



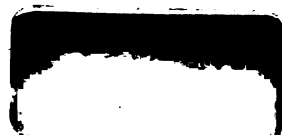
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INJURIOUS EFFECTS OF OVERLIMING
AN ACID SOIL

Thesis for the Degree of M. S.
MICHIGAN STATE COLLEGE

J. Quentin Lynd
1947

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This is to certify that the

thesis entitled

"Injurious Effects of Overliming
an Acid Soil."

presented by

Quentin J. Lynd

has been accepted towards fulfillment
of the requirements for

Master's degree in Soil Science



Major professor

Date May 28, 1947

INJURIOUS EFFECTS OF
OVERLIMING AN ACID SOIL

by
J. QUENTIN LYND

A THESIS

Submitted to the Graduate School of Michigan
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Department of Soil Science

1947

THESIS

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The soil used was collected for the Soil Science Department by Mr. Oscar Dowd, Soil Conservation Service, Paw Paw, Michigan.

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INTRODUCTION

The value of lime as a soil amendment is unquestioned and its use on acid soils for certain crops is accepted as a fundamental practice. The use of lime has greatly increased in recent years and it becomes increasingly important to recognize not only its beneficial effects but also its possible detrimental effects when used in excessive amounts. Prior to about 1920 the harmful effects of an acid soil on plant growth were generally explained on the basis of the toxicity of the H-ion and the rate of applying lime was based largely on the degree and total acidity of soil.

It is now generally recognized that each degree of soil reaction represents a particular set of chemical conditions which may be favorable to the growth of certain plants but unfavorable to others. In other words, plant growth may be affected by any particular degree of soil acidity because of either a depressed solubility of some nutrient elements or to an increased solubility of others. Thus the availability of the plant nutrient elements derived from the soil may be appreciably increased or decreased by the presence of normal or excess quantities of lime.

It is now common knowledge that liming is not necessarily a matter of correcting soil acidity but one of supplying the plants with calcium, a much-needed nutrient on many humid region soils. On this basis liming can be put

into the fertilizer category because one of the principal functions of lime is to supply the nutrient calcium.

Many unsatisfactory results have been reported from the use of excessive amounts of lime on a number of soil types in humid regions. For the most part the harmful effects are a result of the alkaline condition produced by the excess lime or from the high concentration of calcium ions and the injurious effects can be overcome in most instances by proper fertilizer practices.

There is some evidence on several crops grown in southwestern Michigan which indicates injurious effects from excessive applications of lime on the more sandy soils. Peach trees, in particular, have exhibited pronounced injurious effects of overliming. The injurious effects show up as chlorosis of the foliage, premature leaf drop, depressed growth, reduced fruit crop of lower quality and an increased susceptibility to disease. These symptoms appear to be similar to those of the virus disease known as "Little Peach".

The principal objective of this investigation was to produce overliming injury on a soil similar to that on which injurious effects, believed due to overliming, have been observed under field conditions and to determine the possible causes for such injury.

REVIEW OF LITERATURE

Investigations of the injurious effect of overliming have, for the most part, been concerned with the direct effect of excessive calcium ions on the plant and the indirect effect of the change in soil reaction upon the availability of other plant nutrients.

Hoagland and Arnon (11) have shown that calcium is essential for normal absorption by the plant of all nutrients from the medium in which it is grown. However, it has been shown (7, 9, 12, 15, 23) that an excessive concentration of calcium ions tends to decrease the absorption of all other nutrient ions.

No correlation in the growth and nodulation of soybeans was found by Albrecht (1) with H ion concentrations normally encountered in soils. Growth and nodulation was governed largely by the supply of available calcium. In a later paper (2), it was demonstrated that calcium absorption was more active and growth and absorption of other elements increased when calcium was increased to 80% of base saturation with hydrogen as the reciprocal ion on the exchange complex. In using barium, magnesium, and hydrogen ions reciprocal to calcium in varying degrees of calcium saturation, ranging from 40% to 95%, it was found that plant growth, in general, increased with each increment of calcium regardless of the reciprocal ion.

Moser (22) studying the calcium nutrition of plants

at various pH levels below neutrality found good correlations of plant growth with calcium concentrations. With three types of plants it was found that pH was a minor factor in comparison to the supply of available calcium. Increasing the supply of available calcium resulted in increases in plant growth and the absorption of the other nutrient elements.

Davis and Brewer (7) point out that comparatively large quantities of calcium are essential to plant growth. They found that normal absorption of other ions depends on a certain minimal quantity of calcium ions, the amount varying with the plant studied.

Dunn (9) found that an increase of calcium in acid soils resulted in an increase in the uptake of phosphorus, potassium, and nitrogen by the plant. He mentions that this may be due to the increased vigor of the plant to grow and contact plant nutrients in addition to the possible function of calcium in increasing the ability of the plant to absorb and translocate these nutrients.

Excess Calcium and Nutrient Uptake

Albrecht (3) found that high concentrations of calcium in the nutrient medium resulted in a movement of potassium from the plant to the soil. In some cases the amount of potassium in the plant was depleted by 50 per cent. He points out that the potassium uptake

of the plant may be limited in the presence of high calcium concentrations.

Hunter, Toth, and Bear (12) found that increased amounts of available calcium in the soil resulted in increased amounts in the plant. An abrupt decrease in yield was observed when the calcium content of the plant tissue became greater than two per cent. A decrease in the uptake of potassium and magnesium resulted when the calcium content of the plant increased.

In referring to the effect of one cation on the absorption of another, Pierre and Allaway (26) use the term "ion antagonism". They point out that calcium may repress the absorption of other cations in cases of low concentrations of the other elements. In some of the high-lime soils of Iowa, it is found that extreme potassium deficiencies may occur when the exchangeable potassium content is actually higher than is found to be necessary for optimum growth in normal soils. The plants grown on these soils were found to absorb very large amounts of calcium as compared with potassium.

According to these investigators the ratio of calcium to magnesium is not well understood. They point out that high concentrations of calcium may result in magnesium deficiencies but that such is not likely to be found in ordinary agronomic practice as evidenced by the successful use of dolomitic limestone on acid soils.

Working on the problem of the calcium-boron ratio in plants, Drake, Sieling, and Scarseth (8) found that sulphate retards the uptake of calcium by plants and prevents an unfavorable calcium-boron ratio within the plant. High concentrations of calcium in the soil and in the plant were conducive to boron deficiency.

Cook and Millar (6) found that additions of calcium and magnesium carbonates to the soil prevented boron toxicity to plants. Although boron deficiencies occur most frequently on alkaline soils, they are not necessarily brought about by a high pH alone. High calcium concentrations are conducive to boron deficiency and low calcium concentrations are favorable to boron toxicity. However, the apparent availability of boron in these experiments was not changed by raising the pH with sodium carbonate which indicates a relation of calcium to boron in the plant.

That boron is often deficient in plants on heavily limed soils has been pointed out by Pierre and Allaway (26) but they do not attribute this to the solubility of boron but rather to a disturbance within the plant related to the calcium-boron ratio. These authors also mention that a decrease in solubility of manganese, iron, zinc, and copper may occur as the H ion concentration of soils decreases but it is difficult to distinguish between an unavailable form resulting from reaction and inability of

East Lansing, R. J. Baldwin

Michigan State College of
Agriculture & Applied Science
S. Department of Agriculture
operating

January 2

Dear Michigan Muck Farmer:

The Farmer's Week of Michigan muck farming
College in Room 111 of Olds Hall on January
open at 10 o'clock, Eastern War Time. All

At 10:00 o'clock on Wednesday morning
talk on Muck Farming in Indiana. Lucas
his father, has a large muck farm where
George Bouyoucos, Soils Dept., will speak
storages and Dehydrating Plants". He will
treat of the muck which he has developed and which are
widely known. At 11 o'clock Professor K

ditions of crops grown on soils neutralized with calcium carbonate. The occurrence of this condition was associated with a very low manganese content of the affected plants compared with that of normal plants grown on similar but acid soils.

The soil reaction affects the availability of most nutrient elements. At extremely acid reactions, toxic quantities of certain elements may be brought into solution. Alkaline reactions often produce deficiencies by rendering essential elements insoluble. The maximum availability of phosphorus has been shown by many workers to be dependent upon an optimum soil reaction.

Midgley (20) in a critical review of phosphate fixation maintains that lime applied to acid soils increases the availability of native phosphorus to plants. It has been shown that at a soil pH of approximately 6.5 the phosphorus tends to exist in the form of calcium phosphate, thus making the availability of the native soil phosphorus greater than if the soil were more acid. In more acid soils the phosphorus could be changed more easily to the less soluble iron and aluminum compounds. Excess lime on acid soils, however, greatly reduced the water solubility of applied phosphate but does not necessarily reduce its availability to plants, especially in soils containing actively decaying organic matter. The injurious effect of overliming such soils seems to be, accord-

ing to this worker, to a lack of available boron rather than a lack of available phosphate.

A beneficial effect of phosphate application in overcoming liming injury was found by Pierre and Browning (25). There was less injury from overliming with magnesium carbonate than with calcium carbonate which indicates that magnesium phosphate compounds are more available than those of calcium. On this basis, these workers concluded that plants grown on the excessively limed soils made poor growth due to a disturbed phosphate nutrition. They maintained that this injury is only temporary. Heavy soils were found to be less affected by overliming than sandy soils.

Overliming and Biological Activity

Jenny and Shade (13) in studying the potassium-lime problem, using purified clay minerals, found in all systems investigated that lime liberated adsorbed potassium in large quantities. They further point out that micro-organisms may reduce the supply of potassium in the soil solution by absorption into their bodies. Microbiological activity in the soil is often increased many times by the addition of calcium carbonate and in soils of low potassium level this treatment may actually cause a reduction in the available potassium below that of an unlimed soil.

