LIME-INDUCED CHLOROSIS OF CITRUS IN RELATION TO SOIL FACTORS

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Introduction

One of the most important forms of chlorosis (**3, 4**) still widely distributed in some of the best citrus areas is that which may occur when the soil contains an abundance of calcium carbonate. An extensive survey of soils in citrus orchards in southern California has shown that orchard soils may contain considerable calcium carbonate without the leaves of the trees showing symptoms of lime-induced chlorosis. Mild symptoms such as a slight change of the dark green color of the leaves to a more yellowish green may not seriously impair the fruit production provided the growth is vigorous and abundant. In fact, frequently some curtailment brought about in this manner in the quantity of fruit produced may prove desirable in that the size and quality of the fruit may show improvement. When the leaf veins become conspicuous because of their greenness in contrast to the pale yellow or yellowish green of the leaf blade, it is then that chlorosis may require increasing consideration. The soils of many citrus orchards are calcareous and the excellence of some of these orchards is outstanding. The data collected during the survey of citrus orchards (**8**) have indicated that a soil may be calcareous and yet not necessarily be alkaline in reaction (**1**) although potentially it may become so under certain conditions.

Calcium carbonate is one of the buffer substances in soil and has hydrolytic properties that depend not only on the size and form of the particles and the amount of colloidal matter (**1**) but also on the percentage of moisture present, for it is this factor that permits hydrolysis to proceed. In tests of the pH of orchard soils it was concluded (**7**) that no orchard soil has been encountered which, when sufficiently reduced in moisture content, failed to show an acid reaction. This was particularly obvious in dealing with calcareous soils for, at moisture contents greatly above the moisture equivalent, they were quite alkaline while at low moisture contents they were acid.

In some orchard soils the calcium carbonate may occur in a finely divided condition and well distributed throughout the soil mass. In this case the color and physical texture of the soil in addition may require the usual acid test in order to ascertain whether calcium carbonate is present. In other orchard soils the calcium carbonate, while abundantly present, may occur in such a coarsely divided form that large pieces may be collected. Thus frequently the pH of the soil (at the 1:5 soil-water ratio) was found to be considerably higher in the first than in the second case.

In an orchard a very chlorotic tree or a group of chlorotic trees frequently were found growing among healthy appearing trees. In some cases the depth of the top soil to the calcareous subsoil was very shallow under the chlorotic, and somewhat deeper under the healthy trees. In many cases the calcium carbonate was finely divided and well distributed in both the healthy and chlorotic tree areas and even the pH values of the soil gave no assuring differences.

The pH values of the soils in healthy and in chlorotic orchards usually clearly indicate differences that can be related to the growth conditions in the trees; in the same orchard, however, the pH relation of the soil of healthy and of nearby chlorotic areas may not be very clearly indicated. Determinations of the soil moisture and moisture equivalent percentages, thorough inspections of the orchards visited, together with soil samplings and many pH determinations made personally in the field, have been enlightening in regard to the perplexing problem as to why certain trees may be chlorotic while others are healthy in a calcareous area. The rôle of the soil moisture supply in the problem of lime-induced chlorosis is an important one. Single or isolated determinations of pH, while helpful, give the results under only a given set of conditions. The pH of a soil may change from day to day, dependent on the soil moisture supply (**5**, **9**).

The actual soil moisture percentages in calcareous soils are of importance in the pH determination. It is the length of time that the roots of a tree are subjected to a given pH [the continuity (**6**) of a given moisture percentage], however, that is of paramount importance in the nutrition of a tree. With this continuity go the factors of aeration as well as of sustained hydrolysis and its precipitation effects. The key factor in calcareous soils that makes for chlorosis is the factor that makes possible the continuity of a high moisture percentage in the soil.

Excessive soil moisture in calcareous soils may be obtained not only by the frequent use of large amounts of irrigation water but also by interruptions in the percolation of water through the soil. The occurrence of hard pans (cemented or compacted layers often containing some proportions of clay) with or without calcareous impregnation in the soil above them, retards the movement of soil moisture. Unless the greatest care is taken in the irrigation procedure, injury is likely to result from a too prolonged period of excessive soil moisture. Continuous maintenance of a calcareous soil at soil moisture percentages as low as that of the moisture equivalent may be included in the excessive soil moisture class. Strata of soil of greatly different pore space from that of the contacting layers may serve to create excessive soil moisture supplies. Even the coarsest sand as well as the silty clays may operate in this manner.

When there is no calcareous impregnation in the soil, such retardations in the movement of soil moisture (while not bringing about any marked pH changes) do prevent the aeration of the roots and injure them, which in turn interferes with the nitrogen nutrition of the tree. The veins in the oldest leaves become yellow or white and the abscission of affected leaves may take place before an appreciable change occurs in the color of the leaf blade. When injury is severe, only the youngest leaves remain attached. With a calcareous soil, excessive soil moisture results in high pH values that make iron unavailable without or within the tree and chlorosis then becomes evident, often without a serious premature loss of old leaves.

In the calcareous areas the better trees were usually found in soil in which the moisture equivalents either decreased or remained relatively unchanged with increasing depth. In the healthy tree areas the roots were contacting soil of lower water-holding power as they advanced with increasing age deeper into the soil mass. Opportunity thus was afforded the roots for growing in soil of lower pH values and for increased availability of minor elements, as well as for better aeration (**6**). The chlorotic trees frequently were growing in calcareous soils, the moisture equivalents of which increased steadily in heavy soils or abruptly in lighter soils with increasing depth.

The present paper supplies data for the soil conditions in chlorotic citrus orchards in contrast with those in healthy orchards (**8**), for chlorosis in citrus trees is an accompaniment of certain soil conditions. Data are also given to show the changes in the pH values of soils with the topographical location of the orchard in a given citrus area and the relation of minor element deficiencies to the observed pH values.

Methods

Previous papers (**7, 9**) have fully discussed the methods involved in studies of the kind here reported. Close examination of the orchards, sampling of the soils, determinations of pH in the field and in the laboratory, together with supplementary tests such as soil moisture percentages and moisture equivalent values, have permitted the bringing together of data from which to form an advantageous viewpoint. Since no satisfactory iron-containing spray has as yet been found for citrus, the approach to the correction of chlorosis has of necessity been from the soil standpoint.

The selection of orchards in particular areas was made with the view of following the changes in the environment and behavior of orchard trees with increasing or decreasing elevations in the orchard location.

The studies extended throughout the year and in this way the relation of the soil conditions applied to the general tree condition rather than to that of a particular growth cycle.

The depth of the sample represents the auger or soil tube cores for the interval of depth between the bottom of the previous sample and the greatest depth indicated. Where data are given for pH values in soil *in situ*, the values are for a particular location at the depth indicated rather than for an extensive interval in depth.

