Indian Soc. Sci. 17 1-5. Abstract in Soils and Fertilizers. Item 156. 1970. (T)

Noncalcareous sandy loam alluvial soils ranging in pH from 7.1 to 8.1 were extracted using nine different methods. Molar monoammonium phosphate gave manganese values having the highest correlation with yield of sorghum vulgare.

Messing, J. H. L. 1965.
Effects of lime and superphosphate on manganese toxicity in steam-sterilized soil. Plant and Soil. 23:1-16.

Application of superphosphate to soil with pH less than 5.0 generally raised pH and reduced the exchangeable and water-soluble Mn. For pH over 5, the opposite resulted.

Middelburg, H. A. 1950.
Manganese mobilization and fertility of tropical volcanic-ash soils. Trans. 4th Intern. Congr. Soil Sci. 2:136-137 & 4:117-118. (T)

Laboratory experiments showed that waterlogging without fertilizer treatment had no significant effect the solubiliation of Mn, but when the microbe activity was stimulated by adding N, phosphate, or carbohydrate, the amount of mobilized Mn was increased.

Millikan, C. R. 1950.
Relation between nitrogen source and the effect on flax of an excess of manganese or molybdenum in the nutrient solution. Aust. J. Sci. Res. 3:450-473.

Manganese toxicity symptoms from excess Mn in solution culture were present with NO_3 or urea supplied but were absent in N-deficient solutions containing NH_4. Symptoms were slight for NH_4NO_3 solutions.

Misra, S. G., R. G. Tiwari, and P. C. Misra. 1967.
Trace elements in soils of Uttar Pradesh. Res. J. Hindi Sci. Acad. 10:17-23. Abstract in Soils and Fertilizers. (T)

Black soils of India contained 130 to 820 ppm exchangeable plus reducible manganese; red soils, 160 to 187; alkali soils, 7 to 623.

Morris, H. D. 1948.
Soluble manganese content of acid soils and its relation to the growth and manganese content of sweet clover and lespedeza. Soil Sci. Soc. Am. Proc. 13:362-371.

Exchangeable and water-soluble Mn in 25 acid soils ranged from 1.2 to 638 ppm and from 0 to 6.3 ppm, respectively. Water-soluble Mn was related to acidity and exchangeable Mn. The Mn in soil solution of most of the soils studied was high enough to explain poor growth of legumes.

Mortensen, J. L. 1963.
Complexing of metals by soil organic matter. Soil Sci. Soc. Am. Proc. 27:179-186.

A comprehensive review of 126 references. Most evidence is still circumstancial, but a number of low weight compounds known to chelate metals have been separated from soil organic matter.

The author reports work by Bromfield (Plant and Soil 10:147) that water-soluble organic material extracted from air-dried soil dissolved gamma-manganese dioxide but was absent in incubated moist soil. Structural formulae of potential chelating compounds are given.

Motomura, S. 1961.
Dissolution of iron compounds in soils by milk-vetch extracts. Soil Sci. and Plant Nut. 7:43-60.

Motomura, S. 1962.
Effect of organic matter on the formation of ferrous iron in soil. Soil Sci. and Plant Nut. 8:20-29. (T)

Flooding acid soil caused an increase in pH and a decrease in Eh, with consequent effects on solubility of iron.

Muller, A. 1964.
Health status of sisal plants (Agave sisalana) as related to soils and the mineral composition of their leaves. Dep. Res. Royal Trop. Inst. Bull. 281. pp. 1-4. Abstract in "Tropical Abstracts" Item 93. 1964. (T)

Manganese is probably involved in purple leaf tip roll disease of sisal in Tanganika.

Munns, D. N., C. M. Johnson, and L. Jacobson. 1963.
Uptake and distribution of manganese in oat plants. I. Varietal variation. Plant and Soil 19:115-126.

The article presents an interesting approach to find where in a plant-soil system genetic differences affect manganese. Water culture work disposed of the hypothesis that translocation rate is controlled by the level of total root Mn. There is a need for separate examination of the processes of entry into the root and of transport to the shoot. Variety differences may arise from the latter. Biotic differences in Mn concentration persisted in shoots despite drastic differences in environment. Roots showed differences parallel to those in shoots only under some conditions.

Munns, D. N., L. Jacobson, and C. M. Johnson. 1963.
Uptake and distribution of manganese in oat plants. II. A kinetic model. Plant and Soil 19:193-203.