Pierre and Allaway (26) point out that calcium affects the availability of other nutrient elements indirectly

through its influence on the activity of soil micro-organisms. Much of the nitrogen, phosphorus and sulphur in the soil exists in the organic fraction of the soil and is liberated through microbiological action. In acid soils, therefore, the application of lime would increase microbiological activity and bring about an increase in the availability of these nutrients.

PLAN OF STUDY

This study was begun with the idea of producing overliming injury in soils under greenhouse conditions and to determine, if possible, the cause or causes for such injury. The soil which was selected for this work was similar to that in which overliming injury had been observed under field conditions. In view of the fact that this injury had been observed on the lighter textured soils of low fertility, it was thought that the injurious effect was probably due to a disturbance in the availability of some of the nutrient elements. If this was the cause, it was believed that it could be demonstrated, in the greenhouse and laboratory, by studying the effect of increasing amounts of lime, with and without fertilizers, on the yield and composition of crops and on the available nutrient supply of the soil. Special attention was to be given to the effect of adding phosphorus, boron, and manganese to overlimed soils.

The plan of study included the following:

1. Physical properties of soil used.
 - a. Particle size distribution.
 - b. Aggregate analysis.
 - c. Moisture equivalent.
 - d. Total ignition loss.
2. Chemical properties of soil used.
 - a. Base exchange capacity.
 - b. Buffer capacity.

3. The effect of increasing amounts of lime, with and without fertilizers, on yield and composition of soybeans and white beans, and on yield of oats under greenhouse conditions.

a. Soil treatments.

- (1) No lime.
- (2) 40% calcium saturation.
- (3) 60% calcium saturation.
- (4) 100% calcium saturation.
- (5) 250% calcium saturation.
- (6) Each of the above series divided into 4 groups, with the following additional treatments: (a) no treatment, (b) 10 lbs. borax per acre, (c) 300 lbs. 0-20-0 per acre, (d) 50 lbs. MnSO_4 per acre.

b. Soybeans grown first, followed by white beans, and then oats in the same soil.

c. Yield data (dry weights).

d. Analysis of soybean and white bean plant material for total calcium, potassium, phosphorus, and manganese.

4. The effect of increasing amounts of lime on growth of tomato plants.

a. Same lime treatments as for soybeans indicated above.

b. Yield data (dry weight).

5. Soil analyses following soybean crop and also following the white bean crop.
 - a. Adsorbed phosphorus and exchangeable calcium, magnesium, and potassium.
 - b. Phosphorus, calcium, manganese and potassium soluble in 0.1 N. HCl.
6. Nitrate production and accumulation as influenced by increasing amounts of lime.
 - a. In tumblers under laboratory conditions.
 - b. In greenhouse following the oat crop.

DESCRIPTION OF SOIL USED

A soil classed as Coloma loamy sand was selected for this study because overliming injury had been observed on this type of soil under field conditions. The soil was collected from a peach orchard of Mr. Clare Ewald located southwest of Hartford in Van Buren county, Michigan. This was a nine year old peach orchard of the Hale Haven variety. The orchard had been maintained in clean cultivation with no cover crops and the yield was estimated to be about two and one-half bushels per tree annually. The area from which the soil samples were collected had never been limed and the only fertilizer used were annual applications of either ammonium or sodium nitrate. A composite sample was obtained from samples taken down to a depth of eight inches, beneath the drip of several trees.

This soil has an undulating to gently rolling topography and occurs as a grayish-brown to yellowish-brown loamy sand 8 to 12 inches deep underlain by a yellowish-brown or light brown loamy sand. The subsoil from a depth of 15 to 20 inches down to a depth of 36 inches or more is a pale-yellow or light-brown, slightly loamy or loose, medium to coarse sand. The substratum is mainly sand but contains pockets of clay and coarse glacial drift. This soil type is highly leached and usually very acid in reaction. Drainage is usually good and crops suffer in most areas from lack of moisture in dry seasons. On the steeper slopes the soil is subject to considerable erosion.

EXPERIMENTAL PROCEDURE AND RESULTS

Characteristics of Soil

Physical Properties: In order to better characterize the particular soil used in these studies, several of its physical and chemical properties were determined.

The particle size distribution and aggregate analysis are shown in Table 1. It is observed that the combined

Table 1. The Mechanical and Aggregate Analysis of Soil Used.

Mechanical Analysis (1)		Aggregate Analysis (2)	
Particle Size	Per Cent	Aggregate Size	Per Cent
mm.		mm.	
1.0 - 2.0	2.7	2.0 - 4.0	1.1
0.5 - 1.0	9.7	1.0 - 2.0	3.8
0.25 - 0.5	42.9	0.5 - 1.0	21.4
0.10 - 0.25	16.3	0.25 - 0.5	54.1
0.05 - 0.10	15.4	0.10 - 0.25	10.3
0.002 - 0.05	6.5	<0.10	9.3
<.002	6.5		

(1) Determined by wet sieve and hydrometer method.

(2) Determined by wet sieve method using air dry soil.

silt and clay make up less than 15 per cent of the dry weight of the soil and therefore would be classed as a sandy soil. Furthermore, this soil contains a relatively small percentage of water-stable aggregates.

The moisture equivalent of the soil, determined by the method of Briggs and McLane, was 5.46 per cent.

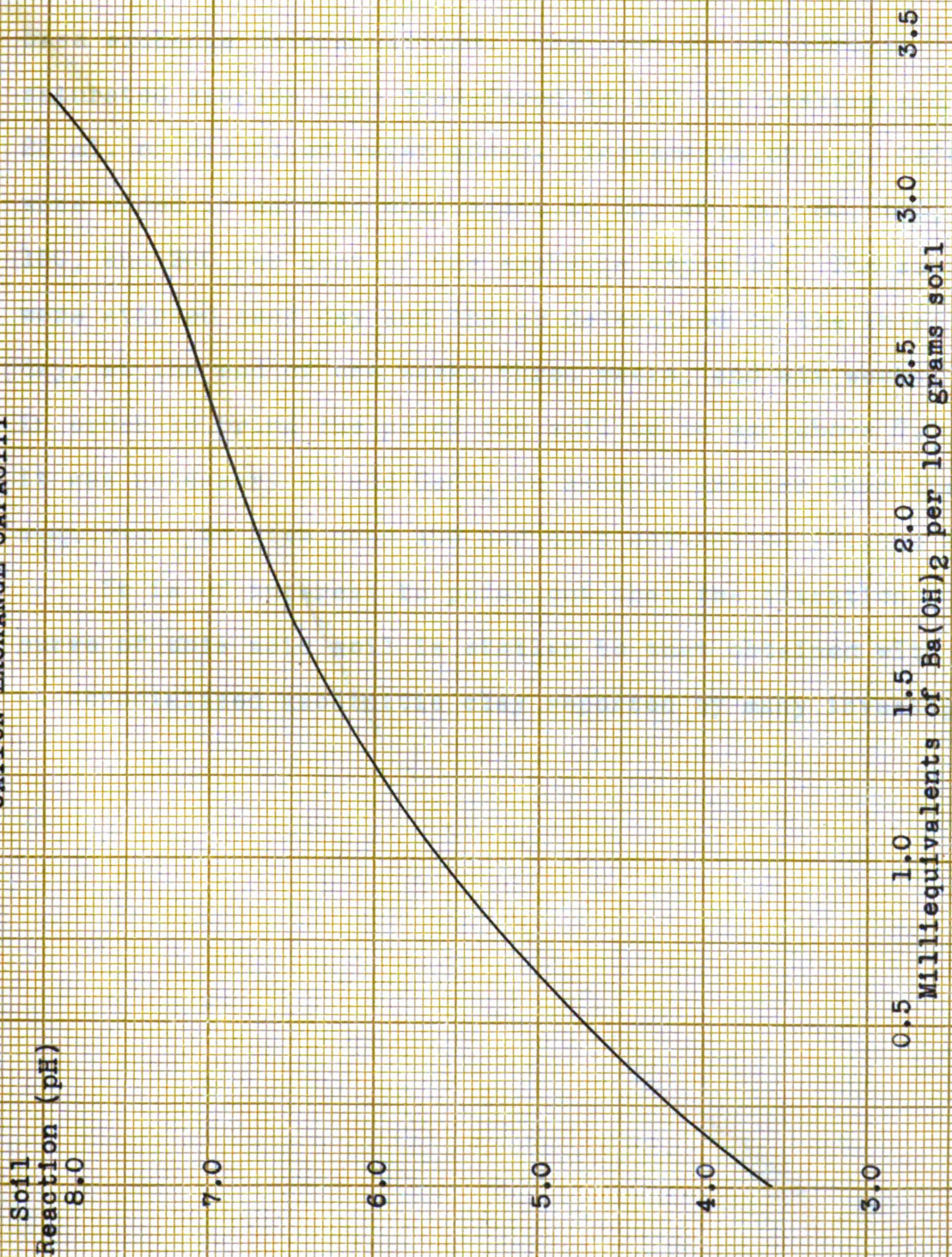
The total ignition loss was 1.56 per cent. It is believed that this is a close approximation to the actual content of organic matter because of the freedom from

carbonates and the low content of the clay separate in this soil.

Chemical Properties: In determining the base exchange and buffer capacity of the soil, a 25 gram sample of air dried soil was placed in a gooch crucible fitted with a filter paper and the sample soaked over night in distilled water. The soil was then leached with 200 ml of .05N HCl and washed with two 300 ml portions of distilled water followed by a washing with 100 ml. of 90 per cent Ethanol. After the sample was dried at 80°C for 12 hours it was transferred to a beaker, 25 ml. of distilled water added, stirred vigorously and the reaction determined potentiometrically.