Results

Data for the soils of a number of chlorotic and healthy citrus orchards are shown in table I. Orchards nos. 1 and 2 adjoin one another and the ages of the trees are 25 and 35 years, respectively. Orchard no. 1 consists of 40 acres and the soil has received large applications of ammonium sulphate over a period of years and now receives liquid (acid) fertilization in the irrigation water. Orchard no. 2 also consists of considerable acreage and the trees are budded on sweet orange rootstock. The pH of the irrigation water is 8.31. Two and one-half pounds of nitrogen in the form of gas ammonia have been used per tree per year for the past 7 years. Table I shows the striking pH differences. The soil in orchard no. 1 is not so wet as that of no. 2 and the pH values at the field moisture content are the more acid in no. 1. The soil in orchard no. 2 contains considerable calcium carbonate as indicated by the marked upwelling of the soil when the juice of green lemons is added. Extreme care in not irrigating orchard no. 2 before the soil moisture content is sufficiently low, has greatly reduced the occurrence of chlorosis in this orchard.

The first three samples in orchard no. 3 were taken in the upper portion of the steeply sloping orchard where the trees were healthy, while the second three samples were taken from the lower or affected portion. The soil in both locations was very friable and in excellent condition. Although the soil samples from orchard no. 3 were brought to the laboratory in closed-tin containers before making the tests, the pH values nevertheless are of interest. The data in table I suggest that the soil in the lower portion of the orchard contains hydrolyzable substances (probably calcium carbonate). The irrigation furrows that run straight down the steep slope tend to keep the soil at the lower portion of the orchard moist for a longer time than that in the upper portion.

Orchard soils may contain considerable calcareous material and still remain healthy when the irrigation is carefully done. Orchard no. 4 consists of excellent 18- to 20-year-old trees. The trees in orchard no. 5 are 17 years of age and have averaged 6 field boxes the past two years. The soil in orchard no. 5 receives two pounds of nitrogen plus 6 cubic feet of steer manure per tree per year.

The trees in orchard no. 6 are 15 to 20 years of age and are of outstanding excellence even though an abundance of calcium carbonate can be seen in the

TABLE I

pH VALUES OF SOILS IN HEALTHY AND IN CHLOROSIS-AFFECTED ORCHARDS

Orchard number and date of sampling	Location of orchard	Tree variety	Presence of chlorosis	Soil type	Depth	Tests in orchards	Tests in laboratory			
						pH of soil at field moisture content (in beaker)	pH of soil at field moisture content (in beaker)	pH (1:5 soil-water ratio)	Moisture percentage	Moisture equivalent
					ft.				%	
1. Dec. 29, 1939	Placentia	Valencia orange	Healthy	Yolo loam	0.5	5.82	....	7.83	17.0	20.4
					1.0	6.00	....	6.90	18.3	
					2.0	6.19	....	7.20	19.6	23.7
					3.0	6.01	....	7.14	14.5	21.9
					4.0	6.21	....	7.18	10.8	....
2. Jan. 3, 1940	Placentia	Valencia orange	Chlorosis	Yolo loam	0.5	7.20	....	8.64	23.9	....
					1.0	7.11	....	8.65	21.8	....
					2.0	6.62	....	8.51	21.9	....
					3.0	7.01	....	8.66	21.0	....
					4.0	6.99	....	8.64	23.8	....
3. Mar. 11, 1940	San Juan Capistrano	Valencia orange	Healthy	Yolo loam	1.0	....	6.74	7.68	19.9	24.9
					2.0	....	7.10	7.68	22.0	24.6
					3.0	....	7.11	7.67	21.3	23.9
			Chlorosis		1.0	....	6.84	8.13	22.4	26.1
					2.0	....	7.23	8.48	18.7	21.8
					3.0	....	7.18	8.01	18.9	24.3
4. Mar. 11, 1940	Santa Ana	Valencia orange	Healthy	Yolo loam	0.5	6.30	....	8.27	22.0	24.1
					1.0	6.81	....	8.37	22.6	24.3
					2.0	6.95	....	8.51	24.1	25.1
					3.0	6.78	....	7.97	23.3	24.3
5. Nov. 27, 1939	Whittier	Valencia orange	Healthy	Yolo clay loam	0.5	6.90	....	7.70	28.7	32.0
					1.0	6.67	....	7.77	27.3	32.1
					2.0	7.00	....	8.39	27.4	31.5
					3.0	6.87	....	8.51	26.2	33.4
					4.0	6.99	....	8.55	25.9	33.4

TABLE I—(*Continued*)

Orchard number and date of sampling	Location of orchard	Tree variety	Presence of chlorosis	Soil type	Depth	Tests in orchards: pH of soil at field moisture content (in beaker)	Tests in laboratory: pH of soil at field moisture content (in beaker)	Tests in laboratory: pH (1: 5 soil-water ratio)	Tests in laboratory: Moisture percentage	Tests in laboratory: Moisture equivalent
					ft.				%	
6. Nov. 11, 1939	Porterville	Washington navel orange	Healthy	Porterville clay loam	Surface	5.82	....	....	....	....
					0.5	6.16	....	8.19	22.2	....
					1.0	6.48	....	8.65	23.2	....
					1.5	6.47	....	9.04	23.4	....
					2.0	6.44	....	9.20	21.9	....
					2.5	6.31	....	9.33	18.7	....
7. Mar. 11, 1940	Tustin	Valencia orange	Healthy	Yolo loam	0.5	6.56	....	8.14	21.5	26.3
					1.0	6.87	....	8.29	25.2	27.4
					2.0	6.87	....	8.39	22.9	25.4
					3.3	6.81	....	8.31	17.4	22.1
8. Oct. 24, 1939	Fillmore	Lemon	Chlorosis	Yolo gravelly loam	0.5	7.13	7.41	8.03	16.9	16.5
					1.0	7.44	7.51	8.48	16.8	
					2.0	7.39	7.38	8.58	12.8	14.0
					3.0	7.15	7.49	8.60	12.8	18.7
					4.0	6.93	7.18	8.33	10.9	....
9. Dec. 29, 1939	Placentia	Valencia orange	Incipient chlorosis	Yolo loam	0.5	7.27	....	7.63	24.8	23.8
					1.0	7.15	....	7.97	22.3	
					2.0	7.11	....	8.52	29.2	22.6
					3.0	7.10	....	8.67	16.6	22.5
					4.0	7.42	....	8.76	18.0	....
10. Mar. 13, 1940	Santa Ana Canyon	Valencia orange	Slight chlorosis	Yolo loam	0.5	6.90	....	8.30	17.4	22.9
					1.0	6.89	....	8.29	18.4	23.3
					2.0	6.90	....	8.54	18.5	22.4
					3.0	6.88	....	8.70	17.3	21.2

TABLE I—(*Concluded*)

