sweet orange, and grapefruit. The susceptibility of other possible rootstocks is being tested in two ways; as seedlings growing in infested subsoil under controlled temperature and as budded Valencia trees planted in a diseased area. The testing of rootstocks is a long-term proposition, because both the disease reactions and the horticultural characteristics must be studied in detail.

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CHELATED IRON AS A CORRECTIVE FOR LIME-INDUCED CHLOROSIS IN CITRUS

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Iron chlorosis of citrus occurs widely throughout Central Florida on both acid and calcareous soils. The acreage of citrus grown on acid soils in Florida is much greater than that on calcareous soils, and iron chlorosis is also more extensive on acid soils. Iron deficiency on calcareous soils, usually called "lime-induced chlorosis" is, however, a matter of serious concern to many citrus growers along Florida's east coast. Some groves in this area have shown severe iron chlorosis for many years. Many of the old trees have been replaced with young trees which have subsequently become chlorotic.

The symptoms of lime-induced chlorosis in citrus are the same as those of iron deficiency in citrus grown on acid soils. The veins of the leaves remain dark green, whereas the interveinal areas turn lighter green in mild chlorosis and yellow or almost white in severe chlorosis.

Cause of Lime-induced Chlorosis

The occurrence of iron deficiency in citrus and other plants growing on calcareous soils is associated with the high lime content and alkaline reaction of the soil. Thorne et al. (10) discussed several hypotheses in an attempt to explain the cause of lime-induced chlorosis. They believe there is not conclusive evidence that iron assimilation by plants is reduced by lime in the soil. Many experiments have been conducted on various aspects of this problem without definitely establishing the cause of the deficiency or finding a satisfactory method of correcting it. In addition to high lime and high soil pH (3, 7, 10), lime-induced chlorosis in plants has been attributed to high soil moisture, poor aeration of the soil, cool soil temperature (3, 10), excessive phosphate (2, 3, 4), too little potassium (3), and high potassium (6) among other possible causes. Some workers believe that chlorotic plants take up as much iron as green plants, but that the iron is immobilized in the roots or elsewhere in the plant and fails to reach the leaves in adequate amounts. Others believe that the iron is rendered largely unavailable in the soil and that very little iron actually enters the roots. It still is not definitely known why some calcareous soils will produce iron chlorosis in plants growing on them, while other soils of similar pH and content of total iron and calcium carbonate will produce green plants.

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Experimental

In previous papers (5, 8, 9), it was reported that the iron chelate of ethylenediamine tetraacetic acid (Fe-EDTA) brought about complete recovery of iron-chlorotic citrus trees growing on acid soils when applied to the soil at the rate of only 10 to 20 grams of iron (Fe) per tree. Subsequently, field plots were set up to test the effectiveness of Fe-EDTA on chlorotic orange trees growing on calcareous soils. The chelate was applied at rates varying from 40 to 600 grams of iron per tree. Inconsistent results were obtained with single soil applications of amounts varying from 40 to 180 grams of iron per tree, but greening of a few trees was observed when 100 or more grams of iron was applied. Single applications of either 300 or 600 grams of iron as Fe-EDTA resulted in excellent greening of the trees. Although this is believed to be the first time a soil application of iron has completely corrected iron chlorosis in citrus growing on calcareous soil, the cost of the chelate makes such high rates of application impractical for field use.

When Fe-EDTA was applied at rates of 40 to 180 grams of iron per tree in each of two separate applications made seven months apart, marked greening of many chlorotic trees was obtained at rates below 100 grams per application per tree. The trees did not, however, become completely green.

During the past two years, extensive studies have been carried out in both the field and the laboratory in an effort to find a chelating agent which will supply iron efficiently to trees growing on calcareous soils. Nineteen different chelating agents have been tested in the field on such soils. Most of these materials were ineffective as sources of available iron for citrus. A few of them produced partial greening of the chlorotic trees, but the amounts required were too high for economical grove use.

Field trials using the iron chelate of hydroxyethyl ethylenediamine triacetic acid (Fe-EDTA-OH),[1] which is closely related to EDTA, were begun in April, 1952. This chelate produced complete greening of chlorotic trees when applied to calcareous soil at rates as low as 40 grams of iron per tree. A short time later plots were set up in which this chelate was applied at rates of 20, 26, 33, 40, 53, and 66 grams of iron per tree. There was some greening of the leaves three months after treatment in the plots receiving 40 or more grams of iron per tree. Accordingly, in April, 1953, the above iron chelate treatments were repeated on the same plots. In addition to applying the same rates used the previous year, new plots were set up and given an application of 100 grams of iron per tree. Trees in all plots greened up markedly even at rates as low as 26 grams of iron per tree. The untreated trees remained chlorotic.