One gram of solid BaCl_2 was then added to the hydrogen saturated sample, stirred two minutes and another 25 ml. of water added. This sample was titrated potentiometrically to a pH of 8.0 using a standard solution of $\text{Ba}(\text{OH})_2$. The base was added in 1 ml. increments to a pH of about 5.0 followed by 0.5 ml. increments. The additions of $\text{Ba}(\text{OH})_2$ were made at one minute intervals and the pH determination was made just prior to each addition. The milliequivalents of base necessary to adjust the soil to pH 7.0 was determined from standard curves for the apparatus used and the temperature conditions under which the determinations were made. On the basis of 12 determinations the base exchange capacity of this soil was found to be 2.46 milliequivalents

Figure 1
CATION EXCHANGE CAPACITY



per 100 grams of soil. The titration curve of the acid soil with $\text{Ba}(\text{OH})_2$ is shown in Figure 1.

In order to determine the buffer curve for this soil twelve samples were prepared and leached as described for base exchange determinations. The oven-dried hydrogen saturated samples were transferred to 100 ml. beakers and 25 ml. of distilled water added. Increments of c.p. CaCO_3 were added in amounts equivalent to 20, 40, 60, 80, 100, 150, and 200 per cent of the exchange capacity. The samples were stirred each day and the pH determined on the third day, at the end of one week, three weeks, and six weeks. In order to bring the pH of the soil up to and above 7.0 it was necessary to add CaCO_3 in amounts greater than that required to give over 100 per cent saturation (Figure 2).

It is of interest to point out that the titration curve of this acid soil is similar to that obtained with electrodialed kaolinitic clay reported by many investigators.

Figure 2 BUFFER CURVE

Soil
Reaction (pH)
8.0

7.0

6.0

5.0

4.0

3.0

20%

40%

60%

80%

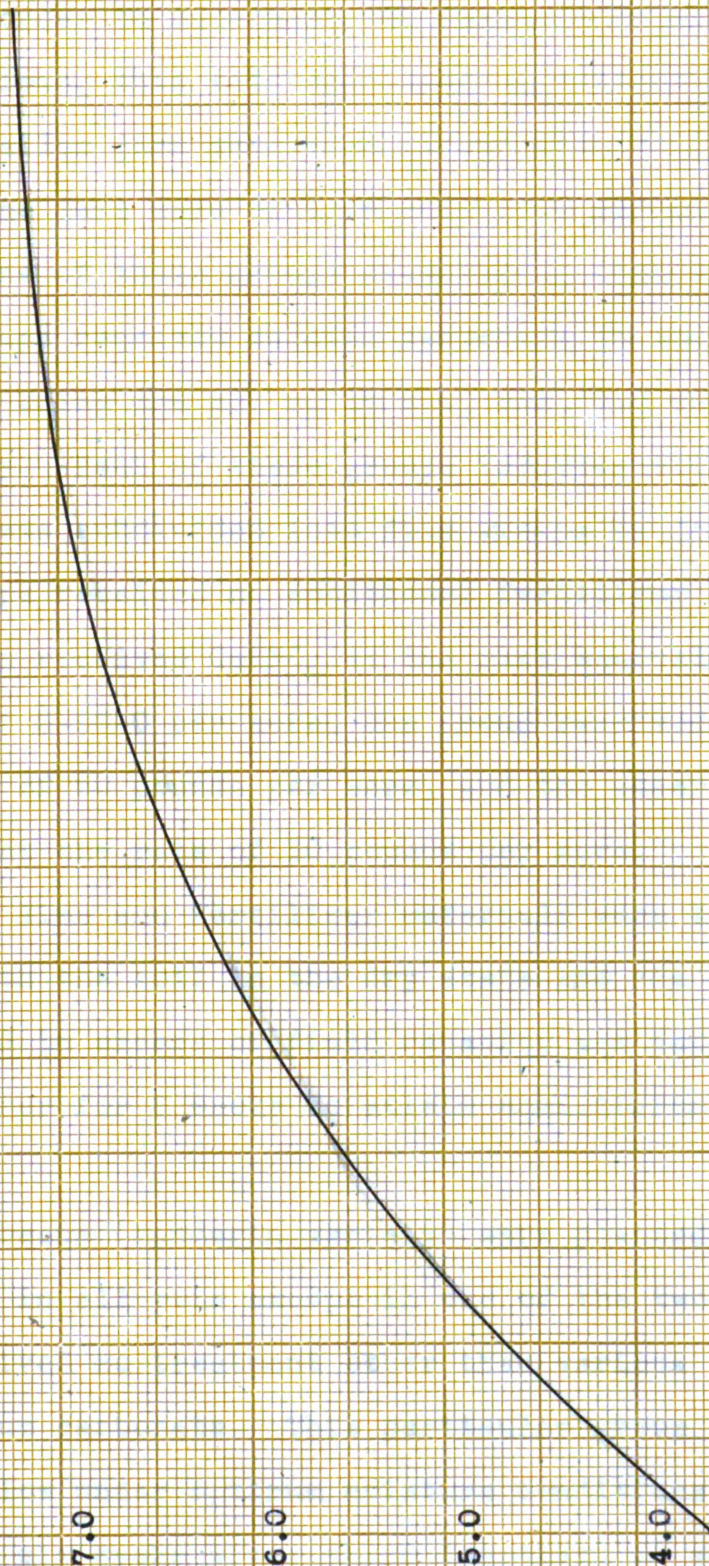
100%

120%

140%

160%

Per cent calcium saturation of exchange capacity



Greenhouse Experiments

In order to determine the possible harmful effects of overliming this acid soil under greenhouse conditions, 75 one-gallon jars were each filled with 4 kilograms of soil. The jars were divided into five groups of 15 jars each. One of these groups received no lime and the other four groups received calcium carbonate in amounts calculated to bring the pH up to 6.0, 6.5, 7.0 and 7.5 respectively. Each of these groups (representing five calcium levels) was subdivided into five groups of three jars each. Two groups received no additional fertilizer treatment, one group received CaHPO_4 at the rate equivalent to 300 pounds of 0-20-0 per acre, one group received MnSO_4 at the rate of 50 pounds per acre, and the other group received $\text{Na}_2\text{B}_4\text{O}_7$ at the rate of 10 pounds per acre.

The lime and fertilizer materials were thoroughly mixed with the soil in the dry state and the soil was moistened in excess of field capacity and maintained in this manner for 6 weeks to attain equilibrium before planting.

Soybeans (Manderin variety) were planted September 20, 1946 in all pots except in one of the two series which had received no treatment other than various quantities of calcium carbonate. This particular group of pots was kept fallow under optimum moisture conditions for an additional six weeks after which tomatoes, as seed, were planted. The soybean crop was followed in turn by white

beans and oats.

A 10-20-20 fertilizer was applied for the white beans at the rate of 300 pounds per acre to each jar of the three groups which had originally received manganese, phosphorus, or boron. Five applications of this fertilizer, representing a total of 300 pounds of 10-20-20, were made from dilute solutions during the growth of the crop.

Results with Soybeans: This crop was planted September 20 and harvested November 2. The yield data are presented in Table 2. Early growth was retarded and all plants appeared to be suffering because of a lack of sufficient nitrogen. After two weeks, the plants which had received moderate rates of lime were beginning to develop normally but those without lime remained stunted (see Plate 1). Plants receiving the greatest amount of lime were small with light green and slightly chlorotic leaves. The over-limed plants responded to both manganese and phosphate. Boron, alone or in combination with any other soil treatment, did not significantly influence the yield of soybeans (see Plates 2, 3, 4, and 5).

The plants were analyzed for total calcium, potassium, phosphorus, and manganese and the results are shown in Table 3 and Figure 3. It is observed that the lime alone resulted in increased calcium content of the plants with increasing rates of liming. The potassium content decreased markedly with the highest lime application. The phosphorus content increased with the first increment of lime

Table 2 The Effect of Increasing Amounts of Lime with and without Phosphorus, Boron, and Manganese on Yield of Soybeans.*

m.e. Ca added per 100 gm soil	Ca % sat.	pH at start	Lime only		Lime plus 10 lb Borax per acre		Lime plus 300 lbs 0-20-0/A		Lime plus 50 lbs MnSO ₄ per acre	
			yield grams	pH at end	yield grams	pH at end	yield grams	pH at end	yield grams	pH at end
-	-	4.6	5.4	5.2	4.2	5.0	3.1	5.1	3.2	5.1
1.1	40	6.0	7.5	5.9	9.0	6.0	8.1	5.9	7.4	6.2
1.5	60	6.5	11.4	6.4	13.6	6.4	10.4	6.4	9.5	6.4
2.5	100	7.0	14.5	6.9	10.5	6.9	13.5	6.9	14.3	6.8
6.1	250	7.5	6.4	7.6	7.7	7.4	11.7	7.5	11.8	7.4

* The yields represent the average of three replications.