Orchard number and date of sampling	Location of orchard	Tree variety	Presence of chlorosis	Soil type	Depth	Tests in orchards: pH of soil at field moisture content (in beaker)	Tests in laboratory: pH of soil at field moisture content (in beaker)	Tests in laboratory: pH (1: 5 soil-water ratio)	Tests in laboratory: Moisture percentage	Tests in laboratory: Moisture equivalent
					ft.				%	
11. Nov. 28, 1939	Rivera	Valencia orange	Slight chlorosis	Hanford sandy loam	0.5	7.96	....	8.08	20.4	21.6
					1.0	7.85	....	8.42	17.0	19.4
					2.0	7.59	....	8.27	14.6	16.2
					3.0	7.94	....	8.40	10.5	14.7
					4.0	7.96	....	8.41	12.1	16.6
12. Nov. 22, 1939	Pico	Valencia orange	Chlorosis	Sorrento silt loam	0.5	7.62	....	7.99	13.7	21.3
					1.0	7.31	....	8.30	12.3	
					2.0	7.05	....	8.22	11.7	22.1
					3.0	7.27	....	8.40	13.5	24.1
					4.0	7.40	....	8.30	14.2	19.7
13. Nov. 18, 1939	San Fernando	Valencia orange	Chlorosis	Yolo gravelly sandy loam	0.5	6.80	....	7.66	16.4	....
					1.0	7.00	....	8.00	15.3	....
					2.0	7.22	....	8.42	14.9	....
					3.0	7.41	....	8.52	18.5	....
					4.0	7.39	....	8.50	12.9	....
14. Nov. 8, 1939	Northridge	Valencia orange	Chlorosis	Yolo loam	0.5	6.96	....	8.37	14.4	....
					1.0	6.66	....	8.60	14.6	....
					2.0	7.31	....	8.79	17.6	....
					3.0	7.22	....	9.01	13.3	....
					4.0	7.31	....	8.70	15.6	....
15. Apr. 9, 1940	Piru	Valencia orange	Chlorosis	Yolo sandy loam	0.5	....	7.22	8.19	16.1	15.1
					1.0	....	7.04	8.62	14.2	15:6
					2.0	....	7.11	8.64	12.0	9.0
					3.0	....	7.20	8.68	10.3	5.5

dark soil. It will be seen from the data for these orchards (nos. 4 to 6 inclusive) in table I that while the pH values of the soil at the 1:5 soil-water ratio show strong hydrolytic potentialities, the pH values of the soil at the field moisture percentages (that were close to those of the moisture equivalent) in most cases were acid. These data illustrate the fallacy in assuming the pH values at the 1:5 soil-water ratio as being necessarily those found under field conditions.

The trees in orchard no. 7 are 10-year-old Valencia orange on sweet orange rootstock and in previous years have been affected with chlorosis. The pH values at the field moisture content show the soil to be acid while the values at the 1:5 soil-water ratio show the alkaline potentialities.

Orchard no. 8 consisted of large old trees that were extremely chlorotic. The samples tested in the field were re-tested later the same day and in some cases the pH values increased during storage in closed tin containers.

Orchard no. 9 consists of about 100 acres on which are growing some of the oldest and largest Valencia orange trees in that area. The soil is basin irrigated and the trees in certain areas are seriously injured by chlorosis. Some of the trees bordering the chlorotic area are considerably younger and the leaves are a yellowish green and may be considered partially affected. As the trees become more mature the chlorosis symptoms are more prominent. Many of the trees in this orchard become increasingly chlorotic during the rainy winter season and become increasingly free of chlorosis as the soil dries out in late spring. With time, much dead wood occurs in the trees, damaging fruit that contact it. One of the chief causes of chlorosis in such orchards is the nature of the irrigation schedule which must be adhered to rather rigidly in order to cover the acreage before the next irrigation period. Were the soil permitted to enter the rainy season in a rather dry condition, considerable danger of wind injury would result were a dry, hot, desert wind suddenly to occur. Portable low sprinklers for better irrigation control are now being used with much promise.

Although orchard no. 10 (27-year-old trees) was once a show place for excellent trees and is still in fair condition, it now produces fruit of small size and the leaf growth indicates the presence of some chlorosis and minor element deficiencies. The pH values at the field moisture content were all slightly acid while the hydrolytic potentialities at the 1:5 soil-water ratio showed an increase with depth.

The trees in orchard no. 11 are 18 years of age and are still in good health (as compared with somewhat chlorotic older trees adjacent to them). The fertilizer applied to the orchard soil used to be 5 to 7 cubic feet of manure plus 5 pounds of ammonium sulphate per tree per year but has been changed to double the commercial, in the absence of any organic fertilizer. The fruit sizes in this area have been smaller than desired for some time.

Orchard no. 12 consists of 108 acres of 30-year-old trees. In the area sampled, the irrigation water was run from two directions which brought too much water to the low places. Hog manure and 12 pounds of ammonium sulphate was the fertilizer applied to the soil per tree per year. Although large, this orchard has not given satisfactory performance. With the lowest moisture content, the pH of the soil at field moisture content was also lowest.

The trees in orchards 13 to 15, inclusive, show varying degrees of chlorosis; those in no. 15 are 40 years of age. Table I shows the very low moisture equivalents and the high moisture percentages for the second and third foot depths in orchard no. 15. It is possible that heavier soil occurs at a somewhat greater depth. This phase will be given greater attention in later tables.

In the Covina Highlands area there are extensive plantings of lemon and avocado trees on the hillsides and the yellow, or chlorotic, trees can be seen for some distance. In one lemon orchard the moisture equivalents of the first and second foot of soil were 41.9 and 41.8 while the pH values at the 1:5 soil-water ratio were 8.31 and 8.29, respectively. In the chlorotic avocado areas, the corresponding moisture equivalents were 37.6, and 37.7, and the pH values 8.09, and 8.31, respectively. These soils not only have high moisture holding capacities but also are calcareous. They remain at high moisture content continuously for long periods during which their pH values are high.

Table I shows the higher pH at the field moisture content of soil in chlorotic orchards and the accompanying pH values (about 8.3 or above) at the 1:5 soil-water ratio. The soil in healthy orchards may have the high pH values at the 1:5 soil-water ratio but at relatively low field moisture percentages the soils react acid somewhere in the root zone.

pH OF SOILS, DEFICIENCY SYMPTOMS, AND THE LOCATION OR ELEVATION OF ORCHARDS

The better orchards are often found at the higher soil locations in a given area. This occurrence is often attributed to higher air and soil temperatures, better air and soil drainage, greater freedom from alkali salts, and to other factors. Opportunity was afforded in two areas to investigate the pH relation of the soil to minor element-deficiency symptoms and to the location or elevation of the orchard.

