ACIDITY OF SOIL AND FERTILIZER BANDS AS RELATED TO MANGANESE TOXICITY AND MANGANESE UPTAKE BY POTATOES AND OATS IN A GREENHOUSE

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This is to certify that the

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Acidity of Soil and Fertilizer Bands as Related to Manganese Toxicity and Manganese Uptake by Potatoes and Oats in the Greenhouse

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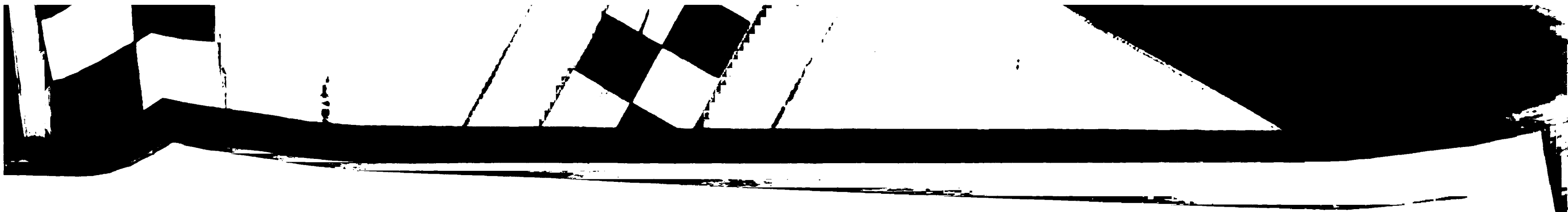

ABSTRACT

ACIDITY OF SOIL AND FERTILIZER BANDS
AS RELATED TO MANGANESE TOXICITY AND
MANGANESE UPTAKE BY POTATOES AND OATS
IN A GREENHOUSE

By Ronald Paul White, Sr.

This investigation was conducted in an effort to determine the role of lime and fertilizer band acidity on the yields and uptake of manganese by Norland and Sebago potatoes grown on an acid soil suspected of containing toxic concentrations of available manganese. Potatoes were grown in a greenhouse on a Montcalm-McBride sandy loam (pH 4.7) with a complete banded fertilizer (nitrogen, phosphorus and potassium). In addition to a treatment containing only the basic fertilizer applications (hereafter called the "check") calcitic hydrate or dolomite was mixed with the soil at 3 rates of lime. Treatments of aluminum sulphate and/or manganous sulphate were added to the banded fertilizer on unlimed soils.

Changes in the pH of the soil in contact with the band, and at a place remote from the band, were observed by

direct contact of the electrodes with the soil. The fertilizer band residues were mixed with the soil after harvesting the potatoes and the residual effects on the soil pH and uptake of manganese by a following oat crop were measured.

Symptoms of manganese toxicity, chlorosis and black specks on the undersides of the leaves and on the stems, were observed on the plants of the unlimed soils. Moreover, the manganese concentrations in the vines were abnormally high. These high levels of manganese were reduced ninefold when the soil pH was increased to only 6.5 by lime and many of the visual symptoms disappeared. In contrast, the manganese concentrations in the vines increased somewhat when manganese sulphate was added to the band. Intensified acidification of the fertilizer band with the addition of aluminum sulphate barely changed the manganese uptake. The Norland variety appeared more manganese-susceptible as was evidenced by its higher manganese concentrations and more intense toxicity symptoms.

In the unlimed check the band pH was initially slightly lower than the soil pH. This difference disappeared after about two weeks. Manganese sulphate added to the band had little effect on the band pH while with aluminum sulphate the band pH was decreased to, and remained at, about 3.5. Soil and band pH's increased with increasing lime applications. With the lowest dolomite applications the soil pH was raised to about 6.3 with essentially no increase in the band pH. At the highest rate of calcitic hydrate application the soil pH was 7.4 and the band pH about 7.0. Mixing the band residues with the soil resulted in a pH depression of about 0.2 pH units for all except the aluminum sulphate treated soils, which were lowered about 0.4 pH units. Residual manganese resulted in significantly higher manganese concentrations in the subsequent oat crop, but the greater acidity from the aluminum residue was associated with even greater manganese uptake.

Since the lowest rate of application of dolomite resulted in a soil pH of 6.3 with essentially no change in the band pH, the marked decrease in manganese uptake by potatoes grown on this treatment suggested that the whole soil was supplying toxic concentrations of available manganese. Apparently soil manganese solubilized by the acid solutions diffusing from the fertilizer bands was not a major source of available manganese.

ACIDITY OF SOIL AND FERTILIZER BANDS AS RELATED TO MANGANESE TOXICITY AND MANGANESE UPTAKE BY POTATOES AND OATS IN A GREENHOUSE

By

Ronald Paul White, Sr.

A THESIS

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For Marilene

I dedicate this thesis to my wife. Without her love, patience, and sacrifice it would never have been accomplished.

ACKNOWLEDGEMENTS

A project such as this requires the assistance of so many people it is impossible to thank each one individually. However I do wish to recognize the special help of certain individuals.

Much appreciation is extended to Dr. Cook, Dr. Robertson, Dr. Ellis, Dr. Knezek, and Dr. Good for serving as members of my guidance committee and for all the time and help they so freely offered.

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Most especially, I sincerely thank Dr. E. C. Doll, my advisor, for his guidance, his encouragement, his help and his apparently inexhaustible patience. His excellent example and ability were strong influences in the completion of this work and in my determination to continue in the field of research.

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INTRODUCTION

Many of the potatoes in Northern Michigan are grown on acid sandy soils needing heavy fertilization for optimum production. When heavily fertilized and frequently irrigated, these soils become depleted of bases (calcium and magnesium) and thus are strongly acid.

The 'Norland' variety of potatoes (Solanum tuberosum) was developed on alkaline soils, and when grown on these acid soils has been observed to die prematurely following the development of black spots, leaf roll, and necrotic areas. Berger and Gerloff (1947) attributed similar symptoms to manganese (Mn) toxicity on potatoes grown on the acid soils of Wisconsin. Some of the symptoms observed on the Norland variety in Michigan also resembled Mg deficiency observed on the Sebago variety of potatoes as reported by Doll and Hossner (1964).

One or more of the following factors could have caused these abnormal growth symptoms: a) Mn and possibly aluminum (Al) toxicity due to large amounts of soluble soil Mn and Al in these strongly acid soils, b) increased solubility of soil Mn and Al due to the strongly acid solution diffusing from banded fertilizers and c) Mg deficiency due to strong acidity and the low level of available Mg in these soils.

Consequently, the greenhouse experiment reported herein was conducted to determine the effect of:

1) rate of application and source of lime on growth and Mn uptake by Norland and Sebago potatoes,

2) rate of application and source of lime on soil pH and the pH in the fertilizer band,

3) additions of soluble Mn and Al to the fertilizer band on the growth and Mn uptake by the two varieties, and on the pH of the fertilizer bands, and

4) the residual effects of mixing the fertilizer band residues with the soil on the growth and Mn uptake by oats and on the soil pH.

REVIEW OF THE LITERATURE

Manganese Toxicity in Plants

Manganese (Mn) toxicity symptoms have been described for a number of plants including barley (Williams and Vlamis, 1957 and 1957a), wheat (Löhnis, 1960), tobacco (Hiatt and Ragland, 1963; and Hurley, Pritchett and Breland, 1956), alfalfa (Ouellette and Dessureaux, 1958; and Sutton and Hallsworth, 1958), beans and peas (Morris and Pierre, 1949), potatoes (Berger and Gerloff, 1947 and 1947a; and Struckmeyer and Berger, 1950) and on other plants (Hewitt, 1963; and Löhnis, 1951). The symptoms most often appear first on the older parts of the plant which usually contain the highest concentrations of Mn. Translocation of Mn within the plant is slight (Jackson, 1967). Toxicity seems to be directly related to the Mn concentration in the leaves, although the level at which toxicity symptoms begin to develop varies both between different species and within the same species under different environmental conditions. Soil solution or nutrient solution levels containing more than one part per million (ppm) Mn have produced toxicity symptoms in legumes (Morris and Pierre, 1949), potatoes (Struckmeyer and Berger, 1950; Berger and Gerloff, 1947 and 1947a) and barley (Williams and Vlamis, 1957).

Toxic concentrations of Mn in the edges of the leaves may be 10 times those in the interveinal areas of leaves (Hewitt, 1963). Legume leaves were reported to contain 3 to 5 times as much Mn as the stems (Morris and Pierre, 1949). Reported leaf concentrations of Mn at which toxicity symptoms have occurred are 3000 ppm in tobacco (Hiatt and Ragland, 1963), and more than 300 ppm for snapbeans and barley (Löhnis, 1960). Chapman (1962) suggests that concentrations of Mn above 473 ppm in potato petioles at tuber setting time may be toxic. Löhnis (1951) observed no symptoms of Mn toxicity on potatoes at leaf concentrations of 1700 ppm Mn. Berger and Gerloff (1947) reported Mn toxicity symptoms on potatoes when the vines contained 693 ppm Mn when grown in a nutrient solution containing 3 ppm Mn. A solution concentration of 1 ppm Mn yielded normal plants containing 313 ppm Mn in the vines after 66 days of growth.

Marked differences in tolerance to high levels of Mn among varieties have been observed within the same species.

Ouellette and Généreux (1965) report differential tolerance among 6 varieties of potatoes, and varietal differences have also been reported for alfalfa (Dessureaux and Ouellette, 1958; and Ouellette and Dessureaux, 1958), wheat (Neenan, 1960) and ryegrass (Vose and Randall, 1962). The root cation exchange capacity has been suggested as a factor in the tolerance of ryegrass to Al and Mn toxicity (Vose and Randall, 1962), and the resistance to Mn toxicity produced in crosses of alfalfa seems to be inherited (Dessureaux and Ouellette, 1958).

Mn toxicity symptoms in potatoes have been described by Berger and Gerloff (1947) as follows:

> The first symptom of manganese toxicity or stem streak necrosis is the appearance of dark brown streaks on the lower stem at the base of the petioles. A pale yellow chlorosis develops in areas between the veins on the lower leaves and quite often small brown necrotic areas, irregular in shape, also appear between the veins near the midrib on the leaflets. As the necrosis becomes more severe, many long, narrow brown streaks will be found on the lower portions of the stem and even on the petioles. The necrotic streaks also effect the inner tissues of the stem. The affected parts become extremely brittle, the petioles break off with a slight touch, and the chlorotic leaves finally dry and fall from the plant. The streaking of the stem and subsequent leaf dropping progress upward on the plant until the terminal bud becomes necrotic and the plant dies prematurely.

Factors Influencing Mn Toxicity

Sutton and Hallsworth (1958) report increased Mn toxicity on alfalfa at high light intensities. Williams and Vlamis (1957) found less toxicity with short days and lower temperatures, while Löhnis (1951) reported that beans were more tolerant to high Mn levels at higher temperatures.

Most applications of Ca to soils are as liming materials so the effects of Ca on Mn toxicity usually are confounded with changes in soil pH. Increased Mn toxicities occurring when $CaSO_4$ is added to a soil are often due to a decrease in soil pH (Hurley et al., 1956; and Morris, 1948). Stewart and Leonard (1963) reported that adding $CaCl_2$ with $MnSO_4$ resulted in greater Mn uptake by citrus than did $MnSO_4$ alone on both acid and alkaline soils.

Increasing the Ca supply while maintaining soil pH constant reduced Mn uptake by alfalfa in a nutrient solution. Decreasing the soil pH while maintaining a constant Ca level also lowered Mn uptake (Sutton and Halsworth, 1958). These effects suggest direct ion competition, but ion competition is not the only factor involved, since with increased Ca supply Ouellette and Dessureaux (1958) showed decreased Mn toxicity and decreased transport of Mn from alfalfa roots,

while the water-soluble and total Ca levels in the roots increased. Water-soluble Mn in roots decreased but total Mn in roots did not, leading them to suggest that water-soluble Ca in the roots favors immobilization of the excess Mn in the roots by precipitation.

Williams and Vlamis (1957) reported decreased Mn uptake by barley over a wide range of solution Mn levels obtained by increasing the macro-salt concentration of a Hoagland's solution from 1/5 to full strength. In a later study (Vlamis and Williams, 1962) single salts were superimposed over a weak balanced nutrient solution and Mn uptake was reduced by the nitrate and sulphate salts of Ca, Mg, and NH_4^+. However, Ca, Mg, and NH_4^+ phosphates were much less effective in reducing Mn uptake and Na and K phosphates increased Mn uptake. Iron and H reduced Mn uptake most effectively. The authors suggest that increased Mn uptake with the Na and K phosphate may have been due to phosphate effects on Fe availability.

Argawala et al. (1964) found that the yields of barley were influenced by the Fe/Mn ratio in the nutrient solution, and stressed that the levels of Mn and Fe in the solution were more critical than the Fe/Mn ratio in determining Mn uptake. Other workers (see Hewitt, 1963) have reported that the Fe/Mn ratio was more important than the Mn level in determining Mn uptake.

Hurley et al. (1956) found less Mn in tobacco leaves when Mg was applied to the soil. The effects of Mg on Mn toxicity both in the field and in solution cultures was studied by Löhnis (1960). Additions of Mg to a Mg-deficient acid soil reduced both the severity of Mn toxicity and the uptake of Mn by beans, yet had no effect on the exchangeable soil Mn. By increasing Mg and Ca levels in solution cultures at different levels of Mn, the Mn content and injury to snap beans was reduced. With rape, Mn uptake was reduced only at toxic levels of solution Mn. With solutions high in Mn and low in Mg, oats exhibited only Mg deficiency symptoms, yet increasing Mg levels markedly reduced the Mn contents of the plants. The Mn content of wheat, barley and rye was decreased when Mg was added to solutions high in Mn, but the Mn content of mangolds, alfalfa, and flax was not decreased. Symptoms of Mg deficiency appeared distinctly different from those of Mn, and both symptoms were observed on the same plants in some cases.

Mn Toxicity on Potatoes

Smith (1937) investigated the effects of soil reaction on the yields and quality of potatoes. By adding lime or sulphuric acid to a soil at pH 5.4-5.7, soil pH levels from 4.75 to 8.00 were established in the field; potatoes were then grown for four years. Less vigorous top growth, chlorosis and early death occurred on the most strongly acid plots compared with the medium pH plots. The same plant symptoms occurred on the very alkaline plots also, but premature death was not as rapid. Total tuber yields, as well as yields of No. one size and the number of tubers per plant were reduced on plots of pH 4.8 or lower and on the soils above pH 7.2. Generally no significant yield differences occurred between those plots ranging from 4.8 to 7.1 in soil pH.

The symptoms observed on the potatoes on the very acid plots are very similar to those used to describe Mn toxicity on potatoes, whereas the symptoms occurring on the plants on the high pH soils might have been those of Mg deficiency. The use of hydrated lime to increase the soil pH to 8.00 may have disturbed the Ca/Mg balance in the soil.