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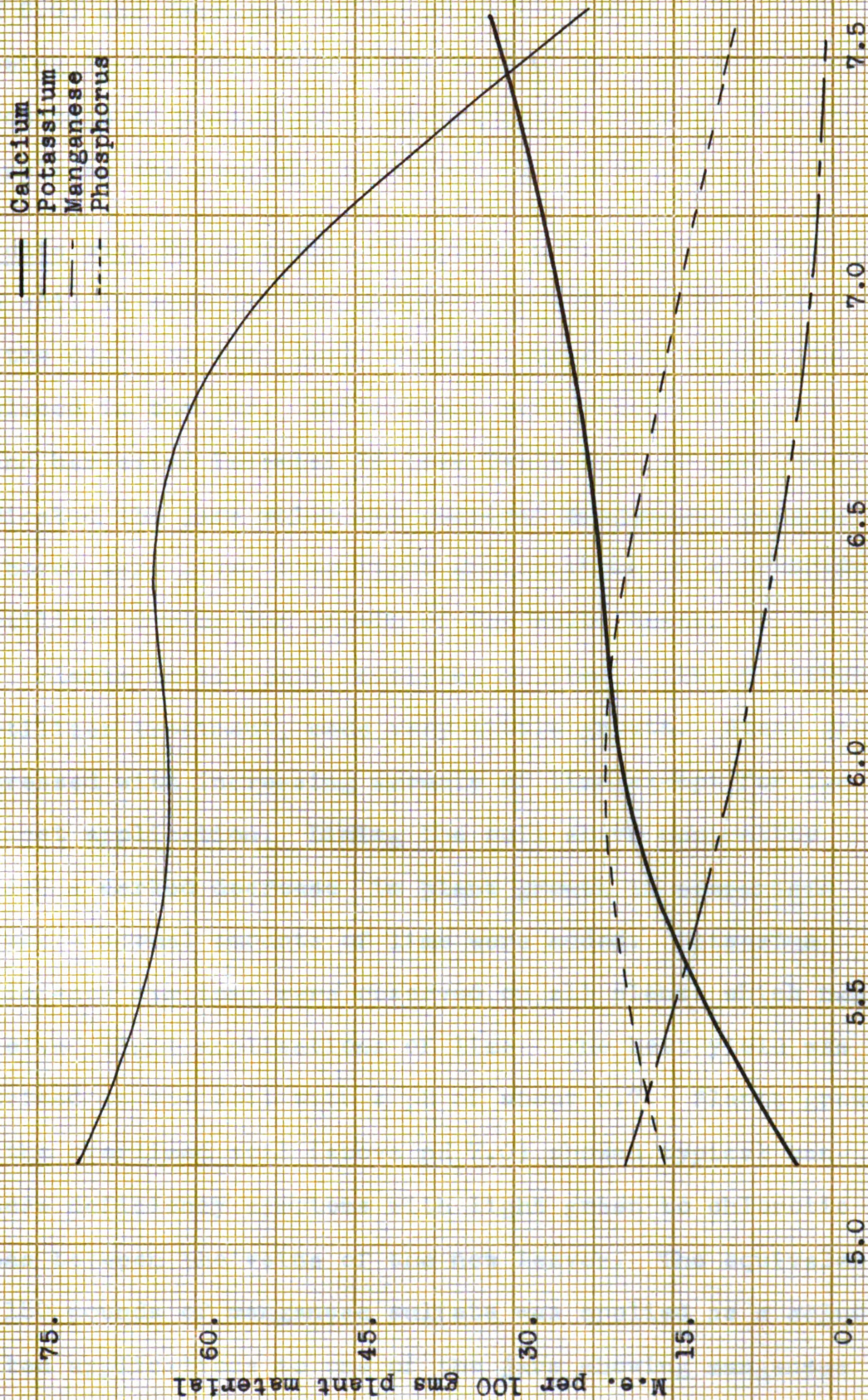
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Table 3 The Effect of Increasing Amounts of Lime on
the Yield and Analysis of Soybean Plants.*

M.e. Ca 100 gms soil	Soil pH	Yield grams	M.e. per 100 gm plant material			
			Calcium	Potassium	Manganese	Phosphorus
-	5.2	5.0	2.21	77.01	19.3	16.4
-	5.2	6.1	3.51	69.35	24.0	14.3
-	5.1	<u>5.2</u>	<u>3.98</u>	<u>72.10</u>	<u>21.3</u>	<u>18.5</u>
ave.		5.4	3.28	72.82	21.5	16.4
1.1	5.9	7.8	21.05	65.30	8.7	22.4
1.1	6.0	6.6	14.22	60.12	6.5	21.0
1.1	6.0	<u>8.1</u>	<u>20.45</u>	<u>62.85</u>	<u>7.3</u>	<u>20.2</u>
ave.		7.5	18.57	62.76	7.5	21.2
1.5	6.6	11.8	18.30	57.00	7.6	18.7
1.5	6.4	12.4	22.53	64.35	6.4	22.0
1.5	6.4	<u>10.1</u>	<u>23.71</u>	<u>68.45</u>	<u>5.2</u>	<u>17.5</u>
ave.		11.4	21.51	63.27	6.4	19.4
2.5	6.9	14.8	24.34	61.50	1.8	16.8
2.5	6.9	14.4	28.45	67.25	3.7	14.5
2.5	6.8	<u>15.2</u>	<u>30.77</u>	<u>51.50</u>	<u>2.8</u>	<u>11.6</u>
ave.		14.8	27.85	60.08	2.8	14.3
6.1	7.4	7.1	31.90	27.84	.5	9.6
6.1	7.6	7.6	31.20	18.75	.4	13.7
6.1	7.6	<u>4.6</u>	<u>32.87</u>	<u>20.45</u>	<u>.5</u>	<u>12.8</u>
ave.		6.4	31.99	22.35	.5	12.0

* Determinations made according to Official and Tentative
Methods of Analysis, A.O.A.C. 1935, Washington, D.C.

Figure 3 The Effect of Increasing Amounts of Lime
on the Analysis of Soybean Plants.*



* Data are presented in Table

(pH 6.0) and decreased with the higher rates. The soybeans growing in the soil with a pH of about 6.0 had the highest percentage of phosphorus. The manganese content decreased sharply as the content of calcium increased in the plant.

Results with White Beans: Following the soybean harvest the soil in each jar was sampled (by taking five cores to the depth of each jar), dumped, thoroughly mixed, and replaced in the jar. White beans were planted November 9 and harvested December 25 (see Table 4). As previously indicated the jars which had received manganese, phosphate, or boron were given five light applications of a 10-20-20 fertilizer during the growth of the white beans.

Plants in the jars receiving no lime, with or without fertilizer treatment, made very little growth. Plant growth increased with increasing amounts of lime except for the highest application. Liming the soil above neutrality caused a marked decrease in plant growth in comparison to where normal amounts of lime were added. Potassium deficiency symptoms were observed on all plants which had received light applications of lime. The best yield was obtained on the soil with a pH of about 6.7. Plants grown in the overlimed soil (above pH 7.0) showed typical manganese deficiency symptoms with light green to chlorotic areas between the veins of the new leaves. The equivalent of 150 pounds of manganese sulfate was applied as a solution in ten applications to one of the jars showing manganese

starvation. The first application was made when the plants were four weeks old and a definite response was obtained, the chlorotic condition being largely corrected by this treatment (Table 4 and Plate 9).

The 10-20-20 fertilizer did not give significantly greater yields than was obtained on the corresponding series receiving only lime. Good plant growth was obtained where boron was added to the soil on the acid range but above pH 7.0 the yield materially dropped. In other words, boron failed to overcome the harmful effect of excess lime on white beans.

The bean plants from the "lime only" series were analyzed for percentage total calcium, potassium, phosphorus, and manganese. These results are presented in Table 5 and shown graphically in Figure 4.

As with the soybean plants, the calcium content increased as the calcium content of the soil was increased. In general, the potassium content of the plants decreased as the calcium content increased. The content of phosphorus in the plants increased with increasing amounts of lime up to a pH of about 7.0. Excess lime decreased the percentage of phosphorus in comparison to normal amounts of lime. The manganese content of the plants decreased from about 16 m.e. per 100 grams of plant material where no lime was added to less than 0.5 m.e. with the highest application of lime.

For comparative purposes with the above experiment,

Table 4 The Effect of Increasing Amounts of Lime with and without Additional Fertilizer Applications on the Yield of White Beans Following the Soybean Crop. *

M.e. Ca added per 100 gm soil	% Ca sat.	pH at start	Lime only		Lime plus 10 lb Borax per acre 300 10-20-20/A		Lime plus 300 lbs. 0-20-0/A		Lime plus 50 lbs MnSO ₄ per acre 300 10-20-20/A	
			yield grams	pH at end	yield grams	pH at end	yield grams	pH at end	yield grams	pH at end
-	-	5.2	2.3	5.0	.3	5.0	.9	5.0	.2	5.0
1.1	40	5.9	7.1	5.8	9.4	5.8	8.9	5.8	5.6	5.9
1.5	60	6.4	11.4	6.4	15.6	6.3	14.4	6.4	13.4	6.4
2.5	100	6.9	15.6	6.7	17.4	6.8	15.1	6.8	16.9	6.7
6.1	250	7.6	7.4	7.5	7.7	7.4	6.9	7.6	9.1 [†]	7.4

* The yields represent the average of three replications.

† This yield is an average of two replications, the third received an additional application of 100 lbs. MnSO₄ per acre, yield was 12.7 gms., soil pH 7.3.