The orchards (each 10 acres or more in size) referred to in table II, are located progressively in the range from high up on the valley and close to the virgin hill area down to the low-lying citrus orchards approaching a creek. The data in table II indicate that the pH values at the 1:5 soil-water ratio were high in the soil of every orchard investigated. Later in the day, the orchard tests of pH at the field moisture content were repeated in the

TABLE II

pH VALUES OF ORCHARD SOILS FROM THE HIGHER TO THE LOWER AREAS NEAR BRYN MAWR, CALIFORNIA

ORCHARD NUMBER AND DATE OF SAMPLING	TREE VARIETY	SOIL TYPE	DEPTH	TESTS IN ORCHARD	TESTS IN LABORATORY			
				pH OF SOIL AT FIELD MOISTURE CONTENT (IN BEAKER)	pH OF SOIL AT FIELD MOISTURE CONTENT (IN BEAKER)	pH (1:5 SOIL-WATER RATIO)	MOISTURE PERCENTAGE	MOISTURE EQUIVALENT
			ft.				%	
1. Aug. 17, 1939	Washington navel and Valencia orange	Hanford loam	0.5*	7.13	6.69	8.54	12.2	....
			1.0	6.90	6.52	8.68	11.2	....
			2.0	7.10	6.62	8.83	10.6	....
			3.0	7.05	6.74	8.90	8.0	....
			3.5	7.02	6.76	8.66	10.5	....
			0.5	6.92	6.90	8.14	14.0	....
			1.0	7.12	6.79	8.50	12.1	....
			2.0	6.90	6.97	8.80	9.7	....
			3.0	6.96	6.82	8.72	13.9	....
			3.5	7.15	6.85	8.90	13.2	....
2. Aug. 17, 1939	Valencia orange	Hanford loam	0.5	6.40	6.74	7.60	12.2	....
			1.0	6.97	6.62	8.10	12.0	....
			2.0	7.10	6.64	8.50	7.3	....
			3.0	7.27	6.72	8.70	8.4	....
			3.5*	7.19	6.53	8.80	7.8	....
3. Oct. 13, 1939	Valencia orange	Hanford fine sandy loam	0.5	6.90	7.61	8.02	11.6	13.4
			1.0	7.12	7.34	8.48	9.5	12.1
			2.0	7.38	7.30	8.70	6.8	11.6
			3.0	7.40	7.15	8.63	4.7	11.8
			4.0	7.14	7.28	8.70	5.8	....
			5.0	7.36	7.24	8.60	8.6	....
			6.0	7.40	7.30	8.60	6.9	....

* pH values of the soil *in situ* were: 6.41, 7.03, 6.80, 6.80, 6.49; 6.95, 6.48, 5.85, 6.39, 6.80; 6.71, 6.62, 6.78, ..., and 6.31, respectively.

TABLE II—(*Continued*)

Orchard number and date of sampling	Tree variety	Soil type	Depth	Tests in orchard	Tests in laboratory			
				pH of soil at field moisture content (in beaker)	pH of soil at field moisture content (in beaker)	pH (1:5 soil-water ratio)	Moisture percentage	Moisture equivalent
			ft.				%	
4. Oct. 13, 1939	Grapefruit	Hanford fine sandy loam	0.5	7.05	7.70	8.15	14.8	15.7
			1.0	7.30	7.42	8.50	8.7	16.8
			2.0	7.31	7.40	8.81	7.9	15.5
			3.0	7.25	7.31	8.80	5.9	13.2
			4.0	7.19	7.06	8.85	5.5	....
			5.0	7.21	7.30	8.76	5.0	....
			6.0	7.21	6.60	8.74	5.6	....
5. Oct. 13, 1939	Washington navel orange	Hanford fine sandy loam	0.5	6.92	7.50	7.80	10.6	13.0
			1.0	7.20	7.36	8.50	10.4	13.4
			2.0	7.41	7.41	8.72	7.5	12.9
			3.0	7.18	7.41	8.75	4.5	12.2
			4.0	7.30	7.26	9.00	4.3	....
			5.0	7.41	7.18	9.33	4.8	....
			6.0	7.20	7.30	8.83	3.2	....
6. Oct. 13, 1939	Washington navel orange	Hanford fine sandy loam	0.5	7.00	7.11	7.10	8.1	10.0
			1.0	7.05	7.30	7.98	6.9	11.3
			2.0	7.21	7.44	8.25	8.6	13.5
			3.0	7.22	7.31	8.45	7.9	15.5
			4.0	7.09	7.31	8.50	6.3	....
			5.0	7.07	7.20	8.85	5.6	....
			6.0	7.14	7.00	9.00	4.8	....

laboratory, making use of the soil samples stored in tightly closed containers. The data in table II[1] indicate that, in general, the pH values of the stored samples from the higher situated orchards nos. 1 and 2 decreased while in nearly all of the stored samples from the lowermost orchard no. 6, the pH values increased with storage. The rôle that sodium and calcium carbonate play in this change during storage is not known.

The trees in the excellent orchards no. 1 and 2 are 47 years of age and show a slight chlorosis. Orchard no. 1, since 1912, has used no cover crop, organic matter, or cultivation, and has used calcium nitrate exclusively as the sole fertilizer. Its past four year average was 400 packed boxes per acre. The first location was between the second and third furrows while the second location was under the second furrow. The location in orchard no. 2 was under the second furrow. Here, in contrast to orchard no. 1, cultivation, cover crop, and ammonium sulphate have been used. At the field moisture content the soil in both orchards was generally acid. The pH values for the soil *in situ* also were indicative of an acid condition.

The remaining orchards (table II) showed minor element deficiencies and some chlorosis, the orchards becoming increasingly poorer toward the base of the slope. The grapefruit orchard (no. 4) was of special interest. Some of the more severely chlorotic old trees were selected as a group the soil of which was to be treated in various ways with sulphur. The soil at the time of sampling was fairly dry (table II) and it was decided to wait until after the irrigation before making holes in the soil for the sulphur applications. Returning to the orchard several weeks later it was found that the soil had been furrowed but that the irrigation would not begin until later that same day. The delay in applying water to the soil had caused a temporary wilting of some of the leaves and it was difficult to locate trees having any symptoms of chlorosis. Thus a sufficient reduction in the soil moisture condition was accompanied by the greening of the chlorotic leaves. This situation was comparable to another chlorotic orchard of Valencia oranges in Orange County in which it was not possible to secure water for a season and in which, to the surprise of many, the chlorotic nature of the foliage disappeared.

A series of orchard soils were also sampled in the La Verne area, beginning with an orchard ten acres distant from the virgin foothills and ending with an orchard far down in the floor of the valley. Table III shows the data obtained.

