A STUDY OF MANGANESE AVAILABILITY IN SEVERAL MICHIGAN SOILS

Thesis for the Degree of M. S.
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Govind Pailoor

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THESIS

A STUDY OF MANGANESE AVAILABILITY
IN SEVERAL MICHIGAN SOILS

By

Govind Pailoor

AN ABSTRACT OF A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
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ABSTRACT

A STUDY OF MANGANESE AVAILABILITY IN SEVERAL MICHIGAN SOILS

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Greenhouse and laboratory investigations were initiated in 1964 to: (1) study the manganese availability of several Michigan soils; (2) evaluate 0.1N H_3PO_4 and 1N NH_4OAc + 0.2 per cent hydroquinone as to their effectiveness in the determination of plant available soil manganese; (3) correlate several soil chemical properties with manganese availability; (4) study the effect of lime and manganese applications on mangnaese availability, and (5) determine the manganese sufficiency level for oats, beans and radishes.

Soils containing less than 30 pp2m of 0.1N H_3PO_4 extractable manganese or less than 62 pp2m of 1N NH_4OAc + 0.2 per cent hydroquinone extractable manganese may be considered to be manganese deficient for beans. Soils containing more than 69 pp2m of easily reducible manganese or 49 pp2m of acid soluble manganese may be considered as sufficient for the bean crop. Twenty-five ppm or less manganese in the bean plant tissue may be considered as a deficient level and more than 35 ppm manganese may be considered as sufficient for normal plant growth.

On mineral soils, 0.1N H_3PO_4 was better in assessing manganese availability than 1N NH_4OAc + 0.2 per cent hydroquinone. However, the latter gave better correlations with plant yield and manganese uptake on organic soils. Generally, soil pH and extractable bases were negatively correlated with extractable soil manganese and plant manganese. Soil phosphorus was positively correlated with soil and plant manganese contents.

The near neutral and/or alklaine, coarse and fine textured soils and also muck soils respond well to manganese fertilization.

Results indicated that nutrient imbalance (Mn, Fe, Al, Cu, B) arising on coarse and medium textured acid soils (pH 4.7 and 5.5) may give rise to abnormal growth of bean plants.

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INTRODUCTION

The importance of an adequate supply of available soil manganese has long been recognized as essential for optimum crop yields. Manganese deficiency in crops is probably the most common micronutrient problem in Michigan. The mineral soils of Michigan may be deficient in this element for specific crops, particularly when the pH is above 6.5. Manganese may be needed for oats, beans, soybeans, potatoes, sudan grass, sugar beets, and spinach. In extreme cases, barley, corn, and wheat may respond to applications of manganese.

Deficiency of this element has occurred most widely on dark colored surface soils with greyish subsoils found in lake bed or glacial outwash areas. Organic soils are also often low in manganese. Manganese deficiency is most likely to occur on organic soils with a pH of 5.8 or greater and is most severe on cold wet soils.

The need for a chemical extractant that will accurately reflect the amount of manganese available to crop plants is apparent. This investigation was initiated to:

1. Evaluate the manganese availability of several Michigan soils.

2. Evaluate two chemical extractants as to their effectiveness in the determination of plant available soil manganese.
3. Correlate the following factors with available soil manganese:
    a. soil texture
    b. soil reaction
    c. extractable soil phosphorus
    d. extractable potassium, calcium, and magnesium
4. Study the effect of lime and manganese applications on manganese uptake by plants.
5. Determine the level of sufficiency and deficiency of plant available soil manganese using oats, beans, and radishes as indicator crops.

REVIEW OF LITERATURE

Chemistry of Manganese

Manganese, like iron, is one of the most abundant heavy metals to be found in the earth's crust. The ores of manganese, chief of which is pyrolusite (MnO_2), are found almost everywhere. Metallic manganese resembles iron both physically and chemically. When pure, it is silvery white like iron, and is the softer of the two. It becomes hard and brittle and grey when it contains carbon. As an active metal it displaces hydrogen slowly from water. However, it dissolves very readily in dilute acids, forming the bivalent ion Mn^{++} and liberating hydrogen.

Manganese forms compounds having valence states from +1 to +7. The most important compounds of manganese are derived from +2, +4 and +7 valence states. MnO, Mn_2O_3, MnO_2, and Mn_2O_7 are the most important of the manganese compounds. MnO and Mn_2O_3 are basic in character. MnO_2 is amphoteric and Mn_2O_7 is strongly acidic since it is derived from permanganic acid ($HMnO_3$), which is one of the strongest acids known. An intermediate oxide (Mn_3O_4), red in color, is also known.

The oxidation of manganese salts or the reduction of manganates or permanganates in alkaline solution will produce a manganese dioxide hydrate. The salts of the hydrate reactions with basic oxides are known as manganites. It will also form salts with very strong acids; however, these are rather unstable because manganese tends to become bivalent in acid conditions.(34).

Forms of Soil Manganese

The following forms of soil manganese have been suggested to be in a state of dynamic equilibrium (31):

$$\text{Water soluble } Mn^{++} \rightleftarrows \text{Exchangeable } Mn^{++} \rightleftarrows$$

$$\text{Colloidal hydrated } MnO \rightleftarrows \text{Inert } MnO_2$$

The divalent form of manganese is considered to be the most important form of available manganese. The soil may have a good reserve of total manganese, but its availability to plants is determined by the form in which it exists. Manganese exists in the soil as divalent manganese, which is present in the soil solution; or as the exchangeable ion; as trivalent manganese Mn_2O_3; and as tetravalent manganese MnO_2 in oxidized forms (14, 16, 32, 36).

Dion and Mann (14) proposed a manganese cycle in the soil based on the oxidation-reduction equilibrium between divalent exchangeable Mn^{++} and tetravalent manganese oxides (MnO_2, Mn^{++++}) and the existence of a trivalent manganese oxide ($Mn_2O_3 . x\ H_2O$, Mn^{+++}) which undergoes dismutation to give both divalent and tetravalent manganese. The trivalent and tetravalent forms are favored by a high pH and oxidizing conditions. The highly stable MnO_2 is more likely to occur in soils at pH values greater than 8.0. The trivalent form is presumably favored by pH values near neutrality while the divalent form is found in acid soils.

Fujimoto and Sherman (16) have proposed a manganese cycle based on the oxidation-reduction system and the hydration-dehydration system in soils. The oxidation-reduction system determines the relative amounts of manganous oxide (MnO), and manganese dioxide (MnO_2). When free manganous oxide, manganese dioxide and water are present in the soil, addition and hydration of the oxides will take place with the formation of a complex hydrated manganese oxide $[(MnO)x.(MnO_2)y.(H_2O)_z]$. This form of oxide is stable when moisture is present and the temperature is low. When the soil becomes dry and the soil temperature rises, this form of the oxide breaks up into its component parts.

Role of Manganese in Plant Nutrition

Manganese is found in plant tissues in small quantities.

It is an essential constituent in the plant because of its catalytic and regulatory role in the chemical processes of the living cells. Manganese acts as a catalyst in the activities of many enzymes like peroxidase, indol acetic acid oxidase, transketolase and hydroxylamine reductase. Tanner and colleagues (62) have found that manganese is necessary for the optimal rate of production of glycollic and malic acids (glycollic oxidase to form glyoxylate) in chlorella cells. Malonate formation requires the presence of manganese as a catalyst (53).

The Hill reaction of molecular oxygen (38) and the similar peroxide formation in illuminated chloroplasts (18) are dependent on the additions of manganese. Synthesis of chlorophyll is determined by both manganese and iron (2). Manganese functions as a co-factor in the oxidative phosphorylation. Manganese acts as a regulator of the intake and the state of oxidation of iron (60). Action of manganese is primarily involved with the oxidized products of photolysis (22).

Benson (4) found that manganese is one of the structural components of the plant membrane, particularly in the quantasomes. These quantasomes are lipo-protein granular structures and are independent photosynthetic functional units of the chloroplast.

Manganese Deficiency Symptoms

Manganese is a slowly mobile nutrient element, and therefore the deficiency symptoms first occur in relatively young leaves (9).

Oats show the severest and most easily recognizable deficiency symptoms among cereals. "Grey Speck" disease or "Haloblight" in oats is a typical manganese deficiency symptom. Mulder and Gerretsen (41) have described the manganese deficiency symptoms in oats as follows: "Marginal grey-brown colored necrotic spots and streaks appear first in the third highest leaves, particularly in the basal half. The streaks tend to elongate and coalesce. At the distal end of the affected basal part, the necrotic spots may soon extend across the blades so that the upper half or two-thirds of the leaf falls over with a sharp kink on the collapsed portion. The distal ends of the leaves remain green for a considerable time. On older leaves, the collapse may be confined to the lower quarter and oval spots of necrotic tissue may appear irregularly on the leaf blade, though less frequently toward the tip end."

Manganese deficiency on soybeans appear first in leaves when they become chlorotic in their interveinal areas while the veins remain green. Whole leaves, excluding the veins, become pale green and then pale yellow; brown spots and necrotic areas develop as the deficiency becomes more severe (43).

Early symptoms of manganese deficiency in sugar cane leaves are characterized by a fading of the normal green color between the vascular bundles, followed by the development of definite, pale yellowish-green to white longitudinal stripes. The stripes are confined to middles and tips and seldom extend the full length of the leaves as in iron deficiency. When manganese deficiency is acute, the chlorotic stripes become white. Reddish brown areas of dead tissues appear, later develop into continuous stripes and split the leaves longitudinally.

In sugar beets the deficiency symptom of manganese is called "speckled yellows" (67) because of the interveinal chlorotic mottling.

In the foliage of tomato plants, manganese deficiency manifests first as a lightening of the green color, which gradually turns to yellow starting from the top and extending towards the base, but the veins remain green. Eventually foliage may become completely yellow; necrosis may set in, appearing first on small brown pin points centering in the yellow areas from the tip. Growth is spindley, little or no blossoming takes place, and fruit does not form (50).

Manganese deficient snap beans grow normally for a short period, the first symptoms to appear being a loss of green color in the trifoliate leaves. The yellowing does not spread to the seed leaves until later in the development of the deficiency. Progressive symptoms show up with small brown spots near and parallel to each side of the mid rib, and veins between the lateral branches may appear before the leaf becomes completely yellow (50).

<u>Levels of available soil manganese</u>

Piper (48) concluded that manganese exists in soil in an oxidation-reduction equilibrium and contended that the amount of manganese in the soil gives information as to the ability of the soil to provide the plant with this element.

Leeper (31) pointed out that 100 ppm of 0.2 percent hydroquinone soluble manganese would be sufficient to prevent "grey speck" in oats.

In the slightly acid to alkaline soils which Sherman and McHargue (55) studied, the trend of manganous-manganic equilibrium was stongly toward manganic manganese. They concluded that soils with less than 25 ppm of easily-reducible manganese dioxide will not supply plants with sufficient manganese for normal growth. Productive soils of this group contained 100 ppm or more of easily reducible manganese dioxide. Soils deficient in mangnaese have a high capacity to oxidize added manganese.

Boken (5) using M $Mg(NO_3)_2$ as the soil manganese extractant, found that 4 ppm of exchangeable manganese in the soil as the sufficiency level for spring cereals.

Henkens (27) reviewing manganese research in the Netherlands, indicated that on soils with humus contents below 2-1/2 percent, limiting value of 60 to 70 ppm reducible manganese is suggested, while on soils with higher humus contents, a reducible manganese level of 100 ppm is needed to prevent the occurrence of manganese deficiency on spring grains.

Results of Hammes and Berger (23) indicated that manganese deficiency in oats can be expected when the soil manganese extracted with EDTA is less than 50 ppm or when the soil manganese extracted with hydroquinone is less than 65 ppm or when the soil manganese extracted with either H_3PO_4 or $NH_4H_2PO_4$ is less than 20 ppm.

On studying the relations among crinkled leaf of cotton and manganese toxicity and soil acidity, Adams and Wear (1) noticed that the severe symptoms of crinkled leaf in cotton were associated with 11 ppm or more manganese in the soil solution.

Levels of Plant Manganese

Sherman et al (55) found that 30 ppm or more of manganese in oat tissue was sufficient for normal growth. Less than 15 ppm resulted in manganese deficiency and a moderate deficiency was associated with concentration of 20-25 ppm of manganese.

Though 15 ppm is a reasonable dividing line between sick and healthy oat plants, sick plants have been reported with as much as 29 ppm (37) and even 36 ppm (55). Hammes and Berger (23) found that young oats containing less than 30 ppm manganese are likely to be deficient whereas mature grain having a manganese concentration of less than 12 ppm would be regarded as deficient. For many crops, the threshold values of manganese have been established (on the oven dry basis) and they range from 10 ppm in the tissue for citrus trees to 40 ppm for soybeans (61).

Available Soil Manganese as Related to Several Factors

Factors which affect manganese availability are the soil type, moisture content, texture, chemical and biological oxidation and reduction, pH, organic matter and plant used to measure the availability (66).

Exchangeable manganese is held in the soil by negative charges arising from isomorphic substitution in clays and largely from ionized carboxyl groupings in the organic fraction. But the chelated manganese is exclusively associated with organic fraction. Therefore, a wide range in organic matter content and different pH levels should influence the relative amounts of exchangeable and chelated manganese present in the soil (66).

Reid and Miller (51) studied the forms of soil manganese in equilibrium with solution manganese using Mn^{54} and their rate studies indicated that there was a rapid exchange reaction operative between solution manganese and hydroquinone soluble manganese oxides. They also found one or more slower exchange reactions operative between solution manganese complexed by organic matter.

Walker and Barber (66) found that soil pH was also significant in predicting available manganese. This is in line with the findings of Cook (11) that the soil reaction should be determined when manganese deficiency is suspected in sugar beets.

Exchangeable manganese content decreased with increasing soil pH (66). Leeper (32) suggests that biological oxidation is the cause for this decrease. He stated that reduction by organic matter is the probable cause of an increase in the bivalent exchangeable manganese content at the low pH values.

Fujimoto and Sherman (16) observed that the oxidation of the manganese ion by oxygen can take place in a basic medium and that the presence of certain finely divided substances will catalytically increase the rate of oxidation.

It has been shown that addition of organic matter with a high carbon-nitrogen ratio will increase availability of manganese in the soil (16). Organic matter with a high carbon-nitrogen ratio contains large amounts of easily oxidizable substances such as starch and sugar. When these substances are added to the soil in the form of residual plant parts, biological oxidation of the organic matter takes place with the formation of carbon dioxide.

It has been stated by Leeper (32) that biological reduction can take place at any pH value if the oxygen tension is low, when the anaerobic bacteria use the higher oxides as a source of oxygen. Reduction of the higher oxides takes place when the biological oxidation of organic matter proceeds at so rapid a rate that the air cannot supply oxygen in adequate amounts. When this occurs, reduction of the higher oxides takes place to supply the needed oxygen. This leads to an increase in the available manganese.

Growing oats in a 1 percent agar nutrient culture solution, Page (44) found that all the oxides studied were available to the plant to a greater or lesser degree, the order of availability being:

> pyrolusite (MnO_2) $<$ manganous manganite (MnO_2) $<$ an oxide prepared as cryptomelane (MnO_2) $<$ manganese dioxide $<$ manganite ($MnO.OH$) $<$ hausmanite (Mn_3O_4)

This presumably means that the insoluble higher oxides of manganese are brought into solution to become available to the plant. Numerous substances present in soil might cause reduction of higher oxides of manganese dioxide, but reduction is not the main path by which manganese becomes available to the plant. Manganese dissolving substances in the root secretions also play an important part. The amount of manganese available to a plant in near neutral and alkaline soils appears to be the net result of the rates of two opposing forces, the solution and fixation. To the many factors which affect the rate of solution of manganese dioxide, the nature and the amount of manganese dissolving root substances must be added (8). This is largely pH dependent. In a study of the modes of manganese retention in the soil in the absence of oxygen and biological activity, Hemstock and Low (26) contend that manganese can be retained by soil organic matter in the form of a chelated complex. Formation of this complex is controlled by pH (45). The organic matter responsible for this complex formation is not dissociated under acid conditions, but is completely dissociated under high pH. He concluded from his studies on manganese fixation by organic complexes in relation to soil pH that the formation of organic matter complexes under controlled pH is the most likely cause of nonavailability of manganese in the soil. The complexes might be formed by the phenolic fraction of soil organic matter, although other possibilities exist.

Page (45) indicated that only 0.4 per cent of organic matter (by weight) in the soil would be enough to account for the complete removal of all the manganese (in 1 gram of soil) under conditions of high pH.

Attempting to study the relationship between soil compaction and manganese deficiency, Passioura and Leeper (47) grew oats sensitive and tolerant to "Grey Speck" on two soils, compacted and uncompacted. For the first soil, bulk density values of 0.85 and 1.0 for the uncompacted and compacted, respectively, were compared with the uncompacted and compacted bulk densities of 1.0 and 1.5 for the second soil. They found that "Grey Speck" was relatively less on the compacted soils, with an approximate 50-fold increase in grain production. Compaction generally resulted in healthier oats and three weeks advance in heading. They suggested this was due to the fact that roots act by "contact reduction" to reduce the reactive MnO_2 and that the compaction works by increasing the area of contact.

Vose and Griffiths (65) studied the relationship between the incidence of "Grey Speck" disease and manganese distribution in shoots and roots. They stated that susceptibility to the "Grey Speck" syndrome is primarily due to the lack of mobility of manganese in the plant. In the susceptible variety of oats they found low root and high leaf manganese content as compared to a tolerant variety of oats. High concentration of manganese in the roots of tolerant variety inhibits the invasion and multiplication of ammonium forming rhizophere organisms, either directly or indirectly through the medium of a root exudate. Resistance to "Grey Speck" has been attributed by Gerretsen (65) to the root system having greater resistance to saprophytic organisms.

Vose and Randall (64) have correlated the plant resistance to aluminum and manganese toxicity and variety and root cation exchange capacity, applying the Donnan theory of low cation exchange capacity favoring monovalent to divalent cation uptake; the lower cation exchange capacity of the toxicity resistance selections may possibly be effective in increasing the uptake of monovalent cations at the expense of the polyvalent cations like aluminum and manganese.

Estimation of Plant Available Soil Manganese

Boken (5) assumed that the so-called exchangeable fraction by extraction with a neutral electrolyte, to constitute that part of the manganese content of the soil which is available to the plants at a given time and a determination of the content of reducible manganese by treatment of the soil with a reducing agent, indicating that part which may be available to the plants over a given period.

Sherman et al (56) concluded that easily reducible manganese gave a reliable estimate of the manganese supplying power to Kentucky soils. Henkens (27) stated that exchangeable manganese is not a good index of the available manganese supply in the soil. Rich (52) obtained a highly significant correlation between exchangeable soil manganese and the manganese content of the upper leaves of the peanut crop.

Walker and Barber (66) concluded that the exchangeable manganese was the most available form of manganese. Using German millet as the test crop, they obtained the best correlation with total manganese content in the tissue and the interaction of chelated manganese times the organic matter. Page et al (45) obtained highly significant correlations with water soluble manganese of the soil and manganese uptake by oats.

Data indicate that in air dried soils both exchangeable and acid soluble manganese are present in greater amounts than in moist soils (16, 17), even up to 600 per cent (6).

The following three types of extractants are commonly employed in the United States to measure available soil manganese: (1) neutral normal ammonium acetate with 0.2 per cent hydroqouinone is most commonly used; (2) 0.1N H_3PO_4 used in Ohio; and (3) 0.05N HCl + 0.025N H_2SO_4 in the Southeastern region of the United States (61).

During the evaluation of the extraction methods to determine the available soil manganese, Boken (5) differentiated between "sick" and "healthy" plants among spring cereals and root crops using 1M Mg $(NO_3)_2$ as the soil extractant on air-dry samples. Heintze (25) used monocalcium disodium versanate solution to determine the divalent manganese present as complex organic matter of the alkaline organic soils. Hoff and Mederski (28) evaluated nine methods of extracting manganese using air dry soil samples. They found that the extraction of soil manganese with 3N $NH_4H_2PO_4$ (r = .899) and 0.1N H_3PO_4 (r = .856) yielded highest correlation coefficients and had the smallest variances with manganese absorbed by soybean plants. Other extractants they evaluated were: 50% aqueous alcohol solution containing 0.05% by hydroquinone (r = .866), 0.1N sulfuric acid (r = .781), 0.05% hydroquinone + 1N NH_4OAc (r = .771), 0.1N nitric acid (r = .742), 1N NH_4OAc (r = .686), sodium acetate (100 gms. sodium acetate + 30 ml glacial acetic acid per litre, (r = .671) and total (r = .481).

Hammes and Berger (23) studied the manganese availability of neutral to slightly alkaline lacustrine soils of eastern

Wisconsin using oats as the indicator crop. They concluded that manganese extraction from air dry soils give much higher correlation coefficients than the moist samples. They correlated the manganese content of oats with available soil manganese extracted by four methods namely: 0.05 M EDTA (r = .785), 0.1N H_3PO_4 (r = .705), 1.5 M $NH_4H_2PO_4$ (r = .658) and 0.2 per cent hydroquinone + 1N neutral NH_4OAc (r = .702).

Conversely, in another experiment, Hammes and Berger (21) found better correlations with 0.1N H_3PO_4 (r = .848) extractable manganese determined from moist soil samples with manganese content of oats.

Manganese Fertilization

The first applications of manganese sulphate were made for rice crop in Japan in 1902 by Aso (3), and in 1903 by Nagaoka (42). Cook (11) applied manganese sulphate as a side dressing and spray in early summer to sugar beets at rates of 100 pounds and 5 pounds per acre, respectively. Marked differences in leaf color were noticeable within 10 days.

Davis (13) found that when the pH of the soil reached 6.5 or above, manganese had to be supplied as $MnSO_4$ to many crops like onions, celery,spearmint, lettuce, table beets, potatoes, carrots, peas, beans, sudan grass and oats. Davis advocated that 4 pounds of $MnSO_4$ per 100 gallons of spray is adequate for most crops.

Gilbert and McLean (20) found that freedom from chlorosis and increased yields of onions were obtained when $MnSO_4$ was applied, especially in the solution form and at a rate of 8 pounds per acre. Knott (29) observed a striking increase in growth of onions when 100 pounds of $MnSO_4$ per acre was applied at planting time.

To correct the manganese deficiency, soil applications of elemental manganese may vary from 5 to 20 pounds per acre. The most commonly used manganese carrier is manganese sulphate. Manganese oxide is used when acid forming fertilizers are used (61).

The most efficient corrective measure for manganese deficiency is by means of foliar application. Ten to 15 pounds of manganese sulphate per acre is usually sprayed on oats and soybeans (61).

Drennan and Berrie (15) have investigated the possible usefulness of seed soaking with concentrations of manganous chloride ranging from 0.2 to 10 per cent on a W/V basis to prevent "Grey Speck" of oats under field conditions. The manganese deficiency symptoms were not obvious in plants from treated grain, while plants from untreated grain showed typical "Grey Speck" and considerably reduced growth.

Tisdale and Bertramson (63) have indicated that soil applications of sulfur may be used in the correction of lime induced manganese deficiency of soybeans. They found a highly significant correlation between the soil pH and both ammonium acetate extractable soil manganese and the manganese content of the plants. They have suggested the role of sulfur as a possible reductant of MnO_2.

EXPERIMENTAL PROCEDURE

I. Greenhouse Study

A. Experiment 1

Surface soil samples from 15 different soil types were collected from various locations in Michigan. The soils were known to be either deficient or contain sufficient available manganese.

Oats (var. Garry) and navy beans (var. Sanilac) were grown in the greenhouse in one-gallon pots lined with polyethylene bags. All soils received a basic application of 100, 70, 104 and 12 pounds per acre of nitrogen, phosphorus, potassium and magnesium, respectively.

The following treatments were replicated three times on all soils: (1) basic fertilizers only; (2) 15 pounds of elemental manganese per acre applied as manganese sulphate; and (3) calcium carbonate, applied at rates that were considered sufficient to induce manganese deficiency.

The soils were moistened and allowed to incubate in the greenhouse from December 5 to December 25, 1964. The pots were arranged on tables in a completely random manner and planted to oats on December 31.

Eight seeds were planted in each pot at a depth of one-fourth to one-half inch. Each pot was thinned to four plants on January 8, 1965. The oats were observed closely and notes were taken for deviations from normal growth. The plants were harvested at their post-blossom stage (64 days) on March 3, 1965.

The plant samples from all treatments consisted of the entire above-ground portion of the plant. Tissue samples were placed in paper bags, dried for three days at approximately 70°C, weighed and ground in a Wiley mill containing a 20 mesh seive.

On June 20, 1965, soil samples were collected from each pot using a sampling tube. The treated soils were chemically analyzed for the following constituents by the University Soil Testing Laboratory: pH, lime requirement, 0.025$\underline{N}$ HCl + 0.03$\underline{N}$ NH_4F extractable phosphorus, and 1$\underline{N}$ NH_4OAc extractable potassium, calcium and magnesium. Manganese was extracted from the soils with 0.1$\underline{N}$ H_3PO_4 and 1$\underline{N}$ NH_4OAc containing 0.2 per cent hydroquinone.

On July 11, 1965, the soils were prepared for growing navy beans (var. Sanilac). The soil was removed from each pot, clods were broken up and root remains were taken out. The soils were placed in the same pots containing a fresh polyethylene liner. No additional fertilizer was added. The entire body of soil in each pot was moistened on July 14 and allowed to dry for five days.

Beans were seeded on July 19, 1965. Six seeds were planted per pot. Water was added sparingly during germination and then regularly to maintain a good moisture level for plant growth. Emergence was uniform and each pot was thinned to three plants on July 26.

Crop growth was closely observed and notes were recorded and photographs taken of the plants to show the differences that developed. Plants were harvested at their pre-blossom stage on August 18, 1965.

Total manganese determinations were made on the oven-dried oat and bean tissue to investigate the relationship of the amount of manganese present in the plants and the amount available to the plants due to various soil treatments; and to determine what effect, if any, this had on the growth and yield of the plants.

B. Experiment 2

In this experiment, 179 soils, submitted from farms throughout Michigan to the University Soil Testing Laboratory were collected at random. The soils varied considerably in pH, texture, and other soil characteristics such as available phosphorus and extractable potassium, calcium and magnesium. Several organic soils were also included in the study.

One hundred and fifty grams of the mineral soils and one hundred grams of the organic soils were weighed and placed in quarter-gallon, wide-mouthed plastic containers. They were thoroughly mixed with three times their weight of inert sand to dilute the soil. The pots containing the soils were arranged on tables in the greenhouse in a completely random manner.

The soils were moistened and oats were planted on December 26, 1964 at the rate of 8 seeds per pot. Water was applied sparingly until the seeds germinated, and they were thinned to 4 seedings per pot on January 7, 1965. Regular waterings were continued. On January 11, nutrient solutions were added at the rate of 10 ml of NH_4NO_3 solution (0.2 gms dissolved in 10 ml), and 10 ml of KH_2PO_4 solution (0.2 gms dissolved in 10 ml), to each pot. Plant growth was closely observed and deficiency symptoms for manganese or other variations were noted.

A second application of nutrient solutions was made on February 3. Plants were harvestd at their post-blossom stage on February 26, 1965. Plant samples consisted of the whole above-ground portion. They were placed in paper bags, dried for three days at approximately 70°C, and the dry weights recorded. The oven dried tissue samples were ground and saved for total manganese analysis.

The soils were prepared on April 5 for planting radishes (var. Sparkler). Soil from each container was transferred to a sheet of paper, loosened, the roots removed, and placed back in the same container. The soils were moistened three days prior to planting and on April 16, 1965, six seeds were planted in each pot. Each pot was thinned to contain three plants on May 1. Growth of the radishes was closely observed and notes recorded to show the differences that developed. An application of the same nutrient solution that was used for the oats was applied on May 2. The plants were harvested on May 19 at the pre-blossom stage, and slight infestations of aphids were noted in four pots just prior to harvest (one day earlier). The entire above-ground portion of the plants were cut and placed in paper bags and dried for three days at approximately 70°C. The dry weights of tissue obtained from all pots were recorded. Since the yield values were comparatively small, it was decided not to analyze the radish tissue for manganese.