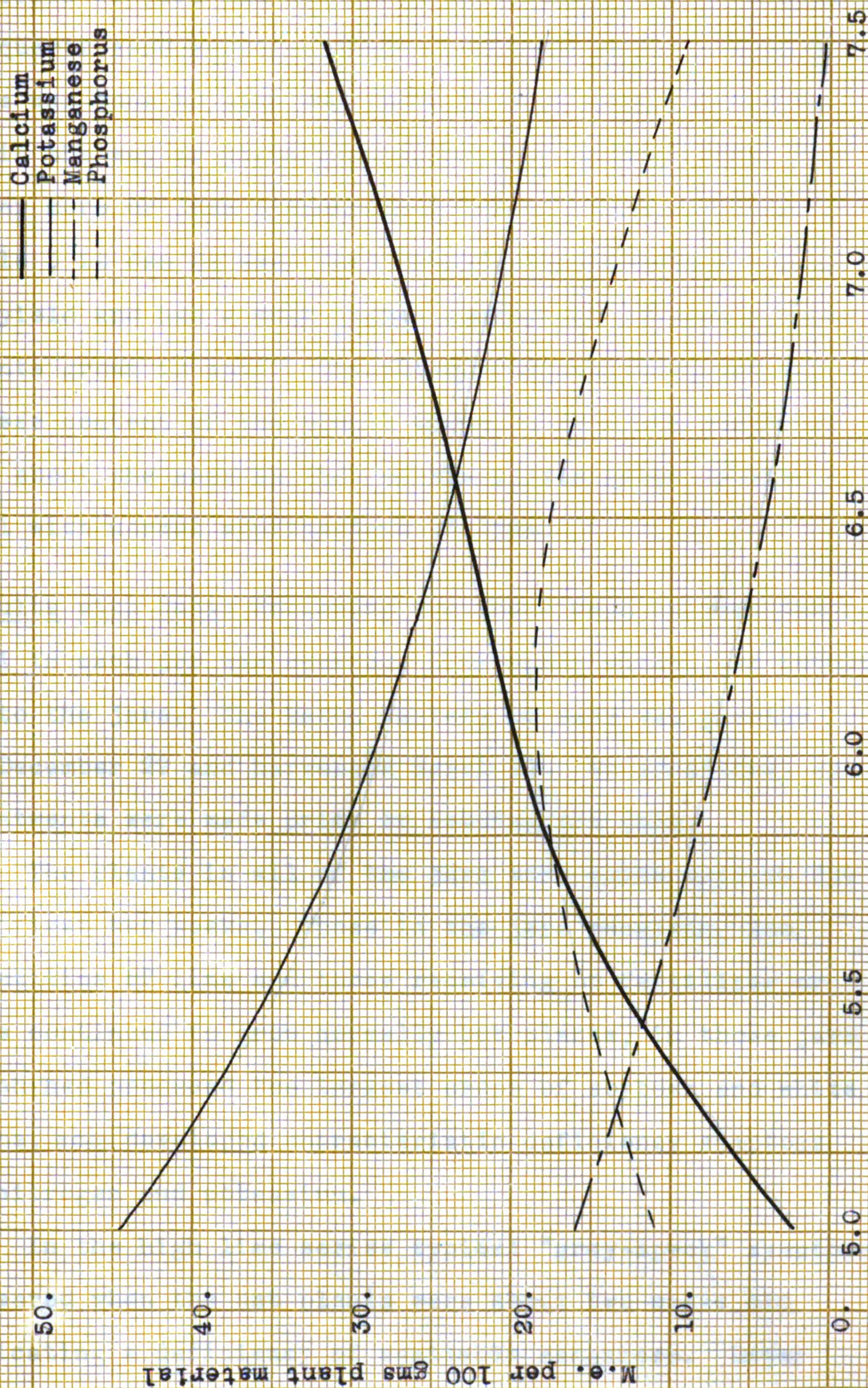
Table 5 The Effect of Increasing Amounts of Lime on
the Yield and Analysis of White Bean Plants.*

M.e. Ca 100 gms soil	Soil pH	Yield grams	M.e. per 100 gm plant material			
			Calcium	Potassium	Manganese	Phosphorus
-	5.1	1.5	2.05	37.5	18.3	9.75
-	5.0	2.0	3.17	43.7	16.5	10.25
-	5.0	<u>3.4</u>	<u>1.99</u>	<u>51.5</u>	<u>12.1</u>	<u>13.05</u>
ave.		2.3	2.40	44.2	15.6	11.01
1.1	5.7	6.8	18.31	36.3	9.7	15.50
1.1	5.8	6.9	15.13	29.5	7.6	17.35
1.1	5.9	<u>8.5</u>	<u>22.84</u>	<u>25.2</u>	<u>8.4</u>	<u>19.35</u>
ave.		7.4	18.76	30.3	8.6	17.40
1.5	6.4	11.8	19.75	26.4	6.5	16.76
1.5	6.3	9.0	20.50	28.5	4.3	20.50
1.5	6.4	<u>12.4</u>	<u>24.35</u>	<u>20.3</u>	<u>3.5</u>	<u>17.50</u>
ave.		11.1	21.53	27.4	4.8	18.25
2.5	6.8	14.8	25.65	22.6	2.2	17.40
2.5	6.7	18.5	24.25	21.0	3.1	14.35
2.5	6.7	<u>13.5</u>	<u>27.10</u>	<u>26.0</u>	<u>1.0</u>	<u>15.79</u>
ave.		15.6	25.66	23.2	2.1	15.85
6.1	7.4	9.0	31.20	17.2	.2	8.50
6.1	7.6	6.8	33.55	21.7	.1	9.67
6.1	7.6	<u>6.4</u>	<u>29.30</u>	<u>12.5</u>	<u>.1</u>	<u>10.50</u>
ave.		7.4	31.35	17.1	.1	9.22
*Nut. Sol.	6.5	25.8	19.98	94.3	6.3	14.50

* Determinations made according to Official and Tentative
Methods of Analysis, A.O.A.C. 1935, Washington, D.C.

* Analysis of white beans grown in quartz sand with a
complete nutrient solution.

Figure 4 The Effect of Increasing Amounts of Lime
on the Analysis of White Bean Plants.*



* Data are presented in Table

a series of jars was set up in which white beans were grown in quartz sand supplied with a complete nutrient solution. This was done to give some idea of what might be expected in the way of yield and composition of this crop grown under more or less optimum conditions. From the data in Table 5 it can be seen that these plants produced a greater yield and had a much higher content of potassium than plants grown in soil. The phosphorus, calcium, and manganese content of the plants grown in nutrient solution was about the same as that of the plants grown in the soil with normal applications of lime.

Results with Oats: Following the white bean harvest the soil in each jar was sampled, thoroughly mixed, and returned to the jars. The Eaton variety of oats was planted on December 29 and harvested March 19. No additional soil treatments were made prior to seeding the oats.

The plants in all of the jars were quite uniform for the first two weeks. Those in the jars receiving low quantities of lime and those receiving no fertilizer or lime continued to grow normally but plants, in those jars which had produced the largest crops of soybean and white beans, soon developed characteristic deficiency symptoms of nitrogen and potassium.

In the high lime series typical "grey-speck" symptoms appeared when the oat plants were about two weeks old indicating a deficiency of available manganese. Later

Table 6 The Effect of Increasing Amounts of Lime with and without Additional Fertilizer Applications in the Yield of Oats Following the White Bean Crop.*

M.e. Ca added per 100 gm soil	% Ca sat. start	pH at start	Lime only				Lime plus 10 lb Borax per acre plus 300 lbs. 10-20-20/acre				Lime plus 300 lbs. 0-20-0/A MnSO ₄ per acre plus 300 lbs. 10-20-20/acre				Lime plus 50 lbs MnSO ₄ per acre plus 300 lbs. 10-20-20/acre			
			yield grams	pH at end	yield grams	pH at end	yield grams	pH at end	yield grams	pH at end	yield grams	pH at end	yield grams	pH at end	yield grams	pH at end	yield grams	pH at end
-	-	5.0	10.4	5.0	13.6	4.9	11.9	5.0	13.6	4.9	5.0	13.6	4.9	5.0	13.6	4.9	5.0	13.6
1.1	40	5.8	15.0	5.7	12.6	5.8	12.5	5.7	13.0	5.9	5.7	13.0	5.9	5.7	13.0	5.9	5.7	13.0
1.5	60	6.4	9.8	6.3	8.4	6.3	10.2	6.3	13.2	6.2	6.3	13.2	6.2	6.3	13.2	6.2	6.3	13.2
2.5	100	6.7	7.5	6.7	8.9	6.8	8.6	6.7	9.6	6.6	6.7	9.6	6.6	6.7	9.6	6.6	6.7	9.6
6.1	250	7.5	6.8	7.5	7.6	7.4	8.5	7.5	7.1 [†]	7.4	7.5	7.1 [†]	7.4	7.5	7.1 [†]	7.4	7.5	7.1 [†]

* The yields represent the average of three replications.

[†] This yield is an average of two replications, the third received an additional application of 100 lbs. MnSO₄ per acre on the preceding crop of white beans. Oat yield for the increased manganese treatment was 9.8 gms., the soil pH 7.3.

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these plants developed symptoms of nitrogen and potassium starvation and seemed to overshadow the effects of the manganese deficiency.

The results (Table 6, Plates 12 and 13) indicate that the available plant nutrients of this soil had been largely removed by the two preceeding crops, particularly in those jars producing the higher yields. Therefore because of the general depletion of soil fertility these data do not illustrate specifically the injurious effects of overliming. The results with the oat crop show that the available supply of nutrients in this soil can be exhausted quickly and that it is unable to deliver available plant nutrients at a sufficiently rapid rate to support continuous cropping. The two preceding crops gave a marked response to normal applications of lime but the highest yields of oats were obtained in those jars which had produced the lowest yields of the previous crops.

Results with Tomatoes: On October 25, tomato seed were planted in a series of jars which had received varying amounts of lime to attain the desired pH levels. The soil in these jars had been maintained at a moisture content equal to field capacity for 12 weeks prior to planting in order for the lime to attain equilibrium with the soil.