Stem streak necrosis, a common problem on Northern Wisconsin's acid potato fields, was studied by Berger and Gerloff (1947 and 1947a). Neither high amounts of Al in a solution culture nor a solution without Al at pH 4.0 produced the stem streak necrosis on the potato plants. Levels of Mn from 3 to 200 ppm Mn in the nutrient solutions reproduced the plant symptoms observed in the field. Increasing levels of Mn in the solutions caused both earlier appearance and increased severity of the plant symptoms. The plant symptoms appeared at 47 days in the 3 ppm Mn solution, at 31 days in the 10 ppm solution and at 9 days at the 200 ppm Mn solution level. The Mn concentrations in the vines, measured after 66 days of growth, were 693, 1354, and 9958 ppm Mn respectively.

Liming of the soil in a greenhouse experiment corrected the abnormal plant symptoms, while additions of Ca and Mg sulphates intensified them. Lower levels of soluble Mn were found in the limed potato fields than in adjacent unlimed fields exhibiting these abnormal plant symptoms.

Ouellette and Généraux (1965) compared the effects of Mn toxicity on six varieties of potatoes both in the field and in nutrient solutions. Toxicity symptoms varied both on

different parts of the plants and in intensity among the different varieties. The greatest varietal differences in symptoms were noted on the stems and the least on the leaves. The different stem symptoms were: tiny black spots on the Keswick variety, necrotic lesions on the Cherokee variety, large, numerous brownish spots on Green Mountain, Katahdin, and Kennebec varieties and no stem symptoms on the Norgleam variety. The petioles had essentially the same symptoms as did the stems, but the petioles of the Norgleam variety had a streaking effect. The Cherokee and Green Mountain varieties had the most brittle petioles and thus lost their leaves first, while the Norgleam and Katahdin petioles were considerably less brittle than the others.

The leaves of the Norgleam and Cherokee varieties had large greyish spots. The Keswick leaves were riddled with tiny dark brown spots and darkened veins. The leaves of the other three varieties had dark brown spots and necrotic streaks on the veins.

Plants grown in a solution containing 250 ppm Mn died after 43-69 days, or at a "physiological age" which varied from 43-55%. The "physiological age" was defined as the age of the plants when death occurred in the 250 ppm Mn solution divided by the age of the plants at maturity in the non-toxic (0.5 ppm Mn) solution times 100 to express as percentage. In this way, the toxicity effects on the different varieties could be evaluated on an equal basis since the normal growth periods of the varieties differed. Those varieties showing the most severe visual symptoms were not necessarily the first to die.

Decreasing tuber yields, decreasing specific gravity of the tubers, and increasing leaf Mn concentrations were observed in a field experiment as applications of 0, 50, and 500 lbs/A of $MnSO_4$ were applied. The application of 500 lbs/A of $MnSO_4$ reduced the yield of the Cherokee variety from 218 to 121 boisseau/Ac (approximately bu/A) and increased the Mn in the leaves of the Keswick variety from 280 ppm to 974 ppm.

Soil Manganese

The forms of Mn in soils are controlled by three factors: physical conditions, chemical conditions, and biological activity (Heintze and Mann, 1949). Manganese exists in soils as the soluble bivalent Mn^{++} ion and as the increasingly more insoluble higher oxides of Mn_2O_3, and MnO_2.

Another important form of Mn is that held in a complexed form by soil organic matter (Beckwith, 1955; Broadbent and Ott, 1957; Heintze, 1957; Hemstock and Low, 1953; and Himes and Barber, 1957). All of these forms tend toward an equilibrium under a given set of soil conditions.

Divalent Mn in the soil solution plus that displaced by *N* NH_4OAc is usually considered to be available to plants (Fujimoto and Sherman, 1948; and Leeper, 1947). Estimates of the availability of the oxides vary. Bromfield (1958) demonstrated that MnO produced by *Corynebacterium* sp. in a liquid media was available to plant roots, and also showed that root washings contained substances which would dissolve MnO. Trivalent Mn in soils is probably not available to plants and tetravalent Mn is likely even lower in availability (Russell, 1961). Manganese chelated with soil organic matter is relatively unavailable to plants (Walker and Barber, 1960).

Certain soil organisms oxidize Mn most rapidly in well aerated soils that test between pH 6.0 and 7.5. Reduction of Mn by some anerobic organisms occurs over a wide pH range under reduced oxygen tension (Leeper, 1947). The addition of organic matter, reducing in nature, to a soil will result in the reduction of higher oxides of Mn to the more available Mn forms. This reaction is more rapid at lower pH

levels due to the increasing ease of reduction of Mn oxides at low pH levels (Fujimoto and Sherman, 1948). Hemstock and Low (1953) reported oxides of Mn were formed directly, without the initial formation of $Mn(OH)_2$, and that Mn retention in the soil they studied was due to oxidation and not to adsorption on the soil colloids. Added fertilizer Mn can be converted into unavailable forms within two hours (Wain, Silk and Wills, 1943). Unpublished data obtained by Alex Kozakiewicz at Michigan State University indicated that 150 ppm of the 400 ppm Mn added to an organic soil was unavailable to an immediate extraction for exchangeable plus easily reduceable Mn. The Mn held was believed to be held in a complexed form.

"Active Mn" refers to the exchangeable Mn plus that which is dissolved by a dilute acid or some mild reducing agent such as neutral quinol or hydroquinone (Marsh and Powers, 1945; and Russell, 1961). Chelated or complexed Mn is usually extracted by adding a divalent cation that is held more strongly than Mn, such as Zn (Reid and Miller, 1963; and Weir and Miller, 1962) or Cu (Beckwith, 1955) or by extraction with buffered pyrophosphates (Heintze and Mann, 1949; and Weir and Miller, 1962). No single extractant for

soil Mn is specific for any given form due to the number of different forms of Mn present in soils in differing degrees of crystallinity under different soil conditions (Heintze and Mann, 1949; Reid and Miller, 1963; and Weir and Miller, 1962).

Morris (1948) studied the Mn status of 25 acid soils and their effects on the growth of sweet clover and lespedeza. Exchangeable Mn in these soils ranged from 1.2 to 638 ppm. The average amount of water-soluble Mn in those soils below pH 5.2 was 2.1 ppm; in those between pH 5.2 and 5.4, 1.0 ppm; and in those above ph 5.4, 0.5 ppm Mn. Of 14 soils which contained less than 100 lbs. of exchangeable Mn per acre, the average water-soluble Mn concentration was 0.6 ppm; on 11 soils which contained more than 100 lbs. per acre the average water-soluble Mn was 2 ppm. He found no correlation between exchangeable soil Mn and soil pH. On those soils containing high amounts of water-soluble Mn both clover and lespedeza exhibited symptoms of Mn toxicity and contained high Mn concentrations.

Additions of $CaCO_3$ increased the soil pH, reduced water-soluble Mn and increased plant growth, whereas additions of $CaSO_4$ decreased the pH, increased the water-soluble Mn and decreased plant growth in spite of increased Ca levels

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in some plants. The Mn concentration in sweet clover was reduced from 502 to 37 ppm by adding $CaCO_3$ which raised the soil pH from 4.81 to 5.26. The equivalent amount of Ca as $CaSO_4$ reduced the pH to 4.71 while the plant Mn increased to 586 ppm.

Soil pH Measurements

Soil pH as an empirical measurement is not without problems, but is extremely useful, especially for comparison purposes (Coleman and Thomas, 1967). The measured pH of a soil sample varies depending on the sample preparation. Usually the sample is diluted with distilled water (soil: water ratio 1:1) and the pH determined in the suspension. A dilute salt solution mixed with the soil sample, such as 0.1 $\underline{M}$ $CaCl_2$ displaces some of the adsorbed H^+ ions and results in a lower pH value than that in distilled water. Schofield and Taylor (1955) suggest 0.01 $\underline{M}$ $CaCl_2$ for the measurement of soil pH. By measuring the Ca concentration in the supernatant liquid one can calculate the lime potential, defined as (pH-1/2pCa), which represents the mean activity of $Ca(OH)_2$ in the sample.

Chapman, Axley and Curtis (1940) were able to obtain reproducible pH measurements on soils at various moisture levels, including those approaching the air dry state, by simply inserting the glass and calomel electrodes firmly into the moist soil. The pH measurements of each of the 50 soils tested was reproducible at moisture contents between the moisture equivalent and the sticky point. To obtain reproducible pH measurements the electrodes had to be in complete contact with the moist soil and drifting of the pH reading was minimized by "conditioning of the electrode." This was done by inserting the electrode into the soil 3 or 4 times at various places before taking the final pH reading. For any one soil, considerable differences in moisture content in the range of the sticky point had little effect on the pH measurement; however, the pH measured in a 1:2.5 soil: water suspension was significantly higher than that measured by direct contact. No differences in pH were observed between the values obtained 5 minutes after rewetting air-dry soil samples and those taken up to 3 days later. In nearly all cases, the pH of a soil in its moist condition directly from the field and the direct contact pH after air-drying and rewetting did not differ materially.

Soil Chemical Reactions Resulting from Fertilizer Bands

The banding of fertilizers in soils leads to conditions in and around the fertilizer band that are not present with broadcast applications or exist only at extremely reduced intensities around the individual fertilizer particles. Lindsay and Stephenson (1959) studied the reaction of monocalcium phosphate (MCP) both in a water system and in a Hartsells fine sandy loam.

When MCP was dissolved in excess water, a metastable solution of newly formed dicalcium phosphate (DCP) dihydrate and undissolved MCP was formed. This solution persisted for at least 24 hours after which the DCP slowly lost water and anhydrous DCP precipitated. The resulting solution was in equilibrium with anhydrous DCP and undissolved MCP (a triple-point solution- pH 1.48).

The soil solution at various distances from a band of MCP in the soil was sampled by means of layers of filter paper imbedded in the soil. Water moved from the soil (0.8 moisture equivalent) to the band and dissolved the MCP creating a wetted front adjacent to the band closely approximating that of the metastable triple-point solution. As this highly concentrated solution moved away from the band Fe, Al and Mn present in the soil were dissolved. The authors suggest that as the solution became diluted by more soil and the pH increased, many compounds of these dissolved substances may have reprecipitated.

No dissolved Mn was detected in the filter paper 5 cm from the band at the end of one day. The Mn concentration in this layer increased to 616 ppm after 2 days and then declined to 55 ppm after 42 days. But after 42 days the Mn level in the soil layer 20 cm from the band reached 588 ppm.

The pH in the layer of soil 0-5 cm from the band was 2.88 after 1 day and increased to 2.95 after 42 days, while the pH in the 15-20 cm layer was 5.56 initially and decreased to 3.72 after 42 days.

The concentrations of Fe and Al dissolved by the wetted front were several thousand times higher than the concentrations normally found in soils and the Mn concentrations were 1/10 those of the Fe and Al. Mn tended to accumulate some distance away from the band, while Fe and Al moved against the solution gradient accumulating in the filter papers adjacent to the band.

To simulate the movement of a triple point solution (TPS) away from the fertilizer band into new volumes of soil, Lindsay and Stephenson (1959a) added successive increments of two soils to a TPS (initial pH - 1.01) all the while maintaining the same soil:solution ratio for each new volume of soil added. The amounts of Fe, Al, and Mn dissolved by the successive extractions were then compared with the amounts dissolved by 3 extractions with 6 N HCl on similar soil samples.

With each successive soil increment added to the TPS the pH of the extracting solution increased slightly and large amounts of Fe, Al and Mn were dissolved. The Hartsells soil (pH 4.6) released more Fe and Al than did the Rosebud soil (pH 7.6), but the Rosebud released the most Mn. The Mn extracted by the TPS was nearly as great as that extracted by the HCl treatments, but HCl extracted considerably more Fe and Al than did the TPS. With successive extractions the solutions became supersaturated with respect to certain phosphate compounds which then precipitated. However, no evidence was obtained that any precipitation of Mn compounds occurred.

When all the MCP is dissolved a TPS ceases to exist, however the authors predicted that water would continue to move from the soil into the fertilizer zone, thus the fertilizer solution would be diluted with more of the soil volume. They suggest that the Ca status of the soil would strongly influence the types of phosphate compounds expected to precipitate as the reactions proceed.

Blanchar and Caldwell (1966) placed fertilizer mixtures in the bottom of cylinders 9 cm in diameter and then alternately covered them with layers of filter paper and 1 cm layers of Nicollet clay loam (pH 5.8) to a depth of 7 cm. The fertilizers consisted of P^{32} tagged MCP, tagged MCP plus NH_4Cl and tagged MCP plus KCl. After 2 weeks of incubation the layers of soil were analyzed for pH and P, K, Ca, NH_4^+, and Cl. Moncalcium phosphate resulted in a reduction of soil pH up to 3 cm away from the fertilizer, while the pH was reduced the full 7 cm distance from the band with the other two treatments. The movement of Ca from the fertilizer zones followed the same pattern as did the pH changes. Phosphorus did not move more than 4 cm distance in any treatment.

Oats were planted in funnels containing Nicollet soil. The roots which grew out of the bottom of the funnels were then placed directly above samples of the fertilizers and above samples from the soil zones located 1, 2, 3, and 4 cm from the fertilizers in an attempt to evaluate P uptake from these zones. The observed root damage, apparently due to the high salt concentrations in each sample, prevented significant P^{32} uptake by the plants.

The oat roots did not grow into any soil zone 0-4 cm from the fertilizers containing NH_4Cl or KCl, nor into the 0-2 cm zone when MCP alone was the fertilizer. Corn plants, grown in test tubes containing these same fertilizer combinations in the bottom of the tubes filled with soil, did not produce any roots within average distances of 2, 8, and 6 cm from MCP, MCP plus NH_4Cl and MCP plus KCl respectively.

In the second phase of their investigation (Blanchar and Caldwell, 1966a) 8.5 cm by 20 cm plexiglass cylinders filled with a Dakota soil containing pellets of these same fertilizers were incubated for 2 weeks, and then leached with 0, 2, 4, and 8 cm of water. Bottomless Dixie cups containing soil and corn seeds were placed directly on top of the leached soil columns. After 2 weeks growth the plants were harvested and analyzed for P^{32} uptake. The columns leached with 4 cm of water were split in half lengthwise for root observations l

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and soil samples were taken above, below, and to the side of the fertilizer pellet for phosphorus analysis.

Only the first increment of leaching increased plant dry matter production, and only trace amounts of fertilizer P were taken up from the unleached columns. Significant uptake of P occurred in those columns leached with 2 or more cm of water. Ammonium chloride increased P uptake from MCP.

No roots grew below the level of the fertilizer pellet in the unleached columns, but roots penetrated both deeper into the soil and closer to the pellets with increased leaching. No roots grew within 5 cm of the pellets containing either NH_4Cl or KCl. In the unleached columns this distance was reduced to 0.5-1 cm with a 2 cm leaching and with the 4 cm leaching roots grew throughout the pellet area.