In order to test Fe-EDTA-OH more fully, additional plots were established in the spring of 1953 at a location different from the plots described above and treated with rates of 25, 40, 50, 60, 75, and 100 grams of iron per tree. Soil samples taken from these plot areas showed the following analyses: 0-6 inches, pH 8.1, $CaCO_3$, 15.5 percent; 6-12 inches, pH 8.1, $CaCO_3$ 18.5 percent; 12-24 inches, pH 8.0, $CaCO_3$, 31.0 percent.

[1] Fe-EDTA-OH is manufactured by the Bersworth Chemical Co., Framingham, Mass. and sold under the trade name "Fe-Versen-ol."

In all plots, the chelate was applied broadcast under the trees over an area 12 feet in diameter. On June 26, the trees in all plots showed considerable greening, and those receiving either 75 or 100 grams of iron per tree were completely green except for an occasional leaf tip. Since that time, the trees receiving the lower rates of iron have shown further recovery from the chlorosis, so that greening of the trees is almost complete in all plots. The untreated trees continued to be severely chlorotic.

At two other locations, Fe-EDTA-OH has not been effective in correcting lime-induced chlorosis in citrus. The reasons for such failure are not yet clear, and this problem is being studied further.

Chaberek and Bersworth (1) state that EDTA-OH forms a 1:1 ferric chelate that is stable against hydrolysis even in strong alkaline solutions. They further state that while the Fe-EDTA complex is decomposed in alkaline medium to ferric hydroxide, the corresponding ferric chelate of EDTA-OH is completely stable against hydroxide precipitation. However, laboratory experiments supplementing the field trials reported here showed that EDTA-OH was only a little more effective than EDTA in holding iron in water-soluble form in soils containing free calcium carbonate.

Iron chlorosis in citrus growing on calcareous soils requires three to four months for correction, whereas iron chlorosis in trees growing on acid soil can be corrected within six weeks by a soil application of Fe-EDTA. When the deficiency is severe, correction of the chlorosis may be followed by vigorous flushes of new growth.

Iron and Chlorophyll Analyses of Citrus Leaves

Chemical analyses have shown that the iron content of leaves from citrus trees growing on Florida's calcareous soils is somewhat lower than that in leaves of trees growing on acid soils. On acid soils, mildly chlorotic leaves contained up to 55 parts per million of iron on the dry basis (5), and leaves from trees given a soil application of Fe-EDTA contained 100 or more parts per million of iron. Leaves from untreated green trees on acid soils contained from 60 to more than 100 parts per million of iron. In contrast to these relatively high values, leaves from green trees growing on calcareous soils contained only 43 parts per million of iron, and chlorotic leaves from untreated trees varied from 17 to 32 parts per million of iron. All leaves analyzed for iron were thoroughly washed with Dreft before drying.

Trees in plots treated twice with Fe-EDTA-OH, which recovered almost completely from lime-induced chlorosis, showed definite increases in iron content of the leaves as compared with untreated chlorotic trees (Table 1). The iron content did not increase uniformly with the quantity of chelate applied. There was a large increase in chlorophyll in the leaves of all treated trees as compared with the chlorotic checks.

Trees in plots treated only once with Fe-EDTA-OH showed substantial increases in both total iron and chlorophyll in the leaves, as compared with the untreated chlorotic checks (Table 2). Again the iron content of the leaves did not increase uniformly as the quantity of chelate was increased, although all of these trees showed excellent recovery from lime-induced chlorosis.

Analyses of Calcareous Soils

Florida's calcareous soils planted to citrus differ in several respects from the acid soils. The calcareous soils are heavier in texture (higher in silt and clay), contain more organic matter, and are more poorly drained than the acid soils. The calcareous soils have a high pH and contain varying amounts of free calcium carbonate. The two latter characteristics present the chief obstacles to correcting iron chlorosis on these soils. Many calcareous soils in groves along Florida's east coast are no longer representative of their soil series classification because of the practice of bedding the groves; that is, the trees are planted on ridges formed by grading up soil out of the middles or water furrows to raise the trees farther above the water table and to improve drainage. The surface soil beneath the trees is therefore likely to be a mixture of the natural topsoil and subsoil. This often results in wide variations in its content of calcium carbonate. In many of these soils, marl is clearly visible between 12 and 18 inches in depth, and solid marl is often encountered between 18 and 30 inches.