II. Laboratory Study

A. Soil Analysis

1. Soil pH was determined by the glass electrode (Soil: water ratio 1:1 for mineral soils and 1:2 for organic soils)

2. Lime requirement was determined by the Shoemaker, MacLean, Pratt buffer method (59).
3. Phosphorus was extracted with 0.025N HCl + .03N NH_4F (soil: extracting solution ratio 1:8) and determined colorimetrically (7). Measurements were made on the Bausch and Lomb Spectronic 20 colorimeter at a wavelength of 500 millimicrons.
4. Calcium, potassium and magnesium were extracted with neutral normal ammonium acetate (1:8 soil: extracting solution ratio). Potassium and calcium were determined flame photometrically on the Coleman Flame Photometer (Model 21). Magnesium was determined on the Beckman DU Spectrophotometer with a flame attachment at a wavelength of 285.2 millimicrons.
5. Available soil manganese was extracted by:
   (a) 0.1N $H3PO_4$
   (b) 1N NH_4OAc + 0.2 per cent hydroquinone

Extraction and determination of manganese using 0.1N H_3PO_4 (28, 68)

Place 5 grams of soil in a 125 ml Erlenmeyer flask. Add 50 ml of 0.1N H_3PO_4 and 7 drops of 0.1N silver nitrate. About a quarter teaspoonful of purified activated carbon is added to obtain a clear filtrate. Shake for 10 minutes. Filter the solution using Whatman No. 40 Filter paper. Pipette 20 ml of filtrate into a 50 ml volumetric flask to which is added 1 ml of concentrated phosphoric acid. Add sodium metaperiodate in excess (approximately 0.1 gm). Bring to boil and heat on a hot plate for 35 minutes. Allow to cool and make to volume. The concentration of manganese in solution is measured on a Bausch and Lomb Spectronic 20 colorimeter at a wavelength of 540 millimicrons.

<u>Extraction and determination of manganese using neutral normal NH_4OAc containing 0.2 per cent hydroquinone</u> (55)

Place 5 gms of soil in a 125 ml Erlenmeyer flask and add 50 ml of the extracting solution. Shake for 6 hours intermittently. (To maintain uniformity, a set of 25 were shaken for one hour alternting with another set). Filter the solution (Whatman No. 40 filter paper) and pipette 25 ml of the extract in a 50 ml volumetric flask. Make to volume. The per cent absorption was determined on a Perkin-Elmer Model 303 Atomic Absorption Spectrophotometer.

B. Plant Analysis

Wet digestion method using perchloric acid (19): Place 1.000 gm ground plant tissue into a 200 ml tallform beaker (plant tissue should be dried overnight at 65-70°C.).

Slowly add 15 ml concentrated nitric acid from an acid dispenser.

Allow to digest 30 minutes without heating. Heat gently, exercising care to prevent frothing. After frothing ceases, boil gently until a light straw color is obtained. Add more nitric acid if needed to complete the predigestion.

Wash sides of beaker completely free of adhering plant tissue with nitric acid from a wash bottle. It is absolutely necessary that all organic material be completely predigested at this stage. Cool to room temperature. Add, 10 ml distilled water; 10 ml concentrated nitric acid; 10 ml concentrated perchloric acid in this order. Heat to 180°F. and boil until solution becomes clear. Remove each beaker from the hot plate as the solution becomes clear.

Place the beaker on a hot plate and slowly take to dryness at a low temperature.

Dissolve the residue in 2.0 N HCl; dilute to volume so that final concentration is 0.1 N with respect to HCl. The per cent absorption was determined on a Perkin-Elmer Model 303 Atomic Absorption Spectrophotometer.

RESULTS AND DISCUSSION

Studies were made to determine the available manganese content of several Michigan soils. The criteria used for estimating available soil manganese were the yield and manganese uptake by oats, beans and radishes. Soils were extracted with 0.1N H_3PO_4 and 1N NH_4OAc + 0.2 per cent hydroquinone to evaluate their ability to measure plant available soil manganese.

The term "available manganese", in general, refers to the more soluble portion of the total soil manganese or that which is present in the soil exchange complex and can be absorbed by the active plant roots.

Experiment 1

This experiment was initiated in the greenhouse to study the effect of lime and manganese applications on the yield and manganese content of oats and beans. An attempt was made to determine the manganese sufficiency and deficiency levels by grouping the indicator crops, oats and beans according to the manganese deficiency symptoms developed. The soil types and chemical characteristics of the 15 soils included in this study are given in Table 1. (See Appendix for description of Soil types).

Table 1. Soil types and chemical properties of the soils used in Experiment 1.

Soil No.	Soil type	pH	Lime requirement	Pounds per acre P	K	Ca	Mg
1	Houghton muck	6.5	0	19	381	12200	1768
2	Houghton muck	6.9	0	18	236	12000	1898
3	Wisner sandy clay loam	7.6	0	83	137	5408	414
4	Wisner sandy clay loam	7.5	0	37	229	5616	589
5	Sims clay loam	6.1	2.0	35	296	5408	768
6	Montcalm sandy loam	4.7	3.5	342	288	496	32
7	Karlin sandy loam	5.2	3.5	152	221	288	8
8	Granby loamy fine sand	7.2	0	12	64	3120	237
9	Hodunk sandy loam	6.1	1.5	72	100	832	118
10	Wisner sandy clay loam	7.3	0	86	312	5200	530
11	Tuscola fine sandy clay loam	7.4	0	74	250	6344	586
12	Brookston sandy clay loam	6.3	1.5	16	104	4680	646
13	Newton loamy sand	7.7	0	36	184	9048	509
14	Houghton muck	6.8	0	57	674	10192	728
15	Oshtemo loamy sand	5.8	1.5	125	32	184	8

Oats did not show the typical "grey speck" so it was not possible to group the soils according to the degree of deficiency symptoms.

However, manganese deficiency symptoms were markedly shown on the bean crop in various stages. Therefore, the manganese deficiency index was established as shown in Table 2.

Table 2. The manganese deficiency index values, their description and number of observations in each group

Index	Description	Group	Number of Observations
1	No apparent manganese deficiency	Manganese sufficiency	97
2	Very slight general yellowing of the leaf and no mottling	Manganese latent deficiency	17
3	Slight mottling between veins		
4	Severe mottling between veins	Manganese deficiency	21
5	Severe mottling and necrosis		
Total			135

Index values 3, 4, and 5 have been grouped together and referred to as manganese deficiency.

The deficiency symptoms (Plate 1) observed on beans were all on lime treated soils except for three observations on control pots (pH 7.5) on Newton loamy sand, soil number 13 as seen from the data in Table 3.

The effect of manganese and lime applications on the yield and uptake of manganese by oats and beans is shown in Table 4.

The application of manganese significantly increased the yield of oats on Soils 1 and 14. It also significantly increased the uptake of manganese by oats on soils 6, 8, 10, 14 and 15 and highly significantly on soils 2, 6, and 9.

The application of manganese significantly increased the yield of beans on soil number 13 and a similar increase in manganese uptake was obtained on soils 2, 8, 13, and 15.

The application of lime significantly increased the yield of oats and beans on soil number 7. The high level of available soil manganese obtained in soil number 7 (Karlin sandy loam, pH 4.7) was apparently sufficient to cause toxic conditions. Though application of lime to this soil did not reduce the available manganese in a great extent (306 pp2m to 293 ppm) the bean tissue manganese was greatly reduced from 2085 ppm to 55 ppm (Table A, Appendix)

Plate 1. Navy bean plant (var. Sanilac) showing manganese deficiency symptoms

Soil type - Houghton Muck
Soil pH 7.1
Available soil manganese 0 pp2m (acid soluble)
22 pp2m (easily reducible)
Bean tissue manganese: 14 ppm

Table 3. Treatment, manganese deficiency index rating of beans and number of observations made on soils showing manganese deficiency

Soil Number	Treatment*	Mn Deficiency Index	Number of Observations
1	C	4	3
2	C	3	3
4	C	5	1
5	C	3	1
8	C	3	2
9	C	5	1
10	C	5	2
11	C	5	2
13	A	5	2
13	A	4	1
13	C	4	2
13	C	5	1
Total			21

* A control
C lime treatment

Table 4. The effect of manganese and lime applications on the yield and uptake of manganese by oats and beans (figures represent mean values of three replications)

Soil No.	Treatment	pH Simple Average	Mn Uptake mgm/pot		Yield gm/pot	
			Oats	Beans	Oats	Beans
1	<u>Houghton muck</u>					
	Check (no Mn, no lime)	6.6	0.072	0.102	9.965	4.758
	15 lbs. Mn/acre	6.6	0.211	0.139	11.315	4.185
	10 tons lime/acre	7.1	0.038	0.042	3.540	3.176
	L.S.D. at 5%		0.061	0.142	1.993	0.431
	1%		1.086	0.250	3.503	0.756
2	<u>Houghton muck</u>					
	Check (no Mn, no lime)	6.3	0.177	0.161	11.177	5.870
	15 lbs. Mn/acre	6.3	0.283	0.200	11.967	5.293
	10 tons lime/acre	7.1	0.067	0.082	6.272	4.278
	L.S.D. at 5%		0.041	0.062	1.822	0.793
	1%		0.073	0.109	3.203	1.393
3	<u>Wisner sandy clay loam</u>					
	Check	7.3	0	0.029	0	0.925
	15 lbs. Mn/acre	7.3	0	0.052	0	1.285
	10 tons lime/acre	7.5	0	0.063	0	1.621
	L.S.D. at 5%			0.010		0.605
	1%			0.183		1.064

Soil No.	Treatment	pH Simple Average	Mn Uptake mgm/pot		Yield gm/pot	
			Oats	Beans	Oats	Beans
4	Wisner sandy clay loam					
	Check	7.5	.165	0.099	8.990	3.232
	15 lbs. Mn/acre	7.5	.185	0.128	8.203	3.357
	5 tons lime/acre	7.4	.099	0.070	9.387	2.998
	L.S.D. at 5%		.089	0.053	1.667	0.980
	1%		.158	0.094	2.930	1.723
5	Sims clay loam					
	Check	6.4	0.299	0.136	15.023	3.943
	15 lbs. Mn/acre	6.4	0.281	0.130	12.253	4.345
	5 tons of lime/acre	7.3	0.065	0.066	11.700	3.210
	L.S.D. at 5%		0.138	0.065	1.628	0.763
	1%		0.235	0.114	2.862	1.341
6	Montcalm sandy loam					
	Check	5.1	5.142	3.365	10.138	1.888
	15 lbs. Mn/acre	5.2	10.848	5.179	10.588	2.125
	5 tons lime/acre	7.1	1.417	0.180	8.105	2.825
	L.S.D. at 5%		1.567	2.665	1.848	1.024
	1%		2.754	4.683	3.248	3.765
7	Karlin sandy loam					
	Check	4.7	9.319	2.140	5.573	1.003
	15 lbs. Mn/acre	4.8	8.979	1.030	5.802	0.338
	3 tons lime/acre	6.9	1.103	0.139	7.516	2.480
	L.S.D. at 5%		1.963	1.923	2.238	0.400
	1%		3.450	3.379	3.934	0.704

Soil No.	Treatment	pH Simple Average	Mn Uptake mgm/pot Oats	Mn Uptake mgm/pot Beans	Yield gm/pot Oats	Yield gm/pot Beans
8	Granby loamy fine sand					
	Check	7.0	0.344	0.080	11.565	3.320
	15 lbs. Mn/acre	7.0	0.716	0.154	11.480	3.512
	4 tons lime/acre	7.4	0.129	0.088	10.960	2.714
	L.S.D. at 5%		0.270	0.036	1.775	.494
	1%		0.475	0.064	3.121	.869
9	Hodunk sandy loam					
	Check	5.3	2.115	0.636	8.690	3.180
	15 lbs. Mn/acre	5.3	3.537	0.515	10.112	2.980
	5 tons lime/acre	7.2	0.141	0.080	6.057	2.493
	L.S.D. at 5%		0.505	0.341	2.123	0.479
	1%		0.888	0.599	3.732	0.843
10	Wisner sandy clay loam					
	Check	7.3	0.148	0.142	7.482	3.148
	15 lbs. Mn/acre	7.4	0.218	0.145	8.118	3.022
	4 tons lime/acre	7.4	0.111	0.184	8.810	2.537
	L.S.D. at 5%		0.005	0.044	1.609	0.247
	1%		0.009	0.077	2.828	0.434
11	Tuscola fine sandy clay loam					
	Check	7.4	0.138	0.067	9.612	2.833
	15 lbs. Mn/acre	7.4	0.177	0.113	10.317	3.004
	5 tons lime/acre	7.5	0.075	0.070	10.220	2.982
	L.S.D. at 5%		0.071	0.031	1.505	0.701
	1%		0.125	0.055	2.645	1.232

Soil No.	Treatment	pH Simple Average	Mn Uptake mgm/pot Oats	Mn Uptake mgm/pot Beans	Yield gm/pot Oats	Yield gm/pot Beans
12	Brookston sandy clay loam					
	Check	6.3	0.188	0.128	11.090	5.508
	15 lbs. Mn/acre	6.3	0.349	0.189	12.312	5.300
	5 tons lime/acre	7.2	0.171	0.131	13.678	4.522
	L.S.D. at-5%		0.158	0.134	2.253	0.428
	1%		0.278	0.236	3.960	0.753
13	Newton loamy sand					
	Check	7.5	0.100	0.028	4.957	2.042
	15 lbs. Mn/acre	7.5	0.156	0.044	7.938	3.083
	4 tons lime/acre	7.6	0.050	0.037	4.770	2.277
	L.S.D. at 5%		0.105	0.020	0.999	0.524
	1%		0.185	0.036	1.757	0.921
14	Houghton muck					
	Check	6.8	0.118	0.154	10.268	5.428
	15 lbs. Mn/acre	6.7	0.274	0.158	11.338	5.293
	10 tons lime/acre	7.3	0.050	0.100	7.945	4.610
	L.S.D. at 5%		0.083	0.080	1.070	0.709
	1%		0.147	0.152	1.880	1.247
15	Oshtemo loamy sand					
	Check	5.5	4.386	2.343	10.563	1.457
	15 lbs. Mn/acre	5.5	7.437	3.418	10.570	1.097
	Lime 4 tons/acre	7.6	0.311	0.039	8.320	1.405
	L.S.D. at 5%		2.537	0.690	1.373	0.247
	1%		4.458	1.214	2.413	0.434

Significantly higher oat and bean yields were obtained on soils 5 and 1,respectively,on treatments receiving no manganese or lime.

These results indicate that the near neutral and/or alkaline, coarse and fine textured soils and also muck soils respond well to manganese fertilization.

Correlation analysis was performed on all soils, i.e. each representing a single treatment and its one replication was considered as one observation (15x3x3 = 135 observations) and on soils grouped according to manganese deficiency index. Simple correlations between the associated factors and multiple correlations among the factors known to be related to manganese availability were calculated.

As indicated in Table 5, highly significant correlations were obtained between 0.1N H_3PO_4 and 1N NH_4OAc + 0.2 per cent hydroquinone extractable soil manganese on all soils (Fig. 1) and when soils were grouped according to manganese deficiency index using beans as the indicator crop.

Tissue manganese and manganese uptake by oats (Fig. 2) and beans were highly significantly correlated with manganese extracted by both the methods on all soils (Table 6). Bean yield was negatively correlated with available soil manganese determined by both methods. Poor correlation was obtained

Table 5. The correlation between manganese extracted with 0.1$\underline{N}$ H_3PO_4 and 1$\underline{N}$ NH_4OAc + 0.2 per cent hydroquinone on soils showing various degrees of manganese deficiency using beans as the indicator crop

0.1$\underline{N}$ H_3PO_4 extractable Mn vs. 1$\underline{N}$ NH_4OAc + 0.2 per cent hydroquinone extractable Mn	Correlation Coefficients
All soils	.9285**
Soils considered to have an adequate supply of Mn	.9529**
Soils showing moderate to severe Mn deficiency	.8460**
Soil showing a slight yellowing on beans classified as latent Mn deficiency	.8334**

** Significant at 1% level

Figure 1. Relationship between 0.1N H_3PO_4 and 1N NH_4OAc + 0.2% hydroquinone extractable manganese on all soils.

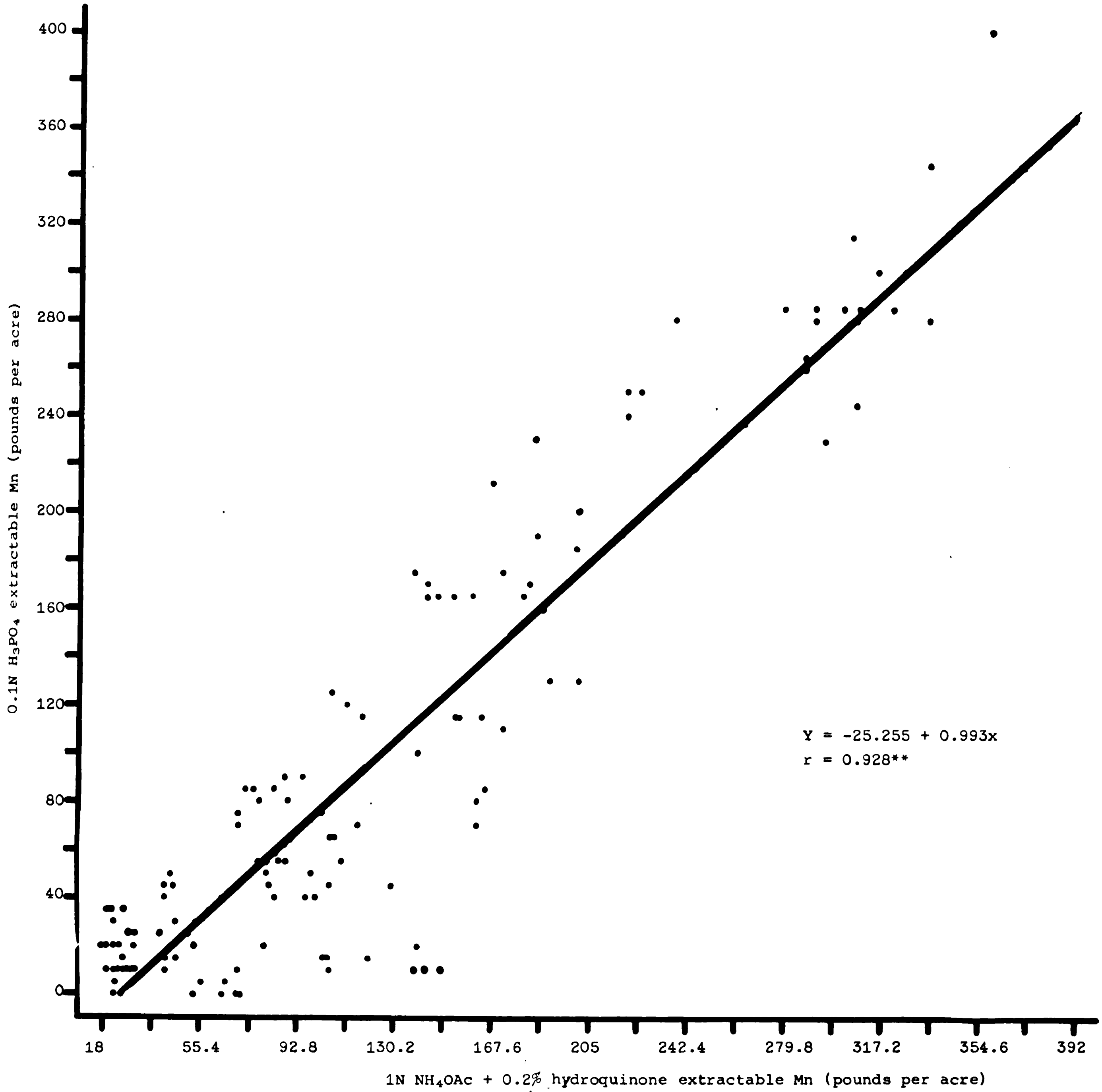


Figure 2. Relationship between 0.1N H_3PO_4 extractable manganese and manganese uptake by oats on all soils.

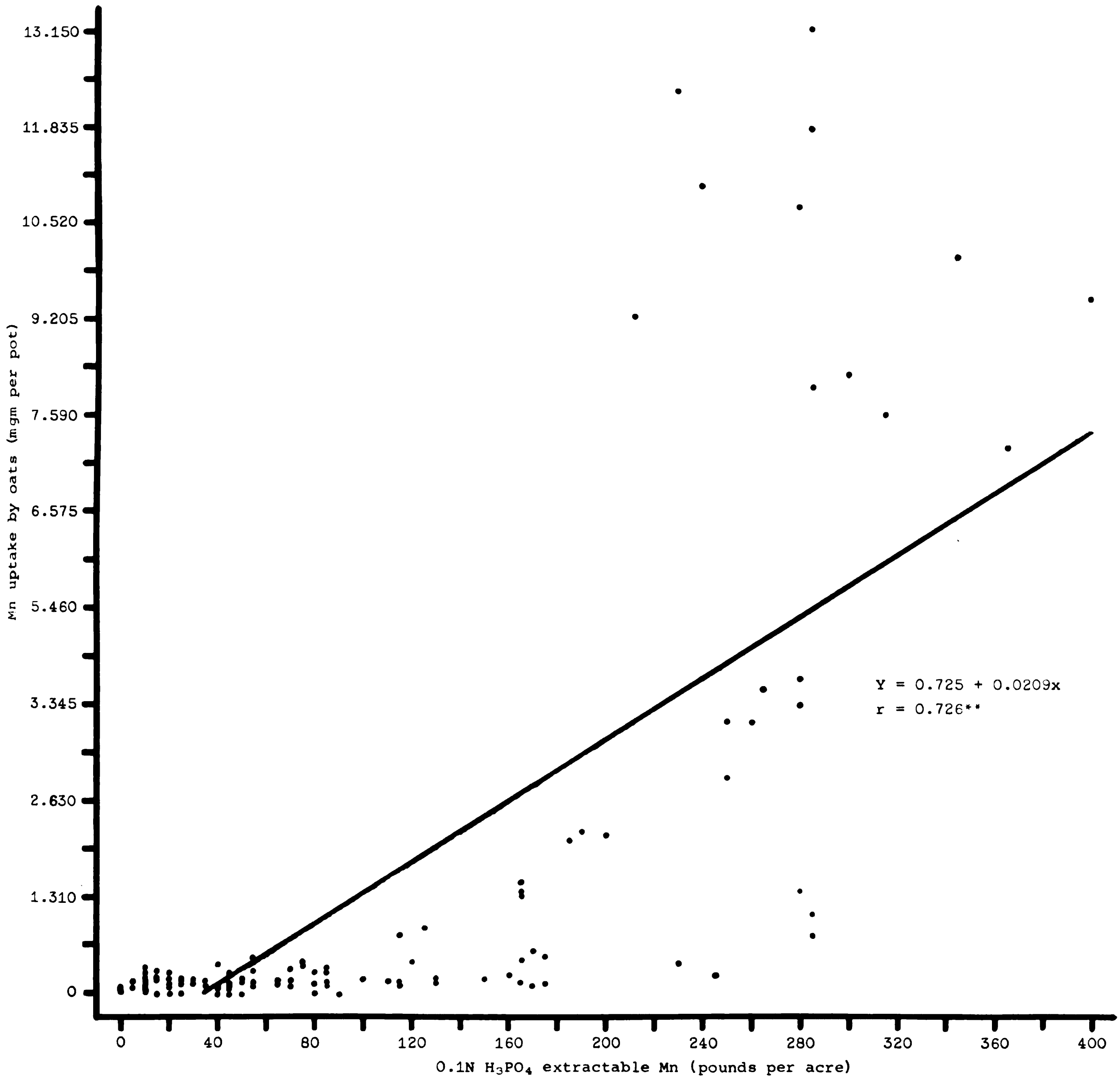


Table 6. The relationship between 0.1$\underline{N}$ H_3PO_4 and 1$\underline{N}$ NH_4OAc + 0.2 per cent hydroquinone extractable manganese for all soils and the yield, tissue manganese (ppm) and manganese uptake by oats and beans

Relationship	Correlation Coefficients	
	Soil Extractant	
	0.1$\underline{N}$ H_3PO_4	1$\underline{N}$ NH_4OAc + 0.2% hydroquinone
	Oats	
Yield	-.0557	+.0202
Tissue Mn	+.7014**	+.6474**
Mn uptake	+.7264**	+.6679**
	Beans	
Yield	-.6048**	-.4834**
Tissue Mn	+.6470**	+.6072**
Mn uptake	+.5483**	+.4756**

** Significant at 1% level

between oat yield and 0.1N H_3PO_4 (r = .0557) and 1N NH_4OAc + 0.2 per cent hydroquinone (r = .0202). In all cases, 0.1N H_3PO_4 extractable manganese gave a better correlation than the 1N NH_4OAc + 0.2 per cent hydroquinone extractable manganese.

The effect of available soil manganese, determined by both methods, on the yield, tissue manganese, and manganese uptake by oats and beans on all soils when extractable phosphorus was included as a soil variable is shown in Table 7. Tissue manganese and manganese uptake of oats and beans gave highly significant correlations with soil manganese extracted by both the methods and soil phosphorus. Bean yield was also highly significantly correlated with the two methods (r = .6323 and .5826, respectively). A comparison of the data in Tables 6 and 7 shows that the oat yield correlation was improved to a significant level when phosphorus was included as a variable with the manganese extracted by 1N NH_4OAc + 0.2 per cent hydroquinone.

When soils were grouped according to the manganese deficiency index using beans as the indicator crop (Table 8), bean yield was poorly correlated with soil manganese for deficiency and latent deficiency groups. However, for the sufficiency group there was a highly significant negative correlation between bean yield and available soil manganese

Table 7. The effect of available soil manganese determined by 0.1$\underline{N}$ H_3PO_4 and 1$\underline{N}$ NH_4OAc + 0.2 per cent hydroquinone on the yield, tissue manganese and manganese uptake by oats and beans on all soils when extractable phosphorus was included as a soil variable

Relationship	Correlation Coefficients: 0.1$\underline{N}$ H_3PO_4 extractable Mn and extractable P	Correlation Coefficients: 1$\underline{N}$ NH_4OAc + 0.2% hydroquinone extractable Mn and extractable P
	Oats	
Yield	.1664	.2096*
Tissue Mn	.7038**	.6503**
Mn uptake	.7271**	.6845**
	Beans	
Yield	.6323**	.5826**
Tissue Mn	.6487**	.6234**
Mn uptake	.6047**	.5877**

* Significant at 5% level
** Significant at 1% level

Table 8. The relationship between 0.1N H_3PO_4 and 1N NH_4OAc + 0.2 per cent hydroquinone extractable soil manganese and the yield, tissue manganese and manganese uptake by beans on soils showing various degrees of manganese deficiency

Mn deficiency	Relationship	Correlation coefficients 0.1N H_3PO_4	1N NH_4OAc + 0.2% hydroquinone
Deficiency	yield	-.3264	-.0960
	tissue Mn	+.4598*	+.6971**
	Mn uptake	+.3702	+.6711**
Latent deficiency	yield	-.2964	-.0896
	tissue Mn	+.5807**	+.6359**
	Mn uptake	+.2478	+.4673**
Sufficiency	yield	-.8166**	-.7161**
	tissue Mn	+.6407**	+.6064**
	Mn uptake	+.5230**	+.4430**

* Significant at 5% level
** Significant at 1% level

extracted by 0.1<u>N</u> H_3PO_4 (r = .8166), (Fig. 3) and 1<u>N</u> NH_4OAc + 0.2 per cent hydroquinone (r = .7161).