Each of the fertilizer combinations created a somewhat concreated sphere of soil 2-3 cm in diameter around the fertilizer pellet which, in the case of MCP, strongly restricted root growth. Leaching decreased the strength of these concretions.

The levels of water soluble P in the soils leached with 4 cm of water were found to be 2000 ppm 1 cm below the fertilizer pellets, 1000 ppm 2 cm below, 500 ppm at 3 cm, 100 ppm at 5 cm and 10 ppm P 5.5-6 cm below the pellets. The gradients of water soluble P above and beside the pellets were much steeper, dropping to 10 ppm P only 2 cm from the pellets. In those cylinders containing NH_4Cl and KCl and leached with 4 cm of water, root accumulations occurred in the soil zones containing 500 - 1000 ppm P.

It appears that not only are the conditions around a fertilizer band drastically different from the rest of the soil volume, but that leaching of water through the band is necessary before plant roots are able to even exist in this area, let alone utilize the nutrients placed there.

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METHODS AND MATERIALS

Greenhouse Procedures

A Montcalm-McBride sandy loam was cropped in a greenhouse to evaluate the effects of the rate and source of lime and additions of aluminum sulphate and manganous sulphate to the fertilizer bands on the growth and mineral uptake by potatoes and oats.

The soil tested pH 4.7, lime requirement 5.5 tons per acre (Shoemaker, McLean and Pratt, 1961), 117 ppm available P (Bray P_1) and 118, 472, and 23 ppm of K, Ca, and Mg respectively (ammonium acetate extraction). The water-extractable Mn content of the soil was 10 ppm, and 50 ppm of Mn was extracted with 0.1 N HCl in 10 minutes.

The experiment was designed as a randomized complete block split plot design with four replications. Ten soil treatments were the main factors and two varieties of potatoes (Norland and Sebago) were the sub-plot factors.

For the low, medium, and high lime treatments (Table 1), the required amount of finely ground lime was thoroughly

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to i

[2] Lime

[3] $CaCO_3$
75% p

[4] $CaCO_3$

TABLE 1.--Rates of application and sources of lime and banded fertilizer treatments supplied for a greenhouse potato crop to samples of a Montcalm-McBride sandy loam soil.

SOIL TREATMENTS				
Mixed with Soil		Banded		
Lime Source	Rate[1]	5-20-20 Fertilizer	Al	Mn
	T/A[2]	-----------lbs/A-----------		
None	----	1000	None	None
None	----	1000	50	None
"	----	1000	None	30
"	----	1000	50	30
Dolomite[3]	2.75	1000	None	None
"	5.5	1000	"	"
"	11.0	1000	"	"
Calcitic hydrate[4]	2.75	1000	None	None
"	5.5	1000	"	"
"	11.0	1000	"	"

[1]Rates expressed as equivalent to 90% $CaCO_3$ lime. Referred to in text as low, medium, and high.

[2]Lime requirement of soil--5.5 T/A of 90% $CaCO_3$ lime.

[3]$CaCO_3$ equivalent--104, 250 ppm Mg, 100% passed 20 mesh, 75% passed 100 mesh.

[4]$CaCO_3$ equivalent--131, 3 ppm Mg, pulverized hydrated lime.

mixed with 30 pounds of air-dry soil which had been passed through a 3/8"-mesh screen. Earthenware pots of four gallon capacity lined with polyethylene bags served as greenhouse containers. The soil in all pots was brought to 10% moisture and incubated for 10 days.

Fertilizer, prepared by mixing reagent grades of $Ca(H_2PO_4)_2 \cdot H_2O$, KCl, and NH_4NO_3, were applied in all pots in a circular band 6" in diameter and 3" below the soil surface at a rate equivalent to 1000 pounds per acre (pp2m) of a 5-20-20 fertilizer. For the appropriate treatments (Table 1), reagent grade aluminum sulphate (Al treatment) and manganous sulphate (Mn treatment) were banded with the fertilizer.

Two 4" long plastic tubes (1/2"I.D.) were placed upright in each pot. The lower end of one tube was placed directly on the fertilizer band, while the lower end of the second tube was placed at the same depth but in the center of the pot (3" away from the fertilizer band). These tubes were used for direct contact pH measurements and were stoppered when not in use. The soils were brought to 20% moisture and allowed to incubate again with drying for 10 days before planting potatoes.

Of the two potato varieties planted, the Norland is an early maturing red variety developed on alkaline soils, while the Sebago is a late maturing round white potato commonly grown in Michigan. Five sprouted eyes, scooped from tubers of both varieties, were planted in each pot about 2 inches directly above the circular fertilizer band.

Each pot was watered daily with distilled water, and weighed once each week to maintain a soil moisture content of 10%. The winter daylength was extended to 14 hours by supplemental flourescent lighting. After 50 days, NH_4NO_3 was added in solution at a rate of 25 ppm N to each pot.

One month after planting, each pot was thinned to 3 plants and then to 2 plants after 48 days. The smallest plant in each pot was harvested at 68 days, dried at 65°C and weighed. The single remaining plant was harvested, dried, and weighed after 90 days. All tubers were removed from the soil for a yield measurement.

Eight months after adding lime, the dry soil in each pot was thoroughly remixed and brought to 10% moisture. No fertilizer was added. In the pots of 2 replications two plastic tubes were inserted in each pot for duplicate direct soil pH measurements. Thirty-five Gary oat seeds were planted in each pot. After 30 days, NH_4NO_3 was added in solution to each soil at a rate to supply 50 ppm N. The oat plants growing in the pots which had contained the Sebago variety of potatoes were harvested after 40 days and after 70 days in the pots where Norlands had been grown. All samples were dried at 65°C and weighed.

Plant Tissue Analysis

The dried vine samples from the 68 and 90 day potato harvests were ground to pass a 20 mesh seive, and duplicate samples of the tissue were digested in nitric and perchloric acid. The Ca, Mn, and Mg content in the digests was determined using a Perken-Elmer 303 atomic absorption spectrophotometer. Potassium was determined using a Coleman flame photometer and P colorimetrically by Method IV of Jackson (1958). The aluminum content was determined in some of the digests by the aluminon method (Jackson, 1958) after interfering anions had been removed from the extracts by the method proposed by Page and Bingham (1962).

One gram samples of the oat tissue, ground to pass a 20 mesh seive, were dry ashed by the method of Peech as reported by Jackson (1958). Twenty-five ml of 1 N HCl added to the samples did not completely dissolve the ash, apparently due to the conversion of some of the Mn to insoluble MnO_2 by HCl (Kendall, 1937). Three drops of 30% H_2O_2 added to each sample dissolved the residue. The solutions were then filtered to remove silica and made to 100 ml volume with 0.1 N HCl. The Ca, Mg, and Mn content was determined in the extracts using a Puken-Elmer Model 290 atomic absorption spectrophotometer. Potassium in the extracts was determined with a Coleman flame photometer.

Technique for Direct Contact Measurements of Soil and Band pH

Throughout the growing period measurements of the pH in the soils and in the fertilizer bands were made by inserting the glass electrode of a Beckman Model N pH meter into each tube so that it was in direct contact with either the soil or the fertilizer band at the base of the tube. The calomel electrode inserted into the surface of the moist soil completed the circuit. The effect of the previous reading was minimized by wiping the glass electrode after each measurement and by either taking all the band or all the soil pH readings successively. At the end of the growth period of the potatoes the soil pH tube was removed and the direct contact pH of the soil immediately below the tube position taken to determine if any packing of the soil at the end of the tube had affected the pH measurements.

Soil Samples

After removing the center soil pH tube, a 1" core of soil, to the depth of the pot, was removed from the position occupied by the plastic tube. After mixing the soil in each pot, prior to planting the oats, representative soil samples were obtained from each pot, and then again after harvesting the oats. All of the samples were analyzed for pH, lime requirement P, K, Ca, and Mg by the Soil Testing Laboratory, Soil Science Department, Michigan State University.

Statistical Analysis Procedures

Data were statistically analyzed utilizing a Controlled Data Corporation (CDC) 3600 digital computer. Data from the potato experiment and all of the soil test data were subjected to analyses of variance using a split plot design with soil treatments as the main factor and varieties as the subfactors. All of the direct contact soil pH data were analyzed using a split-split plot design with the pH measurements in the two different tubes as the sub-subfactors. The data obtained from the oats at the two different dates of harvest and the Al analysis on the Norland potato tissue were analyzed separately by means of a randomized complete block design with 10 soil treatments and 4 replications.

The "honest significant difference" (hsd) as proposed by Tukey (Steel and Torrie, 1960) was calculated from the results of the analysis of variance. Larger differences between means are required for significance using an hsd rather than an lsd but the chances of making a Type I error are greatly lessened when comparing any two means.

RESULTS AND DISCUSSION

A greenhouse experiment with both Norland and Sebago potatoes was conducted to evaluate the effects of liming and of including aluminum sulphate and manganous sulphate in the fertilizer bands on the soil and on the growth and Mn uptake by potatoes, and to duplicate the apparent Mn toxicity symptoms previously observed on potatoes growing in the farmer's fields. The residual effects of these treatments were evaluated by growing oats on these same soils after the potatoes had been harvested.

Potato Crop

Visual Symptoms

The visual symptoms that developed in the greenhouse on the Norland variety were very similar to those observed in farmers' fields. Severe leaf roll, black specks on the stems and undersides of the leaves and necrotic areas on the leaf margins were prevalent on those plants grown in unlimed

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soil. Liming considerably reduced the occurrence of the symptoms. At the high rates of calcitic hydrate the symptoms observed were more typical of reported Mg deficiency symptoms: yellowing of the lower leaves and necrotic spotting occurring throughout the leaf surface area of the older leaves rather than primarily along the edges (Houghland, 1949).

Sebago plants grown on the unlimed soils exhibited essentially the same symptoms as did the Norlands but with less intensity. They also developed the symptoms of apparent Mg deficiency at the higher levels of calcitic hydrate.

Yields of Potato Vines

Higher vine yields were obtained with the Sebago than with the Norland variety, on all treatments (Table 2). With the exception of the check treatment on the Sebagos, all treatments yielded more at the final (90 day) harvest than at the initial (68 day) harvest. The low yield of Sebagos noted on the Al treated soil at the initial harvest as compared with the check is probably not significant, since the yield was higher than the check at the final

TABLE 2.--Yields of Norland and Sebago potato vines at two dates of harvest as affected by rates and sources of lime and additions of aluminum sulphate and manganous sulphate to the fertilizer band.

Treatments			Variety			
	Rate of Application		Norland		Sebago	
Material Applied	Mixed	Additions to Fertilizer Band[1]	68 days	90 days	68 days	90 days
	T/A	lbs/A	---------g/plant---------			
None	--	--	3.62	4.65	8.62	8.37
Al	None	50	3.52	3.89	6.08	10.11
Mn	"	30	3.50	4.42	8.30	8.62
Al+Mn	"	50+30	3.45	4.46	7.42	9.53
Dolomite	2.75	None	3.55	4.75	10.17	12.37
"	5.5	"	4.27	5.44	10.45	11.19
"	11.0	"	3.35	6.08	9.27	13.05
Calcitic hydrate	2.75	None	4.57	5.31	9.27	11.44
"	5.5	"	2.15	3.55	6.17	10.18
"	11.0	"	2.26	3.50	4.02	10.88
hsd (0.05) Treatment within a variety			ns	ns	2.51	3.04

[1]Equivalent of 1000 lbs/A of 5-20-20 banded in all treatments.

harvest. Otherwise, the Al and Mn treatments had no significant effects on vine yields.

Applications of dolomite tended to increase the final yields of Norlands and significantly increased the final yields of Sebagos as compared with the check treatment. With the exception of the low rate (2.75 T/A $CaCO_3$ equivalent), applications of calcitic hydrate reduced yields of the initial harvest on both varieties and of the final harvest of Norlands. Final Sebago yields increased significantly with applications of calcitic hydrate as compared with the check treatment. The yield depressions observed with calcitic hydrate treatments at the initial harvest, as compared with the check treatment, are probably related to the low level of available soil Mg observed on these treatments (Table 6A, appendix). The Norland yields were also depressed at the final harvest while the Sebagos were not. Some bias was introduced in the data by choosing the smallest plant in each pot for the initial harvest.

Treatment Effects on Tubers

Although yields of tubers grown in pots in a greenhouse may not accurately reflect the yield patterns one might obtain in the field, due to the confining nature of the pots and differences in growth conditions, all tubers in each pot were harvested after the final vine harvest. Only about two tubers in each pot exceeded 2" in size, partly due to the fact that only one of the plants was allowed to grow the full 90 days. Additions of aluminum sulphate and/or manganous sulphate tended to decrease yields from the check slightly, as did applications of dolomite lime (Table 1A, appendix). Yields were markedly decreased, especially on the Norlands, by applications of calcitic hydrate. The characteristic red color of the Norlands on the unlimed treatments tended to fade considerably with increasing rates of either source of lime. The coloration of the Sebagos was much duller in appearance when calictic hydrate was applied.

Mineral Contents of the Vines

The data for the vine concentrations and uptake of Ca, K, and P of both varieties are presented in the appendix

and will not be discussed except as related to the specific objectives of this investigation (tables 2A, 3A, and 4A, appendix).

Both varieties had about equal concentrations of Mg in the vines at either harvest, but due to higher yields, the Sebagos contained more Mg (Table 3). Vine Mg concentrations and Mg uptake tended to increase for both varieties from the initial to the final harvest, except on the Al and/or Mn treatments. On these treatments the Mg concentrations of the Norlands were about the same at both harvests and those of the Sebagos tended to decline slightly at the final harvest. Compared with the check, additions of aluminum sulphate and/or manganous sulphate to the band had little effect on the plant Mg concentrations or Mg uptake.

Additions of dolomite resulted in significant increases over the check in both Mg concentrations and Mg uptake. In addition, the high rate of dolomite (11 T/A $CaCO_3$ equivalent) resulted in a significant increase in both Mg concentration and Mg uptake over the low rate of dolomite. Although the Sebagos actually took up more Mg from the dolomite treatments, because of their greater yields, than did the Norlands, the Norlands had the higher Mg concentrations in the vines.

TABLE 3.--Magnesium concentrations in and uptake by Norland and Sebago potato vines at two harvest dates as affected by rates and sources of lime and additions of aluminum sulphate and manganous sulphate to the banded fertilizer.

