In Argentina over 7,000,000 trees were killed in the twenty years after the first symptoms of tristeza were observed. In Florida losses to date have not been spectacular despite the fact that the disease is present in every citrus-growing county, and that tristeza has apparently existed in the State for the last 15 or 20 years. In some areas, however, losses have been greater than elsewhere. For example, in one 75-acre grove in Orange County, approximately 17 per cent of the trees show signs of the disease, and the number of dying trees is growing continually. Other groves in this and adjacent counties seem to be following the same trend. Elsewhere in the State there appears to be an entirely different pattern, with only scattered trees infected and with no evidence of spread.

Suscept Range

Several other differences apparently exist between tristeza in Florida and elsewhere. These relate to the behavior of the virus under experimental conditions. One involves the citrus relative *Aeglopsis Chevalieri.* In Argentina this species produced early and very conspicuous symptoms when infected with tristeza; in fact its reactions were so outstanding as to make it superior to Key lime as a test plant (4). In Florida, however, this same species fails to show any distinct symptoms of infection whenever it is included in Key lime test series.

Another experimental difference relates to the presence of the virus in lemon. According to evidence reported from South America, it was not found possible to retrieve the virus after inoculation into lemon plants. In contrast, our tests show that in Florida the tristeza virus can be transmitted from lemon to Key lime with the subsequent production of vein clearing symptoms. The same has also been accomplished with sour orange as source of the virus.

Conclusions

The differences pointed out above may be explained in many cases by what seems obvious. For example, variations in the rate of spread may be correlated with the presence or absence of vectors. Similarly the extent of damage, once the virus is in the tree, may be explained in terms of virulent and mild strains. Present-day lack of importance may only be illusory; if all tristeza-diseased trees pulled in years past because of stunting were totaled, the amount of damage might actually be considerable. It may also be that sufficient time has not yet elapsed for the disease to appear as a snowballing force.

At the present time, however, such answers are purely inferential, and much work remains to be done before any of these theories can be proved valid. Future research on tristeza will attempt not only to substantiate or reject the various theories but will seek also to establish whether the above-mentioned differences are real or merely apparent. Not until this has been done can any authoritative assurances be given concerning the importance of tristeza to Florida.

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ROOT DISTRIBUTION OF CHLOROTIC AND IRON-CHELATE-TREATED CITRUS TREES

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Iron chlorosis has been one of the important nutritional problems in growing citrus in Florida. The symptoms can not be alleviated effectively with iron from ordinary sources such as iron sulfate. In 1951, studies by Stewart and Leonard (5) on acid sandy soils indicated that soil applications of iron chelated with ethylene-diamine tetracetic acid (EDTA) effectively controlled the foliage chlorosis within a few weeks after treatment. New shoot

Florida Agricultural Experiment Station Journal Series, No. 215.

growth increased the size of the trees considerably within six months after treatment.

Smith and Specht (4) suggested that the main cause of the recent increase of iron chlorosis in Florida citrus is the accumulation of copper in the soil and the consequent root damage it causes. Since copper accumulation occurs primarily in the top-soil it was suggested that trees become chlorotic because of damage to roots in that area. In their experiments, chelated iron applied to seedlings in solution culture did not overcome the stunted root system associated with high copper levels.

Recent studies by Ford (3) have shown that 70 percent of the feeder root system of healthy citrus trees growing on deep sandy soils in Florida is located below 10 inches in the soil.

The purpose of this investigation was to determine the root distribution of iron-deficient trees grown on acid sandy soils of central Florida, and to compare this with the root distribution of trees which received soil applications of Fe EDTA chelate.

Methods

A detailed comparison was made of the physical condition and distribution of feeder roots of iron-deficient, iron-chelate-treated, and non-deficient orange trees on rough lemon rootstock.[1] The chlorotic trees, all of which had shown symptoms of the deficiency for several years, were compared with nearby trees treated with Fe EDTA chelate 6 to 12 months prior to root sampling. An adjustable auger was used to sample citrus feeder roots (1).

Thirteen groves were studied in October and November 1952, four groves in May 1953, and two groves in September and October 1953. These were placed in two groups according to the soil profile. The first group consisted of groves confined to areas around lakes and swamps where the rooting zone was restricted by the water table to five to seven feet. The second group consisted of groves on well-drained, fine sands where the rooting zone extended below nine feet in depth. The groves were further designated as mild, moderate, and severe according to the appearance of the untreated chlorotic trees.

[1] A major portion of the root data was obtained from experimental plots of Ivan Stewart and C. D. Leonard, Fla. Citrus Exp. Sta. and J. Wright, Geigy Co., Orlando. The author expresses his appreciation for the use of their plots.