Oat roots had 30 percent total Mn in "replaceable" form, which could be extracted with electrolyte solution. The "nonreplaceable" Mn is described as: "More labile"--a pool easily and rapidly entered by new Mn and rapidly transported to the shoot. "Non-labile"--a pool slowly entered by Mn and transported to the shoot very slowly.

Munns, D. N., C. M. Johnson, and L. Jacobson. 1963.
Uptake and distribution of manganese in oat plants. III. An analysis of biotic and environmental effects. Plant and Soil 19:285-295.

In young oat plants the mainstream of Mn movement from solution to shoot was regarded as passing through a labile fraction of Mn in the roots and bypassing a non-labile fraction. Variation in total root Mn was largely attributed to the size of the non-labile fraction. When the pH was raised or the temperature lowered this fraction increased more in one variety than in another.

Musierowicz, A. 1960.
Some microelements in soils. Roczniki Gleboznawcze 9:3-25.

Crop rotation of trefoil and perennial herbs may activate Mn in soils.

Nair, K. P. P., and A. Cottenie. 1967.
A study of the plant uptake in relation to changes in extractable amounts of native trace elements from soil profiles using the Neubauer seedling method. Pedologie 17:5-14.

Ap, B, and C horizons of a sandy loam from arable and pasture land in Belgium were used. Normal ammonium acetate at pH 4.8 was used for extraction. Seedlings were grown in 12 cm diameter vessels containing 100 g of soil and 50 g of sand. Tops were cut at 15 and 30 days. Relationships between extractable Mn in the soil and Mn in the plants are reported.

Neenan, M. 1960.
Effects of soil acidity on the growth of cereals with particular reference to the differential reaction of varieties thereto. Plant and Soil 12:324-338.

Differences in growth were related to Mn toxicity.

Obordo, Romeo Acosta. 1969.
Influence of some properties of flooded soils and the reduction of iron and manganese on growth and yield of rice. Diss. Absts. B 3582b. April, 1969. (T)

After flooding, soil pH stabilized at 6.8 to 7.1 from 5.2 to 5.5 initially. Eh was low for constantly flooded and for periodically drained soil, especially where grass was added. Fe and Mn were reduced, but concentrations of Mn were 1/5 to 1/10 those of Fe. Low grain yields were observed with continuous flooding and 0.8 percent grass added. Physiological disease symptoms were noted, perhaps due to Mn or Fe toxicity.

Oserkowsky, J. 1932.
Relation between the green and yellow pigments in chlorotic leaves. Plant Physiol. 7:711-716.

"Active" Fe which can form chlorophyll was found in the HCl extract of dried leaves.

Ouellette, G. J., and L. Dessureaux. 1958.
Chemical composition of alfalfa as related to degree of tolerance to manganese and aluminum. Can. J. Plant Sci. 38:206-214.

Ca decreased Mn toxicity.

Ouellette, G. J., and H. Généreux. 1965.
Influence de l'intoxication manganique sur six variétés de pomme de terre. Can. J. Soil Sci. 45:24-32.

Differences in susceptibility to manganese toxicity were noted among varieties of potatoes.

Page, E. R., E. K. Schofield-Palmer, and A. J. Macgregor. 1963.
Studies in soil and plant manganese. IV. Superphosphate fertilization and manganese content of young oat plants. Plant and Soil 19:255-263.

A statistical analysis of data from eight experimental centers in Western Scotland showed that superphosphate increased Mn content of oats, which was related to decreases in soil pH.

Perold, I. S. 1951.
Manganese and copper deficiences in the South Coastal Region of South Africa. Proc. Spec. Conf. Plant and Animal Nut. in Australia, 1949 136-144. (Soils and Fert. 14:399). (T)

Perold, I. S. (cont'd)

Mn deficiency in the Cape Flats area is attributed to progressive exhaustion of soil organic matter. Heavy leaching in winter counteracts the possible summer increase of available Mn resulting from high temperatures. Organic manure stimulated uptake of added Mn by beans on alkaline soils and reduced uptake on acid soils.

Piszczek, J. 1951.
The influence of fertilization and crop rotation on the content of manganese in soils. Ann. Univ. Mariae Curie-Sklodowska Lublin-Polonia, Sect. E., 7 No. 1, 1-37.