Treatments			Mg Concentration				Mg Uptake			
	Rate of Application		Norland		Sebago		Norland		Sebago	
Material Applied	Mixed	Additions to Fertilizer Band[1]	68 days	90 days	68 days	90 days	68 days	90 days	68 days	90 days
	T/A	lbs/A	-------% dry weight-------				--------mg/plant--------			
None	--	--	0.349	0.496	0.336	0.425	12.7	23.4	31.5	35.9
Al	None	50	0.368	0.398	0.382	0.340	13.0	15.4	23.4	34.5
Mn	"	30	0.337	0.339	0.311	0.312	11.5	17.4	25.7	27.0
Al+Mn	"	50+30	0.353	0.386	0.415	0.361	11.9	17.3	31.4	35.3
Dolomite	2.75	None	1.321	1.591	0.739	1.055	47.5	76.0	75.0	131.2
"	5.5	"	1.424	1.734	0.798	1.127	60.8	93.6	83.4	126.0
"	11.0	"	1.344	1.675	1.024	1.336	44.1	102.2	94.5	174.8
Calcitic hydrate	2.75	None	0.307	0.340	0.288	0.368	13.9	18.0	27.0	42.2
"	5.5	"	0.088	0.143	0.221	0.163	2.2	5.4	14.0	17.1
"	11.0	"	0.005	0.012	0.071	0.090	0.1	0.4	2.7	9.7
hsd (0.05)										
Treatments within a variety			0.198	0.263	0.198	0.263	18.8	28.8	18.8	28.8

[1]Equivalent of 1000 lbs/A of 5-20-20 banded in all treatments.

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Compared with the check, calcitic hydrate tended to reduce the Mg contents of both varieties. The high rate of calcitic hydrate resulted in significantly lower Mg concentrations in the vines than with the low level of calcitic hydrate. The decrease in Mg uptake on these same treatments, though only significant with the Sebagos, was very marked in both varieties. These low plant Mg levels occurring with the higher calcitic hydrate treatments would confirm the Mg deficiency symptoms noted on the plants grown in these treatments. Comparing the two varieties at the high calcitic hydrate level, the Norlands exhibited both lower Mg concentrations and uptake suggesting that they are not able to absorb Mg from the soil at low soil Mg levels as efficiently as can the Sebagos. Yet when Mg was present in adequate amounts, they had the higher Mg concentrations in the vines.

Extension Bulletin E 550 (Michigan State University) reports that sandy soils testing below 33 ppm exchangeable Mg or having an exchangeable K to exchangeable Mg ratio greater than 4/1 might be Mg deficient.

This soil tested 23 ppm Mg with a K/Mg ratio of 5/1; however, the Mg concentrations in the potato vines on the unlimed treatments appeared to be adequate for normal growth

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(Doll and Hossner, 1964). One possible reason why plants were able to obtain as much Mg on the unlimed soils at this low a soil test Mg level is suggested by the findings of Hossner (1965) and Christenson (1968), who reported increased soil Mg availability with decreasing soil pH. The acid solution from the fertilizer bands could have dissolved some of the unavailable soil Mg in the vicinity of these bands rendering it available to the plants. As will be shown later, the fertilizer band pH levels of the calcitic hydrate treatments were above those of the unlimed treatments.

The increased Mg concentrations in the plants on the dolomite treatments is due to the increased soil Mg levels resulting from the solubilization of the dolomite (Table 6A, appendix). Calcium concentrations in the vines were decreased over those of the check by applications of dolomite (Table 3A, appendix).

The marked decreases in Mg concentrations and Mg uptake by plants grown on the medium (5.5 T/A $CaCO_3$ equivalent) and high calcite hydrate treatments appears partly due to the influence of this source of lime on the soil Ca/Mg ratio. Large increases in soil Ca availability apparently resulted in such an imbalanced Ca/Mg ratio that the plants could not

absorb sufficient Mg for normal growth. The Ca concentrations in the vines and the Ca levels in the soil were significantly increased by the calcitic hydrate applications (Tables 3A and 6A, appendix). In addition, available soil Mg levels tended to decrease below the level of the check with additions of calcitic hydrate even though less total Mg had been taken up from these soils by the plants. Christenson (1968) also reports less available soil Mg with increasing soil pH.

Data from a liming experiment in the field on this same soil, indicated that Norland potato petiole Ca concentrations were also decreased and Mg concentrations increased by applications of dolomite and petiole Mg concentrations decreased and Ca concentrations increased by applications of calcitic hydrate as compared with the unlimed soil (unpublished data of R. P. White, Michigan State University).

The Mn concentrations and Mn uptake by the vines were higher in the Norland vines and increased markedly from the initial to the final harvest (Table 4). Due to the higher yields, Mn uptake was greater in the Sebagos at each harvest.

Additions of aluminum sulphate and/or manganous sulphate tended to slightly increase the Mn concentrations in both varieties at the initial harvest, while only the Al plus

TABLE 4.--Manganese concentrations in and uptake by Norland and Sebago potato vines at two harvest dates as affected by rate and source of lime and additions of aluminum sulphate and manganous sulphate to the fertilizer band.

Treatments			Mn Concentration				Mn Uptake			
	Rate of Application		Norland		Sebago		Norland		Sebago	
Material Applied	Mixed	Additions to Fertilizer Band[1]	68 days	90 days	68 days	90 days	68 days	90 days	68 days	90 days
	T/A	lbs/A	----ppm dry weight----				-------mg/plant-----------			
None	--	--	3682	6360	2508	4590	13.60	29.63	21.57	38.09
Al	None	50	4538	6135	2620	4070	15.96	23.93	15.79	40.73
Mn	"	30	4502	7282	3002	4578	15.54	32.05	24.83	39.54
Al+Mn	"	50+30	4445	7748	3392	4962	15.68	34.65	24.91	46.95
Dolomite	2.75	None	592	752	362	548	2.11	3.54	3.69	6.75
"	5.5	"	580	728	415	530	2.45	3.93	4.34	5.96
"	11.0	"	515	660	287	475	1.66	4.02	2.59	6.15
Calcitic hydrate	2.75	None	440	555	395	390	1.96	2.92	3.69	4.41
"	5.5	"	207	265	187	255	0.44	0.95	1.16	2.60
"	11.0	"	132	167	145	180	0.30	0.59	0.58	1.95
hsd (0.05) Treatments within a variety			736	1063	736	1063	7.27	9.64	7.27	9.64

[1]Equivalent of 1000 lbs/A of 5-20-20 banded in all treatments.

Mn banded treatment significantly increased the Mn concentration over that of the check at the final harvest. At the final harvest manganous sulphate added to the band tended to increase the Mn concentration over that of the check in the Norlands but not in the Sebagos. The Al treatment resulted in Mn concentrations lower than the check in both varieties at both harvests.

The trends in Mn uptake for the Al and/or Mn banded treatments were essentially the same as those of the Mn concentration data, except that none of the differences were significant when compared with the check.

Additions of either source of lime at all rates of application drastically reduced the Mn concentrations and Mn uptake by the vines of both varieties at either harvest. Increasing the rates of lime resulted in decreasing Mn concentrations and Mn uptake for each application, and calcitic hydrate was the most effective in this respect due to the resulting higher soil pH levels (Table 5).

The Mn concentrations in the vines of all the unlimed treatments were considerably in excess of any toxicity levels noted in the literature review. Since the water soluble Mn content of the unlimed soil was 10 ppm, which is in excess

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TABLE 5.--Soil pH levels measured by direct contact and 1:1 soil:water dilution as affected by rates and source of lime and additions of aluminum sulphate and manganous sulphate to the fertilizer band 103 days after planting potatoes.

Treatments			Direct Contact		1:1 Soil:Water Dilution
Material Applied	Rate of Application				
	Mixed	Additions to Fertilizer Band[1]	Tube in place	Tube removed	
	T/A	lbs/A			
Check	None	None	5.10	4.96	5.07
Al	None	50	5.07	4.75	5.01
Mn	"	30	5.05	4.85	5.07
Al+Mn	"	50+30	5.00	4.78	4.96
Dolomite	2.75	None	6.37	6.31	6.28
"	5.5	"	6.72	6.75	6.63
"	11.0	"	6.72	6.81	6.85
Calcitic hydrate	2.75	None	6.45	6.53	6.86
"	5.5	"	7.36	7.31	7.63
"	11.0	"	7.40	7.64	8.01
hsd (0.05)					
Treatments with varieties combined			0.35	0.49	0.21

[1]Equivalent of 1000 lbs/A of 5-20-20 banded in all treatments.

of levels reported to cause Mn toxicity in potatoes grown in nutrient solutions (Berger and Gerloff, 1947; Smith, 1937), high plant Mn levels would be expected on the unlimed treatments.

The Mn concentrations in the vines of the dolomite treated soils at the final harvest were about 700 ppm, which Berger and Gerloff (1947) reported to be toxic for potatoes, but below the vine Mn level of 1400 ppm at which Löhnis (1951) observed no toxicity symptoms. As shown by Ouellette and Généreux (1965), varietal differences are important in determining the levels of Mn concentrations in the plants which result in toxicity symptoms.

No direct evidence was obtained either by plant symptoms or nutrient content to suggest Al was responsible for the toxicity symptoms noted (Table 5A, appendix).

Soil and Fertilizer Band Direct Contact pH Measurements

Evaluation of the Method

Although some difficulties were encountered in measuring pH by direct contact of the electrodes with the soil and

the fertilizer bands, this method proved very useful. The condition of the glass electrode was affected by the previous sample so that pH readings could not be taken until drifting of the meter needle had ceased. This drifting was especially noticeable when measuring a high pH after a low pH. Washing the elctrode between samples in an attempt to reduce the drift did not seem to improve the situation, nor did wiping the electrode with a damp cloth. In fact, simply wiping the electrode with the dry palm of the hand resulted in reproducible readings.

The soil pH measurements made by direct contact and those determined in the laboratory in a 1:1 soil:water suspension were quite consistent (Table 5), except that direct contact soil pH readings were lower than those in water at pH levels above 6.7. This may be due to the high concentrations of H^+ ions bound closely adjacent to soil colloids which are not free to diffuse throughout the solution upon dilution with water.

The precision of duplicate pH measurements of a given soil by the direct contact method was very good. There were no significant differences in the soil pH readings taken in the two tubes placed in the soils of two replications du

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during the oat growth period (Table 8A, appendix). The mean pH measurements for any one soil treatment taken at three different times during the oat crop were very consistent. No explanation is offered for the high soil pH levels observed by the direct contact method on the unlimed soils as compared with the lower pH levels measured after harvesting the oats (Table 10A, appendix).

Soil Treatment Effects on Soil pH at the End of the Potato Growth Period

There were no significant decreases in the soil pH levels in the center of the pots 3" horizontally away from the fertilizer bands 103 days after planting the potatoes (Table 5), although the Al band treatment did give the lowest readings with each method of determination. Both Lindsay and Stephenson (1959) and Blanchar and Caldwell (1966) found pH decreases from solutions diffusing from fertilizer bands at distances greater than this. Blanchar and Caldwell (1966) did not present pH data for the soil samples they obtained horizontally away from the fertilizer pellets in soil columns leached with 4 cm of water, but the P concentration data from these samples suggest that, with leaching, movement of the solution from the band occurred primarily in a downward direction. Although the soils in this present experiment were not truly leached by additions of water, due to lack of drainage in the pots, it would seem that the daily additions of water would tend to enhance the downward movement of the solution moving out of the band, thus reducing lateral diffusion.

Significantly different increases in soil pH were noted both between the check treatment and the low rate of either source of lime as well as between the low and high rates of lime. The soil pH at the low rate of lime was the same for both sources of lime as measured by the direct contact method. At the medium and high rates of lime soil pH levels were higher with calcitic hydrate than with dolomite due to the faster rate of reaction of $Ca(OH)_2$ as compared with the crystaline double salt of Ca-Mg carbonate in dolomite.

Treatment Effects on Soil and Band pH Levels During Potato Growth Period

The first complete soil and band pH measurements were made 6 days after planting the potatoes or about 16 days after adding the fertilizer. Random measurements of the band pH levels, determined about one day after planting, indicated that the pH levels in the fertilizer bands were about 1 pH unit lower than the values reported on the 6th day after planting (Figures 1-10). The data of Lindsay and Stephenson (1959) would suggest that band pH levels were even lower immediately after adding the fertilizer to the soil.

In the check treatment (Figure 1) the soil pH and the band pH both approached a pH of 5 after about 15 days and thereafter were relatively constant. Since the soil and band pH levels were not significantly different between 14 and 42 days, one would not expect to find much more dissolved Al or Mn in the band area than throughout the rest of the soil volume unless large amounts of Al and Mn had been dissolved at the initially low band pH and the Mn had not yet precipitated as suggested by Lindsay and Stephenson (1959a).

The tendency for soil pH levels to rise on the 56th day occurred on essentially all treatments and apparently

was the result of making pH measurements shortly after adding water. The soil pH levels had decreased again at 103 days (Table 5).

The addition of aluminum sulphate to the band (Figure 2) depressed the band pH to 3.5, thus one would expect to find much higher levels of Al and Mn dissolved from the soil in this band area. The pH of the band containing aluminum sulphate plus manganous sulphate (Figure 3) was also reduced to 3.5 indicating that the added manganous sulphate had no added effect on the band pH. The similarity of the pH levels noted between the Mn treatment and that of the check treatment confirm this observation (Figure 4).

Although there was a tendency for the soil pH levels to decline with time, it is difficult to evaluate whether this was an effect of the fertilizer bands or due to other factors such as microbial action, changes in nutrient status or greenhouse environmental effects. If there had been any significant pH effect resulting from the fertilizer bands it would have been most marked in the Al treated soils, and there was no real evidence of this.

All of the band pH levels tended to increase with time, as would be expected, as the fertilizer solutions di

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diffused from the band. However, repeated forcing of the electrode into the band would tend to move the electrode through the band so that one would measure more of a band-soil mixture as the experiment progressed.

With the application of the low rate of dolomite (Figure 5) the soil pH was increased from 5 to 6.5 with essentially no effect on the band pH. This change in soil pH, however, had a tremendous effect on the Mn contents in the vines (Table 4). This suggests that the main source of the Mn in the plants was the available Mn in the soil volume throughout the whole root zone and not from the fertilizer band area. This also suggests that the plants were not feeding heavily from the fertilizer band. The medium and high rates of dolomite (Figures 6 and 7) resulted in only slight additional increases in soil and band pH levels. But note that these higher rates resulted in band pH levels higher than the soil pH in the check treatment.

Application of the low rate of calcitic hydrate (Figure 8) resulted in a band pH slightly above that of the soil in the check treatment, a marked increase in the soil pH and a tremendous decrease in the plant Mn contents (Table 4). The medium rate (Figure 9) resulted in an additional

slight increase in band pH and again raised the soil pH. The most marked change in the band pH with a lime treatment occurred with calcitic hydrate at the high rate (Figure 10), where the band pH was raised above 6.5 as compared with the soil pH of about 5.0 in the standard treatment.