In orchard no. 1 the trees were 42 years of age with an average yield of 10 or more field boxes per tree per year. Three pounds of nitrogen per tree per year were used and the soil was irrigatd by the sprinkler system. No

[1] Thanks are extended to MR. O. C. COMPTON of the Division of Irrigation for assistance in the pH tests reported in table II.

TABLE III

pH VALUES OF ORCHARD SOILS FROM THE HIGHER TO THE LOWER AREAS NEAR LA VERNE, CALIFORNIA

Orchard number and date of sampling	Tree variety	Soil type	Depth	Tests in orchards	Tests in laboratory			
				pH of soil at field moisture content (in beaker)	pH of soil at field moisture content (in beaker)	pH (1: 5 soil-water ratio)	Moisture percentage	Moisture equivalent
			ft.				%	
1. Feb. 16, 1940	Washington navel orange	Ramona loam	0.5	5.74	....	5.80	16.9	15.6
			1.0	5.39	....	5.22	11.2	14.5
			1.5	5.42	....	5.70	11.8	14.5
			2.0	5.54	....	6.37	11.5	14.4
			2.5	5.96	....	6.52	10.9	13.3
			3.0	6.10	....	6.63	10.8	13.5
			3.5	6.15	....	6.93	10.9	14.0
			4.5	6.23	....	6.90	8.9	21.3
2. July 3, 1940	Washington navel orange	Ramona loam	0.5	....	5.92	6.74	6.8	19.5
			1.0	....	5.71	6.34	6.8	20.6
			2.0	....	6.12	6.58	8.8	17.6
			3.0	....	6.36	6.63	9.3	16.4
3. April 8, 1940	Thompson navel orange	Ramona loam	0.5	6.64	....	6.57	12.2	12.4
			1.0	6.70	....	6.84	9.6	10.7
			2.0	7.03	....	7.44	10.0	10.3
			3.0	7.06	....	7.53	9.4	8.8
4. April 8, 1940	Valencia orange	Ramona clay loam	0.5	6.89	....	7.38	20.2	19.3
			1.0	6.80	....	7.51	15.8	17.9
			2.0	7.00	....	7.67	19.9	20.1
			3.0	7.07	....	7.96	19.1	22.0

TABLE III—(*Continued*)

Orchard number and date of sampling	Tree variety	Soil type	Depth	Tests in orchards: pH of soil at field moisture content (in beaker)	Tests in laboratory: pH of soil at field moisture content (in beaker)	Tests in laboratory: pH (1:5 soil-water ratio)	Tests in laboratory: Moisture percentage	Tests in laboratory: Moisture equivalent
			ft.				%	
5. Feb. 27, 1940	Washington navel orange	Ramona loam	0.5	......	6.69	6.90	15.1	11.3
			1.0	......	6.83	7.00	13.9	9.2
			2.0	......	7.08	7.47	15.5	12.6
			3.0	......	7.12	7.24	19.9	18.0
6. Feb. 27, 1940	Valencia orange	Hanford sandy loam	0.5	......	6.62	6.67	13.7	9.5
			1.0	......	6.90	7.24	10.7	10.5
			2.0	......	6.90	7.18	9.2	8.8
			3.0	......	7.12	7.25	8.4	8.3
7. Feb. 27, 1940	Washington navel orange	Ramona loam	0.5	......	7.30	8.18	15.5	14.9
			1.0	......	7.53	8.18	13.1	13.6
			2.0	......	7.63	8.29	11.0	11.8
			3.0	......	7.56	8.75	9.5	10.4
8. Feb. 27, 1940	Washington navel orange	Chino clay loam	0.5	......	7.40	8.37	28.3	25.8
			1.0	......	7.46	8.34	24.6	25.1
			2.0	......	...	...	......	......
			3.0	......	7.65	8.67	22.7	24.1

cultivation or organic fertilizers were used. Table III shows the acid condition of the soil to a depth of 4.5 feet. A short distance down the slope is orchard no. 2 with large dark green trees and an acid soil. Orchards nos. 3 and 4 adjoin each other and are about the same distance farther down the slope. Very large oak trees thrive down the slope to a distance including the first four orchards; in some orchards the oak trees were allowed to remain. In orchards nos. 3 and 4 zinc-deficiency symptoms were evident in the leaves and although the 40-year-old trees were large and in good condition this deficiency, together with the reduced fertilization and possible presence of oak root fungus, were affecting the yield.

Beginning with orchard no. 5, the acreage is very large and the irrigation water contains about 385 p.p.m. of total solids of which about 40 p.p.m. are sodium, 4 p.p.m. magnesium, and 31 p.p.m. calcium. Water penetration into the soil is difficult below a depth of 2 feet and in orchards nos. 5 to 8, inclusive, mesophyll collapse has been serious during the late summers of 1939 and 1940. Zinc-deficiency symptoms were evident in slight amount in no. 5, but abundant in no. 6. In nos. 7 and 8 chlorosis was severe, especially so in the case of lemons. Table III indicates the progressive changes in the pH values in the soil that accompanied the changes in the tree condition in the various orchards distributed in the range from the higher to the lower levels. This is only the second such grouping of orchards investigated. In other citrus areas where the soils in the higher locations may be shallow and the hard pan or the dense calcareous subsoil is near the surface, it is possible that a reversal or change in the gradient may be found. The two groupings studied were in areas of deep soil where the slope could be followed for a considerable distance. It should be stated that 10 pounds of sulphur in a furrow close to one side of the trees and extendingly only half way to the drip has been of material aid in greatly improving the tree condition in orchards nos. 7, and 8.

SOIL MOISTURE AS A FACTOR IN CHLOROSIS

In lime-induced chlorosis it is the soil moisture that permits the lime to hydrolyze and induce the chlorosis. The data in table IV show how soil moisture may become such an important factor. In orchards nos. 1 to 6, inclusive, there is no chlorosis present and these orchards may serve as controls. Orchard no. 1 has just been planted on virgin land that lies directly above orchard no. 2 in which 27-year-old trees are growing. Acid is used in the water in orchards nos. 2, 4, and 5. The trees in the 20-acre orchard no. 3 are dark green and the average yield is 10 to 12 field boxes per tree per year. In the soil of orchards nos. 4 and 5 there is present some calcium carbonate as indicated by the pH at the 1:5 soil-water ratio (table IV). In orchards nos. 4 and 5 great care is taken to control the soil moisture and the