Results

The Appearance and Distribution of Feeder Roots. In October 1952, the feeder roots of severely iron deficient trees, to a depth of 30 inches, were ashy gray, rather shriveled, and highly corked with no visible evidence of an actively growing root tip. The majority of the roots were brittle and easily broken. Some of the feeder roots were only fragments one to two centimeters long. At depths below 30 inches in the soil, the feeder roots of chlorotic trees varied in color from light gray to dark brown and were thicker, flexible, and more branching than roots nearer the surface.

Applications of Fe EDTA improved the color of new root growth to a limited extent in several groves. Feeder roots in the upper 30 inches were gray to dark brown and below 30 inches most of the feeder roots were brown in color six months after an application of chelated iron to severely deficient trees.

The growth of new feeder roots on trees treated with chelated iron was increased, but the increase was not uniform throughout the entire rooting zone. The increase in root growth was confined primarily to the zone below 10 inches. Under both chlorotic and chelate-treated trees, feeder roots could usually be found growing near the surface in the leaf mold within 30 inches of the tree trunk in the area not disturbed by cultivation.

In groves with the root system restricted by the water table to five to seven feet in depth, soil applications of chelated iron to iron-deficient trees resulted in a significant increase in feeder root concentration. Severely iron-deficient trees with the poorest root systems showed the greatest percentage increase in feeder roots following treatment with Fe EDTA chelate. As shown in Table 1, the rough lemon feeder root system of severely chlorotic Valencia orange trees increased from one gram to nine grams (dry weight of feeder roots in a square foot column five feet deep) six months after an application of chelated iron. Trees showing moderate symptoms had nine grams of feeder roots per column while nearby treated trees had 16 grams. Trees with mild symptoms had 18 grams of feeder roots per column while treated trees had 21 grams.

It was interesting to note that the feeder root system of iron-deficient trees varied considerably depending on the severity of the deficiency; since severely chlorotic trees had at

Table 1

Distribution of Feeder Roots of Iron Deficient Orange Trees after Treatment with Fe EDTA. The Root Zone of These Trees Was Restricted to 5 - 7 Feet by the Water Table

Depth in Inches	Grams of Feeder Roots per Zone*					
	Severe Deficiency**		Moderate Deficiency**		Mild Deficiency**	
	Chlorotic	Fe EDTA	Chlorotic	Fe EDTA	Chlorotic	Fe EDTA
0-10"	.52	.49	2.84	4.14	5.02	6.43
10-30"	.43	3.33	2.78	4.85	6.93	6.44
30-60"	.40	4.95	3.92	7.50	5.95	8.67
Total	1.35	8.77	9.54	16.49	17.92	21.54

*Expressed as grams dry wt. in a column one foot square the height of each zone.
**Based on the appearance of the untreated chlorotic trees.

least 90 percent less feeder roots than trees with mild chlorotic symptoms.

Trees with mild to moderate chlorotic symptoms prior to treatment with Fe EDTA also showed increased feeder root development below 10 inches; although the contrast in root growth between chlorotic and treated trees was less marked with decreasing severity of deficiency symptoms.

Groves on deep, well-drained Lakeland fine sand showed only mild iron deficiency symptoms. Here the chlorotic trees had 18 to 20 grams of feeder roots (sq. ft. column nine feet deep), whereas healthy trees on rough lemon rootstock usually contained 25 to 32 grams of feeder roots (1). The root symptoms were studied only to a depth of nine feet, although it was known that a considerable number of roots extended deeper than nine feet (3). The only difference in root development between chlorotic, chelated-iron-treated trees, and healthy trees was in the 0-10 inch depth zone. In this zone (Table 2) healthy trees

Table 2

Feeder Root Distribution of Mildly Chlorotic, Fe EDTA Treated, and Healthy Orange Trees Growing on Deep Well-drained Lakeland Fine Sand.

Treatment	Grams of Roots 0-10 Inch Zone* Sampled at 3 Locations		
	Inside of Drip	Drip of Branch**	Outside of Drip**
Iron chlorosis	7.22	1.28	2.59
Chelated iron	10.8	1.95	1.21
Healthy trees	7.92	6.92	7.26

*Expressed as a column one foot square.
**Cultivated several times a year. The disc covered the row middle and under the drip of the branches.

with no visible iron deficiency had approximately the same feeder root concentration 12 feet from the trunk as occurred six feet from the trunk. Trees with symptoms of iron deficiency had more feeder roots under the tree than at the drip of the branches or in the middle of the row in the area covered by cultivation. Chelated iron did not increase root development in the cultivated area.

One grove showing severe chlorotic symptoms on deep St. Lucie sand was studied in September and October 1953. Three levels of chelated iron had been applied in replicated plots in May 1953. Samples were taken during the autumn root flush, September 1, 1953, and from the same trees when the period of rapid root growth ceased by October 12, 1953.