The plants all grew slowly and little difference could be detected among the various treatments during

Table 7 The Effect of Increasing Amounts of
Lime on Weight of Tomato Plants.*

M.e. Ca 100 gms soil	% Ca sat.	pH at start	yield grams	pH at end
-	-	4.6	8.7	5.0
1.1	40	6.0	10.8	5.7
1.5	60	6.5	11.8	6.3
2.5	100	7.0	13.4	6.8
6.1	250	7.5	8.1	7.4

* The yields represent the average of
three replications.

the first 6 weeks. All plants were stunted and showed severe phosphate starvation symptoms.

When the plants were seven weeks old, the soil in the jars was allowed to become sufficiently dry to cause temporary wilting of the tomato plants. Water was then added to bring the soils up to the moisture equivalent and the plants began new growth. They grew rapidly in all except the most heavily limed soil, and developed a normal green color. As noted in Table 7 and Plate 14, the weight of plant material produced increased as the rate of lime increased up to pH 7.0. The injurious effect of overliming on growth of tomatoes seemed to be due primarily to the decreased supply of available phosphate. The root systems of the affected plants were not well developed which is characteristic of phosphate deficiency. These results are in agreement with the work of Pierre and Browning (25) who, among others, have shown that overliming decreases the availability of phosphate.

Soil Analyses

In order to determine the possible effect of the addition of increasing amounts of lime and the effect of plant growth on the nutrient status of the soil, a partial chemical analysis of the soils was made following the growth of soybeans and also white beans. The quantities of adsorbed, or exchangeable, calcium, phosphorus, potassium, and manganese were determined using normal neutral ammonium acetate. The quantities of these elements soluble in 0.1 N HCl were also determined. (See footnotes of Tables 8, 9, 10 and 11 for methods used in making these determinations).

Following the Soybean Crop: From the data for the soil analysis following the soybean crop (Table 8) it is apparent that the quantity of exchangeable potassium was increased by the addition of lime even with the higher rates of application. There was little or no difference in the amounts with the two highest applications of lime yet there was much less plant removal from the alkaline soil because of decreased yield and lower content of potassium in the plant.

The quantities of "exchangeable" calcium increased as the rate of lime increased. These values, however, do not represent exclusively exchangeable calcium because some of the calcium of free calcium carbonate, with the higher rate, was dissolved by the extracting solution and

Table 8^{*} The Quantity of Exchangeable Ions in the Soil Following the Soybean Crop.

M.e. Ca 100 gms pH soil		Calcium ^{1/}		Manganese ^{1/}		Potassium ^{2/}		Phosphorus ^{3/}	
		M.e. ^{4/}	Lbs/acre	M.e. ^{4/}	Lbs/acre	M.e. ^{4/}	Lbs/acre	M.e. ^{4/}	Lbs/acre
-	5.2	.48	192	.018	9.8	.043	34	.031	6.4
-	5.2	.58	232	.018	9.8	.046	36	.024	5.0
-	5.1	<u>.46</u>	<u>184</u>	<u>.017</u>	<u>9.5</u>	<u>.045</u>	<u>35</u>	<u>.031</u>	<u>6.4</u>
ave.		.51	203	.018	9.7	.045	35	.029	5.9
1.1	5.9	.98	392	.016	9.0	.050	39	.031	6.4
1.1	6.0	1.05	420	.020	11.0	.055	43	.034	7.0
1.1	6.0	<u>1.03</u>	<u>412</u>	<u>.017</u>	<u>9.6</u>	<u>.052</u>	<u>41</u>	<u>.031</u>	<u>6.4</u>
ave.		1.02	408	.018	9.9	.052	41	.032	6.6
1.5	6.6	1.58	632	.015	8.0	.056	45	.039	8.0
1.5	6.4	1.56	624	.009	5.0	.063	49	.039	8.0
1.5	6.4	<u>1.62</u>	<u>648</u>	<u>.004</u>	<u>2.0</u>	<u>.066</u>	<u>52</u>	<u>.037</u>	<u>7.6</u>
ave.		1.59	635	.009	5.0	.062	48	.038	7.9
2.5	6.9	2.01	804	.007	4.0	.070	55	.044	9.2
2.5	6.9	1.95	780	.009	5.0	.063	49	.031	6.4
2.5	6.8	<u>1.88</u>	<u>752</u>	<u>.005</u>	<u>3.0</u>	<u>.068</u>	<u>53</u>	<u>.031</u>	<u>6.4</u>
ave.		1.95	779	.007	4.0	.067	53	.035	7.3
6.1	7.4	2.55	1020	-	-	.066	52	.029	6.0
6.1	7.6	3.03	1212	-	-	.070	55	.019	4.0
6.1	7.6	<u>2.88</u>	<u>1152</u>	<u>-</u>	<u>-</u>	<u>.069</u>	<u>54</u>	<u>.025</u>	<u>5.2</u>
ave.		2.82	1128	-	-	.068	54	.024	5.1

- 1/ Determined essentially by the methods of Schollenberger, C. J. and Simon, R. H. Soil Sci., 59: 13-24. 1945.
- 2/ Determined according to Methods of Soil Analysis for Soil Fertility Investigations, March, 1945.
- 3/ Determined according to Bray, R. H. and Kurtz, L. T. Soil Sci., 59: 39-46. 1945.
- 4/ Milliequivalents per 100 grams of soil.

included with the "exchangeable". This is indicated by the fact that some of the values for exchangeable calcium exceed the base exchange capacity of the soil.

The amounts of exchangeable manganese decreased markedly as the rate of lime applied increased. None was found in the alkaline soil (highest rate of lime) and it should be recalled that the least crop removal of manganese was with this treatment.

The quantity of adsorbed phosphorus increased slightly with increasing amounts of lime up to a pH of about 7.0 followed by a small decrease with the higher rate. There was less removal of phosphorus by the crop with the latter treatment.

The effects of increasing amounts of lime on the quantities of calcium, potassium, and phosphorus soluble in 0.1 N HCl in the soil following the soybean crop (Table 9) were essentially the same as those for the exchangeable or adsorbed ions. The soluble calcium and to a slight extent, potassium increased with increasing amounts of lime. There is some indication that phosphorus increased with increasing amounts of lime but the differences are not great. The quantity of acid soluble manganese was not appreciably affected by the addition of lime.

Following the White Bean Crop: By comparing the soil analysis data following the white beans (second legume crop) with that following the soybean crop (Tables 8 and

Table 9 The Quantity of Ions Soluble in .1N HCl
in the Soil Following the Soybean Crop.

M.e. Ca 100 gms soil	pH	Calcium ^{1/}		Manganese ^{1/}		Potassium ^{2/}		Phosphorus ^{3/}	
		M.e. ^{4/}	Lbs/ acre	M.e. ^{4/}	Lbs/ acre	M.e. ^{4/}	Lbs/ acre	M.e. ^{4/}	Lbs/ acre
-	5.2	.45	180	.048	26.5	.127	99	.054	11.2
-	5.2	.56	224	.053	29.0	.125	95	.059	12.1
-	5.1	<u>.46</u>	<u>184</u>	<u>.058</u>	<u>32.0</u>	<u>.120</u>	<u>94</u>	<u>.056</u>	<u>11.5</u>
ave.		.49	196	.053	29.2	.124	97	.056	11.6
1.1	5.9	1.05	420	.056	30.5	.124	97	.053	11.0
1.1	6.0	1.10	440	.043	23.5	.129	101	.059	12.1
1.1	6.0	<u>1.08</u>	<u>432</u>	<u>.048</u>	<u>26.5</u>	<u>.130</u>	<u>105</u>	<u>.064</u>	<u>13.3</u>
ave.		1.08	431	.049	26.8	.128	101	.059	12.1
1.5	6.6	1.42	568	.052	28.5	.133	104	.069	14.3
1.5	6.4	1.88	752	.049	27.0	.127	99	.067	13.8
1.5	6.4	<u>1.64</u>	<u>656</u>	<u>.061</u>	<u>33.5</u>	<u>.129</u>	<u>101</u>	<u>.069</u>	<u>14.3</u>
ave.		1.65	659	.054	29.7	.129	101	.068	14.1
2.5	6.9	2.00	800	.052	28.5	.134	105	.068	14.0
2.5	6.9	2.38	952	.056	30.5	.133	104	.058	12.0
2.5	6.8	<u>2.20</u>	<u>880</u>	<u>.047</u>	<u>26.0</u>	<u>.127</u>	<u>99</u>	<u>.074</u>	<u>15.3</u>
ave.		2.19	877	.052	28.3	.131	103	.067	13.8
6.1	7.4	5.20	2080	.046	25.5	.135	106	.059	12.3
6.1	7.6	4.94	1976	.048	26.5	.134	105	.082	17.0
6.1	7.6	<u>5.56</u>	<u>2224</u>	<u>.052</u>	<u>28.5</u>	<u>.137</u>	<u>107</u>	<u>.065</u>	<u>13.5</u>
ave.		5.23	2093	.049	26.8	.135	106	.069	14.3

- 1/ Determined essentially by the methods of Schollenberger, C. J., and Simon, R. H. Soil Sci., 59: 13-24. 1945.
2/ Determined according to Methods of Soil Analysis for Soil Fertility Investigations, March, 1945.
3/ Determined according to Bray, R. H. and Kurtz, L. T. Soil Sci., 59: 39-46. 1945.
4/ Milliequivalents per 100 grams of soil.

10), it is observed that, in general, the amounts of exchangeable calcium and potassium and adsorbed phosphorus are lower following the second crop. The differences are particularly great in the case of exchangeable potassium. The quantities of exchangeable potassium are only about one-third of that following the first crop. It is evident that the potassium was rapidly becoming depleted by crop removal. The relatively greater amounts of exchangeable potassium following the second crop in the overlimed soils is perhaps due to less removal by the crops because of their inability to utilize adequate quantities of potassium in the presence of excess calcium. It is of interest to note that the quantity of exchangeable manganese in the soil is higher following the second crop than following the first crop except with excess lime where there was none in either case.