This influence of lime on the band pH is important in three ways, first it reduces the solubilization of soil Al and Mn around a fertilizer band, second it reduces the H^+ ion concentration below a level that might prevent plant roots from surviving in the band area and utilizing the nutrients of a fertilizer band and third, it reduces the residual acidity of the band so that mixing the fertilizer residue into the soil by plowing results in less increased acidity.

Just when and how actively the plant roots were able to feed from the fertilizer band areas can not be determined from this experiment since no non-banded treatments or tracer elements were employed. In view of the lack of feeding by plants from the soil zones adjacent to fertilizers, until leaching had occurred, in the work of Blanchar and Caldwell (1966 and 1966a), one questions just when the potato roots were able to penetrate and feed from these fertilizer zones.

Because the pots had no drainage, no actual leaching could occur, although daily additions of water would tend to accelerate movement of the concentrated fertilizer solutions from the bands. Since some increases in plant Mn were noted on the Al and/or Mn treatments in both potato varieties at the 68 day harvest, it would appear that the roots were able to feed somewhat from the soil zones influenced by the bands at this time. The low pH level of the Al treated bands makes one question whether roots could function in this immediate area. Once the salt effects were sufficiently reduced through diffusion and leaching plant roots should have been able to function in all the other treatment bands with their higher pH levels.

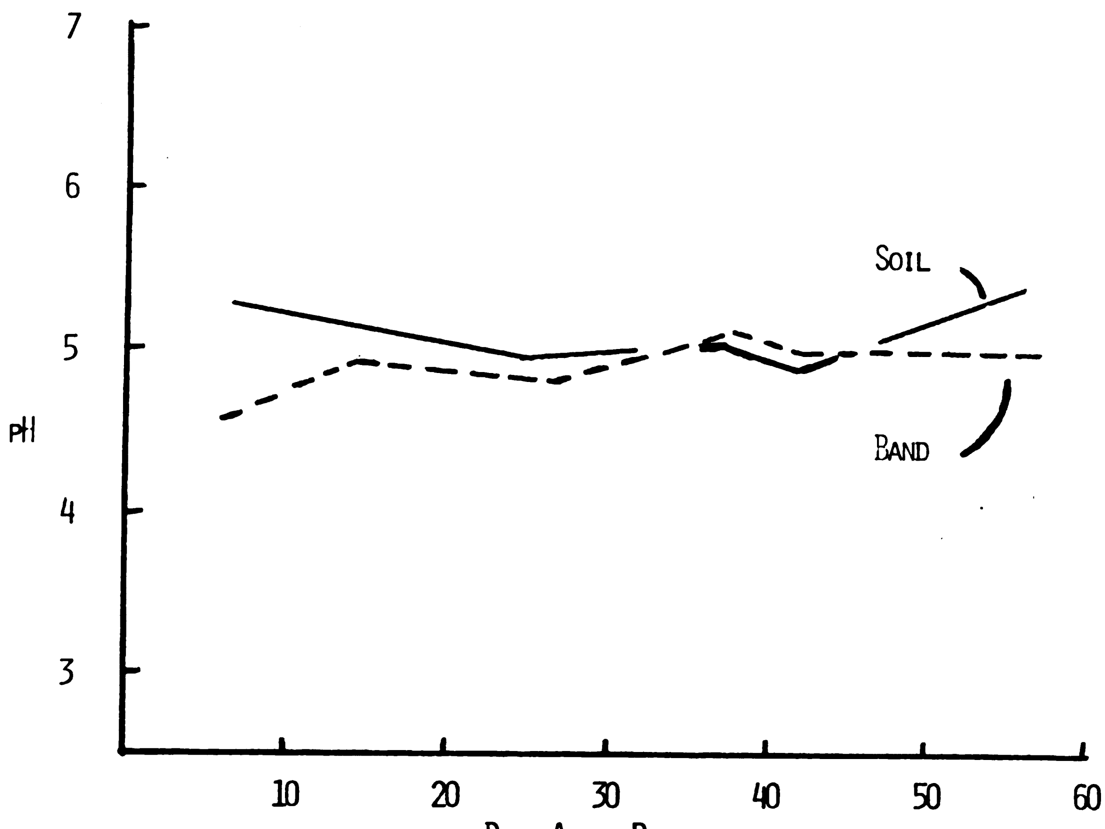

Figure 1. Changes in soil and fertilizer band pH levels with time on unlimed soils receiving only the banded fertilizer.

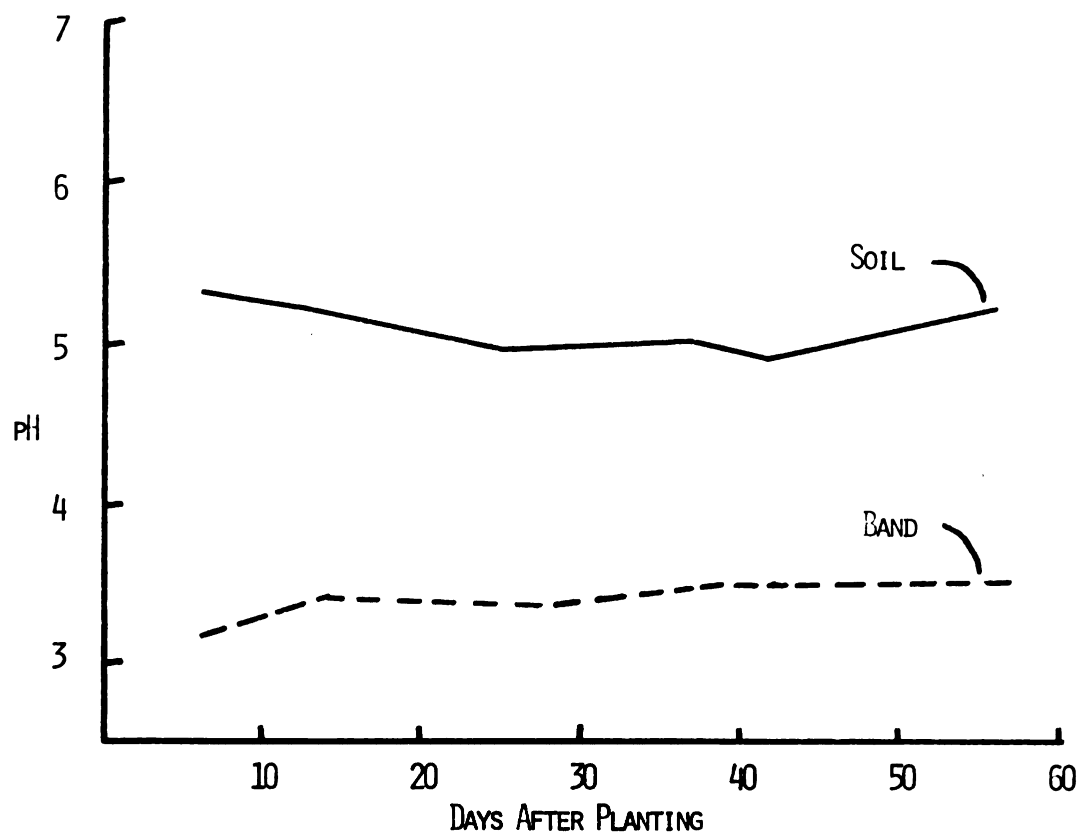

Figure 2. Changes in soil and fertilizer band pH levels with time on unlimed soils containing aluminum sulphate in the fertilizer band.

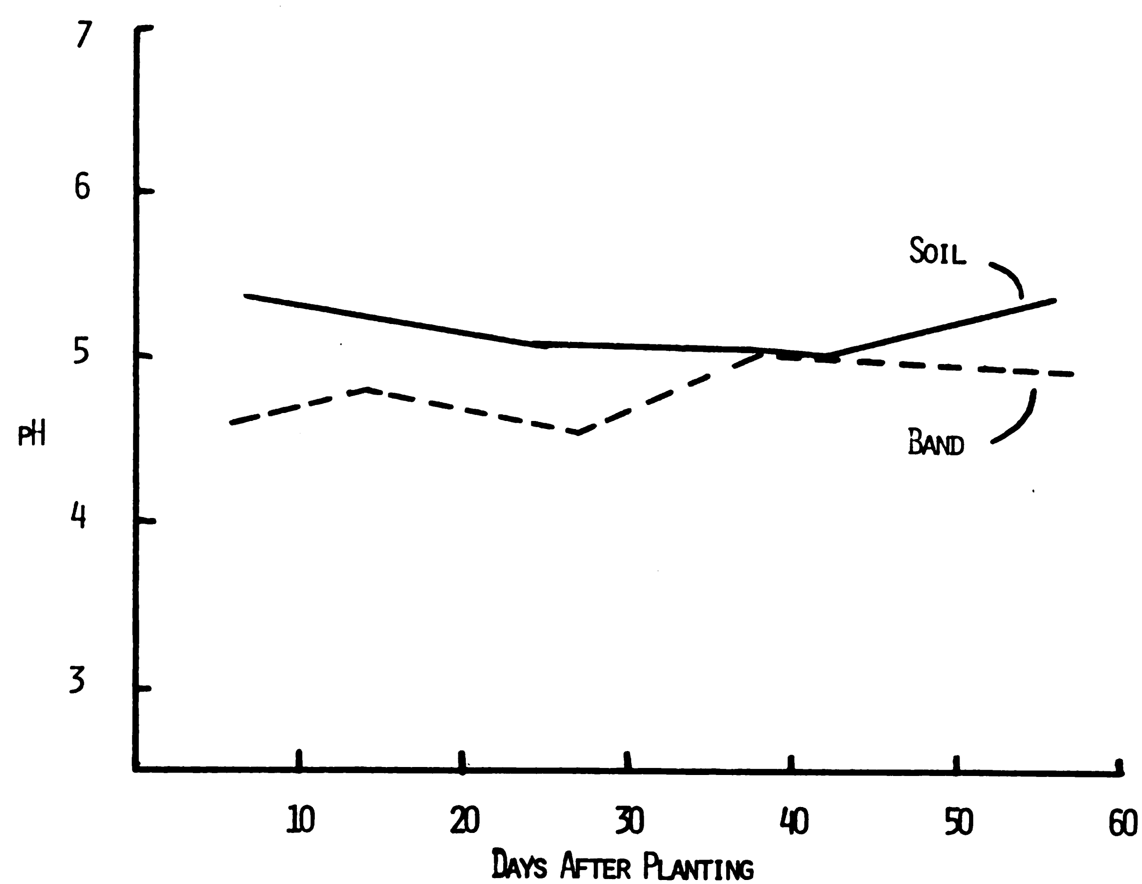

Figure 3. Changes in soil and fertilizer band pH levels with time on unlimed soils containing aluminum sulphate and manganous sulphate in the fertilizer band.

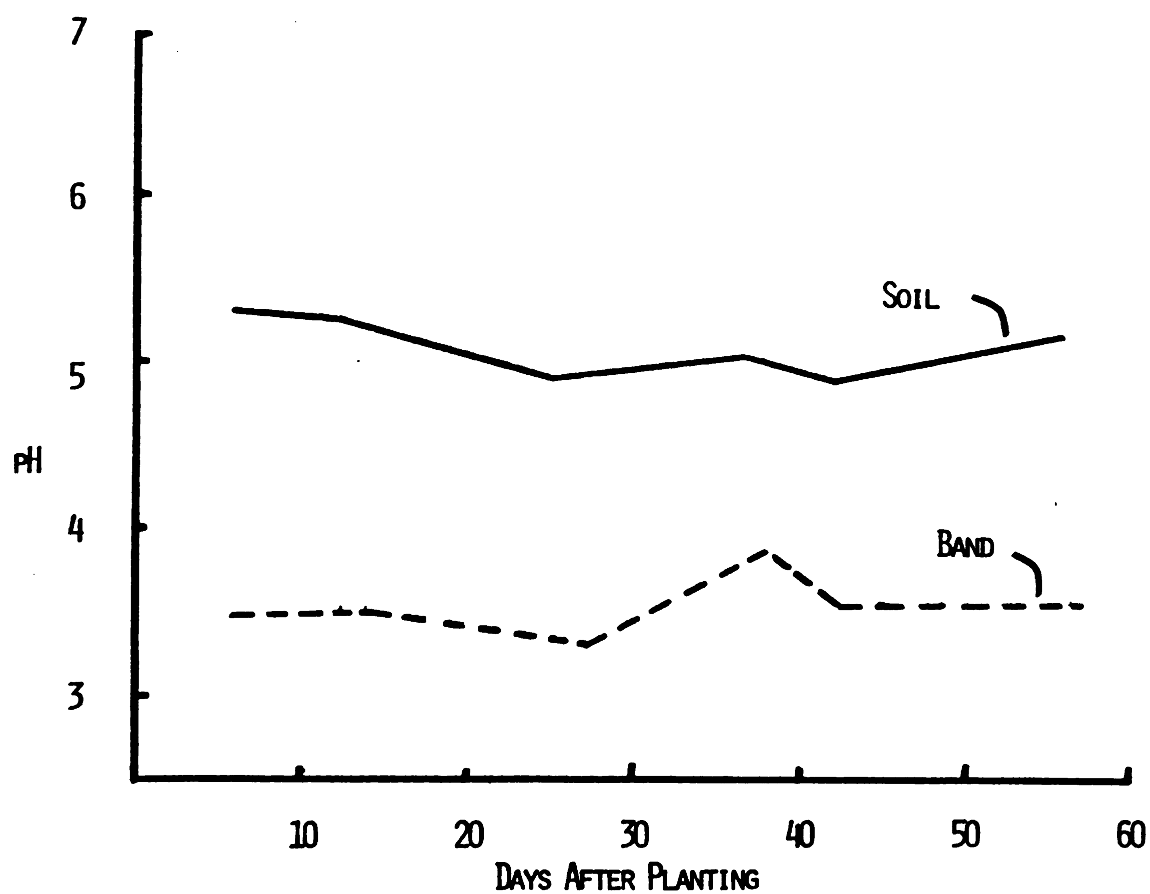

Figure 4. Changed in soil and fertilizer band pH levels with time on unlimed soils containing manganous sulphate in the fertilizer band.