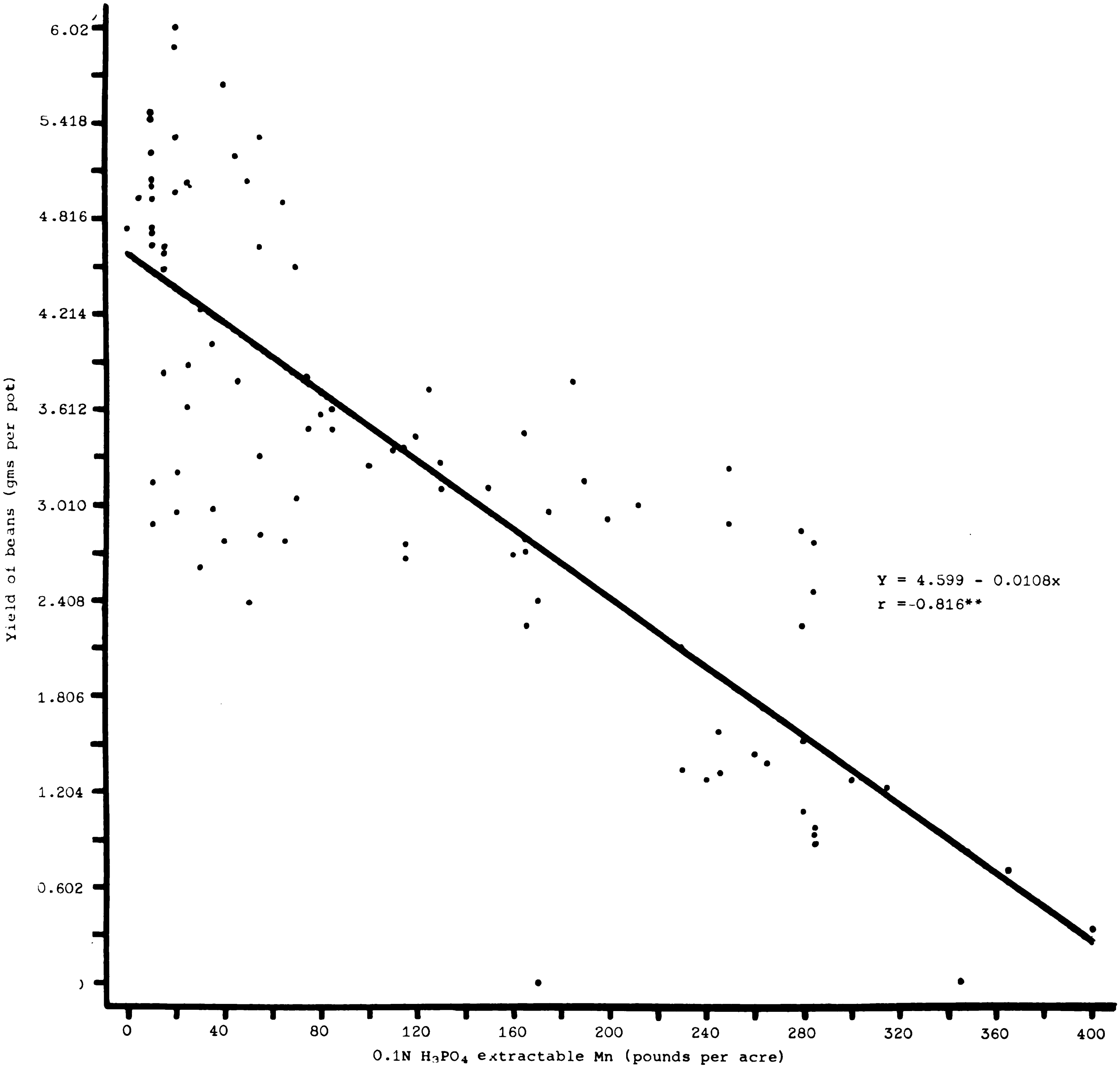
The highly signficant negative relationship between 0.1<u>N</u> H_3PO_4 extractable soil manganese and yield of beans is shown in Figure 3.

According to the manganese deficiency index established in this study, the criterion for the sufficiency group was the negative deficiency symptoms observed on bean plants. This group included the plants grown on soils with relatively low pH (4.7 or greater) and having tissue manganese values up to 3600 ppm (Table A, Appendix). Also included in this group were plants with high levels of Fe, Al, Cu and B (Table 37).

Higher yield values at lower manganese levels in the soil as shown in Figure 3 were obtained mostly from organic soils. The average value for the acid soluble manganese on these soils was approximately 15 pp2m whereas the average value for easily reducible manganese on the same soils was about 100 pp2m.

On organic soils, 1<u>N</u> NH_4OAc + 0.2 per cent hydroquinone extracted more manganese than 0.1<u>N</u> H_3PO_4 (Table 35). On organic soils, easily reducible manganese was better correlated with oat yield than the acid soluble manganese (Table 23).

Figure 3. Relationship between 0.1N H_3PO_4 extractable manganese and yield of beans on soils grouped as manganese sufficiency using beans as the indicator crop.



Therefore in Figure 3, where the regression line intercepts the Y axis, 0.1N H_3PO_4 extractable manganese did not give the expected relationship with bean yield values.

The correlation between bean yield and 0.1N H_3PO_4 extractable soil manganese was consistently higher than the correlation between bean yield and 1N NH_4OAc + 0.2 per cent hydroquinone extractable manganese on all the three groups. For the latent deficiency and sufficieny groups, bean tissue manganese gave highly significant correlations with available soil manganese as determined by both methods. Bean tissue manganese gave a significant correlation with 0.1N H_3PO_4 extractable manganese on the deficient group (r = .4598) and a highly significant correlation with 1N NH_4OAc + 0.2 per cent hydroquinone (r = .6971). For the sufficieny group, bean manganese uptake was highly correlated with available soil manganese extracted by both methods. However, 0.1N H_3PO_4 extractable manganese gave a higher correlation (Table 8). For the deficiency and latent deficiency groups, 1N NH_4OAc + 0.2 per cent hydroquinone extractable manganese gave highly significant correlations (r = .6711 and .4673, respectively) for bean manganese uptake, whereas comparable correlations with 0.1N H_3PO_4 extractable manganese were poor (r = .3702 and .2478, respectively).

In general, for the deficiency and latent deficiency groups, 1N NH_4OAc + 0.2 per cent hydroquinone extractable manganese gave higher correlations than 0.1N H_3PO_4 extractable manganese when correlated with tissue manganese and manganese uptake by beans.

When extractable phosphorus was included with the manganese determined by the two methods for correlations with the yield, tissue manganese and manganese uptake by beans (Table 9) highly significant correlations were obtained for all correlations on the sufficiency group. Correlations were improved to a greater extent for the 1N NH_4OAc + 0.2 per cent hydroquinone extractable manganese. When the correlation coefficients in Tables 8 and 9 were compared, for the deficiency and latent deficiency groups, bean yield correlations with 1N NH_4OAc + 0.2 per cent hydroquinone extractable manganese plus P were increased to highly significant levels (r = .0960 to .5037 on deficiency group and .0896 to .7733 on latent deficiency group). On the latent deficiency group, bean yield correlation with 0.1N H_3PO_4 extractable manganese was improved from r = .2964 to .7538, a highly significant level.

As shown in Tables 8 and 9, the inclusion of available soil phosphorus as a variable with soil manganese improved the correlations between manganese extracted by the two methods and the yield, tissue manganese and manganese uptake for deficiency index levels.

Table 9. The effect of available soil manganese determined by 0.1N H_3PO_4 and 1N NH_4OAc + 0.2 per cent hydroquinone on the yield, tissue manganese and manganese uptake by beans based on manganese deficiency index when extractable phosphorus was included as a soil variable

Mn deficiency index	Relationship	Correlation coefficients: 0.1N H_3PO_4 Extractable Mn and extractable P	Correlation coefficients: 1N NH_4OAc + 0.2% hydroquinone extractable Mn and extractable P
Mn deficiency	yield	.4138	.5037*
	tissue Mn	.5229*	.6975**
	Mn uptake	.4173	.6867**
Latent deficiency	yield	.7538**	.7733**
	tissue Mn	.7479**	.8011**
	Mn uptake	.4518	.6765**
Sufficiency	yield	.8242**	.7651**
	tissue Mn	.6433**	.8011**
	Mn uptake	.5982**	.5847**

* Significant at 5% level
** Significant at 1% level

As indicated in Table 10, available soil manganese extracted by 0.1N H_3PO_4 and 1N NH_4OAc + 0.2 per cent hydroquinone gave highly significant negative correlations with soil pH (r = .6281, (Fig. 4) and -.5721, respectively). They were positively correlated with soil phosphorus (r = .7002, (Fig. 5) and .6210, respectively) and negatively correlated with the sum of extractable bases (r = -.7792 and -.6472, respectively). By comparison, 0.1N H_3PO_4 extractable soil manganese gave better correlations with all soil characteristics than 1N NH_4OAc + 0.2 per cent hydroquinone extractable manganese.

Highly significant positive correlations were obtained between 0.1N H_3PO_4 and 1N NH_4OAc + 0.2 per cent hydroquinone extractable manganese and soil phosphorus and negative relationship with the sum of the extractable potassium, calcium and magnesium on sufficiency and deficiency groups as shown in Table 11. Soil reaction was negatively correlated at the 1 per cent level with available soil manganese as determined by both methods on the sufficiency group. The sum of the extractable potassium, calcium and magnesium and extractable phosphorus gave a highly significant correlation with 0.1N H_3PO_4 extractable soil manganese (r = -.6525) for all three groups. Correlations were similar with 1N NH_4OAc + 0.2 per cent hydroquinone extractable manganese except for low correlations on the latent deficiency group.

Table 10. Simple correlations between pH, sum of the extractable potassium, calcium and magnesium and extractable phosphorus for all soils and the 0.1N H_3PO_4 and 1N NH_4OAc + 0.2 per cent hydroquinone extractable soil manganese

Soil characteristics	Correlation coefficients	
	Soil extractant	
	0.1N H_3PO_4	1N NH_4OAc + 0.2% hydroquinone
pH	-.6281**	-.5721**
Extractable K, Ca and Mg	-.7792**	-.6472**
Extractable P	+.7002**	+.6210**

** Significant at 1% level

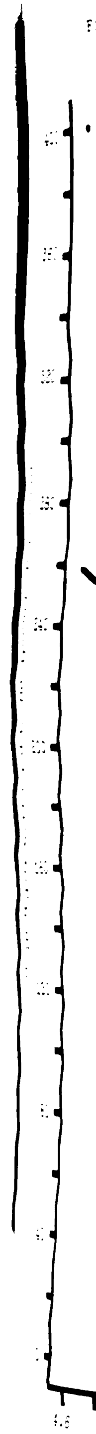


Figure 4. Relationship between soil pH and 0.1N H_3PO_4 extractable manganese on all soils.

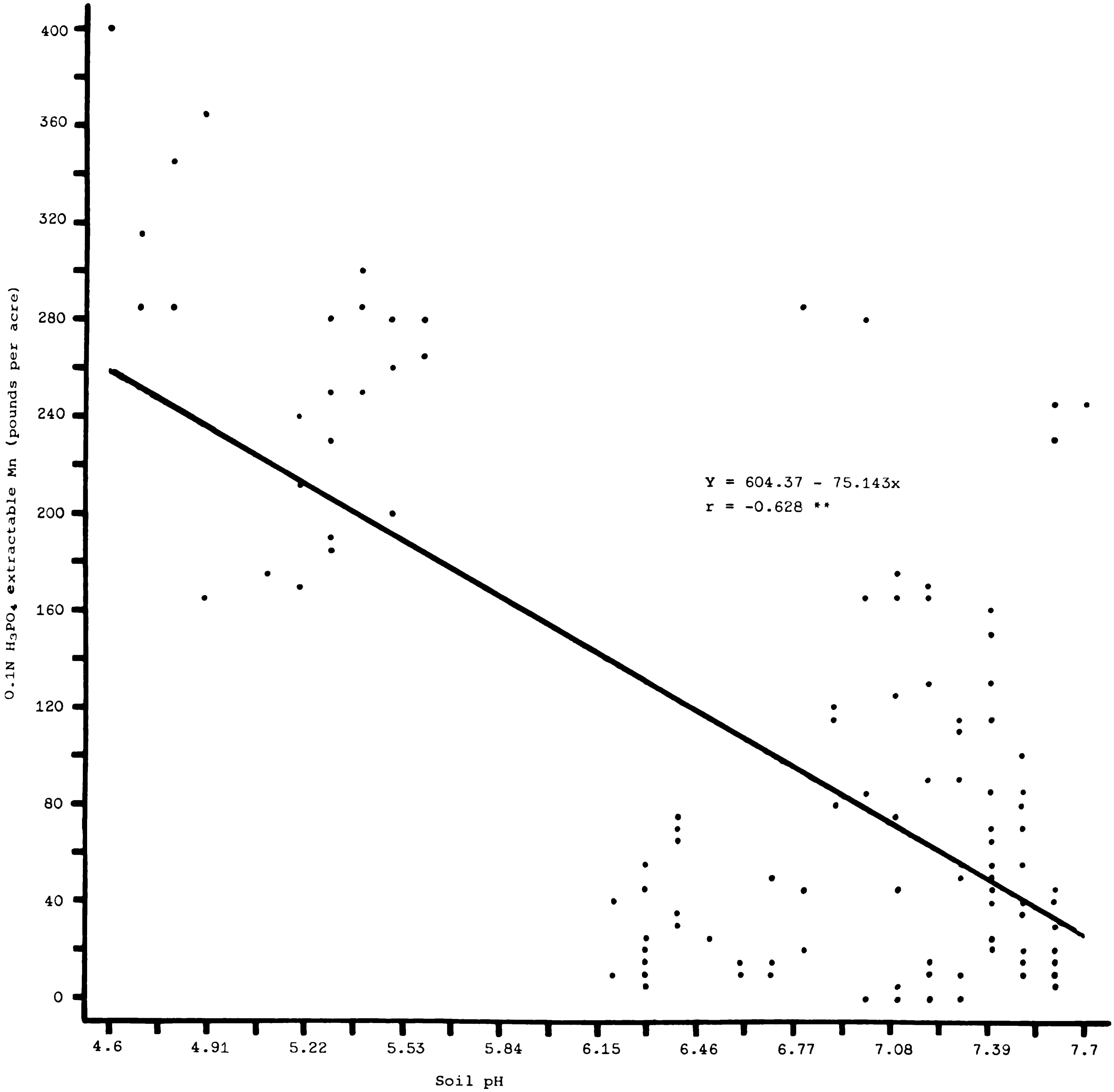


Figure 5. Relationship between extractable phosphorus and $0.1N\ H_3PO_4$ extractable manganese on all soils.

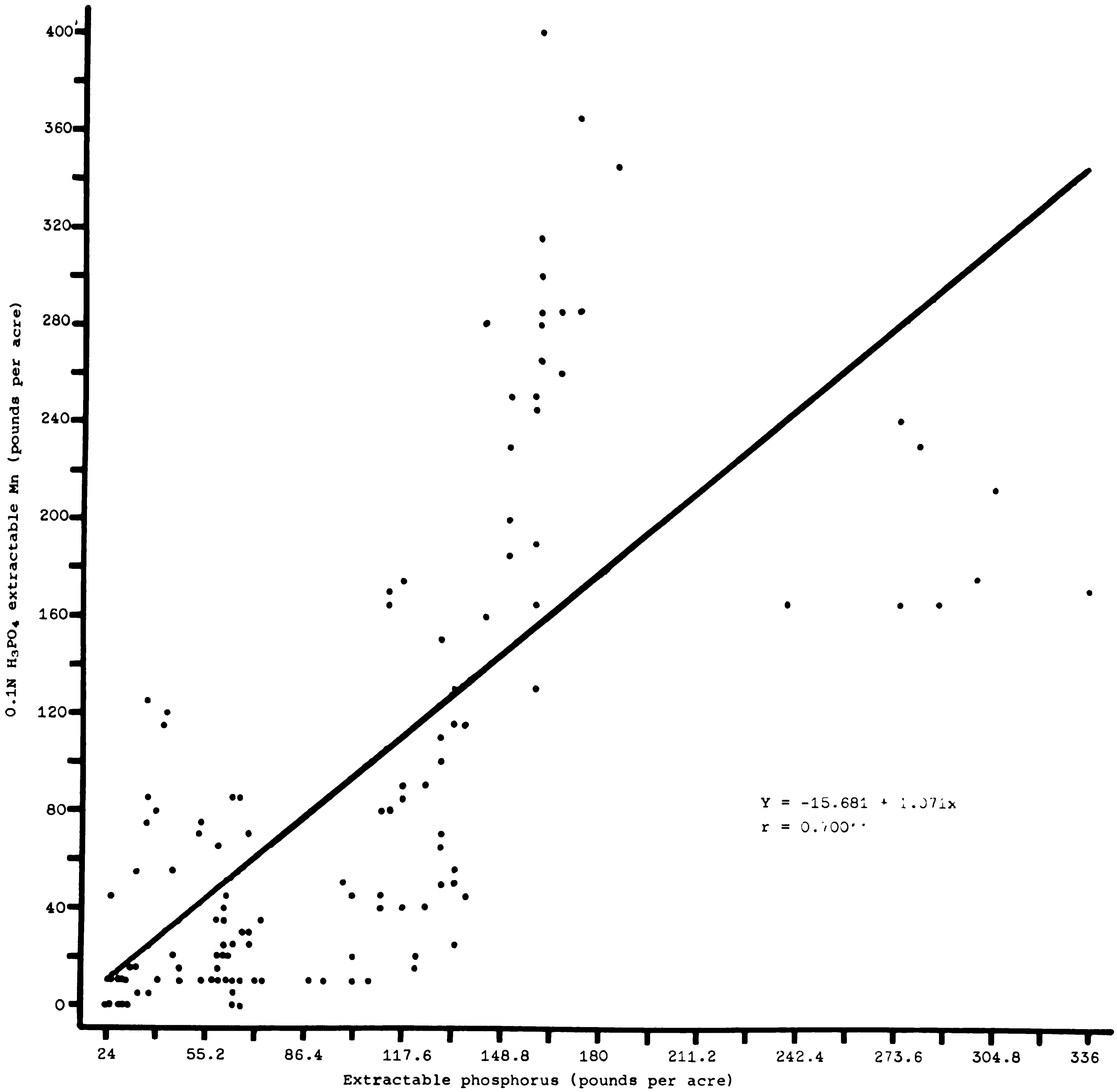


Table 11. Simple correlations between pH, sum of the extractable potassium, calcium and magnesium and extractable phosphorus and 0.1N H_3PO_4 and 1N NH_4OAc + 0.2 per cent hydroquinone extractable manganese for soils grouped according to manganese deficiency index

Mn deficiency index	Soil characteristics	Correlation coefficient: Soil extractant: 0.1N H_3PO_4	Correlation coefficient: Soil extractant: 1N NH_4OAc + 0.2% hydroquinone
Deficiency	pH	-.0232	-.0288
	Extractable K, Ca and Mg	-.7418**	-.6506**
	Extractable P	+.6709**	+.7311**
Latent Deficiency	pH	+.0570	+.2110
	Extractable K, Ca and Mg	-.6525**	-.3872
	Extractable P	+.4241	+.3370
Sufficiency	pH	-.5865**	-.5257**
	Extractable K, Ca and Mg	-.7957**	-.6294**
	Extractable P	+.6841**	+.5905**

** Significant at 1% level

Oat yield was poorly correlated with tissue manganese (r = -.1057) and manganese uptake (r = .0035) when all soils were considered as shown in Table 12. Bean yield was negatively correlated with tissue manganese (r = -.4391) and manganese uptake (r = -.3072) on all soils. When soils were grouped according to manganese deficiency index, bean yield was negatively correlated on the sufficienty group with tissue manganese (r = -.5657) and manganese uptake (r = -.4197).

Significant correlations were also obtained between the yield and bean tissue manganese on the latent deficiency group (r = .4775) and highly significantly correlated with manganese uptake (r = .7352).

Simple correlations shown in Table 13 indicated that the tissue manganese and manganese uptake by oats and beans were highly correlated with soil pH, sum of the extractable potassium, calcium and magnesium and extractable phosphorus. The yield of beans was highly significantly correlated with the sum of the extractable potassium, calcium and magnesium (r = +.5820) and extractable phosphorus (r = -.5551). Non-significant correlations were obtained between oat yield and soil reaction (r = -.2093) sum of the extractable potassium, calcium and magnesium (r = -.0060) and extractable phosphorus (r = -.1509).

Table 12. The relationship between the yield of oats and beans on all soils and tissue manganese and manganese uptake by beans on all soils and on soils grouped according to manganese deficiency index

Manganese deficiency index	Relationship	Correlation coefficients	
		Tissue Mn	Mn uptake
		Oats	
All soils	yield	-.1057	+.0035
		Beans	
All soils	yield	-.4391**	-.3072**
Deficiency	yield	+.1711	+.1135
Latent deficiency	yield	+.4775*	+.7352**
Sufficiency	yield	-.5657**	-.4197**

* Significant at 5% level
** Significant at 1% level

Table 13. Simple correlations between the yield tissue manganese and manganese uptake by oats and beans on all soils and pH, extractable potassium, calcium and magnesium and extractable phosphorus

Relationship	Correlation coefficients		
	pH	Extractable K, Ca and Mg	Extractable P
		Oats	
Yield	-.2093	-.0060	-.1509
Tissue Mn	-.7032**	-.4538**	+.4496**
Mn uptake	-.7293**	-.5017**	+.5322**
		Beans	
Yield	+.1402	+.5829**	-.5551**
Tissue Mn	-.6620**	-.4525**	-.4870**
Mn uptake	-.6460**	-.4327**	+.5660**

** Significant at 1% level

Negative relationship existed between soil pH and tissue manganese and manganese uptake by beans. This was true for the sum of the extractable potassium, calcium and magnesium. But extractable phosphorus was positively correlated with tissue manganese and manganese uptake by oats and beans and negatively correlated with their yield values. Correlation coefficients for oat and bean yields with soil pH and extractable bases indicated negative relationship for yield of oats but positive relationship for yield of beans.

The simple correlations between yield, tissue manganese and manganese uptake by beans and various soil chemical properties of soils grouped according to manganese deficiency index are shown in Table 14. On the sufficiency group of soils, all correlations were highly significant. Soil pH was negatively correlated with yield of beans on the deficiency and latent deficiency groups and was positively correlated on the sufficiency group. Sum of the extractable potassium, calcium and magnesium was positively correlated with bean yield value on all the three groups, and reverse was true with extractable phosphorus.

The multiple correlation coefficients shown in Table 15 indicated that the yield, tissue manganese and manganese uptake were highly significantly correlated when several soil chemical characteristics were considered. Comparisons were made including

Table 14. Simple correlations between yield, tissue manganese and manganese uptake by beans and pH, extractable potassium, calcium and magnesium and extractable phosphorus on soils grouped according to manganese deficiency index

Mn deficiency index	Relationship	Correlation coefficients		
		pH	Extractable K, Ca and Mg	Extractable P
Deficiency	yield	-.5773**	+.5614**	-.4075
	tissue Mn	+.0873	-.5040*	+.4932
	Mn uptake	-.0618	-.3662	+.3912
Latent Deficiency	yield	-.6592**	+.5511*	-.7534**
	tissue Mn	+.4192	-.5736*	+.6730**
	Mn uptake	-.3642	+.1426	-.3030
Sufficiency	yield	+.3390**	+.7331**	-.6402**
	tissue Mn	-.6537**	-.4789**	+.4802**
	Mn uptake	-.6292**	-.4511**	+.5696**

* Significant at 5% level
** Significant at 1% level

Table 15. Relationships among the yield, tissue manganese and manganese uptake by oats and beans and pH, extractable potassium, calcium, and magnesium, extractable phosphorus and manganese extracted by 0.1N H_3PO_4 and 1N NH_4OAc + 0.2 per cent hydroquinone

Relationships	Correlation coefficients		
	pH+(K+Ca+Mg) +P	pH+(K+Ca+Mg) +P+Mn (0.1N H_3PO_4	pH+(K+Ca+mg) +P+Mn (1N NH_4OAc + 0.2% hydroquinone)
		Oats	
Yield	.3505**	.3927**	.3508**
Tissue Mn	.7294**	.7352**	.7644**
Mn uptake	.7743**	.7747**	.7970**
		Beans	
Yield	.6550**	.7099**	.6687**
Tissue Mn	.7032**	.7281**	.7241**
Mn uptake	.7180**	.7183**	.7191**

** Significant at 1% level

the available soil manganese determined by both 0.1N H_3PO_4 and 1N NH_4OAc + 0.2 per cent hydroquinone.

The correlations for all comparisons were improved when available soil manganese extracted by either method was included in the correlation. Multiple correlations with the 0.1N H_3PO_4 extractable soil manganese included as a variable gave better correlations with oat and bean yields. However, manganese uptake by oats and beans was more highly correlated with 1N NH_4OAc + 0.2 per cent hydroquinone extractable manganese than with that extracted by 0.1N H_3PO_4. A similar relationship existed for the manganese contained in the oat tissue.

When soils were grouped according to the manganese deficiency index (Table 16), the multiple correlations with bean yield and tissue manganese were highly significantly correlated on all the three groups.

As shown in Table 16, when soils were grouped according to the manganese deficiency index, the correlations were improved when manganese extracted by either of the two methods was included as a variable along with other soil chemical characteristics.

Multiple correlations in which 1N NH_4OAc + 0.2 per cent hydroquinone extractable manganese was included in the function gave better correlation with bean yield on deficiency and latent deficiency groups and bean tissue manganese and manganese uptake

Table 16. The relationships among the yield, tissue manganese and manganese uptake by beans on soils grouped according to manganese deficiency index and pH, extractable potassium, calcium and magnesium, extractable phosphorus and manganese extractacted by 0.1N H_3PO_4 and 1N NH_4OAc + 0.2 per cent hydroquinone

Mn deficiency index	Relationships	Correlation coefficients		
		pH+(K+Ca+Mg) +P	pH+(K+Ca+Mg) +P+Mn (0.1N H_3PO_4	pH+(K+Ca+Mg) +P+Mn (1N NH_4OAc + 0.2% hydroquinone)
Deficiency	yield	.6534**	.7039**	.7402**
	tissue Mn	.6105**	.7371**	.7271**
	Mn uptake	.5471*	.7581**	.7167**
Latent Deficiency	yield	.8218**	.8220**	.8506**
	tissue Mn	.7050**	.7633**	.8088**
	Mn uptake	.3922	.4999*	.7334**
Sufficiency	yield	.7757**	.8503**	.8249**
	tissue Mn	.7015**	.7282**	.7290**
	Mn uptake	.7111**	.7124**	.7127**

* Significant at 5% level
** Significant at 1% level

on the latent deficiency and sufficiency groups than when 0.1$\underline{N}$ H_3PO_4 extractable manganese was included in the function.

Bean yield and tissue manganese were highly correlated with the several chemical properties on all the three groups (Table 16). On the latent deficiency group, the uptake of manganese by beans was poorly correlated with soil pH, sum of extractable potassium, calcium and magnesium and extractable phosphorus (r = .3922).

The comparison of the multiple correlations obtained between the manganese extracted by 0.1$\underline{N}$ H_3PO_4 and that extracted by 1$\underline{N}$ NH_4OAc + 0.2 per cent hydroquinone and the pH, extractable potassium, calcium and magnesium and extractable phosphorus on all soils and when soils were grouped according to manganese deficiency index rated by beans, is shown in Table 17. All correlations were highly significant except for the 1$\underline{N}$ NH_4OAc + 0.2 per cent hydroquinone extractable manganese and latent deficiency group (r = .4077).