The quantity of adsorbed phosphorus decreased with increasing amounts of lime up to a pH of about 7.0 and an increase was noted with the highest rate of lime. These differences can be explained on the basis of differences in the quantities of phosphorus removed by the plants rather than to a direct effect of the lime on the adsorbed phosphorus.

There was a greater quantity of exchangeable manganese in the soil following the second crop than following the first crop with comparable treatments, except where the soil was overlimed. In either case the amounts decreased

Table 10 The Quantity of Exchangeable Ions in the
Soil Following the White Bean Crop.

M.e. Ca 100 gms soil	pH	Calcium ^{1/}		Manganese ^{1/}		Potassium ^{2/}		Phosphorus ^{3/}	
		M.e. ^{4/}	Lbs/ acre	M.e. ^{4/}	Lbs/ acre	M.e. ^{4/}	Lbs/ acre	M.e. ^{4/}	Lbs/ acre
-	5.1	.17	68	.042	23.0	.051	40	.026	5.2
-	5.0	.04	16	.029	16.0	.035	27	.027	5.4
-	5.0	<u>.12</u>	<u>48</u>	<u>.051</u>	<u>28.0</u>	<u>.031</u>	<u>24</u>	<u>.028</u>	<u>5.6</u>
ave.		.11	44	.041	22.3	.039	30	.027	5.4
1.1	5.7	.59	236	.046	25.0	.029	23	.019	3.8
1.1	5.8	.48	192	.029	16.0	.026	20	.017	3.4
1.1	5.9	<u>.52</u>	<u>208</u>	<u>.018</u>	<u>10.0</u>	<u>.024</u>	<u>19</u>	<u>.018</u>	<u>3.6</u>
ave.		.53	212	.031	17.0	.026	21	.018	3.6
1.5	6.4	.88	352	.016	9.0	.025	19	.016	3.2
1.5	6.3	.78	312	.015	8.0	.020	16	.014	2.8
1.5	6.4	<u>.69</u>	<u>276</u>	<u>.012</u>	<u>6.5</u>	<u>.018</u>	<u>14</u>	<u>.016</u>	<u>3.2</u>
ave.		.78	313	.014	7.8	.021	16	.015	3.1
2.5	6.7	.92	368	.010	5.5	.009	7	.011	2.2
2.5	6.8	.88	352	.005	3.0	.014	11	.011	2.2
2.5	6.7	<u>.84</u>	<u>336</u>	<u>.010</u>	<u>5.5</u>	<u>.012</u>	<u>9</u>	<u>.008</u>	<u>1.6</u>
ave.		.88	352	.008	4.7	.012	9	.010	2.0
6.1	7.4	1.68	672	-	-	.040	31	.031	6.2
6.1	7.6	1.95	870	-	-	.045	35	.029	5.8
6.1	7.6	<u>2.52</u>	<u>1008</u>	<u>-</u>	<u>-</u>	<u>.037</u>	<u>29</u>	<u>.033</u>	<u>6.6</u>
ave.		2.05	820	-	-	.041	32	.031	6.2

- 1/ Determined essentially by the methods of Schollenberger, C. J., and Simon, R. H. Soil Sci., 59: 13-24. 1945.
- 2/ Determined according to Methods of Soil Analysis for Soil Fertility Investigations, March, 1945.
- 3/ Determined according to Bray, R. H. and Kurtz, L. T. Soil Sci., 59: 39-46. 1945.
- 4/ Milliequivalents per 100 grams of soil.

with increasing rates of lime.

The quantity of calcium soluble in 0.1 N HCl in the soil with the lower rates of lime was less following the second crop than following the first crop. There was less acid soluble potassium and phosphorus but little difference in the acid soluble manganese following the second in comparison to the first crop. (See Table 11)

Following the white bean crop, both acid soluble potassium and phosphorus decreased with increasing amounts of lime except where the soil was overlimed. Pierre and Browning (25) found that in some cases water soluble phosphorus often increased in overlimed soils but plants show a deficiency of phosphate and respond to phosphorus fertilization. They point out that in such a situation, water-soluble phosphorus in the soil extract is not a true measure of availability or that under conditions brought about in the soil by overliming, plants require larger amounts of soluble phosphorus for normal growth. Hoagland and Arnon (11) also have shown that excessive amounts of an element such as sodium or calcium may interfere with the absorption of other nutrients even though they may be present in available forms.

The quantities of acid soluble manganese were not greatly affected by the lime treatments or by crop removal. In all of these studies, however, the availability of manganese appears to be closely related to the reaction of the soil.

Table 11 The Quantity of Ions Soluble in .1N HCl in the Soil Following the White Bean Crop.

M.e. Ca 100 gms soil	pH	Calcium ^{1/}		Manganese ^{1/}		Potassium ^{2/}		Phosphorus ^{3/}	
		M.e. ^{4/}	Lbs/ acre	M.e. ^{4/}	Lbs/ acre	M.e. ^{4/}	Lbs/ acre	M.e. ^{4/}	Lbs/ acre
-	5.1	.26	104	.064	35.0	.077	60	.048	9.6
-	5.0	.21	84	.053	29.0	.095	74	.053	10.6
-	5.0	<u>.39</u>	<u>156</u>	<u>.073</u>	<u>40.0</u>	<u>.087</u>	<u>68</u>	<u>.058</u>	<u>11.6</u>
ave.		.29	115	.063	34.7	.086	67	.053	10.6
1.1	5.7	.97	388	.051	28.0	.099	78	.034	6.8
1.1	5.8	.89	356	.046	25.0	.082	64	.029	5.8
1.1	5.9	<u>.82</u>	<u>328</u>	<u>.062</u>	<u>34.0</u>	<u>.074</u>	<u>58</u>	<u>.039</u>	<u>7.8</u>
ave.		.89	357	.053	29.0	.085	67	.034	6.8
1.5	6.4	1.23	492	.065	35.5	.064	50	.021	4.2
1.5	6.3	1.59	586	.052	28.5	.075	59	.016	3.2
1.5	6.4	<u>1.65</u>	<u>660</u>	<u>.042</u>	<u>23.0</u>	<u>.069</u>	<u>54</u>	<u>.023</u>	<u>4.6</u>
ave.		1.49	579	.053	29.0	.069	54	.020	4.0
2.5	6.7	2.03	812	.059	32.5	.063	49	.023	4.6
2.5	6.8	1.92	768	.074	40.5	.055	43	.011	2.2
2.5	6.7	<u>2.31</u>	<u>924</u>	<u>.051</u>	<u>28.0</u>	<u>.052</u>	<u>41</u>	<u>.015</u>	<u>3.0</u>
ave.		2.09	835	.061	33.7	.057	44	.016	3.3
6.1	7.4	4.33	1732	.046	25.0	.093	73	.044	8.8
6.1	7.6	4.25	1700	.034	19.5	.072	56	.053	10.6
6.1	7.6	<u>5.78</u>	<u>2312</u>	<u>.041</u>	<u>22.5</u>	<u>.075</u>	<u>59</u>	<u>.060</u>	<u>12.0</u>
ave.		4.79	1915	.041	22.3	.080	63	.052	10.5

- 1/ Determined essentially by the methods of Schollenberger, C. J. and Simon, R. H. Soil Sci., 59: 13-24. 1945.
- 2/ Determined according to Methods of Soil Analysis for Soil Fertility Investigations, March, 1945.
- 3/ Determined according to Bray, R. H. and Kurtz, L. T. Soil Sci., 59: 39-46. 1945.
- 4/ Milliequivalents per 100 grams of soil.

Nitrate Production and Accumulation

A nitrification test was made in order to determine whether or not differences in the rate of nitrification, with increasing amounts of lime on this soil, might be an important factor affecting plant response. In making this test a series of tumblers were filled with 200 grams of the dry soil and calcium carbonate was added in amounts equivalent to those used in the greenhouse experiments. The soil in the tumblers was maintained at 15% moisture and incubated at laboratory temperatures. Soluble nitrogen (ammonia and nitrate) determinations were made on duplicate tumblers after 6 weeks and again after 12 weeks. The ammonia and nitrate nitrogen was extracted with 4 per cent KCl and determined quantitatively by the reduction method using Devarda's Alloy.

There were no significant differences among the various lime treatments on the accumulation of soluble nitrogen during either the six or twelve weeks period. After six weeks, the "no lime" tumblers contained 3.1 mgm. of soluble nitrogen per 100 grams of dry soil and the tumblers with the highest rate of lime contained 2.4 mgm. Following the incubation period of twelve weeks, the values were 3.6 mgm. and 3.4 mgm. respectively for the "no lime" and "over-limed" tumblers. As pointed out earlier in the report this soil is very low in organic matter and no nitrifiable material was added, therefore, the production of nitrates

could not be expected to be very great. It is believed that these differences are insufficient to materially affect crop yields.

Soluble nitrogen (ammonia and nitrate) determinations were made on soil samples taken from the jars following the greenhouse experiment with oats. Determinations were made only on the series which had received increasing amounts of lime. The values ranged from 0.6 mgm. to 2.5 mgm. of nitrogen per 100 grams of soil with the highest value for the jars which produced the lowest yield of white beans and the highest yield of oats.

DISCUSSION

In these experiments it has been demonstrated that the application of lime in the proper amount will bring an acid soil of low fertility level into a temporary productive condition. However, the addition of excess lime on such soils may be injurious to crop growth.