Lack of fertilization of test plots with N and P was associated with a decrease of Mn in soils. Including clover in the rotation counteracted the decrease of Mn in surface soils. A higher content of active and exchangeable Mn was found in soils in five than three-year rotations.

Ponnamperuma, Felix, N. 1965.
Dynamic aspects of flooded soils and the nutrition of the rice plant. In "The Mineral Nutrition of the Rice Plant". IRRI. pp. 295-328. Johns Hopkins Press. Baltimore. (T)

This is a comprehensive treatment of the subject. Major conclusions include the following: Reduction of the higher oxides of Mn is almost coincident with denitrification after flooding. This occurs via Mn acting as an electron acceptor in the microbial respiration system, or through chemical oxidants of reduction products. Release of Mn precedes that of iron.

Soils with high Mn content regardless of pH and organic matter, show steep increases in divalent Mn during the first few weeks after flooding and decline slowly thereafter. Soils low in active Mn increase slowly in divalent manganese to maximum values considerably less than those for high Mn soils. The overriding factor that determines the level of reduced Mn appears to be Mn content of the soil. However there are big variations from soil to soil. Strongly acid latosolic soils accumulate soluble Mn slightly ahead of Fe, reaching a maximum of =60 ppm and declining to less than 10 ppm after six months submergence. Moderately acid soils show slower increases, lower maxima, and slower declines than strongly acid soils.

Rice needs a considerable, but not too much, Mn. There are conflicting reports of some high leaf Mn contents associated with poor production. IRRI found flooding promoted Mn uptake in neutral soil and retarded it in acid soil (compared to non-flooded plots). Some of the complexities are: (1) The oxidized rhizosphere of rice precipitates Fe more readily than Mn and can drastically alter the Fe/Mn ratio observed in the bulk of the soil solution and (2) there is a promotion of Mn uptake by the addition of nitrate.

Rice Mn deficiencies and toxicities have been shown on various soils.

Ponnamperuma, F. N., R. Bradfield, and M. Peech. 1956.
Chemistry of submerged soils in relation to the growth of rice.
Trans. 6th Intern. Congr. Soil Sci. C:503-506. (T)

This is one of the early papers by Ponnamperuma based on his Ph.D. thesis, and a forerunner of his later comprehensive studies of the subject.

Ponnamperuma, F. N., T. A. Loy, and E. M. Tianco. 1969.
Redox equilibria in flooded soils. II. Manganese oxide systems.
Soil Sci. 108:48-57. (T)

This is an authoritative treatment of the subject.

Mn has seven oxidation states, but only the plus 2, 3, and 4 are found in nature, often with the metal in mixed valance states in the same oxide. More than 150 nonstoichiometric Mn oxides have been reported.

Complex coprecipitates of Fe and Mn form easily (both Fe and Mn have similar changes in valence and their size is very similar). Manganese-rich concretions are thought to form coagulation of fine particles of manganese dioxide and ferric hydroxide that have sorbed divalent Mn and Fe. Sorption is due to pH-dependent charge, negative above the isoelectric point (pH 5-6 for Ferric hydroxide; pH 2-7 for manganese dioxide, varying with the polymorph). Morgan and Stumm found the CEC of colloidal manganese dioxide for divalent Mn to be 1 mole at pH 8, and that of ferric hydroxide 0.3 mole per 100 g. The CEC of manganese dioxide at pH 813 is 1.5 equiv per 100 g compared to 0.1 for montmorillonite--with large surface area. It is thought that some divalent Mn sorbed is incorporated into the structure. These relationships result in 36 Mn oxide minerals in soils and in dynamic systems which are very complex.

Flooded soils show: (a) Redox potentials of high Mn soils are higher than normal soils, (b) pH values of acid soils increase asymptotically to 6.5 to 7.2 in four to six weeks, and sodic and calcareous soils decrease to this, and (c) after four months submergence, the divalent iron in acid soils is 50-100 ppm, and in neutral to alkaline soils, 5-20 ppm. Mn is 5-20 ppm in both.

Randhawa, N. S., J. S. Kanwar, and S. D. Nijhawan. 1961.
Distribution of different forms of manganese in the Punjab soils.
Soil Science 92:106-112. (T)

Mn content follows silt plus clay content in seven Punjab soils profiles. Water-soluble, exchangeable, and easily reducible manganese is highest at the surface, but total Mn increases with depth.