TABLE IV

MOISTURE IN CALCAREOUS SOILS AS A FACTOR IN CHLOROSIS

ORCHARD NUMBER AND DATE OF SAMPLING	LOCATION	TREE VARIETY	SOIL TYPE	GROWTH	DEPTH	TESTS IN ORCHARDS	TESTS IN LABORATORY			
						pH OF SOIL AT FIELD MOISTURE CONTENT (IN BEAKER)	pH OF SOIL AT FIELD MOISTURE CONTENT (IN BEAKER)	pH (1: 5 SOIL-WATER RATIO)	MOISTURE PERCENTAGE	MOISTURE EQUIVALENT
					ft.				%	
1. Mar. 13, 1940	Olive, Santa Ana canyon	Virgin soil (lemon)	Yolo sandy to clay loam	Healthy	0.5	6.55	....	6.19	11.1	17.4
					1.0	5.76	....	6.22	14.2	20.1
					2.0	5.58	....	6.93	21.4	28.4
					3.0	6.08	....	8.08	18.6	35.5
2. Mar. 13, 1940	Olive, Santa Ana canyon	Valencia orange	Yolo sandy loam	Healthy	0.5	5.57	....	7.57	12.2	17.7
					1.0	5.88	....	7.69	14.2	18.3
					2.0	6.54	....	7.65	13.5	13.2
					3.0	6.62	....	7.46	20.5	23.3
3. Nov. 8, 1939	Naranjo	Washington navel orange	Hanford sandy loam	Healthy	0.5	5.24	....	5.51	12.9	9.5
					1.0	5.66	....	6.14	9.8	
					2.0	5.90	....	6.73	8.3	6.8
					3.0	6.20	....	6.98	9.5	7.3
					4.0	6.45	....	7.04	8.9	13.2
4. Nov. 24, 1939	Placentia	Valencia orange	Placentia loam	Healthy	0.5	....	....	....	....	....
					1.0	6.09	....	8.32	9.3	....
					2.0	6.75	....	8.49	8.3	....
					3.0	7.05	....	8.53	8.5	....
					4.0	6.44	....	8.37	13.1	....
5. Nov. 2, 1939	Placentia	Valencia orange	Yolo loam to silt loam	Healthy	0.5	....	....	....	....	....
					1.0	6.51	....	8.32	16.8	25.5
					2.0	7.00	....	8.52	16.8	23.8
					3.0	7.16	....	8.60	19.5	23.5
					4.0	7.00	....	8.60	29.0	35.3

TABLE IV—(*Continued*)

Orchard number and date of sampling	Location	Tree variety	Soil type	Growth	Depth	Tests in orchards	Tests in laboratory			
						pH of soil at field moisture content (in beaker)	pH of soil at field moisture content (in beaker)	pH (1: 5 soil-water ratio)	Moisture percentage	Moisture equivalent
					ft.				%	
6. Dec. 27, 1939	Rialto	Valencia orange	Oakly fine sand over Ramona loam	Water injury	0.5	6.26	....	5.59	5.2	....
					1.0	5.33	....	4.91	6.0	....
					2.0	6.57	....	5.87	7.6	....
					3.0	7.42	....	6.72	11.2	....
					4.0	7.71	....	6.86	13.8	....
7. Mar. 20, 1940	Vista	Avocado	Fallbrook fine sandy loam	Healthy	0.5	5.92	....	6.90	5.6	10.3
					1.0	5.88	....	7.45	7.5	12.7
					2.0	6.10	....	7.68	9.9	16.0
					3.0	6.00	....	7.55	12.4	20.7
				Dead	0.5	6.37	....	6.80	10.9	12.9
					1.0	6.64	....	7.07	8.8	12.2
					2.0	6.41	....	7.40	9.1	35.9
					3.0	5.97	....	8.88	14.1	30.2
8. Feb. 8, 1940	Holtville	Grapefruit	Sandy to clay loam	Chlorosis	1.0	....	7.52	8.58	14.7	14.3
					2.0	....	7.93	8.97	17.9	....
					3.0	....	8.07	9.06	23.2	....
					4.0	....	7.70	8.84	29.1	....
9. Nov. 8, 1939	Woodlake	Washington navel orange	Hanford loam to clay loam	Chlorosis	0.5	7.35	....	8.54	19.5	....
					1.0	7.60	....	8.69	21.7	....
					2.0	7.72	....	8.99	26.7	....
					3.0	7.65	....	9.00	30.3	....
					3.5	7.80	....	9.03	41.1	....

TABLE IV—(*Concluded*)

Orchard number and date of sampling	Location	Tree variety	Soil type	Growth	Depth	Tests in orchards: pH of soil at field moisture content (in beaker)	Tests in laboratory: pH of soil at field moisture content (in beaker)	pH (1: 5 soil-water ratio)	Moisture percentage	Moisture equivalent
					ft.				%	
10. Nov. 27, 1939	Whittier	Valencia orange	Yolo clay loam	Chlorosis	0.5	....	....	....	....	....
					1.0	6.60	....	7.65	18.2	....
					2.0	6.94	....	8.10	16.7	....
					3.0	7.13	....	8.48	16.2	....
					4.0	7.03	....	8.54	20.2	....
11. Mar. 6, 1940	Rivera	Valencia orange	Fine sandy loam along river	Chlorosis	0.5	7.35	....	8.07	7.3	6.6
					1.0	7.60	....	8.11	9.9	8.8
					2.0	7.68	....	8.66	16.1	12.1
					3.0	8.07	....	8.64	16.5	10.6
12. May 8, 1940	Ventura	Valencia orange	Yolo sandy loam	Chlorosis	0.5	....	6.41	7.12	9.6	8.9
					1.0	....	7.05	7.62	7.7	6.1
					2.0	....	7.13	8.06	9.6	6.7
					3.0	....	6.80	8.24	23.4	25.0
13. May 8, 1940	Simi Valley	Valencia orange	Yolo sandy loam to loam	Chlorosis	0.5	....	7.00	7.84	10.8	12.8
					1.0	....	6.75	7.62	12.7	14.2
					2.0	....	6.25	8.41	12.2	16.1
					3.0	....	6.36	8.34	16.3	24.9
14. May 8, 1940	Oxnard	Lemon	Yolo sandy loam	Chlorosis	0.5	....	7.04	7.71	4.8	5.3
					1.0	....	7.15	7.85	5.9	4.6
					2.0	....	7.37	8.61	14.5	13.1
					3.0	....	7.55	8.73	14.8	13.8

soil is kept as dry as is advisable. In this way, together with the acid treatment of the irrigation water, chlorosis is prevented. The average yields are 2.5 and 5 field boxes, respectively, for the 10-year-old trees in orchards nos. 4 and 5. Orchard no. 6 has a very sandy soil underlaid at about 3 feet with a very hard compacted soil (Ramona loam) that greatly retards drainage. Without sufficient buffer or calcium carbonate content the pH values (orchard no. 6) at high moisture content indicate acidity and no chlorosis.

The soils in orchards 1 to 6, inclusive, contain hard or impervious layers at various depths or increase their moisture-holding power with an increase in depth. When the soils were calcareous, no chlorosis occurred when the soil moisture content was controlled and where this was supplemented with acid in the water. When the soils were not calcareous and the soil moisture was not controlled, chlorosis did not occur although the roots were injured and the oldest leaves were lost prematurely. Such injury is commonly ascribed to what is known as over-irrigation. The control of moisture in soils in which the compacted or heavier soil layer is relatively close to the soil surface, may allow so little effective soil that the growth of the trees may become most limited as is suggested by the yields in orchard no. 4.