As shown in Table 18, the soil manganese, extracted by both methods decreased in the following order:

Sufficiency > Latent deficiency > Deficiency

It was clearly seen that the average values of 1$\underline{N}$ NH_4OAc + 0.2 per cent hydroquinone extractable manganese on soils

Table 17. Comparison of the multiple correlations between the manganese extracted by 0.1N H_3PO_4 and 1N NH_4OAc + 0.2 per cent hydroquinone and the pH, extractable potassium, calcium and magnesium and extractable phosphorus on all soils and when soils are grouped according to manganese deficiency index using beans as the indicator crop

Mn deficiency index	Relationships	Correlation coefficients pH+(K+Ca+Mg)+P
All soils	0.1N H_3PO_4 extractable Mn	.8703**
	1N NH_4OAc + 0.2 per cent hydroquinone extractable Mn	.7548**
Deficiency	0.1N H_3PO_4 extractable Mn	.9596**
	1N NH_4OAc + 0.2 per cent hydroquinone extractable Mn	.9382**
Latent Deficiency	0.1N H_3PO_4 extractable Mn	.6795**
	1N NH_4OAc + 0.2 per cent hydroquinone extractable Mn	.4077
Sufficiency	0.1N H_3PO_4 extractable Mn	.8652**
	1N NH_4OAc + 0.2 per cent hydroquinone extractable Mn	.7205**

** Significant at 1% level

Table 18. Mean values and ranges of soil manganese extracted by two methods and their differences on soils grouped according to the manganese deficiency index rated by the bean crop

	Sufficiency		Latent Deficiency		Deficiency	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
			pp2m			
Easily reducible Mn	148.18	97.3	68.55	48.7	62.04	52.90
Acid soluble Mn	122.09	107.6	49.50	44.1	29.20	41.60
Difference	26.09		16.05		32.84	

grouped according to manganese deficiency index rated by the bean crop were higher than the average values of 0.1$\underline{N}$ H_3PO_4 extractable manganese on all groups. Although the manganese contents were lower in the deficiency group, the difference between the manganese values extracted by the two methods were greater in the deficiency group than in the sufficiency group. The difference in manganese extracted by the .1$\underline{N}$ H_3PO_4 and the 1$\underline{N}$ NH_4OAc + 0.2 per cent hydroquinone may be attributed to the increase in the oxides of manganese extracted by the NH_4OAc containing 0.2 per cent hydroquinone.

The simple mean values in Table 19 indicated that the pH increased from 6.5 to 7.35 from the sufficieny group to that classified as deficiency. This is inversely related to the easily reducible manganese and acid soluble manganese and manganese uptake by beans (40).

The data presented in Tables 18 and 19 show decreasing means values for soil manganese from the sufficiency to deficiency group. Similar decrease is observed for plant tissue manganese and available soil phosphorus. These indicate a positive relationship between available soil phosphorus and plant manganese contents. It has been shown by several workers that phosphate increases the uptake of manganese by the plant (30, 35, 40, 46, 58).

Table 19. Mean values and ranges of several soil chemical characteristics and the studied dependent crop variables based on the manganese deficiency index of the bean crop

	Sufficiency		Latent Deficiency		Deficiency	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
pH (simple average)	6.5	.89	7.2	.33	7.35	.21
Extractable P (pds/acre)	116.5	71.2	95.25	38.13	62.8	35.2
Extractable (K+Ca+Mg) (pds/acre)	6198.0	4891.4	8486.1	4261.4	10986.28	4784.9
Bean yield (gm/pot)	3.27	1.43	2.67	1.61	2.95	.75
Bean tissue Mn (ppm)	425.57	914.57	33.30	11.70	25.66	19.58
Bean Mn uptake (mgm/pot)	.658	1.266	.080	.041	.073	.494

An inverse relationship existed between the extractable soil bases (K+Ca+Mg) and the manganese content of soils determined by both extractants. Similarly, on comparing the sufficiency, latent and deficiency groups, the extractable soil K, Ca and Mg increased as the extractable soil manganese decreased.

Experiment 2

In this experiment, 179 soils having a wide range of chemical characteristics and texture (Table B, Appendix) were chosen at random from samples submitted to the University Soil Testing Laboratory. Oats and radishes were chosen as crops to be grown on these soils because of the difference in their growth characteristics and their sensitiveness to manganese deficiency.

The number of soils represented in each textural group are shown in Table 20.

As shown in Table 21, the correlation between 0.1N H_3PO_4 and 1N NH_4OAc + 0.2 per cent hydroquinone extractable soil manganese was highly significant for mineral soils (r = .8570), (Fig. 6). Although the correlation was high (r = .6611), this relationship was not significant for organic soils since there were only nine observations.

Table 20. Soil texture, and number of observations contained in each textural group

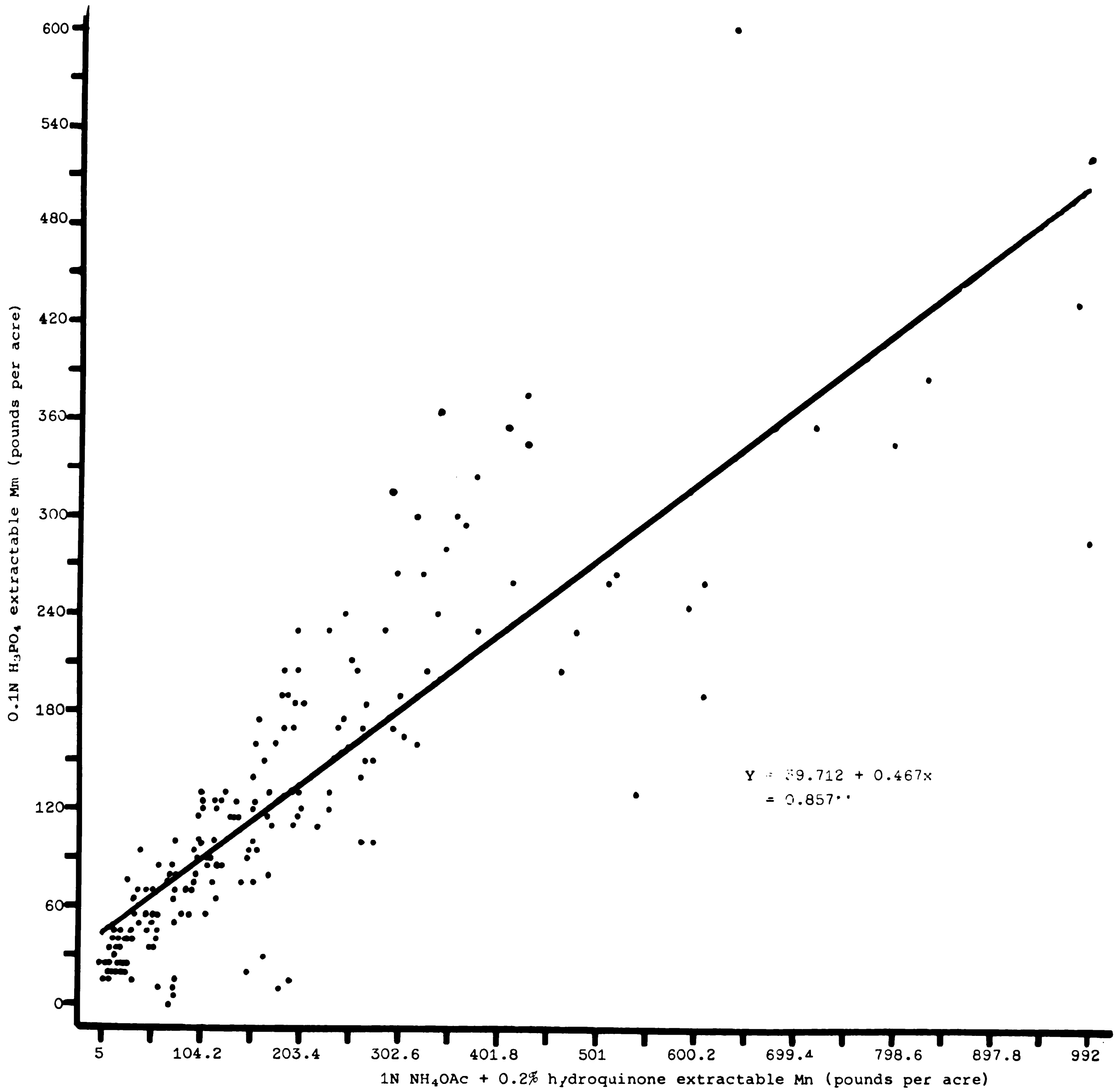
Soil Texture	Number of Observations
Loamy sands	36
Sandy loams	73
Loams	42
Sands	11
Clay	5
Organic soils	9
Loamy sands with high organic matter	3
Total	179

Table 21. The correlation between manganese extracted with 0.1N H_3PO_4 and 1N NH_4OAc + 0.2 per cent hydroquinone on mineral and organic soils

Soils	Correlation coefficients
Mineral soils	.8570**
Organic soils	.6611

** Significant at 1% level

Figure 6. Relationship between 0.1N H_3PO_4 and 1N NH_4OAc + 0.2% hydroquinone extractable manganese on mineral soils.



The correlation between 0.1*N* H_3PO_4 and 1*N* NH_4OAc + 0.2 per cent hydroquinone extractable soil manganese on mineral soils when grouped according to texture are shown in Table 22. The results indicated highly significant correlations on all textures (sands, r = .9597 to loamy sands, r = .7508), but the order of magnitude of the correlations among the textural groups could not be derived because of the wide variation in the number of observations for each textural group as shown in Table 20.

Table 22. The correlation between manganese extracted with 0.1*N* H_3PO_4 and 1*N* NH_4OAc + 0.2 per cent hydroquinone on soils grouped according to texture

Soil Texture	Correlation coefficients
Sands	.9597**
Loams	.9395**
Sandy loams	.8635**
Loamy sands	.7508**

** Significant at 1% level

The effect of available soil manganese, determined by 0.1N H_3PO_4 and 1N NH_4OAc + 0.2 per cent hydroquinone, on the yield of oats and radishes and tissue manganese and manganese uptake by oats is shown in Table 23. Highly significant correlations were obtained between the extractable manganese by both the methods and tissue manganese and manganese uptake by oats on both mineral (Fig. 7 and 8) and organic soils. However, the radish yield was significantly correlated on mineral soils with 0.1N H_3PO_4 extractable manganese only. Oat yield was not significantly correlated with available soil manganese as determined by either method. On organic soils, 1N NH_4OAc + 0.2 per cent hydroquinone extractable manganese gave better correlation with manganese uptake by oats (Fig. 9).

The effect of available soil manganese determined by the two methods on the yield of oats and radishes and tissue manganese and manganese uptake by oats when extractable phosphorus was included as a soil variable on mineral and organic soils is also shown in Table 23.

These data showed that the correlation coefficients were only slightly improved when phosphorus was included. However, on organic soils the relationship between radish yield and extractable manganese by both methods was improved considerably when available soil phosphorus was considered (Table 23).

Table 23. The effect of available soil manganese determined by 0.1N H_3PO_4 and 1N NH_4OAc + 0.2% hydroquinone on the yield of oats and radishes and tissue manganese and manganese uptake by oats and comparison of their effect when extractable phosphorus is included as a soil variable on mineral and organic soils.

Soil Texture	Relationship	Correlation Coefficients: 0.1N H_3PO_4 extractable Mn	0.1N H_3PO_4 extractable Mn and extractable P	1N NH_4OAc + 0.2% hydroquinone extractable Mn	1N NH_4OAc + 0.2% hydroquinone extractable Mn and extractable P
Mineral soils	Oat yield	+.0619	.0988	+.0470	.0834
	Oat tissue Mn	+.3885**	.3885**	+.2549**	.2644**
	Mn uptake	+.3770**	.3771**	+.2319**	.2457**
	Radish yield	-.1787*	.1798*	-.0932	.1098
Organic soils	Oat yield	-.1126	.2432	+.5583	.6410
	Oat tissue Mn	+.8696**	.8718**	+.8371**	.8540**
	Mn uptake	+.8372**	.8376**	+.9130**	.9204**
	Radish yield	+.1636	.4019	+.0115	.3988

* Significant at 5% level
** Significant at 1% level

Figure 7. Relationship between 0.1N H_3PO_4 extractable manganese and manganese uptake by oats on mineral soils.

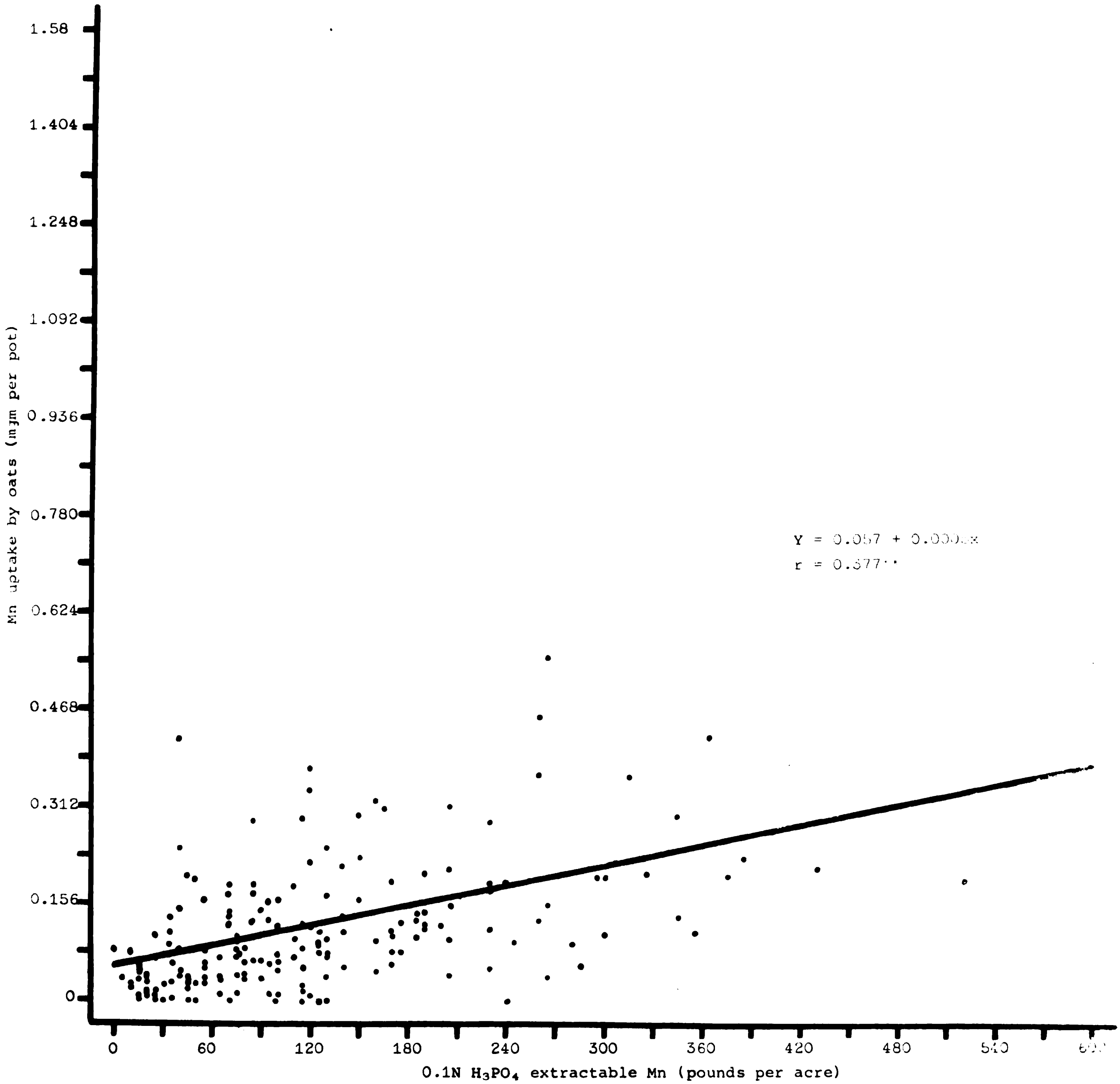


Figure 8. Relationship between 0.1N H_3PO_4 extractable manganese and manganese uptake by oats on organic soils.

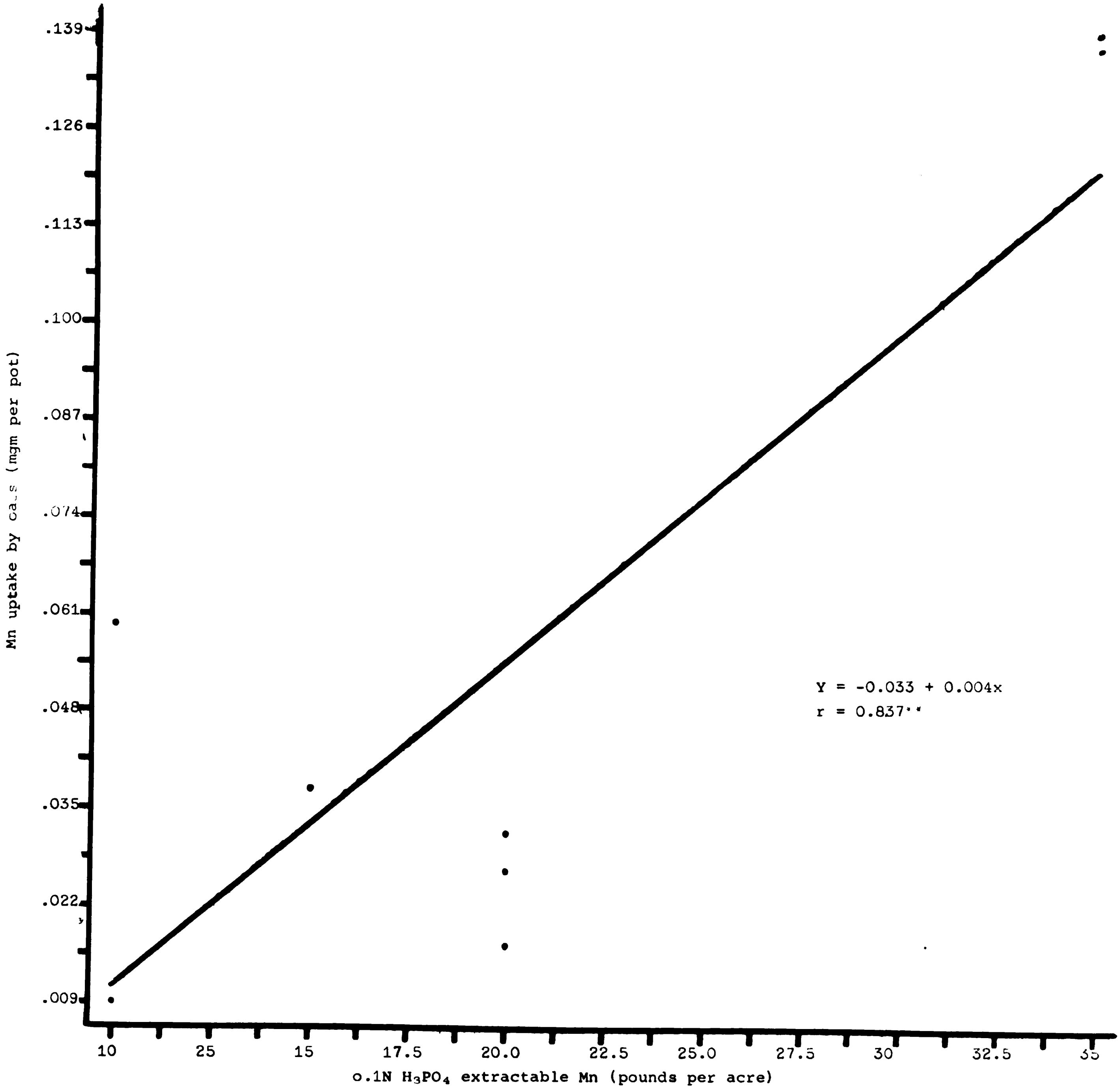
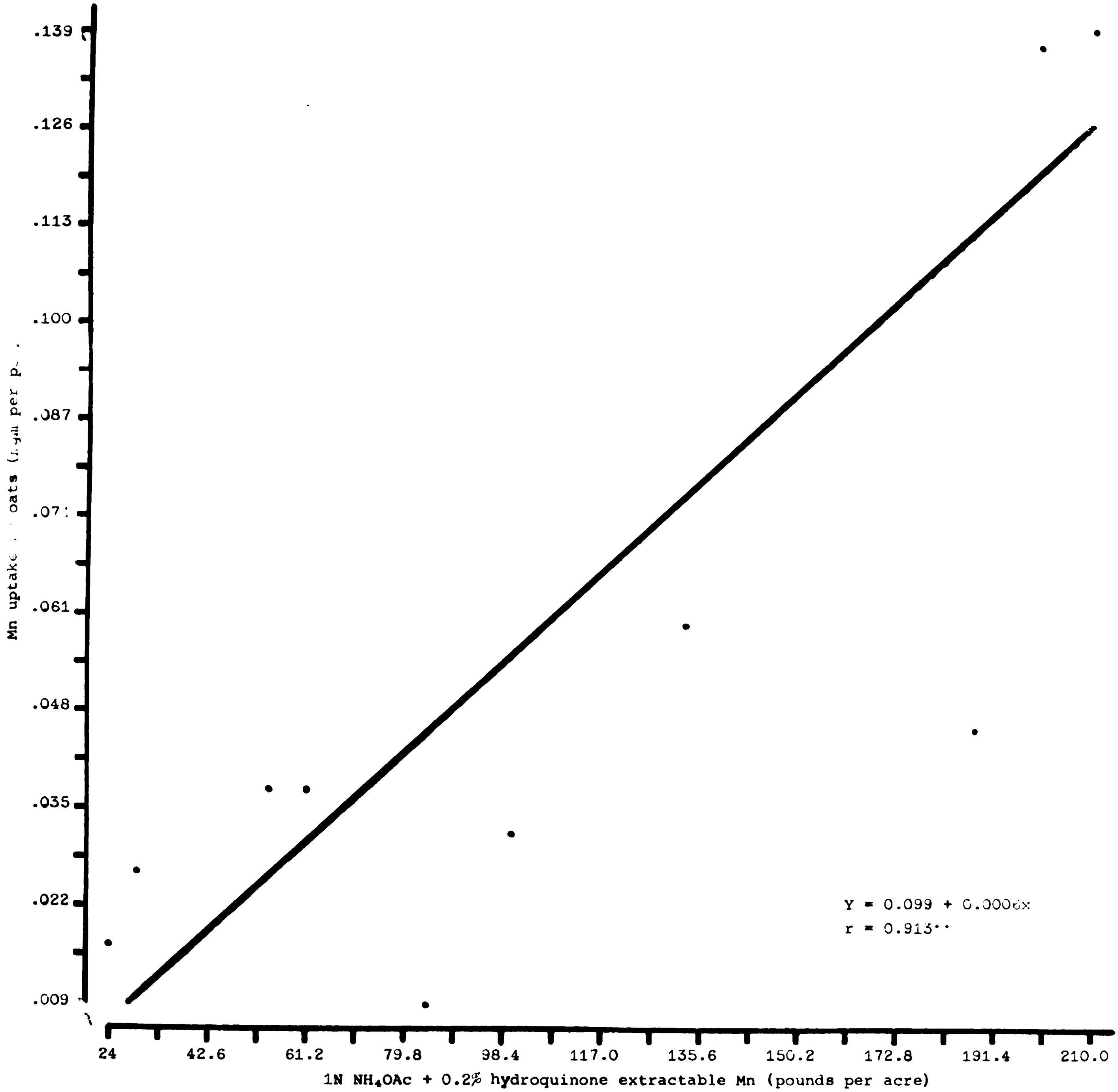


Figure 9. Relationship between 1N NH_4OAc + 0.2% hydroquinone extractable manganese and manganese uptake by oats on organic soils.



The relationship between the available soil manganese determined by two methods and the yield of oats and radishes and the tissue manganese and manganese uptake by oats when mineral soils were grouped according to texture is shown in Table 24.

Oat and radish yield correlations were generally poor for available soil manganese as determined by both methods. Significant correlations were obtained for radish yield on loamy sands and the oat yield on sandy loam soils (Table 24). On sands and loamy sands, tissue manganese and manganese uptake by oats was not significantly correlated with soil manganese as determined by either method. The tissue manganese and manganese uptake by oats obtained from the sandy loam soils (Fig. 10) gave highly significant correlations with soil manganese by both methods. On the loam soils, oat tissue Mn was highly correlated with 0.1<u>N</u> H_3PO_4 extractable manganese (r = .4125) and was significantly correlated with 1<u>N</u> NH_4OAc + 0.2 per cent hydroquinone extractable manganese (r = .3581). The oat manganese uptake values obtained on the loam soils significantly correlated with 0.1<u>N</u> H_3PO_4 extractable manganese (r = .3812) and 1<u>N</u> NH_4OAc + 0.2 per cent hydroquinone extractable manganese (r = .3305).

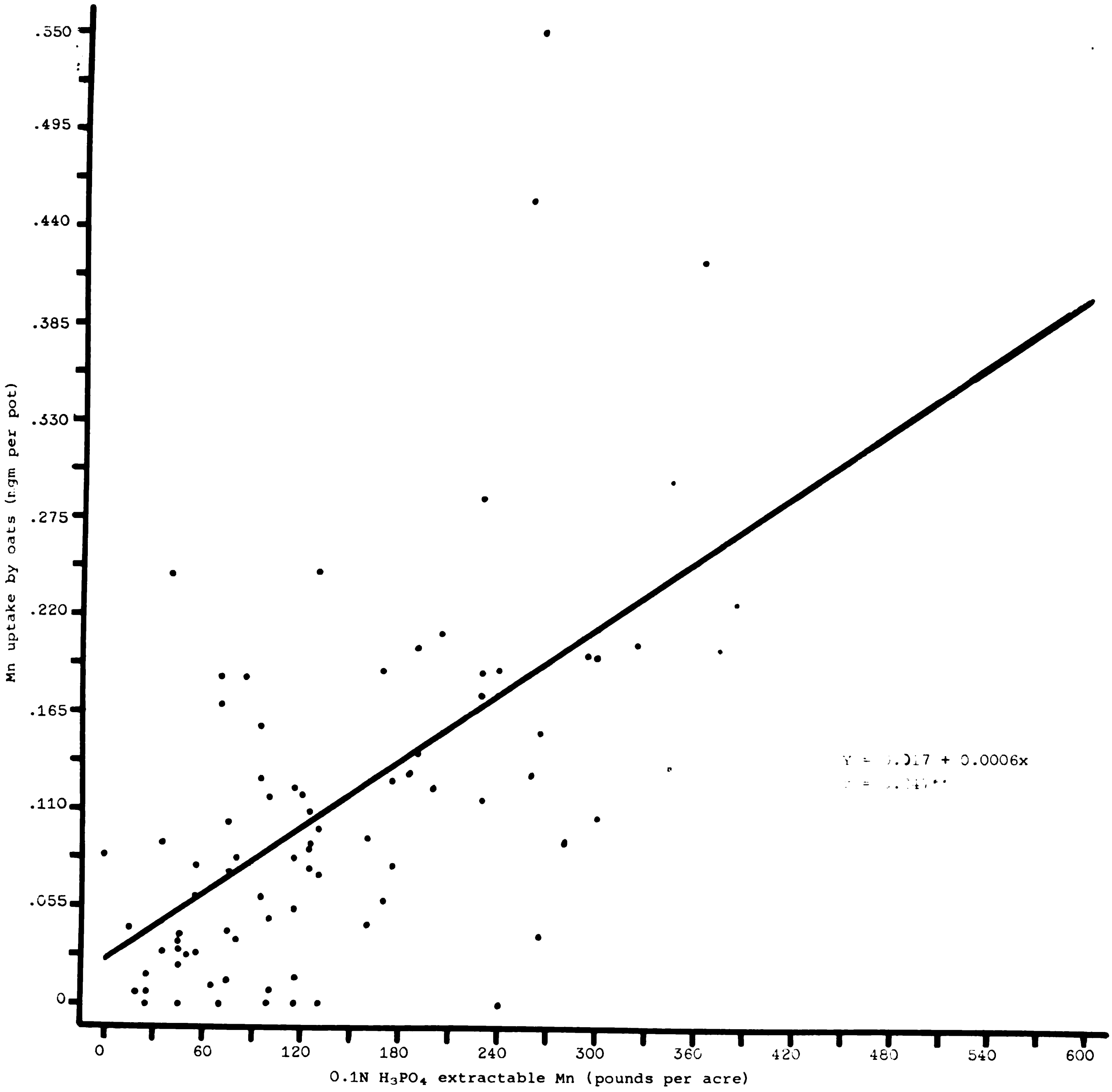
When the simple correlations obtained for oat and radish yields and tissue manganese and manganese uptake by oats versus

Table 24. The effect of available soil manganese determined by 0.1N H_3PO_4 and 1N NH_4OAc + 0.2% hydroquinone on the yield of oats and radishes and tissue manganese and manganese uptake by oats and comparison of their effect when extractable phosphorus was included as a soil variable on soils grouped according to texture

Soil Texture	Relationship	Correlation coefficients: 0.1N H_3PO_4 extractable Mn	0.1N H_3PO_4 extractable Mn and extractable P	1N NH_4OAc + 0.2% hydroquinone extractable Mn	1N NH_4OAc + 0.2% hydroquinone extractable Mn and extractable P
Sands	Oat yield	-.0907	.2574	-.0522	.2732
	Oat tissue Mn	+.3270	.4741	+.4445	.5456
	Oat Mn uptake	-.3561	.4785	+.4816	.5644
	Radish yield	-.0149	.3383	-.0990	.3586
Loamy sands	Oat yield	-.1982	.2634	+.1870	.3099
	Oat tissue Mn	+.2187	.2753	+.0354	.2290
	Oat Mn uptake	+.2197	.2676	+.0550	.2180
	Radish yield	-.3906*	.4164*	-.1005	.2721
Sandy loams	Oat yield	+.2587*	.2692*	+.1344	.1754
	Oat tissue Mn	+.6691**	.6691**	+.5214**	.5282**
	Oat Mn uptake	+.6479**	.6580**	+.4920**	.5027**
	Radish yield	-.1290	.1295	-.1393	.1344
Loams	Oat yield	-.0047	.2075	-.0190	.1597
	Oat tissue Mn	+.4125**	.4203**	+.3581*	.4032**
	Oat Mn uptake	+.3812*	.3820	+.3305*	.3554*
	Radish yield	-.1337	.1373	-.1271	.1272

* Significant at 5% level
** Significant at 1% level

Figure 10. Relationship between 0.1N H_3PO_4 extractable manganese and manganese uptake by oats on sandy loam soils.