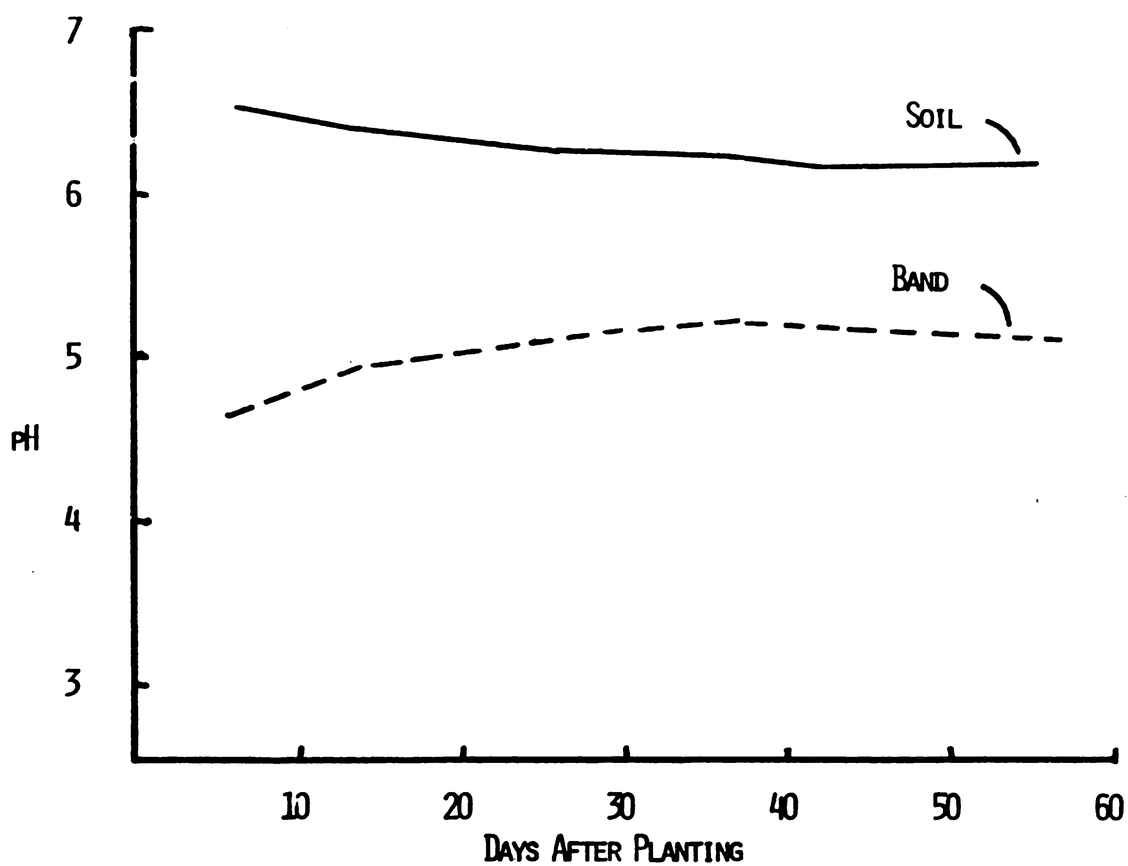

Figure 5. Changes in the soil and fertilizer band pH levels with time on soils receiving one half times the lime requirement as dolomite.

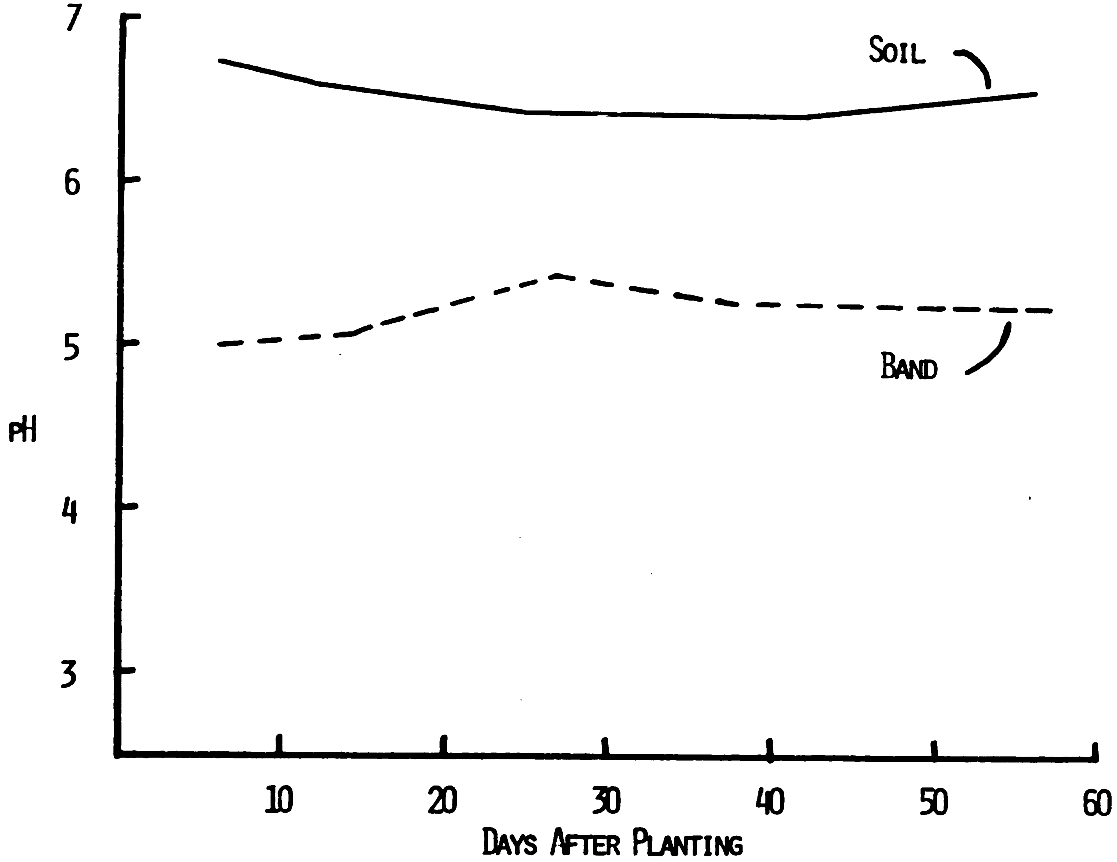

Figure 6. Changes in soil and fertilizer band pH levels with time on soils receiving 1 times the lime requirement as dolomite.

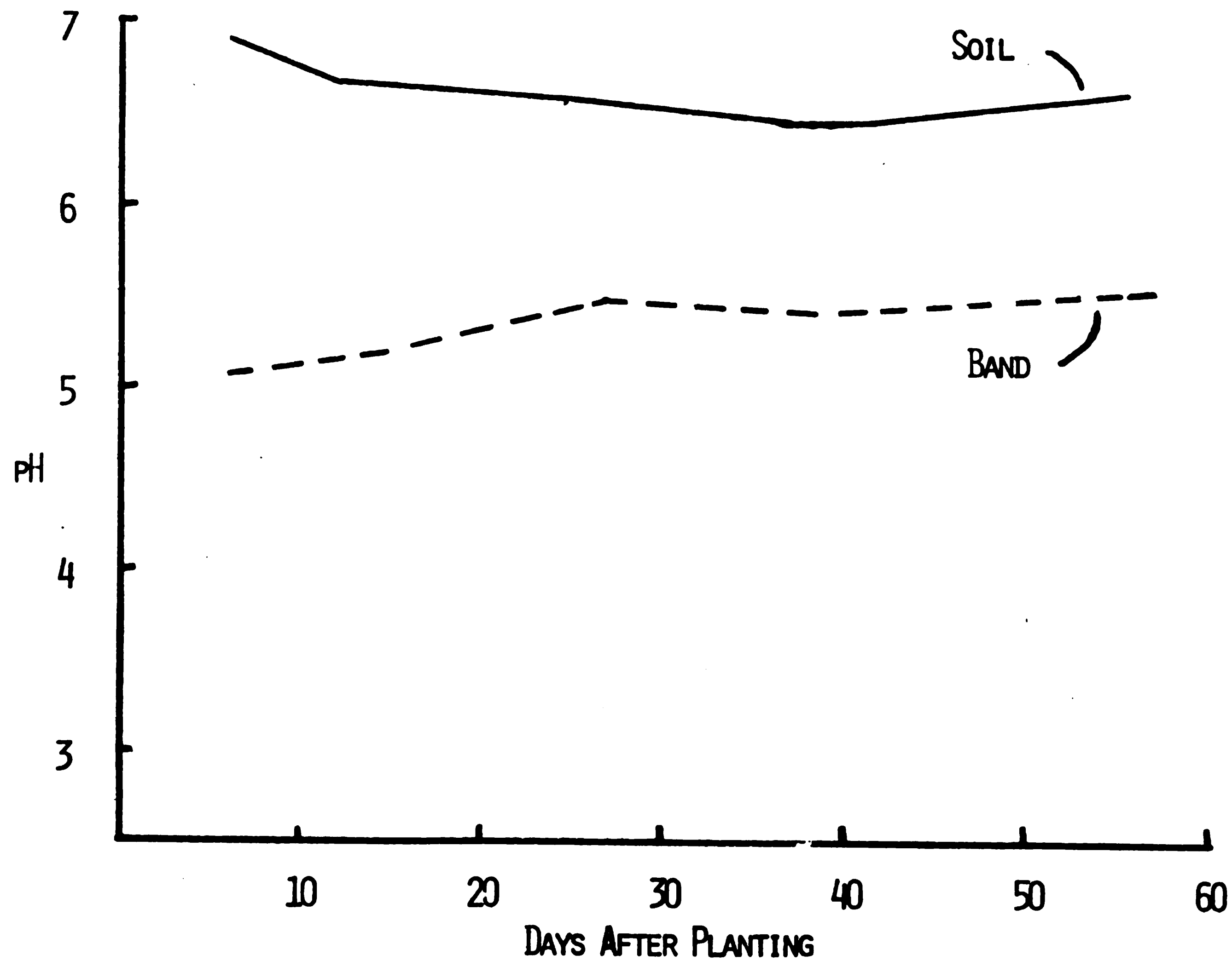

Figure 7. Changes in the soil and fertilizer band pH levels with time or soils receiving 2 times the lime requirement as dolomite.

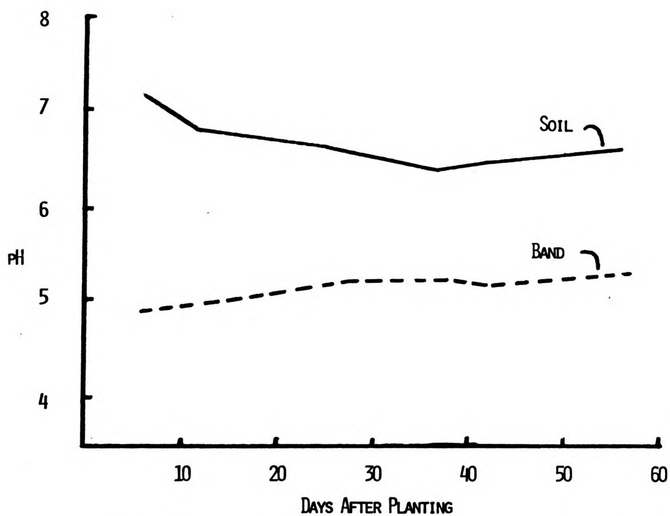

Figure 8. Changes in soil and fertilizer band pH levels with time on soils receiving one half times the lime requirement as calcitic hydrate.

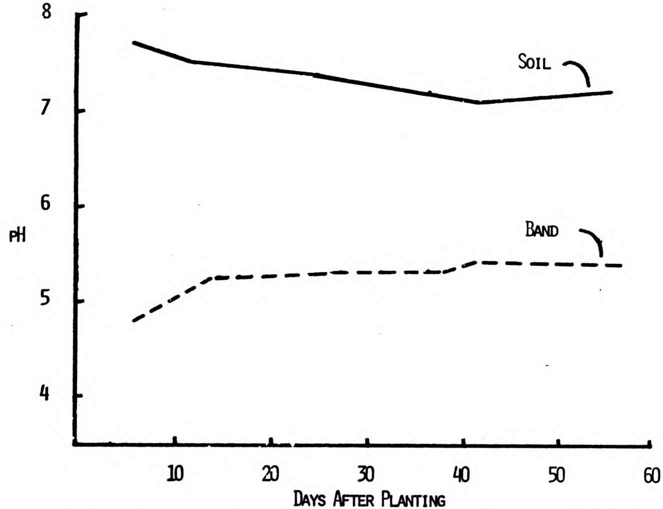

Figure 9. Changes in soil and fertilizer band pH levels with time on soils receiving 1 times the lime requirement as calcitic hydrate.

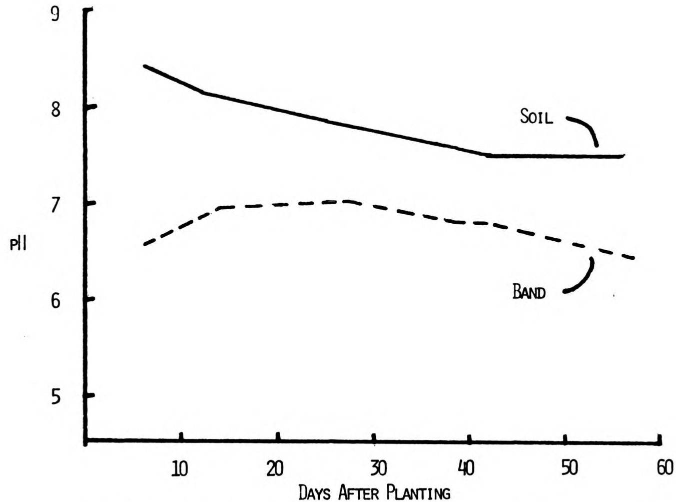

Figure 10. Changes in soil and fertilizer band pH levels with time on soils receiving 2 times the lime requirement as calcitic hydrate.

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Oat Crop

Oats are quite resistant to Mn toxicity (Hewitt, 1963). Oats were therefore planted in the same soils as were the potatoes, after mixing the residues from the fertilizer bands throughout the soils, to evaluate the residual effects of the soil treatments on plant growth and Mn and Mg uptake and to evaluate the residual acidity effects of the band residues.

Yields of Oats

The high rate of calcitic hydrate was the only treatment to significantly reduce the oat yield (Table 6) from that of the check treatment at the 40 day harvest (Sebago pots). No significant yield differences were noted at the 70 day harvest (Norland pots), and yields were about triple those of the 40 day harvest.

Severe symptoms of Mg deficiency were noted on the unlimed and the calcitic hydrate treatments at the early stage of growth but later disappeared, as is often observed (Ferrari and Sluijmans, 1955; and Christenson, 1968).

TABLE 6.--Oven dry weights of oat tissue at two harvest dates as affected by mixing the residues from the fertilizer bands in the treatments originally applied for the potatoes.

Treatments			Growth Period	
Material Applied	Rate of Application		40 days	70 days
	Mixed	Additions to Fertilizer Band[1]		
	T/A	lbs/A	--g dry weight---	
None	--	--	12.80	35.15
Al	None	50	11.77	37.72
Mn	"	30	12.50	36.00
Al+Mn	"	50+30	12.87	37.32
Dolomite	2.75	None	12.45	36.57
"	5.5	"	10.97	36.45
"	11.0	"	11.35	36.92
Calcitic hydrate	2.75	None	11.47	40.02
"	5.5	"	10.90	39.15
"	11.0	"	9.45	35.45
hsd (0.05)				
Treatments within a variety			2.99	ns

[1]Equivalent of 100 lbs. of 5-20-20 banded in all treatments prior to planting potatoes.