Raychauduri, S. P., and N. R. Datta Biswas. 1964.
Trace element status of Indian soils. J. Indian Soc. Soil Sci.
12:207. (T)

Data are tabulated for trace element deficiencies in India and for total and available quantities of Mn and B in soils widely distributed over the country.

Reuther, W., P. F. Smith, and A. W. Specht. 1952.
Accumulation of the major bases and heavy metals in Florida citrus soils in relation to phosphate fertilization. Soil Sci. 73:375-381. (T)

High proportions of copper, manganese, and zinc applied to soils of citrus orchards were retained in surface soils irrespective of phosphate treatment.

Rich, C. I. 1956.
Manganese content of peanut leaves as related to soil factors. Soil Sci. 82:353-363.

Mn content of peanut leaves was found to be a function of the exchangeable Mn in soil.

Robinson, W. O. 1929.
Detection and significance of manganese dioxide in the soil. Soil Sci. 27:335-350.

The decomposition of H_2O_2 by MnO_2 with effervescence can be used as a field test for MnO_2. MnO_2 is reported to occur mainly in sand and silt fractions nad in nodules.

Rorison, I. H., C. D. Sutton, and E. G. Hallsworth. 1958.
Effects of climatic conditions on aluminum and manganese toxicities. In "Nutrition of the Legumes," pp. 62-68. Butterworths, London.

Rosell, R. A., and K. L. Babcock. 1968.
Precipitated manganese isotopically exchanged with ^{54}manganese and chelated by soil organic matter. In "Isotopes and Radiation." Proc. Symp. IAEA/FAO, 1968, pp. 453-468. Abstracted in Soils and Fert., Vol.33, Item 3448, 1970.

Adsorbed Mn exchanges with newly precipitated Mn oxides and hydroxides. Organic matter suspensions from mineral soil extracted and chelated 27 percent of total newly precipitated Mn. Suspensions from organic soil extracted and chelated 16 percent.

Rouseau, L. Z. 1960.
D'influence du type d'humus sur le developpement des plantules de sapin dans les vosges. Ann. Ecole Nat. Eaux For. 17:13-118.

Mn cycled by vegetation remains highly available even in forest soils with bulk pH of 7.

Sanchez, C., and E. J. Kamprath. 1959.
Effect of liming and organic matter content on the availability of native and applied manganese. Soil Sci. Soc. Am. Proc. 23:302-304.

The studies reported indicated that availability of Mn may be more of a problem on poorly drained soils high in organic matter which have been limed than on well drained soils of lower organic matter content.

Savant, N. K., and M. M. Kibe. 1969.
Effect of alternate submergence and drying of soil prior to resubmergence on extractable aluminum, iron, and manganese in rice soils of the Maharashtra State, India. Soil Sci. 108:440-445. (T)

Manganese extracted by Morgan's solution increased with one cycle of flooding followed by air or oven drying but decreased progressively with a second and third cycle to values near those of the untreated soil.

Schmehl, W. R., M. Peech, and R. Bradfield. 1950.
Causes of poor growth of plants on acid soils and beneficial effects of liming: I. Evaluation of factors responsible for acid-soil injury. Soil Sci. 70:393-410.

An excellent article on Mn and Al toxicity of alfalfa in soils of New York.

Serdobolskii, I. P. 1950.
Effect of soil conditions on the transformation of manganese compounds in the soil. Trudy Pochv. Inst. Dokuchaev 43, 192-216. Abstract in Soils and Fert. 14:447.

Seshagiri, Rao, and D. V. Krishna Rao. 1958.
Manganese toxicity in rice. Andhra Agr. J. 5:130-134. (T)

Sherman, G. D., and P. M. Harmer. 1941.
Manganese deficiency of oats on alkaline organic soils. J. Am. Soc. Agron. 33:1080-1092.

Certain reducing agents liberated enough Mn from deficient soils for normal plant growth. Heavy applications of pyrolusite were not helpful unless S was also applied.

Sherman, G. D., and P. M. Harmer. 1942.
The manganous-manganic equilibrium of soils. Soil Sci. Soc. Am. Proc. 7:398-405.

The authors propose that added divalent Mn is precipitated as hydrated manganous oxide in neutral conditions and immediately oxidized to hydrated manganese dioxide. This oxidation is retarded by acidity, which can only be counteracted by strong oxidizing agents. Fine colloidal hydrated Mn dioxide is easily reducible by chemical reactions in soil. Prolonged oxidative conditions and/or dehydrating conditions encourage larger crystals and therefore less availability.