0.1$\underline{N}$ H_3PO_4 and 1$\underline{N}$ NH_4OAc + 0.2 per cent hydroquinone extractable manganese were compared with these two extractants where available soil phosphorus was included, the correlations were improved but not to a marked degree (Table 24).

However, on loams, the correlation of the oat tissue manganese with 1$\underline{N}$ NH_4OAc + 0.2 per cent hydroquinone was improved from r = .3581 to r = .4032, the latter value was significant at the one per cent level.

Table 25. The relationship between 0.1$\underline{N}$ H_3PO_4 and 1$\underline{N}$ NH_4OAc + 0.2 per cent hydroquinone extractable soil manganese and soil pH, lime requirement, extractable potasssium, calcium and magnesium and extractable phosphorus on mineral and organic soils

Soil Texture	Relationship	Correlation coefficients: Soil extractant	
		0.1$\underline{N}$ H_3PO_4	1$\underline{N}$ NH_4OAc + 0.2% hydroquinone
Mineral soils	pH	-.3484**	-.2525**
	Extractable K, Ca, and Mg	-.4647**	-.2847**
	Extractable P	+.4273**	+.3651**
Organic soils	pH	-.7591*	-.5174
	Extractable K, Ca, and Mg	-.7315*	-.6016
	Extractable P	-.2531	-.1349

* Significant at 5% level
** Significant at 1% level

Results of the correlation analysis shown in Table 25 indicated that the 0.1N H_3PO_4 and 1N NH_4OAc + 0.2 percent hydroquinone extractable soil manganese for mineral soils were negatively correlated at the one per cent level with soil pH (r = -.3484 and -.2525, respectively). However, for organic soils, only the 0.1N H_3PO_4 extractable manganese was significantly related to soil pH (r = -.7591).

The sum of the extractable potassium, calcium and magnesium and the extractable phosphorus gave highly significant correlations with soil manganese by both methods on mineral soils. On organic soils, only the extractable potassium, calcium and magnesium were significantly correlated with 0.1N H_3PO_4 extractable soil manganese (r = -.7215).

The relationships between 0.1N H_3PO_4 and 1N NH_4OAc + 0.2 per cent hydroquinone extractable soil manganese and soil pH, extractable potassium, calcium and magnesium and extractable phosphorus for mineral soils grouped according to texture are shown in Table 26. Both the 0.1N H_3PO_4 extractable manganese and that extracted by 1N NH_4OAc + 0.2 per cent hydroquinone were significantly correlated with the pH of the sandy loam soils (r = -.4429 and -.3208). For the loam soils, however, only the 0.1N H_3PO_4 extractable soil manganese was significantly correlated with soil reaction (r = -.3872). There were no significant correlations for these relationships on the sands and loamy sands. The sum

Table 26. The relationship between 0.1$\underline{N}$ H_3PO_4 and 1$\underline{N}$ NH_4OAc + 0.2 per cent hydroquinone extractable soil manganese and soil pH, lime requirement, extractable potassium, calcium and magnesium and extractable phosphorus on soils grouped according to texture

Soil Texture	Relationship	Correlation coefficients — Soil extractant: 0.1$\underline{N}$ H_3PO_4	1$\underline{N}$ NH_4OAc + 0.2% hydroquinone
Sands	pH	-.0834	-.2344
	Extractable K, Ca and Mg	+.0378	-.1308
	Extractable P	-.6032*	-.4598
Loamy sands	pH	-.1839	-.0193
	Extractable K, Ca and Mg	-.4470**	-.0903
	Extractable P	+.3220	+.0991
Sandy loams	pH	-.4429**	-.3208**
	Extractable K, Ca and Mg	-.4871**	-.3899**
	Extractable P	+.1847	+.0643
Loams	pH	-.3872*	-.2727
	Extractable K, Ca and Mg	-.4471**	-.3367*
	Extractable P	+.7780**	+.6404**

* Significant at 5% level
** Significant at 1% level

of the extractable potassium, calcium and magnesium was highly correlated with soil manganese extracted by 0.1N H_3PO_4 on loamy sands, sandy loams and loams (Table 26). The 1N NH_4OAc + 0.2 per cent hydroquinone extractable manganese was significantly correlated with the sum of the extractable potassium, calcium and magnesium on loams (r = .3367), and significantly correlated at the one per cent level on sandy loams (r = -.3899).

A highly significant relationship existed between 0.1N H_3PO_4 and 1N NH_4OAc + 0.2 per cent hydroquinone extractable manganese and extractable phosphorus on loams (r = .7780 and .6404, respectively); and as shown in Table 26, a significant negative correlation was obtained on the sandy soils between 0.1N H_3PO_4 extractable soil manganese and extractable phosphorus (r = -.6032). A rather poor correlation resulted on the loamy sands and sandy loam soils between soil manganese extracted by both methods and extractable phosphorus.

As indicated in Table 27, there was a significant correlation between oat yield and oat manganese uptake on mineral soils (r = .1711). A non-significant correlation for these relationships was obtained on organic soils.

On sandy loams (Table 28), oat yield was significantly correlated at the one per cent level with oat manganese uptake (r = .3067). No significant correlations were obtained on other textural groups for oat yield and tissue manganese and

Table 27. The relationship between oat yield and tissue manganese and manganese uptake by oats on mineral and organic soils

Soil Texture	Relationship	Correlation coefficients	
		Tissue Mn	Mn uptake
Mineral soils	Oat yield	+.0893	+.1711*
Organic soils	Oat yield	+.0753	+.2988

* Significant at 5% level

Table 28. The relationship between oat yield and tissue manganese and manganese uptake by oats on soils grouped according to texture

Soil texture	Relationship	Correlation coefficients	
		Tissue Mn	Mn uptake
Sands	Oat yield	-.3374	-.4437
Loamy sands	Oat yield	+.0726	+.0268
Sandy loams	Oat yield	+.2133	+.3067**
Loams	Oat yield	+.0344	+.2227

** Significant at 1% level

manganese uptake. On sandy soils, oat yield was negatively correlated with tissue manganese and manganese uptake.

As shown in Table 29, oat tissue manganese and manganese uptake were highly correlated (negatively) with soil pH on both mineral (r = -.4847 and -.4700, respectively) and organic soils (r = -.8775 and -.7447, respectively).

The relationship between the yield of oats and soil pH on mineral soils was significant only at the 5 per cent level whereas the yield of radishes was highly significantly correlated with soil pH. On organic soils, both oat and radish yields were not well correlated with soil pH (r = +.3193 and -.0950, respectively).

Highly significant correlations were obtained between extractable bases and oat tissue mangnaese and manganese uptake and radish yield on mineral soils (r = -.3843, -.3838, and +.5890, respectively). This relationship did not apply to the organic soils. Extractable soil phosphorus did not give a good correlation with oat and radish yield and oat tissue manganese and manganese uptake on either mineral or organic soils.

When the mineral soils were grouped according to texture (Table 30), a significant correlation was obtained between the manganese uptake by oats on the loam soils and extractable phosphorus (r = .3119), and oat tissue manganese and extractable phosphorus (r = .3715). It was noted, however, that the

Table 29. The relationship between soil pH, extractable potassium, calcium and magnesium and extractable phosphorus and the yield of oats and radishes and tissue manganese and manganese uptake by oats on mineral and organic soils

Soils	Relationship	Correlation coefficients		
		pH	K+Ca+Mg	P
Mineral soils	Oat yield	-.1689*	-.0403	-.0475
	Oat tissue Mn	-.4847**	-.3843**	+.1576
	Oat Mn uptake	-.4700**	-.3838**	+.1381
	Radish yield	+.3163**	+.5890**	-.0881
Organic soils	Oat yield	+.3193	-.1099	+.2370
	Oat tissue Mn	-.8775**	-.6017	-.2797
	Oat Mn uptake	-.7447*	-.5808	-.2386
	Radish yield	-.0950	+.3278	-.3966

* Significant at 5% level
** Significant at 1% level

correlation of extractable phosphorus with oat and radish yield and oat tissue manganese and manganese uptake was poor on sands, loamy sands, and sany loams. Also, oat yield and manganese uptake were poorly correlated with extractable phosphorus on the loam soils.

The data shown in Table 30 indicated a highly significant correlation between the sum of the extractable potassium, calcium and magnesium and the oat and radish yield on the loamy sands and sandy loam soils. The yield of radishes was significantly correlated on the loam soils with extractable bases (r = .3871). Tissue manganese and manganese uptake by oats obtained on the sandy loams and loams were highly correlated with extractable potassium, calcium and magnesium.

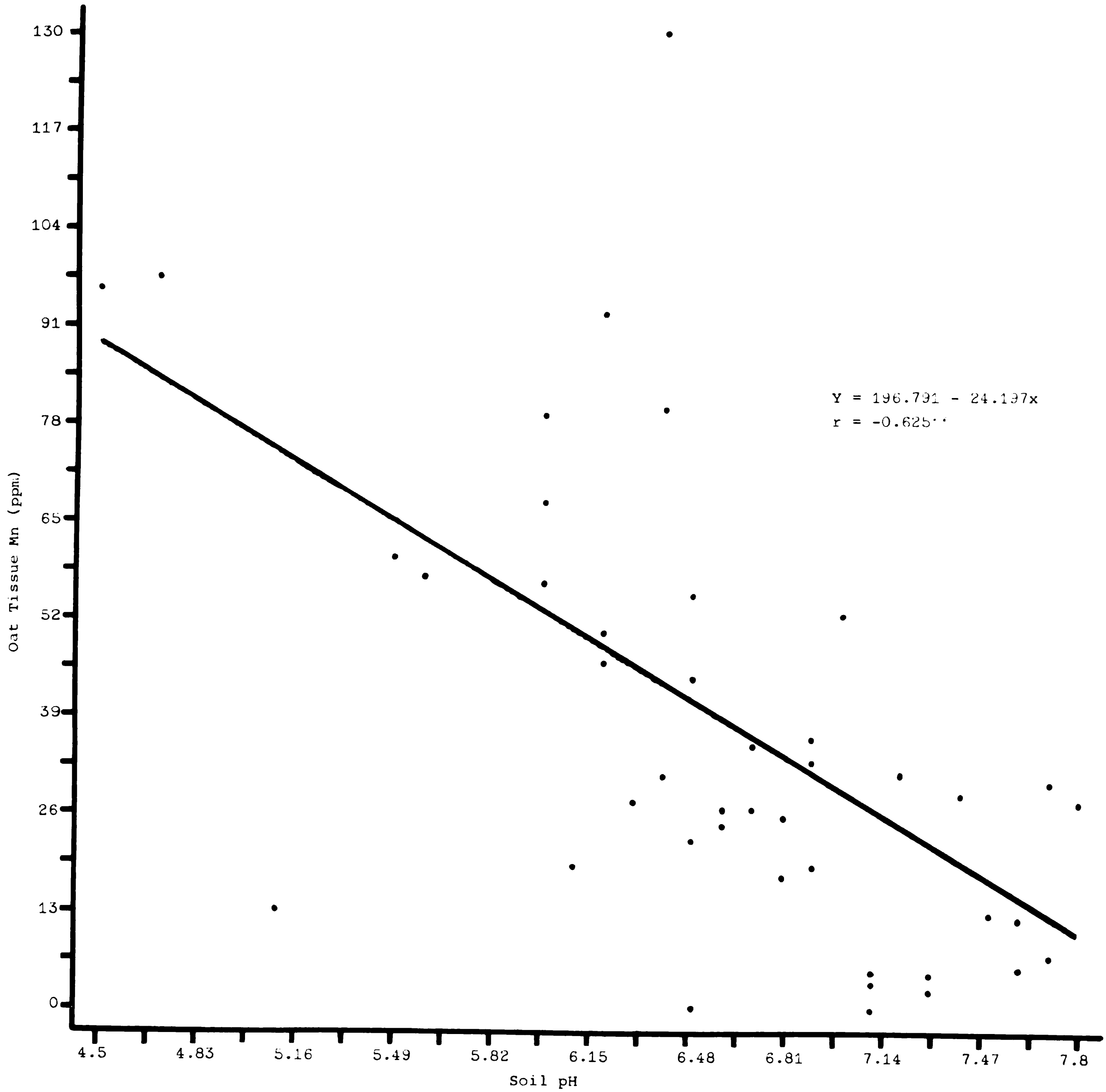
The effect of soil reaction on oat and radish yield and oat tissue manganse and manganese uptake, as shown in Table 30, indicated that oat tissue manganese and manganese uptake were highly correlated with soil reaction on loamy sands, sandy loams and loams (Fig. 11). Oat yield was highly significantly negatively correlated with soil pH on sandy loams (r = -.3541); and radish yield was positively correlated with soil reaction on loams (r = .2681) and sandy loams (r = .2449). On sands, loamy sands and loams, oat yield was not well correlated with soil reaction.

Table 30. The effect of soil pH, extractable potassium and magnesium and extractable phosphorus on the yield of oats and radishes and tissue manganese and manganese uptake by oats on soils grouped according to texture

Soils	Relationship	Correlation coefficients		
		pH	K+Ca+Mg	P
Sands	Oat yield	+.0517	+.1251	+.2622
	Oat tissue Mn	-.7841*	-.5284	+.0766
	Oat Mn uptake	-.7709*	-.5282	+.2605
	Radish yield	+.5626	+.6247	-.2605
Loamy sands	Oat yield	+.0953	+.5797**	-.2274
	Oat tissue Mn	-.4744**	-.2796	+.2287
	Oat Mn uptake	-.4514**	-.2706	+.2154
	Radish yield	+.4230**	+.7359**	-.2628
Sandy loams	Oat yield	-.3541**	-.2954**	+.1211
	Oat tissue Mn	-.5379**	-.4369**	+.1183
	Oat Mn uptake	-.5502**	-.4363**	+.0164
	Radish yield	+.2449	+.3928**	+.1346
Loams	Oat yield	-.1190	-.2100	-.1341
	Oat tissue Mn	-.6256**	-.5106**	+.3715*
	Oat Mn uptake	-.6060**	-.5380**	+.3119*
	Radish yield	+.2686*	+.3871*	-.0844

* Significant at 5% level
** Significant at 1% level

Figure 11. Relationship between soil pH and tissue manganese (ppm) of oats grown on loam soils.



As shown in Table 31, multiple correlations among soil pH, sum of the extractable potassium, calcium and magnesium and extractable phosphorus, oat and radish yield, tissue manganese, manganese uptake by oats when available soil manganese extracted by 0.1N H_3PO_4 and 1N NH_4OAc + 0.2 per cent hydroquinone were compared. Mineral soils gave highly significant correlations for all relationships. When manganese was added as a soil variable in the multiple correlations, the correlations were improved in all cases. However, multiple correlations including available soil manganese extracted by 0.1N H_3PO_4 gave consistently higher correlations as compared to multiple correlations including 1N NH_4OAc + 0.2 per cent hydroquinone extractable manganese on mineral soils.

For the organic soils, however, the multiple correlations improved only slightly, except for the radish yield, when 0.1N H_3PO_4 extractable manganese was included in the correlation. The correlation of radish yield with the variables shown in Table 31 was somewhat improved when 1N NH_4OAc + 0.2 per cent hydroquinone extractable manganese was included (r = .4827 to .4970). The correlation coefficient for the yield of oats as a function of the previously described variables was improved from .4570 to .9753 when reducible manganese was substituted

Table 31. The effect of several soil chemical properties on the yield of oats and radishes and tissue manganese and manganese uptake by oats on mineral and organic soils

Soil texture	Relationship	Correlation coefficients		
		pH+(K+Ca+Mg) +P	pH+(K+Ca+Mg) +P+Mn (0.1N H_3PO_4)	pH+(K+Ca+Mg) +P+Mn (1N NH_4OAc + 0.2% hydroquinone)
Mineral soils	Oat yield	.2092**	.2180**	.2154**
	Oat tissue Mn	.5191**	.5543**	.5314**
	Oat Mn uptake	.5085**	.5426**	.5190**
	Radish yield	.5895**	.6005**	.5950**
Organic soils	Oat yield	.4566	.4570	.9753**
	Oat tissue Mn	.9324**	.9370**	.9913**
	Oat Mn uptake	.8383*	.8544*	.9701**
	Radish yield	.4827	.7490	.4970

* Significant at 5% level
** Significant at 1% level

for 0.1N H_3PO_4 extractable Mn. Similarly, the r values (Table 31) for tissue manganese and manganese uptake by oats were also greater when 1N NH_4OAc + 0.2 per cent hydroquinone extractable manganese was employed in the function.

Where mineral soils were grouped according to texture, as shown in Table 32, the multiple correlation coefficients for tissue manganese and manganese uptake by oats as a function of soil pH, extractable potassium, calcium and magnesium and extractable phosphorus were highly significant. Correlations improved when either 0.1N $H3PO_4$ or 1N NH_4OAc + 0.2 per cent hydroquinone extractable manganese was included as a soil variable. Oat and radish yields gave highly significant correlations with these relationships on loamy sands and sandy loam soils. The inclusion of soil manganese with the other variables on the loam soils did not significantly improve the correlation between radish yield and the previously described variables. The correlation among these variables and the yield of oats on sands and loams was not significantly related to pH, sum of the cations, phosphorus or to soil manganese extracted by either method. Multiple correlations in which 0.1N H_3PO_4 extractable manganese was included, consistently gave better correlations than the 1N NH_4OAc + 0.2 per cent hydroquinone extractable manganese except for oat yields on sands and loamy sands and tissue manganese and manganese uptake by oats on the loam soils.

Table 32. The effect of several soil chemical properties on the tissue manganese and manganese uptake by oats and yield of oats and radishes on soils grouped according to texture

Soil texture	Relationship	Correlation coefficients		
		pH+(K+Ca+Mg) +P	pH+(K+Ca+Mg) +P+Mn (0.1N H_3PO_4	pH+(K+Ca+Mg) +P+Mn (1N NH_4OAc + 0.2% hydroquinone)
Sands	Oat yield	.3693	.4520	.4665
	Oat tissue Mn	.8856**	.8907**	.8864**
	Oat Mn uptake	.8904**	.8946**	.8905**
	Radish yield	.6500	.6513	.6544
Loamy sands	Oat yield	.6531**	.6738**	.7081**
	Oat tissue Mn	.4844**	.4951**	.4846**
	Oat Mn uptake	.4618**	.4746**	.4632**
	Radish yield	.7636**	.7639**	.7636**
Sandy loams	Oat yield	.3750**	.3833**	.3750**
	Oat tissue Mn	.5569**	.7214**	.6550**
	Oat Mn uptake	.5682**	.7187**	.6478**
	Radish yield	.4042**	.4088**	.4044**
Loams	Oat yield	.2914	.3068	.2958
	Oat tissue Mn	.6528**	.6648**	.6677**
	Oat Mn uptake	.6436**	.6555**	.6581**
	Radish yield	.3905*	.3959*	.3095*

* Significant at 5% level
** Significant at 1% level

A comparison of the correlation coefficients obtained for 0.1N H_3PO_4 extractable manganese and that extracted by 1N NH_4OAc + 0.2 per cent hydroquinone as a function of pH, extractable bases and available phosphorus is shown in Table 33. The 0.1N H_3PO_4 extractable manganese was highly correlated with the variables previously described on both mineral and organic soils. The 1N NH_4OAc + 0.2 per cent hydroquione extractable manganese, however, was significantly related to these variables on mineral soils only.

As shown in Table 34, highly significant relationships existed between 0.1N H_3PO_4 and 1N NH_4OAc + 0.2 per cent hydroquinone extractable soil manganese and the variables previously described on sandy loams and loamy soils. The 0.1N H_3PO_4 extractable manganese gave a highly significant correlation with these variables on loamy sands (r = .5406) and a significant correlation on sands (r = .7861). The 1N NH_4OAc + 0.2 per cent hydroquinone extractable manganese was significantly correlated with the variables shown in Table 34, on sands (r = .7359), but poorly correlated on the loamy sand soils (r = .1434). The data indicates that for all textural groups, 0.1N H_3PO_4 extractable manganese gave comparatively better correlations than the 1N NH_4OAc + 0.2 per cent hydroquinone extractable manganese.

Table 33. A comparison of the multiple correlation coefficients obtained for manganese extracted by 0.1N H_3PO_4 and 1N NH_4OAc + 0.2 per cent hydroquinone as a function of soil pH, extractable potassium, calcium, and magnesium, and extractable phosphorus on mineral and organic soils

Soil texture	Relationship	Correlation coefficients pH+(K+Ca+Mg)+P
Mineral soils	0.1N H_3PO_4 extractable Mn	.5655**
	1N NH_4OAc + 0.2 per cent hydroquinone extractable Mn	.4499**
Organic soils	0.1N H_3PO_4 extractable Mn	.9415**
	1N NH_4OAc + 0.2 per cent hydroquinone extractable Mn	.7211

** Significant at 1% level

Table 34. A comparison of the multiple correlation coefficients obtained for manganese extracted by 0.1N H_3PO_4 and 1N NH_4OAc+ 0.2 per cent hydroquinone as a function of pH, extractable potassium, calcium and magnesium and extractable phosphorus on soils grouped according to texture

Soil texture	Relationship	Correlation coefficients pH+(K+Ca+Mg)+P
Sands	0.1N H_3PO_4 extractable Mn	.7861*
	1N NH_4OAc + 0.2 per cent hydroquinone extractable Mn	.7359*
Loamy sands	0.1N H_3PO_4 extractable Mn	.5406*
	1N NH_4OAc + 0.2 per cent hydroquinone extractable Mn	.1434
Sandy loams	0.1N H_3PO_4 extractable Mn	.5298**
	1N NH_4OAc + 0.2 per cent hydroquinone extractable Mn	.4040**
Loams	0.1N H_3PO_4 extractable Mn	.8631**
	1N NH_4OAc + 0.2 per cent hydroquinone extractable Mn	.7125**

* Significant at 5% level
** Significant at 1% level

As shown in Table 35, 1N NH_4OAc + 0.2 per cent hydroquinone extracted more manganese from the soil than 0.1N H_3PO_4 on both mineral and organic soils.

The difference between 1N NH_4OAc + 0.2 per cent hydroquinone and 0.1N H_3PO_4 extractable manganese was greater on organic soils than on mineral soils. Organic soils have been shown to tie up more manganese in the form of chelated complexes (10). Too, the reducing agent hydroquinone extracts more manganese from this form. Greater amount of extractable phosphorus, like manganese was obtained from mineral soils than from organic soils but the reverse was true for the extractable bases (potassium, calcium and magnesium).

Oat and radish yields were higher on organic soils than on mineral soils. However, manganese uptake by oats was greater on mineral soils.

The average values shown in Table 36 indicated that the difference between 1N NH_4OAc + 0.2 per cent hydroquinone and 0.1N H_3PO_4 extractable manganese increased from the sand textured soils to clay soils indicating that 1N NH_4OAc + 0.2 per cent hydroquinone extracted more manganese on fine textured soils than the 0.1N H_3PO_4. The bulk of the exchangeable manganese has been shown to be located in the colloidal fraction (49).

Table 35. Mean values and ranges of several soil chemical characteristics and observed crop variables on mineral and organic soils

Variables	Mineral Soils		Organic Soils	
	Mean	S.D.	Mean	S.D.
Easily reducible Mn (pp2m)	189.52	190.76	99.4	68.8
Acid soluble Mn (pp2m)	128.91	103.4	20.0	9.3
Easily reducible Mn-acid soluble Mn	60.61	-	79.4	-
pH (simple average)	6.54	0.66	6.76	0.55
Extractable P (pds/acre)	59.51	74.34	36.20	18.10
Extractable (K+Ca+Mg) (pds/acre)	3506.0	2871.5	12176.2	2196.9
Oat yield (gms/pot)	2.370	0.415	3.24	0.794
Oat tissue Mn (ppm)	53.063	59.804	16.700	14.300
Oat Mn uptake (mgm/pot)	0.127	0.149	0.055	0.049
Radish yield (gms/pot)	0.74	0.27	1.48	0.30

Soil pH increased in the following manner:

Sands < Clays < Loamy sands < Sandy loams < Loams

Extractable phosphorus increased in the following manner:

Clays < Sands < Loamy sands < Sandy loams < Loams

Extractable bases increased in the following manner:

Sands < Sandy Loams < Loams < Loamy sands < Clays

Oat yield decreased in the following manner:

Sands > Clays > Loamy sands > Sandy loams > Loams

Radish yield decreased in the following manner:

Clays > Loams > Sandy loams > Loamy sands > Sands

Oat manganese uptake decreased as follows:

Sands > Loamy sands > Sandy loams > Loams > Clays

These variations are natural to obtain as the soils included in this study were of wide range in texture and chemical properties and the management practices varied widely.

Table 36. Mean values and ranges of several soil chemical characteristics and observed crop variables on coarse and fine textured soils

Variables	Sands		Loamy Sands		Sandy Loams	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Easily reducible Mn (pp2m)	157.27	147.1	161.19	98.57	221.81	189.42
Acid soluble Mn (pp2m)	109.54	64.0	120.47	72.27	158.57	113.73
Easily reducible Mn-acid soluble Mn	47.73		40.72		63.24	
pH (simple average)	6.02	.87	6.48	.62	6.52	0.59
Extractable P (pds/acre)	57.81	53.16	68.02	47.79	59.3	41.7
Extractable (K+ Ca+Mg) (pds/acre)	1551.9	1097.3	2354.8	2588.31	2155.39	2523.0
Oat yield (gms/ pots)	2.66	.278	2.58	.435	2.3	.377
Oat tissue Mn (ppm)	73.0	63.72	71.04	101.52	53.59	41.1
Oat Mn uptake (mgm/pot)	.187	.151	.180	.252	.126	.111
Radish yield (gms/ pot)	.5	.146	.606	.273	.715	.326

Table 36, cont.