Mineral Contents of the Oat Tissue

The data obtained for the Ca and K concentrations and uptake by the oats are presented in the appendix and will not be specifically discussed (Table 9A, appendix).

The Al and/or Mn banded treatments had no effect on the Mg concentrations or uptake by the oats at either harvest when compared with the check treatment (Table 7). Dolomite applications resulted in very large increases in plant Mg concentrations and uptake, while applications of calcitic hydrate resulted in a progressive decrease in Mg concentrations and Mg uptake.

As was noted with the potatoes, the low levels of available soil Mg on the unlimed treatments were not low enough to be limiting for yields as is evidenced by the yield data and the Mg concentrations in the plant tissue (Tables 6 and 7). Christenson (1968) reports a tissue level of 0.16% Mg for oats grown in the greenhouse as the critical level for development of deficiency symptoms, but notes that Mg levels may be considerably reduced before yields are affected. Tissue Mg levels below 0.16% were noted only on the medium and high rates of calcitic hydrate where both soil Mg levels (Table 10a, appendix) and yields were lower than on the unlimed treatments.

TABLE 7.--Magnesium and Mn concentrations and uptake by oats at two harvest dates as affected by mixing the residues from the fertilizer bands in the treatments originally applied for the potatoes.

Treatments[1]			Magnesium				Manganese			
	Rate of Application		Concentration		Uptake		Concentration		Uptake	
Material	Mixed	Additions to Fertilizer Band[2]	40 days	70 days	40 days	70 days	40 days	70 days	40 days	70 days
	T/A	lbs/A	% dry weight		--Mg/pot--		---ppm----		--Mg/pot---	
None	--	--	0.240	0.180	30.8	61.6	468	705	5.97	24.9
Al	None	50	0.210	0.185	24.8	69.6	928	1105	10.92	41.8
Mn	"	30	0.268	0.225	33.2	80.6	695	920	8.76	33.1
Al+Mn	"	50+30	0.265	0.188	34.2	69.4	1050	1175	13.43	43.8
Dolomite	2.75	None	0.590	0.538	73.4	196.5	75	88	0.93	3.2
"	5.5	"	0.668	0.648	73.0	236.0	58	58	0.60	2.1
"	11.0	"	0.680	0.645	76.0	238.6	58	95	0.66	3.6
Calcitic hydrate	2.75	None	0.178	0.168	20.3	67.1	65	62	0.74	2.5
"	5.5	"	0.120	0.132	13.1	51.5	48	30	0.50	1.2
"	11.0	"	0.088	0.112	8.4	39.9	140	165	1.28	5.8
hsd (0.05) Treatments within a variety.			0.096	0.131	9.8	50.8	200	185	2.59	8.4

[1]Treatments applied for potato crop--soils completely remixed prior to planting oats.

[2]Equivalent of 1000 lbs/A of 5-20-20 banded in all treatments prior to planting potatoes.

TABLE 7.--Magnesium and Mn concentrations and uptake by oats at two harvest dates as affected by mixing the residues from the fertilizer bands in the treatments originally applied for the potatoes.

Treatments[1]			Magnesium				Manganese			
	Rate of Application		Concentration		Uptake		Concentration		Uptake	
Material	Mixed	Additions to Fertilizer Band[2]	40 days	70 days	40 days	70 days	40 days	70 days	40 days	70 days
	T/A	lbs/A	% dry weight		--Mg/pot--		---ppm----		--Mg/pot---	
None	--	--	0.240	0.180	30.8	61.6	468	705	5.97	24.9
Al	None	50	0.210	0.185	24.8	69.6	928	1105	10.92	41.8
Mn	"	30	0.268	0.225	33.2	80.6	695	920	8.76	33.1
Al+Mn	"	50+30	0.265	0.188	34.2	69.4	1050	1175	13.43	43.8
Dolomite	2.75	None	0.590	0.538	73.4	196.5	75	88	0.93	3.2
"	5.5	"	0.668	0.648	73.0	236.0	58	58	0.60	2.1
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Calcitic hydrate	2.75	None	0.178	0.168	20.3	67.1	65	62	0.74	2.5
"	5.5	"	0.120	0.132	13.1	51.5	48	30	0.50	1.2
"	11.0	"	0.088	0.112	8.4	39.9	140	165	1.28	5.8
hsd (0.05) Treatments within a variety.			0.096	0.131	9.8	50.8	200	185	2.59	8.4

[1]Treatments applied for potato crop--soils completely remixed prior to planting oats.

[2]Equivalent of 1000 lbs/A of 5-20-20 banded in all treatments prior to planting potatoes.

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The increase in soil Mg levels noted after mixing the fertilizer residues (Tables 6A and 7A, appendix) may be the result of mixing, throughout the soil, some unavailable soil Mg brought into an available form by the acid solution in the area of the fertilizer bands (Christenson, 1968). However, at these very low soil Mg levels, changes of 20 ppm Mg are within the range of experimental error for determinations made at different times. The precision of samples analyzed as a group (as were the samples of each sampling date) appears much greater than this. Thus some of the increase in soil Mg noted between the samples obtained after the potatoes and those obtained after mixing the residues with the soil may be experimental error (Tables 6A and 7A, appendix).

The same relationships between the Ca and Mg levels in the plants and in the soils that were observed on the potatoes were also noted with the oats (Tables 7 and 9A and 10A, appendix).

Plant Mn concentrations and uptake increased markedly between 40 and 70 days (Table 7). When the residue of the banded Mn fertilizer was mixed with the soil the Mn concentration in the oats was significantly increased at both a

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harvests as compared with the check treatment. Manganese concentrations significantly higher than those due to the Mn band were observed with Al and Al plus Mn treatments which resulted in the same plant Mn concentrations. The uptake data followed essentially the same trends as did the plant Mn concentrations.

Either source of lime drastically reduced Mn concentrations and Mn uptake. Both lime sources resulted in a trend for decreasing Mn concentrations and uptake at the two lower rates of application, but unlike the potatoes both Mn concentrations and Mn uptake increased in both harvests with the application of the highest rate of calcitic hydrate as compared with the lower two rates.

Mixing the residues from the fertilizer bands throughout the soil resulted in a lowering of soil pH levels about 0.2 pH units on all treatments except those containing Al in the band, where the change in pH tended to be slightly greater (Tables 6A and 7A, appendix). The data for Mn concentrations and uptake by the plants suggest that the increased soil Mn availability on the Al and the Al plus Mn treatments was related to these increases in soil acidity which could have come from two possible

sources. First, any Al in the band which had not reacted with the soil, when mixed with the rest of the soil, would tend to depress the soil pH thus reducing some of the Mn oxides in the soil. But this would mean that only a small pH change was responsible for the large increase in Mn availability (Table 7).

The other possibility is that the very low pH levels of the solutions diffusing from the Al and the Al plus Mn treated bands dissolved large amounts of soil Mn and Al which remained in an available form to be distributed throughout the soil upon mixing. Both of these processes probably contributed to the decreased pH and increased Mn availability evidenced by the increased plant Mn concentrations and uptake.

It is very difficult to understand why increases in Mn concentrations and Mn uptake occurred at the highest rates of calcitic hydrate because of the decreasing availability of Mn occurring as soil pH increases. The greater Mn concentrations were not due to lower yields on these treatments since Mn uptake also increased. Manganese uptake has been shown to increase with decreasing Mg levels in nutrient solutions (Löhnis, 1960). In addition one

wonders if the fact that Mn can substitute for Mg in many of the plant enzyme systems is not in some way related to this increased Mn uptake at these very low soil and plant Mg levels (Nason and McElroy, 1963).

It appeared that soil K was a limiting factor; therefore minimal yield differences due to applications of dolomite occurred on the 40 day harvest and none occurred at the 70 day harvest. Soil K levels were considerably reduced by the potato crop and the growth of the oats reduced them even more (Tables 6A, 7A, and 10A, appendix).

Unpublished data of R. P. White, Michigan State University demonstrated that, on a sandy loam soil, greenhouse oat yields increased with soil test K levels up to at least 150 ppm; at this level the K concentration in the tissue was 5%. The soil test K levels in the soils and the K levels in the oat tissue of the present experiment were considerably below these levels (Tables 9A and 10A, appendix). Although the soils in the Norland pots had higher soil K levels prior to planting the oats than did the Sebago pots, the longer growth period of the oats in the Norland pots reduced the soil K levels below those of the Sebago pots.

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CONCLUSIONS

The Sebago plants had higher vine yields than did the Norlands on all treatments. Applications of dolomite tended to increase the final vine yields of the Norland variety and significantly increased the final vine yields of the Sebago variety as compared with the check treatment. With the exception of the low rate which resulted in yields higher than the check, applications of calcitic hydrate reduced yields of the initial harvest on both varieties and of the final harvest of the Norlands. Though all final Sebago vine yields were higher than those of the check, the medium and high calcitic hydrate treatments reduced vine yields as compared with the low rate. These vine yield reductions occurring on the calcitic hydrate treatments were attributed to Mg deficiency apparently resulting from an imbalance in the soil Ca/Mg ratio due to the calcitic hydrate applied. This was evidenced by lower soil Mg levels, deficient levels of Mg in the plant tissue, and visual Mg deficiency symptoms on these treatments.

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Norland vines had higher vine Mn concentrations than did the Sebagos on all treatments, but the Sebago plants took up the most Mn due to their higher yields. Both sources of lime at all rates drastically reduced both vine Mn concentrations and uptake. Levels of plant Mn and uptake decreased with increasing rates of lime, with calcitic hydrate being the most effective in this respect.

Soil pH levels increased with increasing rates of either source of lime and calcitic hydrate, due to its faster rate of reaction, resulted in higher soil pH levels than did dolomite.

The same liming effects were noted on the pH levels in the fertilizer bands. Increasing rates of dolomite raised band pH levels so that at the high rate of dolomite the band pH was about 0.5 pH units above the pH of the check band. Band pH levels were most strongly increased by applications of calcitic hydrate. The medium rate of calcitic hydrate resulted in a band pH level equivalent to that of the high rate of dolomite, while the high rate of calcitic hydrate caused the band pH level to rise nearly 2 pH units above that of the band in the check treatment.

Compared with the check treatment, additions of aluminum sulphate and manganese sulphate to the fertilizer bands had no apparent significant effects on the vine yields of either variety. Manganous concentrations in the plants were the highest when aluminum sulphate plus manganous sulphate was added to the bands. Banded aluminum sulphate treatments resulted in Mn concentrations higher than those of the check at the initial harvest for both varieties but lower concentrations at the final harvest, while additions of manganous sulphate to the band resulted in Mn concentrations higher than the check in the Norlands at both harvests and for the initial harvest of the Sebagos. Plant uptake data followed the same trends.

The pH level of the bands containing manganous sulphate was essentially the same as that of the bands of the check treatment throughout the experimental period, about 4.8. The addition of aluminum sulphate to the band, with or without manganous sulphate reduced the band pH to about 3.5.

Mixing the residues from the fertilizer bands throughout the soil, prior to planting the oats, resulted in a lowering of the soil pH on all treatments; the Al

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treated residue with or without added Mn caused the greatest pH depression. Oat tissue Mn levels were significantly increased over the check treatment by mixing the band residue of the Mn treatment. However mixing the residue of the Al treatment resulted in a significantly higher Mn content than did the Mn treatment, demonstrating that the residual acidity of the fertilizer band was a more important factor influencing soil Mn availability than was the added Mn.

It was apparent that the main problem in the field was Mn toxicity. This was confirmed in the greenhouse by the high vine Mn concentrations that occurred along with the appearance of Mn toxicity symptoms on the plants grown in the unlimed soils.

Although the soil tested low in available soil Mg, and increasing levels of available Mg have been shown to depress Mn uptake (Löhnis, 1960), the Mn toxicity was so severe it is doubtful whether additions of Mg to the soil, without a change in soil pH, would have reduced the high plant Mn concentrations to less than toxic levels.

The lack of substantial increases in vine Mn uptake occurring when aluminum sulphate was added to the band, causing a reduction in the band pH, or when manganous

sulphate was added to the band, indicates that the Mn toxicity resulted from the large amount of available soil Mn present throughout the whole soil volume, rather than due to soil Mn solubilized by the acidity of the solutions diffusing from the fertilizer bands. This interpretation is further supported by the high level of water-extractable soil Mn in the original soil sample, and the marked decrease in Mn uptake that occurred on the limed soils and, most specifically, by the decrease in Mn uptake that occurred on the low dolomite treatment, where the soil pH was increased to 6.5 with essentially no change in the pH of the fertilizer band as compared with the unlimed check treatment.

The Norland variety appeared more susceptible to Mn toxicity than did the Sebago variety, as demonstrated by both higher concentrations of Mn in the vines and more severe toxicity symptoms.

No real evidence was obtained that the plants grown on the unlimed treatments were Mg deficient; however, both the oats and the potatoes grown at the medium and high levels of calcitic hydrate were deficient in Mg as indicated by the low Mg concentrations in the tissue and visual symptoms of Mg deficiency. The large additions of Ca in these

treatments upset the Ca/Mg balance in both the soil and the plant as was shown by both soil tests and the mineral contents of the tissue.

To eliminate Mn toxicity on this soil it appears necessary to lime the soil with about 5 tons of dolomite in order to bring the soil pH to a level of 6.0 to 6.5, where it should be maintained by correcting residual acidity from banded fertilizers with additions of lime as indicated by future soil tests.

Allowing the soil pH to decrease to very low levels (below 5) is an unwise practice. Not only might yields be reduced by toxic concentrations of Mn, Al, and possibly H^+ ions, but Schafer (1968) suggests that when soils reach these low pH levels there may be an irreversible disintegration of some soil colloids. He indicates that restoration of the soil to its former condition may be both expensive and time consuming.

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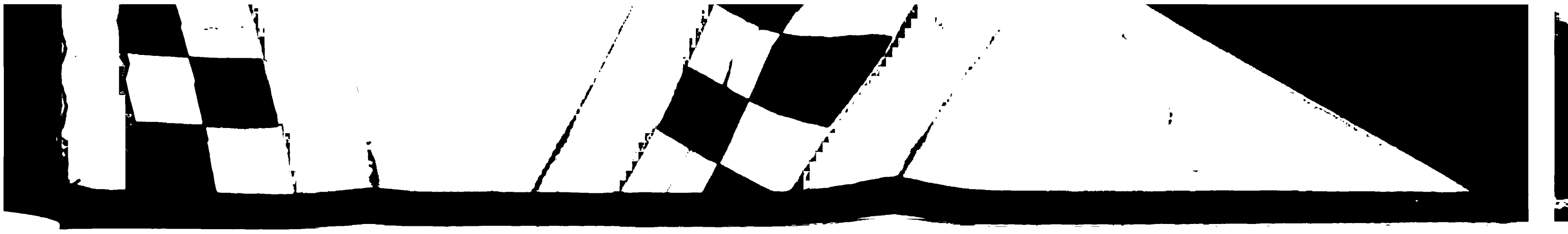

APPENDIX

TABLE 1A.--Yields of Norland and Sebago potato tubers after 90 days growth as affected by ratio and source of lime and additions of aluminum sulphate and manganous sulphate to the fertilizer bands.