Sherman, G. D., and C. K. Fujimoto. 1946.
Effect of the use of lime, soil fumigants, and mulch on the solubility of manganese in Hawaiian soils. Soil Sci. Soc. Am. Proc. 11:206-210. (T)

The authors have reviewed the early work on Mn in soils of Hawaii, including Johnson's studies in 1924 which corrected chlorosis of pineapple with iron sulfate sprays. They reported reduction of amounts of exchangeable Mn with liming but reduction of yields of pineapple by the practice. Mulches lowered soil temperature 20°C, decreased

Sherman, G. D., and C. K. Fujimoto. 1946 (cont'd)

exchangeable Mn, and increased yields of pineapple and lettuce. The effectiveness of the mulch was thought due to prevention of dehydration. Bad effects of dehydration persisted several months after irrigation of dehydrated soil.

Shive, J. W. 1941.
Significant roles of trace elements in the nutrition of plants. Plant Physiol. 16:435-445.

The article reviews the state of understanding of the roles of Fe and Mn in plant nutrition in 1941, stressing the interdependence of the two elements and their oxidation-reduction systems.

Sideris, C. P., and H. Y. Young. 1949.
Growth and chemical composition of Ananas Comosus (L.) Merr., in solution cultures with different iron-manganese ratios. Plant Physiology. 24:416-440. (T)

This article, with 67 references, reports solution-culture studies of pineapple with different combinations of Fe and Mn concentrations and discusses the results in terms of their physiological functions.

Singh, M., and A. N. Pathak. 1969.
Manganese in relation to climate and soil character. Agrochimica 14:213-222. (T)

In 82 samples of soil, total Mn increased with increasing rain. Following are ranges of amounts of Mn in different forms reported.

	Total	Exchangeable	Water-soluble
Topsoil	556-1100	1-20	0-3
Subsoil	480-1100	1-21	0-3

Single, W. V., and I. F. Bird. 1958.
Mobility of manganese in the wheat plant. II. Redistribution in relation to concentration and chemical state. Ann. Botany (London) N.S. 22:489-502.

Somers, J. W., S. G. Gilbert, and J. W. Shive. 1942.
The iron-manganese ratio in relation to the respiratory CO_2 and deficiency-toxicity symptoms in soybeans. Plant Physiol. 17:317-320.

The authors conclude that, within reasonable limits, the absolute concentrations of Fe and Mn, either in the nutrient substrate or in the plant, are relatively unimportant so long as they are present in proper proportions.

Sommers, I. I., and J. W. Shive. 1942.
Iron-manganese relations in plant metabolism. Plant Physiology 17:582-602.

Both Fe deficiency and Mn excess resulted in the same physical imbalance and plant symptoms. See also Shive, 1941.

Stiles, W. 1946.
Trace elements in plants and animals. 178 pp. Cambridge Univ. Press. Cambridge.

Szalay, A., and M. Szilágyi. 1968.
Laboratory experiments on the retention of micronutrients by peat humic acids. Plant and Soil 29:219-224.

Takkar, P. N. 1969.
Effect of organic matter on iron and manganese. Soil Science 108:108-112. (T)

Finely ground sugar can trash at 0, 0.5, 1, 2, 4, and 8 percent was added to acidic, neutral, calcareous, and saline soils from Baijnath, Ludhiana, Abohar, and Nabha, India in bottles at 60 percent field capacity and under water-logged conditions. In general the active Mn increased with time and with organic matter added. Hydroxy acids are thought to form from the organic matter; manganous salts of these acids were readily oxidizable at pH greater than 7. In acid soils, dissolution of manganese dioxide resulted from organic matter addition. The paper lacks information about some conditions of the experiments.

Takkar, P. N., and D. R. Bhumbla. 1968.
Distribution of iron and manganese forms in acid and neutral soils of the Himachal I. Agrochimica 12:412. (T)

Takkar, P. N., D. R. Bhumbla, and B. R. Arora. 1969.
Distribution of iron and manganese forms in calcareous soils of the Punjab and Haryana III. Agrochimica. 13:56-63. (T)

Soils from 20 sites were studied. Iron and Mn appeared to have accumulated together. Amounts of Mn in various forms ranged as follows: Total Mn - 165 to 382 ppm; "free" Mn - 36 to 165 ppm; "active" Mn - 29 to 115 ppm. Evidence was presented that iron in different forms is correlated with organic matter.