Numerous soil samples from 0 to 6 and 6 to 12-inch depths were taken in groves in which experiments are being conducted. Determinations were made of soil pH, and total iron and calcium carbonate. A few representative analyses are shown in Table 3. These analyses show that the total iron (Fe) in the top 6 inches of soil under chlorotic trees varied from 4,700 to 15,000 pounds per acre. Surface soils taken from beneath untreated green trees varied in total iron from 1,500 to 27,000 pounds per acre. Total iron often varied considerably between surface soil (0 to 6 inches) and the 6 to 12-inch depth. These data indicate that there is little or no relationship between total iron in the soil and lime-induced chlorosis in citrus trees.

Table 1
Effect of two soil applications of iron chelated with hydroxyethyl ethylenediamine triacetic acid (Fe-EDTA*OH) on total iron and chlorophyll content of leaves and on greening of chlorotic orange trees growing on calcareous soils.

Fe applied per tree* grams	Total Fe ppm.	Chlorophyll** mgm.	Amount of greening***
20	44	131	2-3
26	42	123	2
33	50	156	1
40	43	138	2
53	48	125	2
66	45	147	2
100	55	156	1
None (Chlorotic trees)	30	61	4
None (Green trees)	43	—	1

*Treatments applied September 26, 1952 and April 30, 1953, except the 100-gram treatment which was applied only on April 30, 1953.

**Milligrams chlorophyll per gram dry weight of leaves.

***Key: 1 = trees completely green; 2 = a few chlorotic leaves; 3 = moderately chlorotic trees; 4 = considerable chlorosis (moderate to severe) ; 5 = severely chlorotic trees.

Table 2
Effect of a single soil application of iron chelated with hydroxyethyl ethylenediamine triacetic acid (Fe-EDTA-OH) on total iron and chlorophyll content of leaves, and on greening of chlorotic orange trees growing on calcareous soils.

Fe applied per tree grams	Total Fe ppm.	Chlorophyll mgm.*	Amount of greening**
25	50	140	2
40	47	141	1
50	58	153	1
60	52	142	1
75	50	151	1
100	70	144	1
None (Chlorotic trees)	25	63	4
None (Green trees)	43	—	1

*Milligrams chlorophyll per gram dry weight of leaves.

**Key: 1 = trees completely green; 2 = a few chlorotic leaves; 3 = moderately chlorotic trees; 4 = considerable chlorosis (moderate to severe); 5 = severely chlorotic trees.

Table 3
Total iron and calcium carbonate content and pH of calcareous soils as related to lime-induced chlorosis in Florida citrus.

Depth, inches	Condition of trees	Total Fe lbs./acre	$CaCO_3$, percent	pH
0-6	Moderate to severe chlorosis	4700	14.0	7.6
6-12	" " " "	7900	9.5	7.7
0-6	" " " "	15620	15.5	7.65
6-12	" " " "	13780	14.0	7.7
0-6	" " " "	—	15.5	7.7
6-12	" " " "	—	33.0	7.9
0-6	" " " "	—	22.5	7.8
6-12	" " " "	—	29.5	7.7
0-6	" " " "	—	15.5	8.1
6-12	" " " "	—	18.5	8.1
12-24	" " " "	—	31.0	8.0
0-6	Green	3420	2.0	6.6
6-12	"	5020	2.0	6.5
0-6	Green	1520	1.5	4.55
6-12	"	1920	1.0	4.8
0-6	Green	27200	2.2	6.6
6-12	"	32200	2.7	7.2
0-6	Green	26000	2.7	7.2
6-12	"	29200	3.2	7.3
0-6	Mild chlorosis	8520	5.5	6.9
6-12	" "	7100	10.5	7.4

The pH of surface soils beneath moderately to severely chlorotic trees varied from 7.4 to 8.1. However, surface soils taken from beneath untreated green trees had a pH below 7.0 in every instance except one. In most cases samples taken from beneath green trees at both the 0 to 6 and 6 to 12-inch depths were acid in reaction. In a few cases samples taken from the 0 to 6-inch depth were acid and those from the 6 to 12-inch depth were alkaline.

The calcium carbonate content of the surface soils (0 to 6 inches) beneath chlorotic trees varied from 7.0 to 22.5 percent. Soils from beneath untreated green trees varied from 1.0 to 2.0 percent calcium carbonate. In most instances there were only small differences in calcium carbonate content of the 0 to 6-inch and the 6 to 12-inch layers.

Use of Acidifying Materials with Chelated Iron

As stated previously, the iron chelate of EDTA is extremely effective in correcting iron chlorosis when applied to acid soils, but effective in only relatively large amounts per tree on calcareous soils. Accordingly, experiments were set up to determine whether it is practical to lower the pH of calcareous soils in local areas with acidifying materials sufficiently to make this chelate effective in correcting lime-induced chlorosis. For this purpose, field tests were made with three acidifying materials: technical grade sulfuric acid, wettable sulfur, and aluminum sulfate. All three materials were applied uniformly under the trees over an area 10-12 feet in diameter.