Variables	Loams		Clays	
	Mean	S.D.	Mean	S.D.*
Easily reducible Mn (pp2m)	173.1	254.7	199.8	
Acid soluble Mn (pp2m)	100.2	100.8	57.0	
Easily reducible Mn-acid soluble Mn	72.9		142.8	
pH (simple average)	6.62	.77	6.3	
Extractable P (pds/acre)	62.76	130.11	30	
Extractable (K+ Ca+Mg) (pds/acre)	2158.0	1217.6	9339	
Oat yield (gms/ pots)	2.22	.349	2.600	
Oat tissue Mn (ppm)	38.39	29.62	21.8	
Oat Mn uptake (mgm/pot)	.085	.068	.056	
Radish yield (gm/pot)	.827	.204	1.284	

*S.D. was not calculated as there were only 5 number of observations

GENERAL DISCUSSION

The mangnaese content varied considerably in the 179 soils included in this study. The acid soluble manganese ranged from 0 to 600 pp2m and easily reducible manganese ranged from 5 to 997 pp2m. The average manganese contents of mineral and organic soils were 129 and 20 pp2m of acid soluble manganese, and 190 and 100 pp2m of easily reducible manganese, respectively.

When soils were grouped according to manganese deficiency index rated by the bean crop for the 11 soil types represented in the study, the average values for easily reducible and acid soluble manganese were as follows: 148 and 122 pp2m (sufficiency group); 68.55 and 49.5 pp2m (latent deficiency group) and 62 and 29 pp2m (deficiency group).

These values indicate that soils having less than 62 pp2m of easily reducible manganese or less than 30 pp2m of acid soluble manganese may be considered as manganese deficient using beans as the indicator crop. Soils containing more than 69 pp2m of easily reducible manganese or 49 pp2m of acid soluble manganese may be considered as sufficient for the bean crop.

Twenty-five ppm or less manganese in the bean tissue may be considered deficient and more than 35 ppm manganese can be considered as a sufficient level for normal plant growth. Naturally there is a limit for the plant manganese content for normal growth above which plants will suffer from manganese toxicity.

The subnormal shrunken characteristic symptoms of the plants grown on Soils 6, 7 and 15, are shown in Plate 2. This disorder initially appeared to be associated with manganese toxicity.

Bean plants grown on all three treatments of Soils 6, 7 and 15 (Montcalm sandy loam, Karlin sandy loam, and Osthemo loamy sand, respectively) had well-spread green primary leaves to begin with, but the secondary leaves were very slow to emerge and, on emergence, their size was subnormal and were rather rubbery and with wavy margins (Plate 3). Plants were taken to the Plant Disease Diagnostic Laboratory on August 17 to see if the symptoms were of a pathological nature. Findings were negative.

The leaf characteristics showed veins that were almost transparent; the remaining areas were dark green and puckered. Leaf tips were sickle-shaped with wavy margins (Plate 4).

In contrast to these leaf characteristics, Gorter et al (21) has described the auxin herbicide effect on leaves as follows: "Growth of the mesophyll seems to be controlled by a

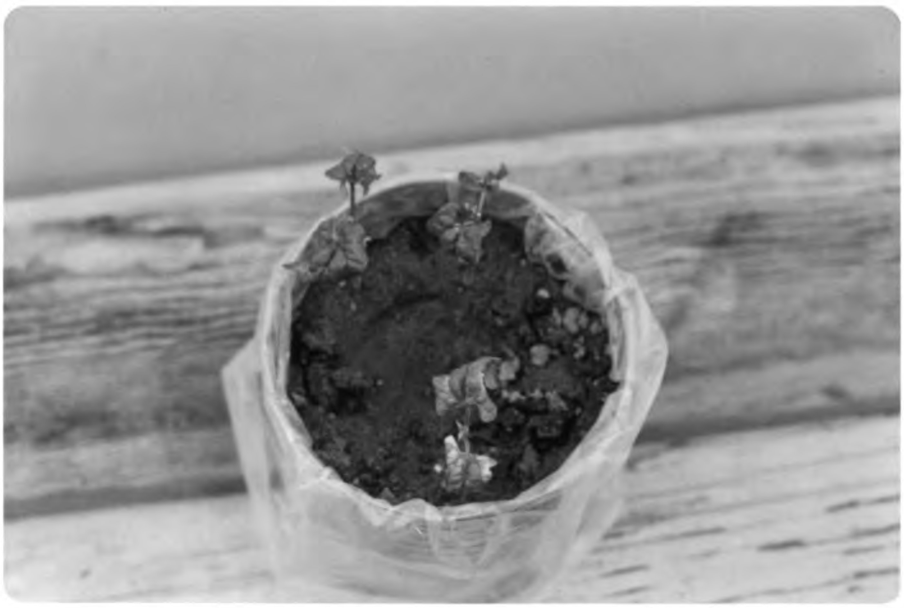


Plate 2. Effect of nutrient imbalance in the plant as shown on navy beans (var. Sanilac)

Soil type: Osthemo loamy sand
Soil pH: 5.4
Available soil manganese: 280 pp2m (acid soluble)
336 pp2m (easily reducible)
Bean tissue manganese: 3600 ppm

Plate 3. Navy bean (var. Sanilac) plant showing well developed primary leaves and abnormal secondary leaves

Soil type: Karlin sandy loam
Soil pH: 4.8
Available soil manganese: 285 pp2m (acid soluble)
303 pp2m (easily reducible)
Bean tissue manganese: 2140 ppm

Plate 4. Normal bean leaf (var. Sanilac) shown on the left and abnormal leaf on the right affected by nutrient imbalance

Soil type: Montcalm sandy loam
Soil pH: 5.1
Available soil manganese: 175 pp2m (acid soluble)
138 pp2m (easily reducible)
Bean tissue manganese: 1360 ppm

mechanism different from that for the growth of veins, for an auxin herbicide may reduce the amount of mesophyll without influencing the development of the veins. A pointed or even strap-like leaf may be the result. In extreme cases, complete absence of the mesophyll occurs. Crisped leaves are formed when vein growth is more retarded than mesophyll growth. The latter tissue then bulges out between the veins giving the leaves their crisped appearance. Crisping of leaves caused by auxin herbicides very much resembles the effects to be observed in virus diseased plants. Abnormal vein patterns as the band-like spreading of the tissue of the central vein and sometimes of veins of the second or third order also is commonly combined with inhibited development of the mesophyll tissue."

Comparing the observed abnormality of the leaves and the characteristic damage by the herbicide (2,4-D particularly) and observing them to be not quite similar, it was suspected that the two strains of virus may cause similar symptoms. The two suspected virus diseases were Curly Top and Bean Mosaic (57).

The three possible causes of these characteristic symptoms were as follows:

(a) a herbicidal damage
(b) a virus disease infection
(c) a nutritional disorder.

In order to ascertain which of these caused the symptoms previously described, inoculation studies were made in fresh soil samples as suggested by Dr. D. J. deZeeuw of the Botany and Plant Pathology Department, Michigan State University.

Beans were grown on suspected field soils (soils 6, 7 and 15) and on field soils not ordinarily producing the symptoms. The beans in the latter soil failed to give the virus-like symptoms and no disease could be transmitted from these plants to either tobacco or navy beans. Beans grown in the suspected soil produced the typical symptoms. Transmission of symptoms from these, however, was also negative on tobacco and navy beans. There was a lack of evidence for soil transmitted virus. No specific insect was noted for such virus as Curly Top and no contact or transmission from symptom-expressing plants could be obtained. It was concluded, therefore, that the symptoms observed on the bean plants were not due to a virus infection.

Dr. N. Leeling, Department of Entomology, Michigan State University, analyzed the soils and plants grown on those soils showing symptoms by gas chromatography to trace the herbicidal residue in the soil or taken up by the plant in its growing stages. Standards were established for the possible herbicides used: Randox, Eptam, and both ester and amine compounds of 2-4-D. Chromatographic column, 6 feet by 1/8 inch, contained five per cent DC-11 Silicone oil on Chromosorb (60-80 mesh). The temperature was 200°C and the nitrogen gas flow rate was 55 ml. per minute. The chromatographic curves failed to show similar peaks against the standards.

Rejection of these two possibilities gives more weight to the possibility that these symptoms were due to some nutritional disorder, more of a toxic nature. Bean tissues from the soils receiving no treatment and with manganese added were extremely high in manganese and the plants showed the subnormal, shrunken growth with characteristic symptoms. Plants similar to these were obtained on the soils treated with lime. But the plant content of manganese was very much reduced (Table 36).

From these data it appears that the kind of physiological disorder that developed may be the result of nutrient element interaction or nutrient imbalance.

To compare the chemical composition of tissues obtained from normal and abnormal bean plants, a spectrographic analysis was carried out by Dr. A. L. Kenworthy, Horticulture Department, Michigan State University.

Results of the Spectrographic Analysis are shown in Table 37.

Table 37. Total manganese, iron, aluminum, copper and boron contents of tissue in the normal bean plants and plants showing nutritional disorder symptoms (Average of 7 observations)

Plant Growth	Treatment	Nutrient content in the plant tissue (ppm)				
		Mn	Fe	Al	Cu	B
Normal		26	277	173	15.2	43.3
Abnormal	Check	2200	200	100	16.0	42.0
	15 lbs/Mn acre	2972	340	161	22.0	70.0
	Lime treatment	40	55	90	17.0	6.0

When the ratios of other elements with manganese in the normal and abnormal plant tissues were compared (Table 38), the following observations were made: there was a 115-fold increase in manganese as compared to iron; 150-fold increase as compared to aluminum; approximately a 250-fold increase as compared to copper; and a 100-fold increase in boron. These ratios decreased with the application of manganese to the soil since the other nutrient contents also increased in the plant tissue. The application of lime brought about a sharp decrease in the manganese content of the bean tissue. The concentration of iron, aluminum, copper and boron also decreased but the ratio of manganese to these elements deviated considerably from that found in the normal tissue. This may have contributed to the similar symptoms that developed on the beans grown in the lime treated soils (Plate 5).

Evaluation of two extraction methods as to their effectiveness in determining available soil manganese:

The available soil manganese extracted by both methods were highly correlated on mineral soils (Experiment 2) and on soils grouped according to manganese deficiency index (Experiment 1). It was not significant on organic soils. It was noted that 1N NH_4OAc + 0.2 per cent hydroquinone consistently extracted more manganese on both mineral and organic soils.

Table 38. Ratios of manganese to other micronutrient elements in normal and abnormal plant tissue

Plant Growth	Treatment	Ratios			
		Fe:Mn	Al:Mn	Cu:Mn	B:Mn
Normal		1:0.09	1:0.15	1:0.58	1:0.60
Abnormal	Check	1:11.0	1:22.0	1:137.5	1:52.38
	15 lbs Mn/ acre	1:8.74	1:18.46	1:135.10	1:42.46
	Lime treat- ment	1:1.38	1:2.30	1:2.35	1:6.80

Plate 5. Navy bean (var. Sanilac) plant showing abnormal leaf symptoms

Soil type: Karlin sandy loam (lime treatment)
Soil pH: 7.0
Available soil manganese: 280 pp2m (acid soluble)
308 pp2m (easily reducible)
Bean tissue manganese: 51 ppm

However, it was also observed that the difference between 1N NH_4OAc + 0.2 per cent hydroquinone and 0.1N H_3PO_4 extractable manganese was greatest on the clays and least on the sandy loam soils. This difference was greater for organic soils (79 pp2m) than for mineral soils (60 pp2m). This may indicate that more manganese is extracted by 1N NH_4OAc containing 0.2 per cent hydroquinone from clays and soils high in organic matter. Too, 1N NH_4OAc + 0.2 per cent hydroquinone extractable manganese was better correlated with manganese uptake by oats on organic soils than on mineral soils.

The soil manganese as determined by the two extraction methods were highly correlated with oat manganese uptake on both mineral and organic soils.

The yield of radishes obtained on the mineral soils was significantly correlated with 0.1N H_3PO_4 extractable manganese.

Soil manganese extracted by both methods were found to be negatively associated with soil chemical properties, such as pH and extractable bases on both mineral and organic soils. However, extractable phosphorus was positively correlated with soil manganese on mineral soils and negatively correlated on organic soils. The degree of association was higher for 0.1N H_3PO_4 extractable manganese on all occasions.

A higher degree of correlation was associated with 1N NH_4OAc + 0.2 per cent hydroquinone extractable manganese on organic soils for oat and radish yields when soil phosphorus was included as a variable in the function.

On comparing the merits of the two extraction methods, it was found that 0.1N H_3PO_4 extractant gave higher correlations than 1N NH_4OAc + 0.2 per cent hydroquinone with plant yield and plant manganese content on mineral soils and on soils placed in the manganese sufficiency group as rated by the bean crop.

It can be stated that on mineral soils 0.1N H_3PO_4 is more effective in determining the available manganese and on organic soils, 1N NH_4OAc + 0.2 per cent hydroquinone is a better extractant to determine the available soil manganese.

Soil manganese as related to soil texture:

The manganese content of the different textural groups varied considerably. The easily reducible manganese ranged from 157 pp2m in sands to 227 pp2m in sandy loams while the acid soluble manganese varied from 57 pp2m in clays to 158 pp2m in sandy loams.

Even with this difference, manganese content in oats decreased in a uniform pattern from coarse to fine textured soils. On the average, both the coarse (sands, loamy sands and sandy loams) and fine textured soils (loams and clays) contained an equal amount of easily reducible manganese. But the acid soluble manganese in the coarse textured soils was approximately one and a half times greater than the fine textured soils (Table 36). The manganese content of oats grown on coarse textured soils was twice as great as that obtained from the fine textured soils. From this relationship, it may be concluded that 0.1N H_3PO_4 is more effective in determining the plant available manganese than 1N NH_4OAc + 0.2 per cent hydroquinone on mineral soils. The same trend was observed for the yield of oats. The yield of radishes, however, increased from coarse to fine textured soils. Soil manganese was highly correlated with plant manganese on medium textured soils but this was not true for the coarse textured soils. Except on sandy soils, acid soluble manganese was better correlated with plant manganese than the easily reducible manganese.

Soil manganese as related to soil reaction:

Soil manganese determined by both methods was highly negatively correlated with soil reaction on medium textured soils and on soils considered to be manganese sufficient as rated by the bean crop. Too, plant manganese uptake was negatively correlated with soil reaction on both mineral and organic soils and on soils grouped as manganese sufficient. However on organic soils, easily reducible manganese did not appear to be related significantly to soil pH. Soil pH increased from the sufficiency to deficiency group and the acid soluble and easily reducible manganese decreased. Similarly, the plant manganese content decreased. The yield of beans was more closely negatively related to soil pH on the deficiency group of soils and was positively related on the sufficiency group.

Soil manganese as related to the sum of the extractable potassium, calcium and magnesium:

Both acid soluble and easily reducible manganese were negatively correlated with extractable bases on mineral soils, organic soils, and on the soils grouped according to their manganese deficiency index. Acid soluble manganese was highly significantly correlated on all occasions. Extractable bases increased from sufficiency to deficiency group while soil and plant manganese decreased. The yield of beans was more closely related (negatively) to the sum of the extractable bases on the sufficiency group.

Soil manganese as related to extractable phosphorus:

The effect of phosphate on the increased uptake of manganese by crops has been observed by several workers (30, 35, 40, 46, 58). The direct effect has been attributed to the chemical mobilization of Mn brought about by the reaction between calcium mono-phosphate on the manganese compounds by precipitating them as manganous phosphate since this compound forms at pH 5.8 or above (35). This retards the oxidation of Mn and provides a constant and slow supply of Mn to the plant. Indirect effect of the superphosphate is by lowering the pH and thus increasing the divalent form of manganese (46).

In the present investigation, soil manganese as determined by the two methods, and plant manganese were highly positively correlated with soil phosphorus on medium textured soils and on all three groups classed according to the manganese deficiency index. However, the relationship was negative on sandy soils and organic soils. The uptake of manganese by beans was closely positively related to soil phosphorus on the deficiency group. Bean yield was negatively related to soil phosphorus on all the three groups rated according to the manganese deficiency index.

The highly significant multiple correlations obtained in this study indicate that the available soil manganese as determined by both soil extractants and the plant manganese were highly associated with such soil properties as pH, exchangeable bases and P on mineral and organic soils and when soils were grouped according to the manganese deficiency index. The easily reducible manganese was poorly related to these factors on organic soils.

The results of this study indicate that the near neutral and/or alkaline, coarse and fine textured soils and also muck soils respond well to manganese fertilizaton.

SUMMARY AND CONCLUSIONS

Greenhouse and laboratory investigations were initiated in 1964 to (1) study the manganese availability of several Michigan soils; (2) evaluate two extraction methods; (3) correlate several soil chemical properties with manganese availability; (4) study the effect of lime and manganese applications on manganese availability; and (5) to determine the manganese sufficiency level for oats, beans and radishes.

In the first experiment, 11 soil types, obtained from 15 locations in Michigan, were treated with manganese and lime to determine the manganese sufficiency levels using oats and beans as the indicator crops and to study the effect of manganese and lime applications on manganese availability. In the second experiment, 179 soils were selected at random from the University Soil Testing Laboratory and mixed with sand (1 part soil to 3 parts sand) and planted to oats and radishes. The results can be summarized as follows:

1. The manganese content of the soils studied varied widely.

2. When 0.1N H_3PO_4 extractable manganese is below 30 pp2m or when 1N NH_4OAc + 0.2 per cent hydroquinone extractable manganese is below 62 pp2m the soil may be considered as deficient in this element for optimum growth of beans.

3. Twenty-five ppm or less manganese in the bean plant tissue may be considered as deficient level and more than 35 ppm manganese may be considered as sufficient for normal plant growth.

4. The 0.1N H_3PO_4 extractable manganese gave better correlations with plant manganese and yield on mineral soils. However, the yield and manganese content of plants grown on organic soils were better correlated with 1N NH_4OAc + 0.2 per cent hydroquinone extractable manganese.

5. Soil texture imparted a significant influence on manganese availability. Coarse textured soils contained a greater amount of manganese compared to the fine textured soils.

6. Soil pH related negatively with the availability of manganese and thus uptake of manganese by the plant.

7. Soil phosphorus affected the manganese availability on medium textured soils. A positive relationship existed between extractable soil manganese and extractable phosphorus.

8. Acid soluble manganese was negatively correlated with extractable bases on all textures, organic soils and on the soils grouped according to their manganese deficiency index. Easily reducible manganese was not

related to the sum of the extractable bases on the organic soils in Experiment 2 and on the manganese latent deficiency group in Experiment 1.

9. The near neutral and/or alkaline, coarse and fine textured soils and also muck soils respond well to manganese fertilization.

10. The nutrient imbalance (Mn, Fe, Al, Cu, B) arising on coarse and medium textured acid soils (pH 4.7 to 5.5) may give rise to abnormal growth of bean plants.

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APPENDIX

HOUGHTON SERIES

Houghton series consists of organic soils developed from fibrous plant remains consisting of grasses, sedge, reeds, and other non-woody water tolerant plants over 42 inches thick.

<u>Soil Profile</u>:		Houghton muck
01	0-7"	Black (10YR 2/1) to very dark brown (10YR 2/2); muck composed of fibrous plant remains; weak to moderate, fine to medium, granular structure; very friable; medium acid; diffuse smooth boundary. 5 to 20 inches thick.
02	7-24"	Dark brown (7.5YR 3/2) to brown (7.5YR 5/4); muck or partially decomposed peat; moderate, medium, granular grading downward to fine, fibrous fragments in lower part; friable; medium to slightly acid; diffuse smooth boundary. 7 to 15 inches thick.
03	24"+	Brown (7.5YR 5/4); moderately decomposed muck grading downward to fibrous peat, largely reeds and sedges; massive; friable; slightly acid to neutral.

<u>Topography</u>: Nearly level areas, depressions or broad depressed flats, in out-wash plains, till plains, and moraines.

<u>Drainage and Permeability</u>: Very poorly drained. Run-off is slow to ponded. Water table at or near the surface, except where artificially drained. Permeability is moderate.

WISNER SERIES

The Wisner series comprises poorly drained humic-clay soils developed in highly calcareous clay loam or silty clay loam till which has probably been reworked by water in many areas.

<u>Soil Profile</u>:		Wisner clay loam
Ap	0-8"	Clay loam; black (10YR 2/1) or very dark gray (10YR 3/1); moderate to strong coarse, granular structure; firm; calcareous to mildly alkaline; abrupt smooth boundary. 6 to 9 inches thick.
B_{2g}	8-18"	Clay loam or silty clay loam; dark gray (5YR 4/1) or gray (5Y 5/1) mottled with brown (7.5YR 5/4-4/4), mottles are common, medium, and distinct; moderate to strong, medium, angular or subangular blocky structure; firm; calcareous; gradual wavy boundary. 5 to 15 inches thick.
Cg	18"+	Clay loam or silty clay loam; brown (7.5YR 5/2); (10YR 5/3) mottled with gray (5Y 5/1-6/1), pale brown (10YR 6/3), and yellowish brown (10YR 5/6-5/8), mottles are many, coarse, and distinct; weak medium and coarse, angular blocky or massive structure; firm; calcareous.

<u>Topography</u>: Nearly level to depressed areas in old lake plains. Dominant relief is less than 2 per cent slope, the areas were covered by former glacial lakes.

<u>Drainage and Permeability</u>: Poorly drained. Run-off is very slow to ponded. Permeability is slow to very slow.

SIMS SERIES

The Sims series included poorly drained Humic-Gley soils developed in calcareous clay loam or silty clay loam till. Sims soils are the poorly to very poorly drained member of the drainage sequence that included the well to moderately well drained Nester and the imperfectly drained Kawkawlin soils.

Soil Profile:		Sims clay loam
Ap	0-7"	Clay loam; black (10YR 2/1) or very dark gray (10YR 3/1); moderate, medium, granular structure; firm to friable; slightly acid to mildly alkaline; abrupt smooth boundary. 6 to 9 inches thick.
B21g	7-15"	Clay loam or silty clay loam; light brownish gray (10YR 6/2) or gray (10YR 5/1) mottled with brown (10YR 5/3-4/3) and yellowish brown (10YR 5/4-5/6), mottles are few, medium, and distinct; moderate, medium, angular or subangular blocky structure; firm; slightly acid to mildly alkaline; gradual wavy boundary. 5 to 12 inches thick.
B22g	15-32"	Clay loam or silty clay loam; light gray (10YR 7/1) or light brownish gray (10YR 6/2) mottled with yellowish brown (10YR 5/4-5/6) and dark yellowish brown (10YR 4/4), mottles are many, coarse, and distinct; moderate to strong, medium, angular blocky structure; firm; neutral to mildly alkaline; clear wavy boundary. 5 to 20 inches thick.

Cg	32"+	Clay loam or silty clay loam; light gray (10YR 7/1) or light brown (10YR 5/2) mottled with yellowish brown (10YR 5/4) and brown (10YR 5/3-4/3); mottles are many, coarse, and distinct; weak, or moderate, medium and coarse, angular blocky structure; firm; calcareous.

Physiography: Nearly level to depressed areas in till plains and low moraines.

Drainage and Permeability: Poorly to very poorly drained. Run-off is very slow to ponded. Permeability is slow.

MONTCALM SERIES

Montcalm series includes well to moderately well drained biseque soils with a minimal Podzol upper sequum and a Gray Wooded lower sequum which developed in slightly acid to calcareous loamy sand or sand drift. Montcalm soils are the well to moderately well drained member of the catena that includes the imperfectly drained Otisco and the poorly to very poorly drained Edmore soils.

<u>Soil Profile</u>:		Montcalm loamy sand
Ap	0-7"	Dark grayish brown (10YR 4/2) to dark brown (10YR 3/3); loamy sand; very weak, fine, granular structure; very friable; slightly to strongly acid; low to moderate organic matter content; abrupt smooth boundary. 6 to 12 inches thick.
A2	7-9"	Light gray (10YR 7/2) to grayish brown (10YR 5/2); loamy sand; very weak, fine, granular structure; very friable; medium to strongly acid; smooth clear boundary. 1 to 7 inches thick.
B2ir	9-15"	Brown (7.5YR 4/4-5/4) to yellowish brown (10YR 5/4-5/6); loamy sand; very weak, fine, granular structure; very friable to loose; medium to strongly acid; gradual boundary. 4 to 10 inches thick.
A2	15-26"	Pale brown (10YR 6/3) to light yellowish brown (10YR 6/4); loamy sand, very weak, thin, platy structure; very friable to slightly compact and brittle; medium to strongly acid; clear wavy boundary. 8 to 18 inches thick.

Bt	26-33"	Reddish brown (5YR 4/4) to brown (7.5YR 5/4-4/4); sandy loam to coarse, sandy clay loam; weak to moderate, medium and coarse, sub-angular blocky structure; friable to slightly firm; slightly to strongly acid; abrupt wavy boundary. 3 to 12 inches thick.
A2 and Bt sequence	33-60"	Light brownish gray (10YR 6/2) to pale brown (10YR 6/3); medium to coarse and representing the A2 with thin bands, layers, and lenses, 1/2 to 4 inches thick, of reddish brown (5YR 4/4) to brown (7.5YR 4/4) of fine, loamy sand to sandy loam, representing the Bt horizons; the A2 has single grain structure and is loose; while the Bt is massive to very weak, medium, subangular blocky structure and is very friable to friable; slightly to medium acid; abrupt wavy boundary between the last Bt horizons and the C horizon. 15 to 42 inches thick.
C	60"+	Pale brown (10YR 6/3) to yellowish brown (10YR 5/4); medium to coarse loamy sand to sand; single grain; loose; slightly acid, neutral to calcareous.

Topography: Nearly level to strongly sloping to steep areas in moraines, till plains, and outwash plains.

Drainage and Permeability: Well to moderately well drained. Run-off is medium on the milder slopes and rapid on the strongly sloping areas. Permeability is moderate to rapid.

KARLIN SERIES

The Karlin series consist of well-drained Podzols developed in loamy fine sand to find sandy loam, 15 to 42 inches thick, overlying sand. Weak, thin textural B horizons are often present below depths of 36 inches. Karlin soils are the well drained member of the catena (toposequence) that includes the imperfectly drained Sigma and the poorly to very poorly drained Sagaing soils.

Soil Profile:		Karlin fine sandy loam
Ap	0-8"	Fine sandy loam; very dark grayish brown (10YR 3/2); very weak, granular structure; fine, very friable; moderate in organic matter; slightly to medium acid; abrupt smooth boundary. 6 to 11 inches thick.
A2	8-9"	Sandy loam; pinkish gray (7.5YR 6/2-72/); very weak, coarse, granular structure; very friable; medium to strongly acid; abrupt wavy boundary. 1 to 3 inches thick.
B2ir	9-23"	Coarse, sandy loam; dark brown (10YR 4/3-7.5YR 4/4); very weak, medium subangular block structure; very friable; medium to strongly acid; gradual wavy boundary. 9 to 20 inches thick.
IIB2	23-30"	Sand; yellowish brown (10YR 5/4-5/6); single grain structure; loose; medium acid; gradual wavy boundary. 8 to 15 inches thick.
IIB3	30"+	Sand; light yellowish brown (10YR 6/4); single grain structure; loose; medium to slightly acid.

Topography: Nearly level to strongly sloping areas in outwash plains and old glacial drainageways.

Drainage and Permeability: Well-drained. Run-off is slow to medium. Permeability is rapdi.

GRANBY SERIES

Granby series includes Humic-Gley soils developed in neutral to calcareous sands. Granby soils are the poorly to very poorly drained member of the catena (toposequence), that includes the well-drained Oakville, moderately well-drained Ottokee, imperfectly drained Tedrow, and the very poorly drained very dark colored Maumee soils.