The data for the avocado orchard (no. 7) are included for the purpose of comparison with citrus. The orchard contains its own control trees. The higher area, in which healthy trees occur, was first sampled, followed by the lower area in which most of the trees are dead. The data in table IV show the abrupt change in moisture equivalents in the samples from the lower area in the orchard. With calcareous deposits not evident except in the dense subsoil at a depth of three feet in which roots could scarcely penetrate, it is reasonable to assume that the pH of the soil was not the factor responsible for the death of the trees and that this condition resulted from a lack of soil aeration (**6**).

The large, old trees in orchard no. 8 were chlorotic as well as nitrogen-deficient and the soil was very wet, free water occurring above the clay at the 4-foot level. Each basin irrigation for the remaining healthy trees added to the injury of the affected trees, for the basins of every tree were irrigated alike.

Chlorosis was most severe in orchard no. 9; the pH values of the soil were high and the moisture equivalents increased markedly with increased depth. Orchard no. 10 consisted of 50-year-old trees and had only a 5 field-box average. In the sandy soil in orchard no. 11 the moisture percentage values changed abruptly in the second foot and the growth of these 10-year-old trees indicated the high pH values in the soil. Orchard no. 12 consists of young chlorotic trees while orchard no. 13 consists of old trees that show both zinc and iron deficiencies. The trees in orchard no. 14, which is 10 acres in extent, are also very chlorotic.

Old Valencia orange trees in an orchard near Anaheim were basin irrigated and were very chlorotic. A trench slightly more than one foot deep was made just inside the ridge of a basin and only two small roots were found. Under the tree in the dry area within two feet from the trunk there was an abundance of roots. The moisture equivalents of the first and second foot of soil were 5.6 and 4.0, respectively. The soil is calcareous and dense clay layers occur at various depths above 3.5 feet; this tends to keep the upper soil layers continuously at a high moisture content. The continuous and high hydrolysis of the calcium carbonate was accompanied by symptoms of chlorosis in the leaves. The inability to secure water with which to irrigate such an orchard during much of the season, frequently is of benefit to the chlorotic trees.

In table V are given data (obtained from a number of orchards in Orange County) in support of the view that it is frequently the continuity of a given high moisture supply that is responsible for the occurrence of chlorosis. The samples from orchard no. 1 show a considerable hydrolysis at the 1:5 soil-water ratio. The moisture equivalent decreases until the fourth foot depth where a dense clay is encountered. The soil is tile drained but as the moisture percentages indicate, the excess of soil moisture increases with depth.

Orchard no. 2 consists of 35 acres of 23-year-old trees. The soil is calcareous and is a fine sandy loam in the first six inches followed by a silt loam to the fourth foot where it becomes a coarse sand. This is underlaid by a heavy soil which maintains a continuously high moisture content. Even without the heavier soil, the fourth foot of soil, because of its abrupt change of pore space, possibly serves to maintain the soil-moisture above it at a high level.

Orchard no. 3 consists of 22-year-old trees growing in soil that is irrigated by the basin system. The first foot of soil is very sandy. The second foot is also sandy with dense clay in its lower portion. The sand and clay fractions were easily separated by hand, the data for the sand fraction in the second foot being given first (table V). The third foot of soil consisted entirely of clay. The difficulty in irrigating such soil is that this clay layer varies in thickness and in its depth below the surface of the soil. In such cases each basin becomes an irrigation problem of its own. Many of the soils (**2**) that were made by the action of the Santa Ana river present such irrigation problems.

In March 1938 the Santa Ana river flooded the 26-year-old orchard no. 4. Below the first six inches the moisture equivalents of the soil samples taken near the drip of a healthy tree show no abrupt change with depth while those of the samples taken near the drip of a chlorotic tree increase with depth. The pH values at the 1:5 soil-water ratio for the samples from the healthy area are lower than those of the chlorotic area. Three rows away

TABLE V

CHLOROSIS IN VALENCIA ORANGE TREES IN CALCAREOUS SOILS AND THE CONTINUITY OF HIGH SOIL MOISTURE PERCENTAGES

Orchard number and date of sampling	Growth	Depth	Tests in orchards	Tests in laboratory			
			pH of soil at field moisture content (in beaker)	pH of soil at field moisture content (in beaker)	pH (1:5 soil-water ratio)	Moisture percentage	Moisture equivalent
		ft.				%	
1. Mar. 11, 1940	Chlorosis	0.5	7.08	......	8.60	22.1	24.8
		1.0	7.46	......	8.70	23.2	21.6
		2.0	7.69	......	8.70	18.5	13.3
		3.0	7.61	......	8.53	19.4	10.6
2. Nov. 24, 1939	Chlorosis	0.5	7.40	......	8.20	12.9	......
		1.0	7.59	......	8.60	23.2	......
		2.0	7.46	......	8.55	29.8	......
		3.0	7.62	......	9.10	14.7	......
		4.0	7.22	......	7.30	1.6	......
3. Jan. 18, 1940	Chlorosis	1.0	6.90	......	7.28	5.1	3.5
		2.0	7.46	......	8.60	4.9	2.5
		2.0	7.61	......	8.80	30.7	......
		3.0	7.48	......	8.84	29.2	......
4. Mar. 13, 1940	Healthy	0.5	6.78	......	7.97	14.3	17.5
		1.0	6.86	......	8.17	16.8	21.3
		2.0	7.18	......	8.15	21.8	21.8
		3.0	7.37	......	8.49	26.3	22.9
4. Dec. 16, 1940	Chlorosis	0.5	......	......	8.52	......	19.3
		1.0	......	......	8.52	......	16.4
		2.0	......	......	8.41	......	23.0
		3.0	......	......	8.42	......	25.7
5. Feb. 28, 1940	Healthy	0.5	7.03	......	8.46	23.5 }	29.3
		1.0	7.44	......	8.55	27.5 }	
		2.0	7.73	......	8.50	25.7	27.2
		3.0	7.40	......	8.53	20.8	21.5
	Chlorosis	0.5	7.88	......	8.38	23.9 }	23.2
		1.0	7.77	......	8.63	20.8 }	
		2.0	7.71	......	8.70	25.6	27.0
		3.0	7.57	......	8.77	26.3	29.5

TABLE V—(*Continued*)