Taper, C. D., and W. Leach. 1957.
Effect of calcium concentration in culture solutions upon absorption of iron and manganese by dwarf kidney beans. Can. J. Bot. 35:773-777.

Ca decreased Mn toxicity.

Taylor, R. M., R. M. McKenzie, and K. Norrish. 1964.
The mineralogy and chemistry of manganese in some Australian soils. Aust. J. Soil Res. 2:235-248.

The authors stressed the absence of simple Mn oxides and hydroxides in soils.

Trelles, R. A., F. D. Amato, and E. Catalano. 1951.
Manganese in the soils and some profiles of Argentina. Anales. Soc. Cient. Argentina 141:225-227. From chemical Abstracts 46:4157. (T)

The paper reports levels of Mn in soils of various parts of Argentina. Values reported range from as low as 20 ppm to as high as 1150 ppm.

Vinayak, C. P., N. R. Talati, and C. M. Mathur. 1964.
Distribution of manganese in saline-alkaline soils and its relation with some of the soil characteristics. J. Indian Soc. Soil Sci. 12 275-279. (T)

Water-soluble Mn content was higher in surface than in subsoils. Relationships between Mn contents and other soil properties are reported.

Vinayak, C. P., K. M. Mehta, and S. P. Seth. 1967.
Manganese status of Rajasthan soils. Soil Sci. and Plant Nut. 13:201-205. (T)

In a survey of 80 soils in northeastern India, exchangeable, easily-reducible and active and total Mn were correlated at the 1 percent level with organic matter content. All but exchangeable Mn were also correlated with clay content.

Vose, P. B., and D. G. Jones. 1963.
Interaction of manganese and calcium on nodulation and growth in varieties of trifolium repens. Plant and Soil 18:372-385.

Ca was found to depress Mn uptake in water culture. There were distinct varietal differences. A level of 0.5 ppm of soluble Mn was tolerated, but all varieties showed toxicity at more than 10 ppm. An increase in Mn concentration was associated with a decrease in the number and size of nodules.

Wallace, T., E. J. Hewitt, and D. J. D. Nicholas. 1945.
Determination of factors injurious to plants in acid soils. Nature 156:778-779.

Increasing concentration of calcium in sand culture alleviated Mn toxicity for runner beans at 12-25 ppm Mn.

Warcup, J. H. 1957.
Chemical and biological aspects of soil sterilization. Soils and Fertilizers. 20:1-5.

Flooding detoxified steam sterilized soil.

Warnock, R. E. 1970.
Micronutrient uptake and mobility within corn plants in relation to phosphorus-induced zinc deficiency. Soil Sci. Soc. Am. Proc. 34:765.

High levels of P and low levels of Zn on calcareous Sacramento clay loam increased the mobility of Fe and Mn within the plant, and decreased Zn mobility. The uptake of Fe was greatly increased, and that of Mn slightly increased. The high levels of these two elements appeared to interfere with normal functioning of the plant.

White, P. P., E. C. Doll, and J. R. Melton. 1970.
Growth and manganese uptake by potatoes as related to liming and acidity of fertilizer bands. Soil Sci. Soc. Am. Proc. 34:268-271.

Manganese and Al were added to the fertilizer band. The addition of Al had no effect on the uptake of Mn.

Williams, D. E., and J. Vlamis. 1957.
Manganese toxicity in standard culture solutions. Plant and Soil 8:183-193.

Willis, L. G. 1929.
Manganese as a fertilizer for South Atlantic Coastal Plain soils. Am. Fert. 71:17.

Mn deficiency was observed most in wet seasons and on wet soils.

Winterholder, D. K. 1963.
Differencial resistance of two species of Eucalyptus to toxic soil manganese levels. Aust. J. Sci. 25:363-364.

A spray of Fe EDTA or iron salts was used to offset excess manganese, and for diagnosis.

Yuan, W. L., and F. N. Ponnamperuma. 1966.
Chemical retardation of flooded soils and the growth of rice. Plant and Soil 25:347-360. (T)

Redox potential was higher in soils high in Mn than in other soils.

Zende, G. K. 1954.
Effect of air-drying on the level of extractable manganese in the soil. J. Indian Soc. Soil Sci. 2:55-61. (T)

Air-drying increased extractable Mn.