Two important functions of lime on acid soils are to lower soil acidity and to furnish the nutrient element calcium. Kelly (14) discusses the agronomic importance of calcium and points out the relationship of high calcium soils to their productiveness for most crops, particularly, legumes. It must be kept in mind that the nutrition of a plant with reference to any single nutrient is complicated by the interrelation of the various nutrient elements in the process of plant metabolism. The injurious effect of overliming, often temporary in nature, is probably due to a complicated combination of factors which vary with the soil type, the climatic conditions, and the type of plant.

Lundegardh (16) has stressed the complicated soil-plant relationship in an investigation on the influence of the soil on the growth of plants. Bender and Eisenmenger (4) in studying the intake of certain elements by plants on soils of varying pH levels found wide variations with the same plant species and also among plants of different species. Numerous reciprocal effects caused by the use of fertilizers and lime have been studied for many years

with the view of increasing the availability in the soil and absorption by plants of the various nutrients.

Although it is recognized that the mineral composition of crops can be affected only within certain limits by the availability of plant nutrients, a plant analysis may give an indication of certain reciprocal relationships of certain nutrients. Too great an excess, as well as too great a deficiency, of a particular nutritive element brings with it an injury to the crop which is reflected in lowered vitality and diminished yield. Between the limits of excess and deficiency for the nutritive elements is an optimum range which will vary with the plant and environmental conditions. To obtain this optimum, with respect to the available plant nutrients, is the principal objective for which lime is applied to soils but when it is exceeded unfavorable conditions for plant growth may result. Any factor which causes a change in the cation equilibrium; increased or decreased absorption of cations by plants; efficient or inefficient utilization of cations within the plant; or increased liberation from or fixation of cations in the difficultly available form tends to affect the amounts of replaceable bases in the soil and the consequent crop response.

These experimental results indicate a definite crop response to manganese and phosphorus when applied to over-limed soil. Boron had no significant effect in the high lime treatments on any of the crops grown. Naftel (24)

has attributed overliming injury to a disturbed calcium-boron relationship. This worker obtained no response from manganese or phosphorus but was able to overcome injury completely by applying borax.

The use of complete fertilizer did not overcome the overliming injury in these experiments. Midgley (19) also found that a complete fertilizer did not overcome the injury from excessive liming and attributes this failure to respond to a disturbed root development, particularly, of seedlings and young plants.

The response to phosphorus in these experiments is in accord with the results of Benne, Perkins, and King (5). They found a precipitation of calcium phosphate at pH levels above 7.36 and CaO caused complete precipitation at a level of pH 7.46. McGeorge, Buehrer, and Breazeale (18) point out that free hydroxyl ions reduce the amount of phosphate available in the soil by greatly reducing the H_2PO_4 ion which is preferred by plants. The results with tomatoes in these experiments indicate low phosphorus availability with the application of excessive amounts of lime.

Manganese gave the greatest response in overcoming injury to the legume crops grown in these experiments. The depressive effect of a high pH or excess calcium on manganese availability has been shown by Gilbert and McLean (10), Mann (17), Schollenberger (27), and Sherman and Harmer (28). Acid soils which have undergone consider-

able leaching are usually depleted in manganese as the acid condition is favorable for the formation of the soluble manganous form. When such soils are limed in excess the manganese equilibrium will tend to shift toward the manganic form which is not available to plants.

The plant analysis of the two legume crops shows a general depressing effect on the absorption of other nutrients, particularly potassium, as a result of increasing calcium uptake with increasing amounts in the soil. Moser (22), in growing several types of plants in complete nutrient cultures with variable pH and calcium concentration, found the nutrient uptake of the plant increased with the increase of available calcium with no relation to the pH level. The absorption of potassium was depressed in some instances by the increased absorption of calcium but in most of the plants increased amounts of potassium were observed in high calcium treatments.

The soil analysis data following the legume crops indicate a general release or increased availability of nutrients, with the exception of manganese, as lime applications were increased. The amount of exchangeable manganese decreased sharply with increase of pH, however, the amount of manganese soluble in .1N HCl was about the same for all treatments. Schollenberger (27) using .1 N HCl was able to obtain a substantial increase in extractable manganese upon the addition of lime to an acid soil. He points out that the ease with which manganese oxides

in the soil are reduced by supplying an active base may introduce a significant complication in soil reaction studies.

A decrease of available nutrients in those treatments which produced the largest growth of the legume crops was evident, particularly in the amount of exchangeable potassium. The results obtained from the oat crop reflected the depleted condition of the soil from which the largest yields of legumes were obtained. In other words it is believed that the oat crop failed to show overliming injury because the two preceding crops had largely depleted the available nutrient supply in those jars which had received normal or adequate amounts of lime.

According to results obtained, this acid sandy soil with a very low fertility level has the ability to produce, temporarily, good yields of leguminous crops simply by the addition of lime in the proper amount.

The lime application necessary to bring about the most favorable condition for legume growth proved to be about one ton per acre. The rate of lime application to those peach orchards which were injured by overliming was usually in the order of two to three tons per acre. The rate of three tons per acre produced definite injurious results in these greenhouse experiments.

Some orchardists in Michigan depend upon leguminous green manure crops as a source of nitrogen. In order to grow these crops satisfactorily it is often

necessary to apply lime. The experimental results herein reported, indicate that on acid sandy soils of low fertility injurious effects may be produced if too much lime is applied. However, if the rate of applying lime is carefully controlled and if supplemented with adequate fertilizers, leguminous crops can be grown satisfactorily on such soils. The injurious effects of overliming according to the results reported herein may be due to either a decreased intake of potassium by plants, a decreased availability of manganese, a decreased availability of phosphorus or a combination of these effects.

SUMMARY

In this investigation, involving greenhouse and laboratory studies, the objective was to study the cause or causes of overliming injury on peach trees growing on some of the lighter soils in the southwestern part of Michigan. A Coloma loamy sand, on which overliming injury had been observed, was selected for these studies.

The effect of increasing amounts of lime, with and without fertilizer, was determined on soybeans, white beans, oats, and tomatoes. Special emphasis was given to the relation of boron, manganese, and phosphorus to the overliming injury.

A partial chemical analysis was made of the crops and of the soils after cropping in order to aid in diagnosing the overliming injury.

As a result of these studies the following statements can be made:

1. Because of the low buffer capacity of this soil, a relatively small amount of lime (about one ton per acre) is required to bring it to a desirable reaction near neutrality.

2. Small amounts of lime proved highly beneficial on crop growth.

3. Definite injury was obtained when the lime requirement of the soil was exceeded.

4. Overliming injury was not prevented or corrected

by the addition of boron to the soil.

5. Overliming injury was partially, though not completely, prevented by the application of phosphorus and manganese.

6. Overliming (above pH 7.0) resulted in an increase in content of calcium, a decrease in content of potassium and manganese, and in general, a decrease in content of phosphorus in all the plants studied.

7. There was a marked decrease in exchangeable manganese in the soil with increasing rates of lime.

8. The quantity of exchangeable potassium or adsorbed phosphorus in the soil was not appreciably affected by increasing amounts of lime.

9. When limed sufficiently to grow good crops the available nutrient supply in this soil was quickly exhausted, indicating a low reserve supply.

10. No significant differences were noted in the rate of nitrification in the soils as influenced by increasing amounts of lime.

11. Caution should be exercised in liming acid sandy soils of low fertility level unless adequately supplemented with fertilizers.



Plate 1. The effect of increasing amounts of lime on the growth of soybeans at 4 weeks. See Table 2 for soil treatments and results.



Plate 2. The effect of increasing amounts of lime with ten lbs. borax applied per acre on the growth of soybeans at 4 weeks. See Table 2 for soil treatments and results.



Plate 3. The effect of increasing amounts of lime with 50 lbs. MnSO_4 applied per acre on growth of soybeans at 4 weeks. See Table 2 for soil treatments and yields.



Plate 4. The effect of increasing amounts of lime with 300 lbs. 0-20-0 applied per acre on growth of soybeans at 4 weeks. See Table 2 for soil treatments and yields.



Plate 5. The effect of boron, manganese, and phosphorus in overcoming the detrimental effect of overliming on soybeans at 4 weeks. See Table 2 for soil treatments and yields.



Plate 6. The effect of increasing amounts of lime on the growth of white beans at 6 weeks. See Table 4 for soil treatments and yields.



Plate 7. The effect of increasing amounts of lime with additional fertilizer applications on growth of white beans at 6 weeks. See Table 4 for soil treatments and yields.



Plate 8. The effect of increasing amounts of lime with additional fertilizer applications on the growth of white beans at 6 weeks. See Table 4 for soil treatments and yields.



Plate 9. The effect of increasing amounts of lime with additional fertilizer applications on the growth of white beans at 6 weeks. See Table 4 for soil treatments and yields.



Plate 10. The effect of various fertilizers on the over-limed crop of white beans compared with a quartz sand nutrient solution culture. Plants at 6 weeks. See Table 4 for soil treatments and yields.



Plate 11. The effect of manganese in overcoming the overliming injury on white beans. Plants on left received $1\frac{1}{2}$ ton lime per acre and 50 lbs $MnSO_4$. Plants on right received 3 ton lime per acre and 150 lbs. $MnSO_4$. Both received 300 lbs. 10-20-20 per acre. Plants at 6 weeks.



Plate 12. The effect of increasing amounts of lime on the growth of oats following the white bean crop compared with quartz sand nutrient culture at 6 weeks. See Table 6 for soil treatments and yields.



Plate 13. The effect of increasing amounts of lime with additional fertilizer treatment on the growth of oats compared to a quartz sand nutrient culture. Plants at 6 weeks. See Table 6 for soil treatments and yields.



Plate 14. The effect of increasing amounts of lime on the growth of tomatoes compared with growth in a quartz sand nutrient culture. Plants at 10 weeks. See Table 7 for soil treatments and yields.

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