Soil Profile:		Granby loamy fine sand
Ap	0-8"	Loamy fine sand; very dark grayish brown (10YR 2/2) or very dark gray (10YR 3/1); very weak, medium, granular structure; very friable; medium acid to neutral; abrupt smooth boundary. 7 to 10 inches thick.
A12	8-12"	Loamy fine sand; very dark gray (10YR 3/1); very weak, coarse, granular structure; very friable; medium acid to neutral; gradual wavy boundary. 2 to 6 inches thick.
Bg	12-40"	Loamy sand to sand; yellowish brown (10YR 5/6-5/8) mottled with gray (10YR 5/1), brownish yellow (10YR 6/6), and dark brown (7.5YR 5/2-4/4); mottles are common, medium and distinct in upper part with gradual change to many, coarse, and distinct in lower part; coatings of very dark gray are on many sand grains in upper 3 or 4 inches; single grain structure; loose; slightly acid to neutral; diffuse irregular boundary. 20 to 40 inches thick.

Cg 30"+ Sand; gray (10YR 5/1) or light brownish gray (10YR 6/2) mottled with yellowish brown (10YR 5/6-5/8), dark yellowish brown (10YR 4/4), and brownish yellow (10YR 6/6-6/8); mottles are many, coarse, and distinct, single grain structure; loose, mildly alkaline to calcareous.

Topography: Nearly level to slightly depressed areas in outwash and lake plains.

Drainage and Permeability: Poorly to very poorly drained. Run-off is very slow to ponded. Permeability is very rapid.

HODUNK SERIES

The Hodunk series consists of moderately well drained Gray-Brown Podzolic soils with fragipans which developed on calcareous sandy loam glacial till. Hodunk soils are found in association with the well drained Hillsdale and moderately well drained Elmdale series which are also developed on calcareous sandy loam till.

<u>Soil Profile</u>:		Hodunk sandy loam
Ap	0-7"	Dark grayish brown (10YR 4/2) to very dark grayish brown (10YR 3/2); sandy loam; moderate, fine, granular structure; friable when moist and soft when dry; medium content of organic matter; medium to slightly acid; abrupt smooth boundary. 6 to 11 inches thick.
A2	7-16"	Yellowish brown (10YR 5/4); pale brown (10YR 6/3) or light yellowish brown (10YR 6/4); sandy loam; weak, fine, granular to weak, fine, subangular blocky structure; very friable when moist and soft when dry; medium acid; abrupt wavy boundary. 6 to 20 inches thick.
Bim	16-25"	Brown (10YR 5/3) to pale brown (10YR 6/3); sandy loam to light sandy clay loam; massive to weak, thick, platy structure; firm when moist and brittle when dry; weak to moderately developed fragipan; few thick clay flows; medium to strongly acid; clear wavy boundary. 4 to 12 inches thick.

B2g	25-46"	Brown (10YR 5/3) to yellowish brown (10YR 5/4) mottled with yellowish bronw (10 YR 5/8) and dark brown (7.5YR 4/4), mottles are common, medium, distinct; sandy clay loam, heavy sandy loam, or light clay loam; few thick clay flows; weak, medium, subangular blocky structure; firm when moist, strongly to medium acid in the upper part and slightly acid in the lower part; abrupt irregular boundary. 15 to 30 inches thick.
Cg	46"+	Light yellowish bronw (10YR 6/4) to brown (10YR 5/3) mottled with yellowish brown (10YR 5/6-5/8), mottles are commong, medium, distinct; sandy loam; massive to very weak, coarse, subangular blocky structure; friable when moist and hard when dry; calcareous.

Topography: Gently to moderately sloping till plains and moraines.

Drainage and Permeability: Moderately well drained. Surface run-off is slow to moderate. Permeability is moderate to slow depending upon the degree of development of the fragipan.

TUSCOLA SERIES

The Tuscola series comprises moderately well drained Gray-Brown Podzolic soils which developed in stratified silts, very fine sands, and fine sands. Tuscola series is the moderately well drained member of the drainage sequence that includes the well drained Sisson, imperfectly drained Kibbie, and the poorly to very poorly drained Colwood soils.

Soil Profile:		Tuscola fine sandy loam
Ap	0-9"	Fine sandy loam; dark grayish brown (10YR 4/2), very dark grayish brown (10YR 3/2); weak, coarse, granular structure; friable; slightly acid; abrupt smooth boundary. 7 to 10 inches thick.
A2	9-13"	Fine sandy loam; yellowish brown (10YR 5/4) or brown (10YR 5/3) with grayish brown (10YR 3/2) organic coatings on some ped faces and in warm casts; weak, fine, subangular blocky to weak, thin, platy structure; friable; slightly acid to neutral; clear smooth boundary. 3 to 6 inches thick.
B21	13-24"	Fine sandy loam or loamy; dark yellowish brown (10YR 4/4) with a few pads coated with dark grayish brown (10YR 4/2); weak to moderate, medium, subangular blocky structure; slightly firm; very thin discontinuous clay flows; slightly acid to neutral; gradual smooth boundary. 8 to 17 inches thick.

B22	24-34"	Very fine sandy loam or silt loam; brown (10YR 5/3) with common, medium, faint yellowish brown (10YR 5/8) and common, fine, distinct gray (10YR 5/1) mottles weak, medium, subangular blocky structure; slightly firm; very thick discontinuous or patchy clay flows; slightly acid to neutral; clear smooth boundary. 6 to 14 inches thick.
B23g	34-42"	Silt loam or silts; grayish brown (10YR 5/2) with common, medium, distinct yellowish brown (10YR 5/6-5/8) mottles; weak, medium, subangular blocky structure; slightly firm; very thin patchy clay flows; neutral; clear wavy boundary. 6 to 12 inches thick.
B3g	42-44"	Very fine sandy loam; grayish brown (10YR 5/2) mottled with yellowish brown (10YR 5/6-5/8) and gray (10YR 5/1), mottles are common, medium, and distinct; massive (stratified) to very weak, coarse, subangular blocky structure; friable; mildly alkaline; abrupt wavy boundary. 1 to 10 inches thick.
Cg	44-54"	Silts and very fine sands; gray (10YR 5/1) mottled with grayish brown (10YR 5/2), and dark brown (7.5YR 4/4) mottles are common, medium, and distinct; massive (stratified) friable; calcareous.

Topography: Nearly level to gently sloping areas on lake plains and deltas.

Drainage and Permeability: Moderately well drained. Run-off is slow. Permeability is moderate.

BROOKSTON SERIES

Brookston series comprises poorly drained Humic-Gley soils developed in calcareous loam and silt loam till in the Gray Brown Podzolic Soil Region. Brookston soils are the poorly drained member of the drainage sequence that includes the well drained Miami, the moderately well drained Celina, the imperfectly drained Conover, and the very poorly drained, very dark-colored Kokomo soils.

Soil Profile:		Brookston clay loam
Ap	0-8"	Clay loam; very dark grayish brown (10YR 3/2) or very dark brown (10YR 2/2); weak, coarse, granular structure; usually cloddy when dry; friable to firm; slightly acid to neutral; abrupt smooth boundary. 6 to 10 inches thick.
A1	8-12"	Clay loam or silty clay loam; very dark brown (10YR 3/2) or very dark gray (10YR 3/1); weak, coarse, granular to moderate, fine, subangular blocky structure; firm, slightly acid to neutral; clear wavy boundary. 2 to 5 inches thick.
B21	12-15"	Clay loam or silty clay loam; yellow brown (10YR 5/6-5/8) or dark yellowish brown (10YR 4/4) mottled with grayish brown (10YR 5/2) gray (10YR 5/1), and pale brown (10YR 6/3) mottles are common, medium, and distinct; very dark brown (10YR 2/2) coatings occur on many pod faces and in cracks throughout the horizon; moderate, medium to coarse, subangular blocky structure; firm, slightly acid to mildly alkaline; gradual wavy boundary. 2 to 8 inches thick.

B22	15-48"	Clay loam or silty clay loam; dark yellowish brown (10YR 4/4) or yellowish brown (10YR 5/6-5/8) mottled with gray (10YR 5/1), brownish yellow (10YR 6/6), and light olive brown (2.5Y 5/4), mottles are many, coarse, and distinct; thick to thin clay coatings on many pod faces; weak, coarse, prismatic which breaks to moderate to strong, coarse, angular blocky structure; firm to very firm; neutral to mildly alkaline abrupt irregular boundary. 20 to 40 inches thick.
C1	48"+	Loam or silt loam; yellowish brown (10YR 5/4) or light olive brown (2.5Y 5/4) mottled with gray (10YR 5/2), grayish brown (10YR 5/2), and dark yellowish brown (10YR 4/4), mottles are many, coarse, and distinct; massive; friable, calcareous.

<u>Topography</u>: Nearly level broad depressed flats and depressions in till plains and morainic areas.

<u>Drainage and Permeability</u>: Poorly to very poorly drained. Surface run-off is very slow to ponded. Permeability is low.

NEWTON SERIES

Newton series comprises Humic-Gley soils developed in strongly to very strongly acid sands. They are the poorly to very poorly drained member of the catena (toposequence) that includes the well drained Plainfield, moderately well drained Nekoosa, imperfectly drained Morocco, and the very poorly drained, very dark-colored Dillon series.

<u>Soil Profile</u>:		Newton loamy fine sand
Ap	0-8"	Loamy fine sand; very dark brown (10YR 2/2) or very dark gray (10YR 3/1) very weak, medium, granular structure; very friable; medium to very strongly acid; abrupt smooth boundary. 7 to 10 inches thick.
A12	8-12"	Loamy fine sand; very dark gray (10YR 3/1); few, fine distinct mottles of yellowish-brown (10YR 5/6-5/8) in lower part; very weak, coarse, granular structure; very friable; strongly to very strongly acid; clear wavy boundary. 2 to 6 inches thick.
Bg	12-30"	Loamy sand to sand; grayish-brown (10YR 5/2) or gray (10YR 5/1) mottled with yellowish-brown (10YR 5/6-5/8), dark yellowish-brown (10YR 4/4), and strong brown (7.5YR 5/6), mottles are common, medium, and distinct in the upper part, with gradual change to many, coarse and distinct in lower part; single grain structure; loose; strongly to very strongly acid; diffuse irregular boundary. 14 to 30 inches thick.

Cg	30"+	Sand; yellowish brown (10YR 5/6) or brownish yellow (10YR 6/6-6/8) mottled with gray (10YR 5/1), dark yellowish brown (YR 4/4), and dark brown (7.5YR 4/2-4/4); mottles are common, medium, and distinct; single grain structure; loose; strongly to very strongly acid; gradual change below 60 inches to medium or slightly acid reaction.

<u>Topography</u>: Nearly level to slightly depressed areas in outwash and lake plains.

<u>Drainage and Permeability</u>: Poorly to very poorly drained. Run-off is very slow to ponded. Permeability is very rapid.

OSHTEMO SERIES

The Oshtemo series comprises well drained Gray Brown Podzolic soils developed in sandy loam, loam, or loamy sand outwash materials underlain by neutral to calcareous sand and fine gravel to 42 to 66 inches or more. Oshtemo soils are the well drained member of the drainage sequence that includes the moderately well drained Bronson, the imperfectly drained Brady, and the poorly to very poorly drained Gilford soils.

<u>Soil Profile</u>		Oshtemo sandy loam
Ap	0-9"	Sandy loam; dark grayish brown (10YR 4/2) or very dark grayish brown (10YR 3/2); weak, coarse, granular structure; very friable; slightly acid; abrupt smooth boundary. 7 to 12 inches thick.
A2	9-14"	Loamy sand or sandy loam; dark brown (7.5YR 4/2) brown (10YR 5/3) or yellowish brown (10YR 5/4); very weak, fine, subangular blocky structure; very friable; numerous worn and root channels filled with Ap material; medium to strongly acid; clear smooth boundary. 4 to 10 inches thick.
B21	14-26"	Sandy loam; dark reddish brown (5YR 3/4); very weak, coarse, subangular blocky structure; friable; slight increase in clay content from top to bottom of horizon, tubular fillings of Ap material extend into the upper part of horizon with a few thin discontinuous clay films; medium to strongly acid; clear wavy boundary. 6 to 20 inches thick.

B22	26-35"	Sandy loam or sandy clay loam; dark brown (7.5YR 4/4); weak, coarse, subangular block structure; friable; medium to strongly acid; gradual wavy boundary. 3 to 10 inches thick.
B31	35-46"	Loamy sand or sand with sandy loam stratra; very friable, medium acid; diffuse irregular boundary. 5 to 25 inches thick,
B32	46-63"	Loamy sand or sand with sandy loam stratra; dark brown (7.5YR 3/2) or stratra of variable thickness; sand grains have nearly continuous dark brown (7.5YR 3/2) coatings; massive or very weak, coarse, subangular blocky structure; very friable; medium to slightly acid; abrupt irregular boundary. 8 to 25 inches thick.
IIC	63-74"+	Sand and fine gravel; grayish brown (10YR 5/2); single grain (structureless); loose; neutral to calcareous; some gravel has lime coatings on lower side.

Topography: Nearly level to strongly sloping areas on outwash plains, valley trains, and moraines.

Drainage and Permeability: Well drained. Run-off is slow on the level to gently sloping areas and medium to rapid on the steeper slopes. Permeability is moderately rapid.

Table A. The soil types, manganese deficiency index values, soil chemical properties, and yield and plant manganese data: (Experiment 1)

Soil Type	Treatment[1]	Replication	Mn Deficiency Index[2]	pH	Lime Requirement	Pounds per acre: P	Pounds per acre: K	Pounds per acre: Ca	Pounds per acre: Mg	pp2m Mn Extractants: 0.1N H_3PO_4	pp2m Mn Extractants: 1N NH_4OAc + 0.2 per cent Hydroquinone	Oat Yield gms/pot	Oat Tissue Mn ppm	Oat Mn Uptake mgm/pot	Bean Yield gms/pot	Bean Tissue Mn ppm	Bean Mn Uptake mgm/pot
Houghton muck (Soil Number 1)	A	1	2	6.6	0	40	378	14200	3120	10	28	8.815	7	.062	4.570	21	.096
	A	2	2	6.7	0	28	259	13600	2912	10	28	11.415	11	.126	4.975	23	.114
	A	3	1	6.6	0	29	370	14000	2912	10	27	9.655	9	.087	4.730	20	.095
	B	1	1	6.7	0	32	259	14650	2561	15	103	12.494	18	.225	4.595	36	.165
	B	2	1	6.6	0	47	264	8320	2574	15	104	10.540	19	.200	4.500	21	.095
	B	3	1	6.6	0	30	378	14200	2353	10	105	10.910	19	.207	4.760	33	.157
	C	1	5	7.0	0	25	582	14800	2912	0	25	3.365	26	.087	3.290	11	.036
	C	2	5	7.1	0	28	522	13400	3120	0	22	4.120	3	.012	2.825	14	.039
	C	3	5	7.1	0	24	540	14200	3328	0	22	3.135	5	.016	3.415	15	.051
Houghton muck (Soil Number 2)	A	1	1	6.3	0	26	438	10400	1898	10	70	11.955	13	.155	5.235	32	.168
	A	2	1	6.3	0	37	546	13000	2249	5	65	11.150	14	.156	4.950	29	.144
	A	3	1	6.2	0	107	793	13200	2080	10	70	10.425	22	.229	5.025	34	.171
	B	1	1	6.3	0	33	432	14000	2249	15	120	12.175	24	.292	4.645	41	.190
	B	2	1	6.3	0	45	344	14200	2249	20	139	12.620	22	.278	5.335	28	.149
	B	3	1	6.3	0	45	480	14200	2353	20	139	11.105	25	.278	5.900	44	.260
	C	1	3	7.1	0	34	654	13200	2249	5	56	5.990	11	.066	3.565	18	.064
	C	2	3	7.1	0	30	627	12800	2249	0	53	5.380	10	.054	4.279	24	.103
	C	3	3	7.2	0	29	582	12800	2561	0	53	7.445	11	.082	4.990	16	.080
Wisner sandy clay loam (Soil Number 3)	A	1	2	7.1	0	138	299	6448	542	45	42	0			.520	31	.016
	A	2	2	7.3	0	130	282	5304	541	50	44	0			.910	32	.029
	A	3	2	7.4	0	125	291	5616	515	40	42	0			1.345	31	.042
	B	1	1	7.2	0	32	259	6448	640	90	88	0			1.550	33	.051
	B	2	1	7.3	0	47	264	6760	640	90	95	0			1.165	38	.044
	B	3	1	7.5	0	30	378	5096	589	80	89	0			1.140	53	.060
	C	1	2	7.5	0	122	258	5304	541	15	42	0			1.585	38	.060

Table A, Cont.

Soil Type	Treatment[1]	Replication	Mn Deficiency Index[2]	pH	Lime Requirement	Pounds per acre: P	K	Ca	Mg	pp2m Mn Extractants: 0.1N H_3PO_4	1N NH_4OAc 0.2 per cent Hydroquinone	Oat Yield	Oat Tissue Mn	Oat Mn Uptake	Bean Yield	Bean Tissue Mn	Bean Mn Uptake
												gms/pot	ppm	mgm/pot	gms/pot	ppm	mgm/pot
Wisner sandy clay loam (Soil Number 3)	C	2	2	7.6	0	122	264	5720	515	20	30	0			1.803	33	.059
	C	3	2	7.4	0	134	280	5408	541	25	30	0			1.475	47	.059
Wisner sandy clay loam (Soil Number 4)	A	1	1	7.5	0	73	267	5304	720	35	21	10.560	16	.169	4.025	25	.101
	A	2	1	7.6	0	67	277	4576	640	30	22	8.910	16	.143	2.620	23	.060
	A	3	1	7.5	0	69	299	4992	688	70	70	8.000	23	.184	3.050	45	.137
	B	1	1	7.5	0	51	259	4784	837	35	20	8.195	14	.123	2.980	29	.086
	B	2	1	7.5	0	64	267	5304	776	85	84	8.520	32	.273	3.480	39	.136
	B	3	1	7.4	0	66	282	5512	776	85	73	7.295	22	.160	3.610	45	.162
	C	1	5	7.4	0	59	264	5512	659	20	18	8.535	12	.102	3.050	27	.082
	C	2	1	7.4	0	51	236	4680	659	20	22	9.725	10	.097	3.213	19	.061
	C	3	2	7.5	0	61	236	4784	589	20	24	9.810	10	.098	2.730	24	.066
Sims clay loam (Soil Number 5)	A	1	1	6.4	2.0	69	307	5824	1040	30	46	14.550	13	.189	4.235	27	.114
	A	2	1	6.3	2.0	62	299	5304	1075	45	45	14.635	19	.278	3.790	50	.190
	A	3	1	6.4	1.5	54	282	5304	1120	75	102	15.885	27	.429	3.805	27	.103
	B	1	1	6.5	2.0	64	299	5304	1120	25	40	12.300	16	.197	3.895	38	.148
	B	2	1	6.4	2.0	53	291	5616	1075	70	116	13.775	24	.331	4.505	25	.113
	B	3	1	6.3	2.0	66	332	5616	1040	55	88	11.685	27	.315	4.635	28	.130
	C	1	3	7.3	0	58	295	6344	837	10	42	11.000	8	.088	3.780	21	.079
	C	2	1	7.3	0	71	280	6552	867	10	30	11.600	5	.058	2.891	15	.043
	C	3	1	7.3	0	66	272	5512	898	10	29	12.500	4	.050	3.160	24	.076
Montcalm sandy loam (Soil Number 6)	A	3	1	5.2	4.0	160	320	1040	50	165	147	8.895	510	4.536	2.705	1000	2.705
	A	2	1	5.1	3.5	300	344	932	61	175	138	10.140	505	5.130	2.960	1360	4.026
	A	3	1	5.2	3.5	336	237	828	61	170	143	11.380	505	5.760			

Table A, Cont.

Soil Type	Treatment[1]	Replication	Mn Deficiency Index[2]	pH	Lime Requirement	Pounds per acre P	K	Ca	Mg	pp2m Mn Extractants 0.1N H_3PO_4	1N NH_4OAc-0.2 per cent Hydroquinone	Oat Yield	Oat Tissue Mn	Oat Mn Uptake	Bean Yield	Bean Tissue Mn	Bean Mn Uptake
												gms/pot	ppm	mgm/pot	gms/pot	ppm	mgm/pot
Montcalm sandy loam (Soil Number 6)	B	1	1	5.3	3.5	282	307	1144	61	230	184	10.480	1175	12.314	2.105	2600	5.473
	B	2	1	5.2	3.5	276	307	1040	67	240	220	11.005	1000	11.005	1.270	3200	4.064
	B	3	1	5.2	3.5	306	338	1040	67	212	168	10.250	900	9.225	3.000	2000	6.000
	C	1	1	7.1	0	240	295	3328	98	165	143	9.005	169	1.522	3.450	73	.252
	C	2	1	7.0	0	288	301	3016	78	165	153	7.310	183	2.785	1.338	54	.150
	C	3	1	7.1	0	276	301	2704	61	165	160	8.000	174	1.392	2.240	62	.139
Karlin sandy loam (Soil Number 7)	A	1	1	4.7	4.0	162	238	416	50	285	309	5.120	2300	11.776	.920	863	.794
	A	2	1	4.8	5.0	168	277	384	43	285	303	7.695	1075	8.272	.870	2140	1.862
	A	3	1	4.7	3.5	162	344	392	67	315	306	3.905	2025	7.908	1.220	3250	3.965
	B	1	1	4.8	4.0	186	408	400	61	345	336	4.780	2100	10.038	0.0	0	0.0
	B	2	1	4.9	5.0	174	320	456	61	365	392	7.445	1000	7.445	.695	3300	2.294
	B	3	1	4.6	4.0	162	277	440	61	400	360	5.180	1825	9.454	.319	2400	.766
	C	1	1	7.0	0	162	236	2392	43	280	308	8.170	172	1.405	2.235	51	.114
	C	2	1	6.8	0	162	264	2392	35	285	292	5.985	135	.808	2.760	73	.201
	C	3	1	6.8	0	162	264	2080	31	285	280	8.395	130	1.091	2.445	42	.103
Granby loamy fine sand (high organic matter) (Soil Number 8)	A	1	2	7.0	0	37	83	3328	414	85	76	11.355	31	.352	2.905	27	.078
	A	2	1	7.1	0	37	83	3744	414	75	70	12.425	31	.385	3.480	21	.073
	A	3	1	6.9	0	40	84	3224	432	80	78	10.915	27	.295	3.575	25	.089
	B	1	1	6.9	0	42	136	3744	453	115	118	11.795	68	.802	3.370	49	.165
	B	2	1	6.9	0	43	99	3536	414	120	112	10.575	41	.434	3.435	32	.110
	B	3	1	7.1	0	37	76	3224	414	125	106	12.160	75	.912	3.730	50	.187
	C	1	1	7.5	0	45	69	3640	414	55	81	12.215	13	.159	2.821	30	.085
	C	2	3	7.3	0	34	84	3952	339	55	78	10.020	11	.110	2.850	35	.100
	C	3	3	7.4	0	26	69	3536	302	45	82	10.645	11	.117	2.471	47	.116

Table A, Cont.

Soil Type	Treat-ment[1]	Repli-cation	Mn Defi-ciency Index[2]	pH	Lime Require-ment	Pounds per acre P	K	Ca	Mg	pp2m Mn Extractants 0.1N H_3PO_4	1N NH_4OAc-0.2 per cent Hydro-quinone	Oat Yield gms/pot	Oat Tissue Mn ppm	Oat Mn Uptake mgm/pot	Bean Yield gms/pot	Bean Tissue Mn ppm	Bean Mn Uptake mgm/pot
Hodunk sandy loam (Soil Number 9)	A	1	1	5.3	3.0	160	188	1144	173	190	185	8.320	265	2.205	3.150	220	.693
	A	2	1	5.3	2.0	152	144	1144	193	185	200	8.880	235	2.087	3.780	121	.457
	A	3	1	5.5	3.0	152	130	1144	173	200	201	8.870	245	2.173	2.910	260	.757
	B	1	1	5.4	3.5	160	124	1040	173	250	220	10.470	355	3.717	3.230	210	.678
	B	2	1	5.3	2.0	152	130	932	197	250	225	8.435	350	2.952	2.880	260	.748
	B	3	1	5.3	3.0	144	76	1144	210	280	238	11.430	345	3.943	2.830	106	.300
	C	1	5	7.1	0	118	158	3120	67	175	172	6.050	24	.145	2.460	20	.049
	C	2	2	7.2	0	114	180	2912	50	165	180	6.735	23	.155	2.620	42	.110
	C	3	1	7.2	0	114	172	3224	67	170	182	5.385	23	.124	2.400	33	.080
Wisner sandy clay loam (Soil Number 10)	A	1	2	7.3	0	138	301	5096	776	115	164	8.215	20	.164	3.340	46	.154
	A	2	1	7.3	0	130	374	4992	936	110	172	7.120	25	.178	3.350	38	.127
	A	3	1	7.4	0	138	308	4992	776	115	155	7.110	17	.121	2.755	53	.146
	B	1	1	7.2	0	134	280	4744	659	130	201	7.265	29	.211	3.270	58	.190
	B	2	1	7.4	0	130	308	4264	640	150	176	7.400	26	.192	3.112	48	.149
	B	3	1	7.4	0	144	280	4160	776	160	187	9.690	26	.252	2.685	36	.097
	C	1	5	7.4	0	130	308	5616	659	70	162	8.325	11	.092	2.575	82	.211
	C	2	2	7.5	0	114	272	5304	659	80	162	8.640	16	.138	2.605	61	.159
	C	3	5	7.4	0	118	301	5720	688	85	165	9.465	11	.104	2.430	75	.182
Tuscola fine sandy clay loam (Soil Number 11)	A	1	1	7.4	0	130	208	5512	936	65	107	9.795	14	.137	2.780	28	.078
	A	2	1	7.4	0	134	221	5200	867	55	110	9.535	9	.086	3.320	19	.063
	A	3	1	7.4	0	134	208	6136	867	50	98	9.505	20	.190	2.400	25	.060
	B	1	1	7.5	0	130	194	5304	744	100	139	10.225	21	.215	3.245	31	.101
	B	2	1	7.4	0	134	236	4368	898	115	154	11.975	14	.167	2.662	43	.114

Table A, Cont.