The rooting environment was different than for groves on Lakeland fine sand. Severely chlorotic orange trees had more feeder roots from 0-10 inches than from ten inches to nine feet deep (Table 3). All chlorotic trees

Table 3

Feeder Root Distribution of Severely Chlorotic and Fe EDTA Treated Orange Trees Growing on Deep St. Lucie Sand As Measured in September and October 1953.[a]

Depth in Inches	Iron Def.		Grams of Iron in the Fe EDTA					
			18		9		3	
	Sept.	Oct.	Sept.	Oct.	Sept.	Oct.	Sept.	Oct.
0-10"	2.94	1.89	3.45	3.76	4.76	4.60	2.54	2.36
10-30"	1.33	.59	2.35	2.62	1.93	1.89	1.24	2.00
30-60"	.32	.03	1.06	2.21	1.44	1.14	1.52	1.35
5-9"	.03	0	.48	.17	.07	0	.33	0
Total	4.62	2.51	7.34	8.76	8.20	7.63	5.63	5.71

[a]Each value is the mean of 4 plots expressed as the grams of feeder roots in a column one foot square the height of each zone.

showed a reduction in root concentration from September to October because of feeder root disintegration.

Nine grams and 18 grams of iron per tree (expressed as iron in Fe EDTA) increased feeder root development during the autumn root flush in September and the new feeder roots survived in October. Three grams of iron per tree did not increase root concentration in comparison to chlorotic trees in September; however, the root flush survived in October.

The Effect of Cultivation and Soil pH. The majority of citrus groves in central Florida are cultivated by discing several times during the winter months. The disc usually penetrates the soil about three inches and the implement passes within about six feet of the trunk. The fact that chlorotic trees are smaller permits cultivation closer to the trunk.

It was observed that the majority of groves showing severe chlorotic symptoms were cultivated to within 30 inches of the trunk. In the cultivated region of the drip and row

Table 4

The Effect of Cultivation on Root Distribution to a Depth of 10 Inches on Chlorotic and Iron Chelate Treated Orange Trees

Treatment	Grams of Feeder Roots 0-10 Inch Zone* Sampled at Three Positions		
	3 Ft. Inside Drip	Drip	3 Ft. Outside of Drip
CULTIVATION			
Chlorosis	5.49	2.29	.70
Iron Chelate treated	7.33	2.0	.89
NONCULTIVATION			
Chlorosis	4.69	4.10	3.04
Iron Chelate treated	5.00	5.02	7.68

*Expressed as a column one foot square.

middle (Table 4), there were practically no feeder roots to a depth of 10 inches even when treated with chelated iron (except for occasional isolated feeder root pockets). Numerous lateral roots were found showing the scars of missing feeder roots.

In noncultivated regions of the drip and row middle, feeder roots were found under moderately deficient and adjacent chelate-treated trees. In this case the iron treatment resulted in an increase in feeder root concentration primarily in the zero to three inch zone. The effect of noncultivation has not been observed on severely chlorotic trees that had been treated with chelated iron.

Only two groves were found satisfactory for studying changes in root distribution with changes in soil pH, so that the data presented here are limited (Table 5). In the first grove the soil pH was 4.8 in October 1952 under the moderately iron-deficient trees. Seven months later the soil pH of one group of the same chlorotic trees was 4.5 and another small group was pH 4.2. The soil pH was 4.6 in October under the Fe EDTA treated trees. The area was divided into trees with a soil pH of 4.5 and another of pH 4.3 in May 1953. For the chlorotic trees, there was a considerable difference in feeder root distribution from October to May. Where the soil pH was not below 4.5, the additional feeder-root loss was confined primarily to the 0-10 inch zone. However, when the pH was 4.2 a significant reduction in feeder root concentration occurred at all levels to a depth of five feet.

The chelate treated trees did not show the root loss with lowering soil pH that was noted on the iron deficient trees. In fact, new feeder roots continued to develop in the 30-60 inch depth zone during the seven month period.

In the second grove, which consisted of trees showing severe deficiency symptoms, the soil pH was raised from pH 4.6 to 5.2 with an application of dolomite. Over the seven month period chlorotic trees showed only a slight increase in feeder root development as a result of liming, whereas the Fe EDTA treated trees showed a five-fold increase in surface roots (0-10″) and a slight increase in total feeder root concentration at the lower depth zones from 10-60 inches.