Wettable sulfur was applied at rates of 10, 25, and 50 pounds per tree, in combination with Fe-EDTA at the rate of either 30 or 60 grams of iron per tree. Greening of the trees was obtained in some instances, but the results were not consistent. There was no detectable lowering of the pH of the surface six inches of soil as a result of the sulfur treatments. Wettable sulfur in combination with Fe-EDTA and with Fe-EDTA-OH is being tested further to determine whether sulfur will help correct lime-induced chlorosis.

Chlorotic trees were treated with aluminum sulfate, $Al_2(SO_4)_3 \cdot 18H_2O$, at rates of 5 and 10 pounds per tree, in combination with Fe-EDTA at the rate of 30 grams of iron per tree. The trees showed a little improvement but recovery from chlorosis was not satisfactory at the rates of aluminum sulfate and Fe-EDTA used. Aluminum sulfate is also being tested further for this purpose.

Technical grade concentrated sulfuric acid (66° Baume) was applied to calcareous soils at rates of 4.5 and 9 pounds per tree. The acid was diluted to a volume of five gallons with water and sprinkled beneath the trees over an area either 8 or 12 feet in diameter. These acid treatments have given variable results in lowering the pH of the surface soil, their effectiveness depending primarily on the calcium carbonate content of the soil. Even when there was little lowering of the soil pH, Fe-EDTA applied at the rate of 60 grams of iron per tree following the acid treatment produced good greening of chlorotic trees and substantial increases in the total iron content of the leaves (Table 4). Fe-EDTA applied at the rate of 30 grams of iron per tree was somewhat less effective than the 60-gram rate, but still produced considerable greening.

Uniform applications of nine pounds of sulfuric acid per tree without adding Fe-EDTA produced no detectable greening of chlorotic trees. These trees were a little less chlorotic before treatment than the check trees. This accounts for their rating of four in amount of greening (Table 4) as compared with a rating of five for the checks. In soils containing enough calcium carbonate to prevent appreciable lowering of the pH of the surface soil with one nine-pound bottle of acid, there appears to have been sufficient lowering of the pH in

Table 4
Effect of soil treatment with sulfuric acid prior to application of Fe-EDTA on total iron content of the leaves and on greening of chlorotic citrus trees growing on calcareous soils.

Fe applied per tree grams	Concentrated H_2SO_4 applied per tree, lbs.	Method of Application*	Total Fe ppm.	Amount of greening**
30	4.5	12 ft. diam.	37	3
60	4.5	12 ft. diam.	56	2
30	9.0	12 ft. diam.	41	2
60	9.0	12 ft. diam.	46	2
30	9.0	8 ft. diam.	38	2
None	9.0	8 ft. diam.	28	4
None	9.0	12 ft. diam.	36	4
60	None	12 ft. diam.	—	5
60	4.5	6 holes	40	1
60	4.5	12 holes	36	2
60	9.0	12 holes	43	2
60	9.0	9 holes	47	1
60	18.0	12 holes	50	2
60	18.0	18 holes	38	2
60	None	6 holes	—	5
None (Chlorotic)	None	——	25	5
None (Green trees)	None	——	41	1

*Twelve ft. diameter means the acid(diluted to 5 gallons) was sprinkled beneath the trees over an area 12 ft. in diameter, and then the Fe-EDTA was applied broadcast over the same area. Where holes were used, they were about 8 inches in diameter and 3 to 4 inches deep; both the acid (diluted) and Fe-EDTA were applied only in the holes.

**Key: 1 = trees completely green; 2 = a few chlorotic leaves; 3 = moderately chlorotic trees; 4 = considerable chlorosis (moderate to severe); 5 = severely chlorotic trees.

small localized areas to make Fe-EDTA effective as a source of iron for the trees. Many citrus roots grow very close to the soil surface in Florida east coast groves.

Sulfuric acid was also applied in holes scattered under the trees. This method concentrates the acid in a smaller area and tends to lower the pH to a greater depth in the soil. In these trials, the acid was diluted to five gallons with water and poured into holes dug in the soil beneath the trees. The holes were dug about eight inches in diameter and three or four inches deep. The number of holes per tree varied from 6 to 18, and sulfuric acid was applied at rates of 4.5, 9, and 18 pounds per tree (Table 4). The 4.5-pound rate of acid—applied in six holes per tree and followed by the application of Fe-EDTA at the rate of 60 grams of iron per tree—produced excellent recovery from lime-induced chlorosis. The same amounts of acid and Fe-EDTA applied in 12 holes per tree has also been effective, but produced slightly less greening of the trees than the treatment in six holes. Treatment with larger amounts of acid in from 9 to 18 holes per tree also resulted in good recovery from the chlorosis, even in very severely affected trees. Application of Fe-EDTA at the rate of 60 grams of iron in six holes per tree without acid produced no detectable greening of severely chlorotic trees. Broadcast application of Fe-EDTA at the rate of 60 grams of iron per tree without acidifying materials also failed to green up chlorotic trees.