Soil Type	Treatment[1]	Replication	Mn Deficiency Index[2]	pH	Lime Requirement	Pounds per acre P	K	Ca	Mg	pp2m Mn Extractants 0.1N H_3PO_4	1N NH_4OAc-0.2 per cent Hydroquinone	Oat Yield	Oat Tissue Mn	Oat Mn Uptake	Bean Yield	Bean Tissue Mn	Bean Mn Uptake
												gms/pot	ppm	mgm/pot	gms/pot	ppm	mgm/pot
Tuscola fine sandy clay loam (Soil Number 11)	B	3	1	7.4	0	160	250	5304	867	130	190	8.750	17	.149	3.105	40	.124
	C	1	5	7.6	0	111	200	5824	776	40	96	10.170	9	.092	3.400	28	.095
	C	2	1	7.5	0	118	208	6552	776	40	100	10.535	8	.084	2.780	24	.067
	C	3	5	7.6	0	111	208	6344	776	45	129	9.955	5	.050	2.765	17	.047
Brookston sandy clay loam (high organic matter) (Soil Number 12)	A	1	1	6.3	1.5	61	137	4680	1005	25	38	10.340	16	.165	5.045	27	.136
	A	2	2	6.4	1.5	59	130	4992	936	35	26	11.515	16	.184	6.490	23	.149
	A	3	1	6.3	1.5	62	137	4888	898	20	30	11.440	10	.114	4.990	20	.100
	B	1	1	6.4	1.5	59	166	4368	960	65	106	11.055	16	.177	4.915	28	.138
	B	2	1	6.3	1.5	66	144	4264	939	55	86	13.375	36	.482	5.325	20	.107
	B	3	1	6.2	1.5	61	137	4472	936	40	84	12.505	31	.388	5.660	57	.323
	C	1	1	7.2	0	54	200	6240	936	10	26	14.370	12	.172	5.070	33	.167
	C	2	1	7.2	0	47	124	6136	898	15	26	11.955	15	.179	3.845	22	.085
	C	3	1	7.2	0	47	104	5096	867	10	24	14.710	11	.162	4.650	30	.140
Newton loamy sand (Soil Number 13)	A	1	5	7.5	0	59	398	10296	867	10	20	6.315	11	.069	2.690	10	.027
	A	2	4	7.5	0	62	308	9468	837	20	19	4.065	48	.195	2.005	11	.022
	A	3	5	7.6	0	62	264	7618	837	10	20	4.490	8	.036	2.430	15	.036
	B	1	1	7.4	0	69	272	8112	744	25	51	8.250	18	.149	3.625	20	.023
	B	2	1	7.4	0	62	356	9646	800	20	53	7.910	16	.127	2.965	20	.059
	B	3	2	7.6	0	59	243	8424	688	15	46	7.655	25	.191	2.660	19	.050
	C	1	4	7.6	0	73	374	9152	898	10	22	5.380	5	.027	2.240	17	.038
	C	2	5	7.6	0	64	295	9984	898	10	24	4.920	9	.044	2.310	19	.043
	C	3	4	7.6	0	54	374	9360	936	5	23	4.010	20	.080	2.131	17	.036
Houghton muck (Soil Number 14)	A	1	1	6.8	0	102	780	14400	2146	45	105	11.160	7	.078	5.210	35	.182
	A	2	1	6.7	0	99	897	14200	1342	50	81	8.470	18	.152	5.050	35	.177
	A	3	1	6.8	0	102	728	13400	1342	20	80	11.175	11	.123	6.025	17	.102

Table A, Cont.

Soil Type	Treatment[1]	Replication	Mn Deficiency Index[2]	pH	Lime Requirement	Pounds per acre P	K	Ca	Mg	pp2m Mn Extractants 0.1N H_3PO_4	1N NH_4OAc + 0.2 per cent Hydroquinone	Oat Yield gms/pot	Oat Tissue Mn ppm	Oat Mn Uptake mgm/pot	Bean Yield gms/pot	Bean Tissue Mn ppm	Bean Mn Uptake mgm/pot
Houghton muck (Soil Number 14)	B	1	1	6.7	0	88	770	9984	1040	10	142	12.060	23	.277	5.445	20	.109
	B	2	1	6.7	0	93	897	9870	1120	10	148	10.810	32	.346	5.680	28	.153
	B	3	1	6.7	0	102	770	10296	1040	10	138	11.145	16	.178	4.955	43	.213
	C	1	2	7.3	0	66	988	13400	1157	0	71	8.890	7	.062	4.580	25	.115
	C	2	2	7.3	0	64	780	12400	1157	0	64	6.940	8	.056	4.490	19	.085
	C	3	1	7.3	0	64	780	12600	1157	0	70	8.005	4	.032	4.760	21	.100
Ostemo loamy sand (Soil Number 15)	A	1	1	5.6	1.5	162	76	360	31	265	288	10.800	385	4.158	1.375	1805	2.482
	A	2	1	5.5	1.5	168	84	296	31	260	288	9.875	375	3.703	1.425	1240	1.767
	A	3	1	5.5	1.5	162	69	256	19	280	292	11.015	390	4.296	1.570	1945	3.054
	B	1	1	5.6	1.5	162	76	320	31	280	336	10.460	1025	10.722	1.055	3600	3.834
	B	2	1	5.4	1.5	174	60	266	31	285	322	10.520	1250	13.150	.960	2800	2.688
	B	3	1	5.4	1.5	162	48	272	16	300	316	10.550	800	8.440	1.265	2950	3.732
	C	1	1	7.6	0	152	69	2392	16	230	296	9.755	43	.419	1.330	15	.020
	C	2	1	7.6	0	160	69	2496	16	265	308	6.820	36	.246	1.570	30	.047
	C	3	1	7.7	0	160	76	2184	19	245	308	8.385	32	.268	1.315	38	.050

[1]Treatment:
- A Control
- B 15 pounds of manganese per acre
- C Lime application sufficient to induce manganese deficiency

* Plant tissue tested for herbicidal traces (Gas Chromatography)

[2]Manganese Deficiency Index:
1. No apparent manganese deficiency, classified as Mn sufficiency
2. Very slight general yellowing of the leaves but no mottling, classified as Mn latent deficiency
3. Slight mottling between veins — Classified as Mn deficiency
4. Severe mottling between veins — Classified as Mn deficiency
5. Severe mottling and necrosis — Classified as Mn deficiency

Table B. Soil textural class, chemical properties, plant yield values and manganese uptake data on 170 mineral soils and 9 organic soils. (Experiment 2)

Soil Number	Soil Textural Class*	pH	Lime Requirement	Pounds per acre P	K	Ca	Mg	pp2m Mn Extractants 0.1N H_3PO_4	1N NH_4OAc+ 0.2 percent Hydroquinone	Oat Yield gms/pot	Oat Tissue Mn ppm	Oat Mn Uptake mgm/pot	Radish Yield gms/pot
1	5	6.4	1.5	12	112	2600	370	245	592	2.400	40.0	.096	.750
2	3	6.7	0.0	35	72	1560	96	230	232	2.620	67.0	.176	.740
3	4	6.7	0.0	7	112	2080	248	85	62	2.425	26.5	.064	.570
4	4	7.3	0.0	6	80	3848	370	140	156	2.400	22.0	.053	1.050
5	3	7.3	0.0	115	120	3016	274	115	142	2.795	5.5	.015	.850
6	2	6.2	1.0	32	35	1040	160	212	256	2.360	70.0	.165	.430
7	1	5.9	4.0	139	56	416	112	35	23	2.895	37.5	.109	.590
8	3	7.3	0.0	123	216	3536	176	25	29	1.800	3.5	.975	.006
9	3	7.3	0.0	48	96	4160	274	25	27	2.080	8.0	.016	1.280
10	4	7.1	0.0	38	88	3598	646	120	156	2.405	3.5	.008	.630
11	3	6.4	1.0	37	80	2080	237	100	118	2.360	50.0	.118	.830
12	3	6.4	1.0	30	56	1976	128	80	99	2.325	35.5	.083	.790

Table B. continued

Soil Number	Soil Textural Class*	pH	Lime Requirement	P (Pounds per acre)	K (Pounds per acre)	Ca (Pounds per acre)	Mg (Pounds per acre)	pp2m Mn Extractants 0.1N H_3PO_4	pp2m Mn Extractants 1N NH_4OAc+ 0.2 percent Hydroquinone	Oat Yield gms/pot	Oat Tissue Mn ppm	Oat Mn Uptake mgm/pot	Radish Yield gms/pot
13	4	6.5	0.0	16	64	2392	203	85	124	2.305	55.0	.127	.620
14	3	6.2	1.5	85	88	3266	203	76	30	2.440	31.0	.890	.075
15	4	7.6	0.0	45	88	10296	237	20	26	2.740	5.5	.015	1.280
16	1	5.8	3.0	6	40	512	80	260	512	2.350	155.0	.364	.350
17	2	5.5	5.0	44	100	1331	112	55	38	2.370	68.0	.161	.540
18	2	5.4	3.0	87	100	832	64	35	19	2.895	46.5	.135	.540
19	3	6.4	1.0	33	64	1248	112	355	412	2.475	44.0	.109	.750
20	3	6.4	1.0	29	64	1248	136	265	520	2.240	69.0	.155	.610
21	3	6.4	1.0	43	120	1331	104	375	430	2.660	76.0	.202	.680
22	3	6.4	1.0	74	200	1248	64	300	320	2.810	70.5	.198	.640
23	3	5.6	5.0	64	160	1560	112	230	380	2.640	109.0	.288	.800
24	2	7.1	0.0	35	136	2392	144	205	188	2.610	58.5	.153	.700

Table B. continued

Soil Number	Soil Textural Class*	pH	Lime Requirement	Pounds per acre P	K	Ca	Mg	ppm Mn Extractants 0.1N H_3PO_4	1N NH_4OAc+ 0.2 percent Hydroquinone	Oat Yield gms/pot	Oat Tissue Mn ppm	Oat Mn Uptake mgm/pot	Radish Yield gms/pot
25	2	7.2	0.0	24	104	1976	144	80	78	2.790	22.5	.063	.590
26	2	7.1	0.0	37	56	2184	176	40	29	2.555	19.0	.049	.770
27	3	7.3	0.0	27	72	3744	384	100	265	1.870	25.5	.048	.660
28	2	7.1	0.0	30	35	1664	136	30	17	2.325	11.0	.026	.530
29	2	6.1	1.5	131	112	1248	56	230	200	2.500	20.5	.051	.440
30	2	5.4	4.0	76	136	400	72	120	105	2.110	160.5	.339	.150
31	1	5.1	3.0	139	35	520	32	40	21	2.217	189.5	.420	.300
32	2	6.5	0.0	99	72	1144	72	315	296	2.600	139.0	.361	.330
33	3	5.7	1.5	60	100	832	104	600	640	2.430	225.0	.547	.450
34	3	6.3	1.5	99	80	832	112	260	416	2.355	194.5	.458	.560
35	4	4.5	5.0	564	348	1248	32	430	985	2.230	96.0	.214	.650
36	4	4.7	5.0	690	344	1144	38	520	997	2.005	97.5	.195	.720

Table B. continued

Soil Number	Soil Textural Class*	pH	Lime Require-Ment	Pounds per acre P	K	Ca	Mg	pp2m Mn Extractants 0.1N H_3PO_4	1N NH_4OAc+ 0.2 percent Hydroquinone	Oat Yield gms/pot	Oat Tissue Mn ppm	Oat Mn Uptake mgm/pot	Radish Yield gms/pot
37	4	7.0	0.0	4	72	3016	408	190	608	2.220	52.5	.117	.770
38	4	6.5	0.0	10	112	2600	272	205	464	2.245	44.0	.099	.670
39	3	6.8	0.0	6	80	2704	312	75	116	2.495	16.5	.041	.810
40	2	6.4	1.0	17	104	1040	64	115	101	2.745	106.5	.292	.670
41	2	7.1	0.0	12	88	2392	192	90	100	2.430	26.5	.064	.760
42	3	6.6	0.0	30	100	2496	312	115	170	2.450	50.0	.123	.680
43	4	6.4	1.5	10	192	2704	384	120	232	2.790	80.0	.223	.900
44	3	5.6	2.0	38	112	1560	120	295	368	2.210	90.0	.199	.460
45	3	6.5	0.0	16	160	3120	328	130	541	2.090	47.5	.099	.670
46	3	7.3	0.0	32	100	3848	448	55	60	1.785	16.0	.028	.790
47	3	7.5	0.0	35	112	3848	424	35	56	2.160	13.5	.029	.570
48	2	7.8	0.0	99	244	3598	128	25	9	1.620	2.5	.004	.780

Table B. continued

Soil Number	Soil Textural Class*	pH	Lime Requirement	P (Pounds per acre)	K (Pounds per acre)	Ca (Pounds per acre)	Mg (Pounds per acre)	pp2m Mn Extractants 0.1N H_3PO4	pp2m Mn Extractants 1N NH_4OAc+ 0.2 percent Hydroquinone	Oat Yield gm/pot	Oat Tissue Mn ppm	Oat Mn Uptake mgm/pot	Radish Yield gms/pot
49	3	7.1	0.0	72	104	1768	93	260	608	2.160	60.0	.130	.650
50	3	6.5	0.0	60	200	1331	176	345	800	2.355	57.5	.135	.640
51	2	6.4	1.0	21	56	592	160	85	74	2.525	68.0	.172	.345
52	2	6.8	0.0	22	80	1560	224	100	278	2.930	55.0	.161	.490
53	1	6.5	0.0	46	104	1040	176	140	156	2.875	46.5	.134	.510
54	2	6.6	0.0	39	104	1872	93	205	330	2.405	16.5	.040	.640
55	1	6.7	1.0	48	64	1456	80	90	110	2.900	50.0	.145	.410
56	1	6.4	1.0	43	64	1040	72	120	204	2.770	135.0	.374	.340
57	1	6.4	1.0	30	40	1331	72	160	320	2.775	116.0	.322	.710
58	4	6.2	2.0	37	112	4160	424	25	10	2.310	46.0	.106	1.000
59	4	6.9	0.0	50	128	5304	384	20	12	1.965	19.0	.037	.920
60	4	6.9	0.0	35	104	3016	328	100	156	2.115	36.0	.076	.915

Table B. continued

Soil Number	Soil Textural Class*	pH	Lime Requirement	P (Pounds per acre)	K (Pounds per acre)	Ca (Pounds per acre)	Mg (Pounds per acre)	pp2m Mn Extractants 0.1N H_3PO_4	pp2m Mn Extractants 1N NH_4OAc+ 0.2 per cent Hydroquinone	Oat Yield gms/pot	Oat Tissue Mn ppm	Oat Uptake mgm/pot	Radish Yield gms/pot
61	4	6.7	0.0	51	184	3848	468	75	70	2.015	35.0	.071	.780
62	2	6.6	0.0	64	96	832	160	140	264	2.870	75.0	.215	.480
63	2	6.5	0.0	19	64	1331	93	110	221	2.610	70.0	.183	.590
64	2	6.5	0.0	36	120	1456	93	165	308	2.955	105.0	.310	.710
65	2	6.2	1.0	82	80	1248	80	150	268	2.890	56.5	.163	.500
66	2	6.1	1.5	51	112	624	80	150	276	2.740	83.5	.229	.530
67	2	6.8	0.0	66	136	1144	99	190	304	2.540	48.0	.122	.570
68	4	6.0	2.5	51	160	4888	720	50	55	2.450	79.0	.194	.900
69	4	5.1	3.5	22	104	1560	208	65	76	2.630	13.0	.034	.850
70	4	6.6	0.0	126	224	3120	424	100	78	2.325	26.5	.062	.860
71	4	7.3	0.0	64	352	8216	368	25	13	2.205	2.5	.006	.940
72	6	6.8	0.0	43	128	12200	952	15	54	3.305	11.5	.038	1.120

Table B. continued

Soil Number	Soil Textural Class*	pH	Lime Requirement	Pounds per acre P	K	Ca	Mg	ppm Mn Extractants 0.1N H_3PO_4	1N NH_4OAc+ 0.2 per cent Hydroquinone	Oat Yield gms/pot	Oat Tissue Mn	Oat Uptake mgm/pot	Radish Yield gms/pot
73	4	7.3	0.0	57	208	8008	328	20	18	2.040	4.5	.009	.610
74	3	5.9	2.0	56	112	1331	96	160	160	3.100	30.5	.095	1.050
75	4	6.0	2.5	30	104	3390	336	40	17	2.205	67.5	.149	.810
76	4	6.6	0.0	32	56	6760	480	25	5	2.820	24.5	.069	.370
77	3	5.5	3.5	46	88	1664	112	125	158	2.350	37.5	.088	.700
78	3	6.9	0.0	32	64	8736	586	15	8	2.625	16.5	.043	1.320
79	3	7.1	0.0	59	136	3848	352	80	172	2.475	14.5	.036	.700
80	3	7.0	0.0	70	152	3744	394	95	160	2.370	25.5	.060	.620
81	3	7.1	0.0	37	72	3598	210	55	72	2.590	32.5	.084	.690
82	4	6.4	1.5	16	88	2600	237	85	120	2.205	130.0	.287	.650
83	4	6.2	2.0	43	112	3744	304	45	24	2.160	92.5	.200	.930
84	4	6.0	2.5	16	120	2184	192	70	56	2.180	56.5	.123	.630

Table B. continued

Soil Number	Soil Textural Class*	pH	Lime Requirement	Pounds per acre P	K	Ca	Mg	pp2m Mn Extractants 0.1N H_3PO_4	1N NH_4OAc+ 0.2 per cent Hydroquinone	Oat Yield gms/pot	Oat Tissue Mn ppm	Oat Mn Uptake mgm/pot	Radish Yield gms/pot
85	3	7.2	0.0	62	100	3016	166	170	265	2.530	23.5	.059	.750
86	1	6.9	0.0	135	196	1456	128	90	150	3.010	11.5	.035	.470
87	3	6.2	1.5	27	80	2912	192	95	152	2.470	64.0	.158	.660
88	3	7.1	0.0	115	576	3120	150	160	180	3.040	14.8	.045	.940
89	3	7.1	0.0	78	112	7384	456	45	60	2.525	15.0	.038	.980
90	6	5.6	0.0	30	360	8008	530	35	210	2.980	47.0	.140	1.330
91	6	6.4	0.0	35	584	8632	480	35	200	4.005	34.5	.138	1.740
92	2	6.8	0.0	59	384	5616	530	40	60	2.820	30.0	.085	.540
93	2	7.3	0.0	68	832	12000	704	10	184	3.355	6.0	.020	1.310
94	2	6.3	0.0	35	600	8944	394	20	152	4.280	7.0	.030	1.330
95	3	7.1	0.0	8	112	3600	999	115	170	2.480	33.5	.083	1.140
96	4	7.7	0.0	82	296	8216	352	15	36	1.550	30.0	.047	1.020

Table B. continued

Soil Number	Soil Textural Class*	pH	Lime Requirement	Pounds per acre P	K	Ca	Mg	pp2m Mn Extractants 0.1N H PO4	1N NH OAc+ 0.2 per cent Hydroquinone	Oat Yield gms/pot	Oat Tissue Mn ppm	Oat Uptake mgm/pot	Radish Yield gms/pot
97	3	6.1	2.0	18	96	1872	93	70	78	2.625	71.0	.186	.430
98	3	7.0	0.0	17	80	3266	274	130	200	2.350	31.0	.073	.930
99	6	7.2	0.0	72	320	9568	832	10	84	3.710	2.5	.009	1.030
100	7	6.1	1.5	174	360	4680	237	70	50	2.390	56.5	.135	.310
101	6	7.4	0.0	23	296	11200	203	20	100	3.545	9.0	.032	1.270
102	6	7.3	0.0	29	216	14650	352	10	133	4.535	13.0	.060	1.790
103	2	5.6	5.0	76	96	368	11[illegible]	15	12	2.360	21.5	.051	.390
104	3	5.7	3.0	27	56	1040	51	130	172	2.340	105.0	.246	.610
105	4	6.8	0.0	30	104	2808	394	55	85	2.090	17.5	.037	1.030
106	3	6.5	0.0	16	80	2392	274	75	156	2.335	44.0	.103	.790
107	4	5.5	1.5	7	88	1560	192	70	90	2.310	60.0	.139	.550
108	3	5.7	1.5	16	88	1560	138	230	480	2.225	85.0	.189	.850

Table B. continued

Soil Number	Soil Textural Class*	pH	Lime Requirement	Pounds per acre P	K	Ca	Mg	pp2m Mn Extractants 0.1N H_3PO_4	1N NH_4OAc+ 0.2 percent Hydroquinone	Oat Yield gms/pot	Oat Tissue Mn ppm	Oat Uptake mgm/pot	Radish Yield gms/pot
109	4	6.2	2.0	24	128	3390	274	110	196	1.955	50.0	.098	.670
110	4	6.8	0.0	30	104	2808	394	55	109	2.090	25.5	.053	.920
111	4	7.1	0.0	37	136	3598	352	75	145	2.190	5.0	.011	.460
112	7	7.5	0.0	28	112	10192	832	15	36	1.855	4.0	.007	1.190
113	4	7.5	0.0	46	120	4368	336	55	56	2.155	12.5	.027	.600
114	3	7.5	0.0	42	128	6136	304	25	25	.195	16.5	.0003	.450
115	4	5.6	3.0	30	304	1331	176	90	112	2.490	57.5	.143	.950
116	4	7.4	0.0	39	160	4056	560	110	176	2.420	28.5	.069	.950
117	4	7.6	0.0	50	196	4888	614	115	200	2.035	12.0	.024	1.050
118	4	6.5	0.0	15	168	5096	274	65	120	3.000	22.5	.068	.990
119	3	6.0	2.0	18	96	3536	182	55	92	1.910	41.5	.079	.080
120	3	6.0	2.0	23	80	3390	210	45	50	1.865	18.5	.035	.720

Table B. continued

Soil Number	Soil Textural Class*	pH	Lime Requirement	Pounds per acre P	K	Ca	Mg	ppm Mn Extractants 0.1 N H_3PO_4	1 N NH_4OAc + 0.2 percent Hydroquinone	Oat Yield gms/pot	Oat Tissue Mn ppm	Oat Mn Uptake mgm/pot	Radish Yield gms/pot
121	2	7.0	0.0	36	56	1456	83	140	216	2.260	48.5	.110	.640
122	2	6.2	0.0	50	80	1456	61	170	196	2.300	45.0	.104	.635
123	2	7.0	0.0	29	112	1768	61	170	240	2.515	45.0	.113	.640
124	4	6.3	2.0	15	160	3536	352	35	54	2.170	27.5	.060	.680
125	3	6.1		198	248	1040	83	185	204	2.620	54.0	.141	.600
126	3	6.2	1.5	144	168	728	80	175	162	2.570	49.5	.127	.650
127	3	6.2	1.5	150	152	1144	93	120	120	2.270	52.5	.119	.740
128	3	6.0	2.0	66	72	1560	51	95	98	2.350	54.5	.128	.740
129	3	6.3	1.5	39	72	2704	160	35	214	2.280	40.0	.091	.570
130	3	6.6	0.0	39	100	1144	138	280	348	2.005	46.0	.092	.620
131	5	6.4	0.0	85	616	13000	800	15	192	3.160	10.5	.033	1.630
132	3	7.0	0.0	32	80	3744	262	50	42	2.270	12.0	.027	.700

Table B. continued

Soil Number	Soil Textural Class*	pH	Lime Requirement	Pounds per acre P	K	Ca	Mg	ppm Mn Extractants 0.1N H_3PO_4	1N NH_4OAc+ 0.2 percent Hydroquinone	Oat Yield gms/pot	Oat Tissue Mn	Oat Mn Uptake mgm/pot	Radish Yield gms/pot
133	3	6.0	2.0	40	104	2704	210	55	50	2.225	27.5	.061	1.190
134	3	5.7	2.0	50	80	1331	64	205	261	2.410	87.5	.211	.740
135	3	6.7	0.0	28	104	2080	182	45	23	2.320	9.0	.021	.840
136	3	6.1	2.0	21	88	2184	83	125	105	2.285	33.5	.077	1.120
137	3	6.2	1.5	72	256	1976	166	200	346	2.275	53.5	.122	.900
138	3	6.5	0.0	35	88	2288	176	175	248	2.225	35.0	.078	.680
139	1	7.9	0.0	12	40	4160	210	130	128	2.560	15.0	.038	.750
140	1	7.3	0.0	26	16	2184	203	75	70	2.690	30.0	.081	.540
141	1	8.0	0.0	12	32	1040	64	65	36	2.250	17.0	.038	.530
142	3	7.0	0.0	42	64	2808	61	185	270	2.410	54.5	.131	.790
143	2	7.0	0.0	29	56	1976	32	100	103	2.745	43.5	.119	.500
144	2	6.8	0.0	22	80	2184	40	75	70	2.150	45.0	.097	.620

Table B. continued

Soil Number	Soil Textural Class*	pH	Lime Requirement	P (Pounds per acre)	K (Pounds per acre)	Ca (Pounds per acre)	Mg (Pounds per acre)	pp2m Mn Extractants 0.1N H_3PO_4	pp2m Mn Extractants 1N NH_4OAc+ 0.2 percent Hydroquinone	Oat Yield gms/pot	Oat Tissue Mn	Oat Mn Uptake mgm/pot	Radish Yield gms/pot
145	3	6.2	1.5	70	144	1872	40	385	832	2.395	95.0	.228	.900
146	3	6.8	0.0	38	184	2912	118	355	720	2.020	54.0	.109	.970
147	5	6.0	0.0	27	96	11000	614	5	77	2.295	15.5	.036	1.400
148	3	6.8	0.0	144	104	1872	80	125	118	2.385	37.5	.090	.580
149	4	6.9	0.0	18	72	2288	176	170	188	2.350	33.0	.078	.890
150	3	5.6	3.5	99	160	1248	93	240	342	2.015	95.0	.191	.816
151	4	6.4	1.5	36	160	7176	480	35	22	.815	31.0	.003	.860
152	3	6.7	0.0	87	168	2288	51	325	380	2.410	85.0	.205	.610
153	3	5.9	1.5	99	192	1560	138	365	344	2.600	162.5	.423	.750
154	3	5.4	3.0	105	120	1444	64	265	300	2.910	190.0	.553	.970
155	3	6.3	1.5	89	112	2184	118	345	432	1.990	149.5	.298	1.630
156	5	6.5	0.0	11	88	12000	960	10	76	3.190	25.5	.081	.710

Table B. continued

Soil Number	Soil Textural Class*	pH	Lime Requirement	P	K	Ca	Mg	0.1N H3PO4	1N NH4OAc+ 0.2 percent Hydroquinone	Oat Yield	Oat Tissue Mn	Oat Mn Uptake	Radish Yield
				Pounds per acre				pp2m Mn Extractants					
										gms/pot		mgm/pot	gms/pot
157	2	5.8	2.0	68	100	1248	96	130	172	2.380	70.0	.167	.800
158	2	5.9	1.5	50	96	1248	118	150	168	2.420	123.0	.298	.620
159	2	6.2	1.0	222	104	1456	51	205	200	2.715	115.0	.312	.460
160	2	5.1	3.5	210	72	440	32	185	198	1.720	60.0	.102	.490
161	4	7.7	0.0	150	999	4992	702	95	44	1.850	7.0	.013	1.140
162	3	6.7	0.0	32	72	3266	237	70	42	2.400	71.0	.170	.760
163	3	7.1	0.0	14	164	3390	248	125	140	2.300	67.5	.109	.780
164	4	7.8	0.0	6	64	5200	288	285	997	2.115	27.5	.058	.860
165	3	6.4	1.0	22	96	1768	32	230	288	2.200	52.5	.116	.690
166	4	7.2	0.0	6	96	4264	530	130	232	2.205	31.5	.070	1.120
167	6	6.5	0.0	19	381	12200	1768	15	61	2.500	15.0	.038	1.711
168	6	6.9	0.0	18	236	12000	1898	20	24	2.010	8.5	.017	1.620

Table B. continued

Soil Number	Soil Textural Class*	pH	Lime Requirement	Pounds per acre P	K	Ca	Mg	pp2m Mn Extractants 0.1N H_3PO_4	1N NH_4OAc+ 0.2 percent Hydroquinone	Oat Yield gms/pot	Oat Tissue Mn	Oat Mn Uptake mgm/pot	Radish Yield gms/pot
169	3	7.5	0.0	35	229	5616	589	45	18	1.565	20.0	.031	1.180
170	4	6.1	0.0	35	296	5408	768	40	30	2.050	19.0	.039	1.190
171	3	5.2	3.5	152	221	288	8	265	326	2.705	14.5	.039	.390
172	2	7.2	0.0	12	64	3120	237	80	73	2.580	15.5	.040	1.370
173	3	6.1	0.0	72	100	832	118	190	186	2.410	59.0	.142	1.140
174	3	7.3	0.0	86	312	5200	530	115	138	1.940	27.5	.053	1.450
175	3	7.2	0.0	74	250	6344	586	75	97	1.580	8.5	.013	1.050
176	5	6.3	0.0	16	104	4680	656	20	24	1.955	17.5	.034	.930
177	7	7.7	0.0	36	184	0948	509	25	22	1.455	5.0	.007	1.530
178	6	6.8	0.0	57	672	10192	728	20	29	2.650	10.0	.027	1.790
179	3	5.8	1.5	125	32	184	8	170	296	2.125	88.5	.190	.510

*Soil textural class:
1. Sands
2. Loamy sands
3. Sandy loams
4. Loams
5. Clay
6. Organic soils
7. Loamy sands with high organic matter