Discussion

Feeder root damage in orange trees affected with severe iron deficiency was not confined to the topsoil. Feeder root damage, similar to that described for copper toxicity (5) was found to a depth of five feet in groves located near lakes and swamps. Soil pH in the 0 to 10-inch zone in such groves was below five with the subsoil at pH 3.9-4.4. All of the groves had high concentrations of copper in

Table 5

Root Distribution of Iron Deficient and Fe EDTA Treated Orange Trees at Various Soil pH Levels*

Depth in Inches	Grove No. 1						Grove No. 2			
	Iron Def.			Fe EDTA			Iron Def.		Fe EDTA	
	Sept. '52 pH 4.8	May '53 pH 4.5	May '53 pH 4.2	Sept. '52 pH 4.6	May '53 pH 4.5	May '53 pH 4.3	Oct. '52 pH 4.6	May '53 pH 5.2	Oct. '52 pH 4.6	May '53 pH 5.2
0-10"	3.54	2.61	1.80	4.14	3.96	3.15	.52	.48	.49	2.55
10-30"	4.38	3.94	2.55	6.85	5.08	3.76	.43	.73	3.33	3.86
30-60"	4.95	4.66	2.24	5.50	6.52	7.66	.40	.84	4.95	5.08
Total	12.87	11.21	6.59	16.49	15.56	14.57	1.35	2.05	8.77	11.49

*Expressed as the grams of feeder roots in a column one foot square the height of each zone.

the topsoil. An application of Fe EDTA chelate to chlorotic trees that showed extensive root damage to a depth of five feet, resulted in pronounced new growth of roots in the subsoil. The increase was proportionately greater with increasing depth, so that there were often more new roots in the 30 to 60-inch zone than in the 10 to 30-inch zone.

Thus, where Fe EDTA resulted in new leaf and shoot growth, a corresponding increase in feeder root growth occurred, primarily below ten inches in the soil. In general, if feeder roots were found in the 0 to 10-inch-zone under chlorotic trees, the iron-chelate treatment resulted in an increase in the number of feeder roots on the laterals in that particular surface region. However, if no feeder roots were found on lateral roots in a specified surface region under chlorotic trees, then no new feeder roots were present on the laterals in the same region under the Fe EDTA trees.

It was not the purpose of this investigation specifically to evaluate copper toxicity in relation to feeder root growth of chlorotic trees when treated with Fe EDTA chelate. Root distribution patterns presented certainly do not detract from the concept that heavy metals, particularly copper, are major factors in feeder root disintegration associated with iron chlorosis. The data do, however, illustrate the complexity of the entire rooting profile as found in iron-deficient commercial groves. The presence of feeder-root pockets in the topsoil, the growth of roots in the surface leaf mold, the effect of cultivation, and the difference in rooting environment between the topsoil and the subsoil must be taken into consideration. The problem is further complicated by the behavior of the root system following changes in soil pH. It is difficult to explain why, following a reduction in soil pH over a seven-month period, severely chlorotic trees lost feeder roots throughout the entire root profile instead of only in the 0 to 30-inch depth zone. Whether other factors in addition to copper toxicity influence feeder root survival on iron deficient trees remains to be determined.

The presence of feeder roots in the undisturbed 0-to-3-inch zone under chlorotic and Fe EDTA treated trees indicates that the topsoil root system could be increased under a program of noncultivation. Groves are usually cultivated two or three times during the dry winter months to reduce moisture loss and to reduce the fire hazard. It is an open question whether the increased root growth would so further increase the size and productivity of Fe EDTA-treated trees as to offset the disadvantages of noncultivation.

A more practical method would undoubtedly be to raise the soil pH and at the same time apply Fe EDTA chelate, since considerably greater topsoil root growth occurred over a seven-month period under this treatment than where the pH was raised without the addition of Fe EDTA. When the topsoil pH is sufficiently high, copper is largely immobilized (4). Liming would tend to reduce the availability of iron, but if sufficient available iron is present new root growth should occur. Trees with severe iron deficiency symptoms are in a reduced state of vigor and some grove soils are low in total iron. The rapid elimination of leaf symptoms and increase in iron within the tree following the use of Fe EDTA chelate apparently is conducive to rapid feeder root development if the soil environment is such that new feeder roots can survive.

Summary

Soil applications of iron chelated with ethylenediamine tetraacetic acid (EDTA) to iron deficient citrus trees resulted in a significant increase in feeder roots. In general, chelated iron increased root growth in proportion to the degree of chlorosis.

Feeder roots were missing to a depth of 10 inches in the cultivated region of the drip and row middle even when treated with chelated iron. When the grove was not cultivated, the Fe EDTA treatment resulted in an increase in feeder root concentration primarily in the 0 to 3-inch zone.

Changes in soil pH influenced the distribution of feeder roots throughout the entire root profile.

In general, Fe EDTA chelate, in addition to eliminating leaf symptoms, resulted in rapid feeder root development when the soil environment was such that new feeder roots could survive.

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