Sulfuric acid is very corrosive and must be handled with care. Its application involves considerable hand labor; this may limit its practical usefulness in groves as an aid in correcting iron chlorosis. The use of sulfuric acid is being studied further in combination with both Fe-EDTA and Fe-EDTA-OH as an aid in correcting lime-induced chlorosis in citrus.

Summary

The iron chelate of hydroxyethyl ethylenediamine triacetic acid (Fe-EDTA-OH) was found to be considerably more effective than the iron chelate of ethylenediamine tetraacetic acid (Fe-EDTA) in correcting lime-induced chlorosis in Florida citrus. Fe-EDTA-OH, when applied to calcareous soils at the rate of 25 to 100 grams of iron per tree, in most instances has produced excellent recovery from lime-induced chlorosis within three to four months after application. In contrast, about 300 grams of iron per tree in the form of Fe-EDTA was required to bring about complete recovery from the chlorosis.

The total iron content of leaves from citrus trees growing on calcareous soils in Florida is somewhat lower than that in leaves from trees growing on acid soils. Correction of lime-induced chlorosis was accompanied by substantial increases in total iron and chlorophyll content of the leaves.

Since Fe-EDTA is an excellent corrective for iron chlorosis on acid soils, field experiments were carried out with this chelate in combination with acidifying materials as a possible means of correcting lime-induced chlorosis on soils where Fe-EDTA-OH was not effective. As little as 4.5 pounds of technical grade sulfuric acid applied broadcast or in holes dug beneath the trees, followed by relatively small applications of iron as Fe-EDTA, resulted in good greening of chlorotic trees on calcareous soils. Some good results were obtained with a combination of wettable sulfur and Fe-EDTA, but the results were not consistent.

The calcium carbonate content of the calcareous surface soils producing chlorotic trees varied from 7 to 22 percent, and the soil pH ranged from 7.4 to 8.1. The surface soil be-

neath most of the green trees in chlorotic groves was slightly acid in reaction.

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THE EFFECT OF FERTILIZER TIMING AND RATE OF APPLICATION ON FRUIT QUALITY AND PRODUCTION OF HAMLIN ORANGES

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Experiments have been conducted, both in pot cultures (4) and in the field, in an attempt to discover relationships between the use of variable amounts of fertility elements and the growth and yield of citrus. Little information is available, however, concerning the effects of timing or rates of application of a definite ratio of fertility elements on the production and quality of citrus under commercial practices. In the experiments to be described in this progress report nitrogen, phosphorus, potash, magnesium, manganese and copper were not varied independently, instead they were used in the same ratio at different times of the year in the timing experiment and in the same ratio but at different amounts in the rate experiment.

A block of Hamlin oranges* was offered for such experiments in cooperation with the Citrus Experiment Station at Lake Alfred in the fall of 1948. At that time the trees were 8 years old and producing about 4 boxes per tree. Starting with the November 10, 1948 fall application the timing experiment was begun in which two plots of 32 trees each received fertilizer applications three times per year, i.e., fall, spring and summer. Three other plots of 32 trees each received an equivalent amount of fertilizer but in two equal applications per year. These applications were made either in the fall and spring, fall and summer or spring and summer, thus omitting one of the usual application dates.

In the fall of 1949 the rate portion of the experiment was begun in which three plots in duplicate received variable amounts of fertilizer. Two plots in the timing experiment which received fertilizer three times per year were used for the highest rate of application.

It is the purpose of this report to describe in terms of yield, fruit quality, leaf analysis and soil analysis the results obtained to date under the different fertilizer rates and timing which were used.

PROCEDURE

Total amounts of each fertilizer component applied per year per tree are listed in Table 1. All trees in the timing experiment received an amount of mixed fertilizer which would supply 0.4 pound of N per box of fruit per year. During the period from 1949 through 1951 an anticipated average production of 4 boxes of fruit per tree was used as the basis for calculating total fertilizer poundage. This figure was increased to 6 boxes after 1951. These anticipated production figures were also used for the rate of application experiment. The rates of application of the mixed fertilizer were

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