Treatments			Variety	
Material Applied	Rate of Application		Norland	Sebago
	Mixed	Additions to Fertilizer Bands[1]		
	T/A	lbs/A	--g dry weight--	
Check	None	None	246	190
Al	None	50	190	180
Mn	"	30	228	168
Al + Mn	"	50+30	192	152
Dolomite	2.75	None	226	156
"	5.5	"	206	144
"	11.0	"	198	164
Calcitic hydrate	2.75	None	174	177
"	5.5	"	86	91
"	11.0	"	62	91
hsd (0.05)				
Treatments within a variety			65	65

[1]Equivalent of 1000 lbs/A of 5-20-20 banded in all treatments.

TABLE 2A.--Phosphorus concentrations in and uptake by Norland and Sebago potato vines at two dates of harvest as affected by rates and source of lime and additions of aluminum sulphate and manganous sulphate to the fertilizer band.

Treatments			Phosphorus Concentration				Phosphorus Uptake			
	Rate of Application		Norland		Sebago		Norland		Sebago	
Material Applied	Mixed	Additions to Fertilizer Band[1]	68 days	90 days	68 days	90 days	68 days	90 days	68 days	90 days
	T/A	lbs/A	-----% dry weight-----				-------mg/plant--------			
Check	None	None	0.20	0.17	0.26	0.17	7.36	7.66	22.5	14.6
Al	None	50	0.22	0.14	0.27	0.17	7.85	5.50	16.5	16.1
Mn	"	30	0.19	0.16	0.25	0.17	6.56	7.18	20.3	14.9
Al+Mn	"	50+30	0.22	0.15	0.28	0.18	7.81	6.81	20.6	17.6
Dolomite	2.75	None	0.19	0.17	0.26	0.19	6.87	8.23	25.9	23.5
"	5.5	"	0.16	0.18	0.29	0.19	7.05	9.98	30.1	21.8
"	11.0	"	0.22	0.16	0.27	0.19	7.42	10.00	25.0	25.2
Calcitic hydrate	2.75	None	0.20	0.13	0.26	0.20	9.71	6.89	23.7	23.7
"	5.5	"	0.24	0.13	0.25	0.15	4.91	4.73	15.5	15.1
"	11.0	"	0.19	0.14	0.22	0.16	4.20	4.70	8.7	17.4
hsd (0.05)										
Treatments within a variety			ns	ns	ns	ns	ns	ns	8.4	7.7

[1]Equivalent of 1000 lbs/A of 5-20-20 banded in all treatments.

TABLE 3A.--Calcium concentrations in and uptake by Norland and Sebago potato vines at two dates of harvest as affected by rates and source of lime and additions

TABLE 3A.--Calcium concentrations in and uptake by Norland and Sebago potato vines at two dates of harvest as affected by rates and source of lime and additions of aluminum sulphate and manganous sulphate to the fertilizer band.

Treatments			Calcium Concentration				Calcium Uptake			
	Rate of Application		Norland		Sebago		Norland		Sebago	
Material Applied	Mixed	Additions to Fertilizer Band[1]	68 days	90 days	68 days	90 days	68 days	90 days	68 days	90 days
	T/A	lbs/A	-----% dry weight-----				------mg/plant--------			
Check	None	None	2.58	3.29	1.07	2.36	92	154	92	197
Al	None	50	2.55	3.28	0.92	1.78	90	128	56	180
Mn	"	30	2.56	3.24	1.20	2.24	89	142	100	194
Al+Mn	"	50+30	2.12	3.18	0.90	2.20	71	141	67	209
Dolomite	2.75	None	2.51	2.82	1.07	1.93	90	135	109	242
"	5.5	"	2.66	2.94	1.06	1.71	112	159	111	189
"	11.0	"	2.32	2.58	0.90	2.00	75	157	83	260
Calcitic hydrate	2.75	None	3.52	3.82	2.14	3.02	160	202	199	343
"	5.5	"	3.86	4.55	2.66	2.77	80	161	165	283
"	11.0	"	3.07	3.45	1.97	2.26	71	121	80	245
hsd (0.05)										
Treatments within a variety			0.76	0.73	0.76	0.73	56	ns	56	99

[1]Equivalent of 1000 lbs/A of 5-20-20 banded in all treatments.

TABLE 4A.--Potassium concentrations in and uptake by Norland and Sebago potato vines at two dates of harvest as affected by rates and source of lime and additions of aluminum sulphate and manganous sulphate in the fertilizer band.

Treatments			Potassium Concentration				Potassium Uptake			
Material Applied	Rate of Application		Norland		Sebago		Norland		Sebago	
	Mixed	Additions to Fertilizer Band[1]	68 days	90 days	68 days	90 days	68 days	90 days	68 days	90 days
	T/A	lbs/A	-----% dry weight-----				-------mg/plant-------			
Check	None	None	7.15	6.93	6.65	6.65	258	322	574	557
Al	None	50	7.44	7.96	7.65	6.60	262	309	467	662
Mn	"	30	7.19	7.69	7.30	7.09	253	338	603	609
Al+Mn	"	50+30	7.18	8.65	6.95	6.99	248	387	514	669
Dolomite	2.75	None	5.88	5.22	5.42	5.08	208	247	551	627
"	5.5	"	5.80	5.46	6.50	5.04	247	298	672	571
"	11.0	"	6.17	5.42	5.56	4.85	203	330	510	634
Calcitic hydrate	2.75	None	6.27	5.58	5.94	5.34	287	298	551	609
"	5.5	"	7.14	7.55	7.22	6.46	151	270	444	660
"	11.0	"	6.24	6.90	6.58	6.56	140	242	264	703
hsd (0.05)										
Treatments within a variety			1.23	1.24	1.23	1.24	ns	ns	173	ns

[1]Equivalent of 1000 lbs/A of 5-20-20 banded in all treatments.

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TABLE 5A.--Aluminum concentrations in Norland potato vines after 90 days growth as affected by rates and source of lime and additions of aluminum sulphate and manganese sulphate to the fertilizer band.

Treatments			Aluminum Concentration
Material Applied	Rate of Application: Mixed	Rate of Application: Additions to Fertilizer Band[1]	
	T/A	lbs/A	-----ppm--------
Check	None	None	406
Al	None	50	453
Mn	"	30	330
Al+Mn	"	50+30	558
Dolomite	2.75	None	215
"	5.5	"	312
"	11.0	"	232
Calcitic hydrate	2.75	None	185
"	5.5	"	135
"	11.0	"	214
hsd (0.05)			
Treatments			279
% Coefficient of Variation			23%

[1]Equivalent of 100 lbs/A of 5-20-20 banded in all treatments.

TABLE 6A.--Soil test levels in soil core removed from center of pots 103 days after
planting potatoes as affected by rates and source of lime and additions of

TABLE 6A.--Soil test levels in soil core removed from center of pots 103 days after planting potatoes as affected by rates and source of lime and additions of aluminum sulphate and manganous sulphate to the fertilizer band.

Material Applied	Treatments: Rate of Application: Mixed	Treatments: Rate of Application: Additions to Fertilizer Band[1]	pH	Lime Require-ment	P	K: Norland pots	K: Sebago pots	Ca	Mg
	T/A	lbs/A		T/A	ppm				
Check	None	None	5.07	3.1	146	78	69	424	22
Al	None	50	5.01	2.9	135	107	77	471	26
Mn	"	30	5.07	3.5	137	83	58	384	25
Al+Mn	"	50+30	4.96	3.6	132	109	86	457	29
Dolomite	2.75	None	6.28	1.5	131	79	70	711	172
"	5.5	"	6.63	0.0	120	74	56	752	221
"	11.0	"	6.85	0.0	125	75	58	780	208
Calcitic hydrate	2.75	None	6.86	0.0	124	86	55	1196	18
"	5.5	"	7.63	0.0	112	125	82	1825	15
"	11.0	"	8.01	0.0	116	122	97	2165	15
hsd (0.05)									
Treatments			0.21	--	28	--	--	172	30
Variety			ns	--	ns	--	--	ns	ns
Variety within a treatment			--	--	--	----18-----		--	--
Treatment within a variety			--	--	--	----35-----		--	--

[1]Equivalent of 100 lbs/A of 5-20-20 banded in all treatments prior to potato crop.

TABLE 7A.--Soil test levels in samples obtained after mixing residue of fertilizer band throughout the soil after harvesting the potatoes.

TABLE 7A.--Soil test levels in samples obtained after mixing residue of fertilizer band throughout the soil after harvesting the potatoes.

Treatments									
Material Applied	Rate of Application		pH	Lime Requirement	P	K		Ca	Mg
	Mixed	Additions to Fertilizer Band[1]				Norland pots	Sebago pots		
	T/A	lbs/A		T/A	-----	-----	ppm	-----	-----
Check	None	None	4.81	3.8	186	105	91	413	42
Al	None	50	4.67	4.4	186	136	107	570	42
Mn	"	30	4.76	4.5	189	118	99	440	55
Al+Mn	"	50+30	4.63	4.1	200	134	106	518	48
Dolomite	2.75	None	6.05	1.5	168	118	94	732	228
"	5.5	"	6.53	0.4	150	116	92	832	245
"	11.0	"	6.82	0.0	146	127	88	930	324
Calcitic hydrate	2.75	None	6.51	0.2	161	129	88	1228	56
"	5.5	"	7.45	0.0	136	157	115	2953	30
"	11.0	"	7.80	0.0	142	158	121	2444	28
hsd (0.05)									
Treatments			0.21	--	35	--	--	186	53
Variety			ns	--	ns	--	--	ns	ns
Variety within a treatment			--	--	--	19	19	--	--
Treatment within a variety			--	--	--	-----31----		--	--

[1]Equivalent of 1000 lbs. of 5-20-20 banded in all treatments prior to potato crop.

TABLE 8A.--Soil pH measurements by direct contact at two locations within a given soil at 3 different times during the growth period of the oats as affected by residues of treatments applied prior to potato crop.

Material Applied	Treatments: Rate of application: Mixed	Additions to Fertilizer Band[1]	Days after Planting Oats: 31	44	62
	T/A	lbs/A	----Soil pH[2]----		
Check	None	None	5.61	5.45	5.43
Al	None	50	5.42	5.48	5.40
Mn	"	30	5.71	5.81	5.57
Al+Mn	"	50+30	5.41	5.43	5.36
Dolomite	2.75	None	6.65	6.47	6.45
"	5.5	"	6.68	6.73	6.87
"	11.0	"	6.98	6.96	6.78
Calcitic hydrate	2.75	None	6.88	6.50	6.75
"	5.5	"	7.21	7.08	7.30
"	11.0	"	7.37	7.26	7.25
hsd (0.05)					
Treatments			0.40	0.44	0.54
Differences in pH between tube positions			ns	ns	ns

[1]Equivalent of 1000 lbs/A of 5-20-20 banded in all treatments prior to potato crop. Soils thoroughly mixed prior to planting oats.

[2]Each value is the average of 1 observation in each of two tubes in each pot of two replications.

TABLE 9A.--Potassium and calcium concentrations in and uptake by oats at two different dates of harvest as affected by residues of treatments applied prior to potato crop.

Treatments			Potassium				Calcium			
Material Applied	Rate of application		Concentration		Uptake		Concentration		Uptake	
	Mixed	Additions to Fertilizer Band[1]	40 days	70 days	40 days	70 days	40 days	70 days	40 days	70 days
	T/A	lbs/A	---ppm----		--mg/pot---		---ppm----		--mg/pot--	
Check	None	None	4.04	2.26	518	784	1.22	1.23	156	428
Al	None	50	4.08	2.56	483	967	1.12	1.14	132	431
Mn	"	30	4.30	2.32	537	837	1.20	1.21	150	435
Al+Mn	"	50+30	4.38	2.47	563	923	1.15	1.05	149	390
Dolomite	2.75	None	3.66	2.39	455	875	0.78	0.80	97	293
"	5.5	"	4.01	2.38	438	868	0.82	0.84	89	307
"	11.0	"	3.61	2.52	414	930	0.73	0.81	82	299
Calcitic hydrate	2.75	None	3.75	2.53	430	1001	1.55	1.28	178	509
"	5.5	"	2.80	3.57	302	1404	1.32	1.56	143	615
"	11.0	"	3.90	4.12	364	1449	1.34	1.58	126	559
hsd (0.05)										
Treatments within a variety			1.56	1.02	180	378	0.17	0.30	38	123

[1]Equivalent of 1000 lbs/A of 5-20-20 banded in all treatments prior to planting potato crop. Soils mixed thoroughly prior to planting oats.

Soil test levels after harvesting oats (317 days after Planting

TABLE 10A--Soil test levels after harvesting oats (317 days after planting potatoes) as affected by residues of treatments applied prior to oat crop.

Treatments												
Material Applied	Rate of Application		pH		Lime Require-ment	P	K		Ca	Mg		
	Mixed	Additions to Fertilizer Band[1]	Norland pots	Sebago pots			Norland pots	Sebago pots		Norland pots	Sebago pots	
	T/A	lbs/A										
Check	None	None	4.92	4.90	3.8	168	50	73	493	6	14	
Al	None	50	4.90	4.95	3.8	178	54	82	578	7	11	
Mn	"	30	4.92	4.90	3.6	154	52	70	506	11	12	
Al+Mn	"	50+30	4.78	4.80	4.0	156	54	76	460	9	15	
Dolomite	2.75	None	6.45	6.32	1.1	170	56	70	754	184	206	
"	5.5	"	6.95	6.80	0.0	152	56	71	845	258	282	
"	11.0	"	7.20	7.07	0.0	146	56	66	910	270	282	
Calcitic hydrate	2.75	None	6.70	6.55	0.2	140	61	70	1151	11	13	
"	5.5	"	7.78	7.60	0.0	150	62	85	1737	4	6	
"	11.0	"	8.10	7.98	0.0	137	64	88	2438	4	4	
hsd (0.05)												
Treatments			--	--	--	ns	--	--	121	--	--	
Variety			--	--	--	ns	--	--	ns	--	--	
Variety within a treatment			---0.13----		--	ns	----24----		--	----12-----		
Treatment within a variety			---0.20----		--	ns	----18----		--	----20-----		

[1]Equivalent of 1000 lbs/A of 5-20-20 banded in all treatments prior to planting potato crop. Soils thoroughly mixed prior to planting oats.