Orchard number and date of sampling	Growth	Depth	Tests in orchards	Tests in laboratory			
			pH of soil at field moisture content (in beaker)	pH of soil at field moisture content (in beaker)	pH (1: 5 soil-water ratio)	Moisture percentage	Moisture equivalent
		ft.				%	
6. Mar. 14, 1940	Healthy	0.5	6.63	....	7.10	10.4	7.7
		1.0	6.76	....	7.20	7.9	5.9
		2.0	7.07	....	8.30	8.1	5.8
		3.0	7.53	....	9.28	8.5	6.2
	Chlorosis	0.5	6.66	....	7.72	10.8	9.2
		1.0	6.86	....	8.01	7.9	7.1
		2.0	7.10	....	8.62	15.9	15.3
		3.0	7.56	....	9.00	16.8	17.2
7. July 24, 1940	Healthy	1.0	....	7.44	8.67	15.6	25.0
		2.0	....	7.60	8.67	15.8	24.6
		3.0	....	7.77	8.96	15.7	22.7
		4.0	....	7.82	8.91	16.3	21.8
	Chlorosis	1.0	....	7.61	8.63	17.5	23.6
		2.0	....	7.49	8.76	20.9	27.0
		3.0	....	7.61	8.70	22.2	31.0
		4.0	....	7.40	8.57	18.9	29.7
7. Aug. 21, 1940	Healthy	1.0	....	7.43	8.60	19.1	....
		2.0	....	7.52	8.63	19.3	....
		3.0	....	....	8.92	17.3	....
		4.0	....	....	9.00	16.0	....
	Chlorosis	1.0	....	7.56	8.63	20.9	....
		2.0	....	....	8.62	21.4	....
		3.0	....	....	8.62	24.8	....
		4.0	....	....	8.72	24.1	....

from the chlorotic tree were fairly green trees. The pH values at the 1:5 soil-water ratio of soil for corresponding depths at the drip of one of these fairly green trees were 8.13, 8.37, 8.89 and 8.71, respectively, while the moisture equivalents were 13.4, 11.6, 8.1 and 18.4, respectively. Although these pH values were high and an abrupt change occurred in the moisture equivalents of the second and third foot samples, the soil was sufficiently light and permeable to permit rapid drainage and thereby prevent a severe case of chlorosis.

The trees in orchard no. 5 were planted three years ago. Some trees were very chlorotic while others adjoining them were healthy. The soil at the drip of two such adjacent trees in a row was sampled. The data in table V indicate that the soils were quite wet for the sampling occurred during the rainy season. It is common field knowledge, and many times experimentally shown with controlled laboratory cultures with citrus, that a chlorotic tree uses less moisture than a healthy green tree of approximately the same age. During warm weather the healthy tree withdraws the soil moisture more rapidly than does the chlorotic tree, thereby the more profoundly reducing the pH values of its soil at the field moisture content (**7**, **8**). The moisture equivalents of the soil from under the healthy tree decreased with increasing depth while the opposite gradient occurred in the samples from under the chlorotic tree. Thus the advancing roots of the healthy tree enter soils of lower and lower moisture-holding power with increasing depth while those of the chlorotic tree must penetrate soil of increasing water-holding power (**7**).

The 26-year-old trees in orchard no. 6 are on sweet orange rootstock and the soil has received manure and calcium nitrate. Two adjacent trees in a row were selected as being a healthy tree in one case and a chlorotic tree in the other. When the sampling occurred the soil was quite moist. The pH values were slightly higher in the samples taken at the drip of the chlorotic tree. The moisture equivalent values were fairly constant, and low, in the soil under the healthy tree while they were abruptly higher after the second foot of soil under the chlorotic tree.

Chlorosis has been a factor in orchard no. 7 for the past 15 years. Organic fertilizers were used from 1925–1932 after which ammonium sulphate was used exclusively. Twelve pounds of iron sulphate per tree per year has been broadcast or placed in the irrigation furrow. The orchard is on a slope with the better trees in the upper half. The first samples were taken in the middle between the furrows and the second ones were taken in a furrow. Samples were collected near a healthy tree in the upper half and likewise near a chlorotic tree in the lower half of the orchard. The data show that in the soil near the healthy tree the moisture equivalent values decreased with increased depth while in that near the chlorotic tree they increased rather than decreased. In this orchard when iron sulphate was first used, various amounts were applied broadcast in the tree square. Although the amounts tested ranged from 50 to 200 pounds per tree square, only at the 200 pound application was the healthy color restored in the leaves.

The broadcasting of sulphur (1000 pounds per acre) was of little or no value as regards the pH of soil in a 5-acre orchard of 10-year-old Valencia orange trees on sour orange stock as compared with no sulphur in the other 5-acre portion of an original 10-acre tract. In the sulphured orchard for example at the 0.5, 1.0, 2.0, and 3.0-foot depths, the pH values at the 1:5 soil-water ratio were 7.74, 8.07, 8.42, and 8.54, respectively, as compared with 7.87, 8.26, 8.43, and 8.64 in the unsulphured orchard. No significant differences occurred in the pH values at the field moisture content.

When sufficient sulphur is localized the effect on the pH of the soil is obvious. Fifty pounds of sulphur broadcast in a tree square in a 30-year-old Valencia orange orchard changed the pH of the first and second six inches of soil from 7.63 and 7.69 to 3.70 and 6.06, respectively, at the 1:5 soil-water ratio and from 4.89 and 5.28 to 3.36 and 4.93, respectively, at the field moisture content of about 20 per cent. (m.e. 23 per cent.). Sulphur, lime sulphur, iron sulphate, sulphuric and phosphoric acids, as well as acid-forming nitrogenous fertilizers, are now used in the overcoming of chlorosis. In a chlorotic orchard a thorough knowledge of the soil conditions together with the control of soil moisture is essential in order to minimize the hydrolysis of the calcium carbonate.

Summary

Lime-induced chlorosis is an important physiological disturbance in the nutrition of citrus. A calcareous soil is potentially, but not necessarily, an alkaline soil and therein lies some hope in dealing with this problem.

The tree condition and soil pH values in orchards in certain citrus areas changed with increasing or decreasing elevations in the orchard location.

At moisture percentages near or greatly above the moisture equivalents, calcareous soils may be quite alkaline while at low moisture contents they may be quite acid. The pH values of a soil at the field moisture content and at the 1:5 soil-water ratio are usually lower in the soils of healthy than in those of chlorotic orchards. When the soils of adjacent healthy and chlorotic trees are sampled the pH relation may require supplementary data such as the moisture percentage and moisture equivalents.

The length of time that the roots of a tree in a calcareous soil are subjected to a given pH and hence the continuity of a given soil moisture percentage are of importance in the problem of chlorosis. With this continuity

go the factors of aeration as well as those of sustained hydrolysis and its precipitation effects.

In healthy citrus tree areas in calcareous soils the moisture equivalents either decreased or remained unchanged with increasing depth. In chlorotic areas in calcareous soils the moisture equivalents steadily increased in heavy soils and abruptly increased in lighter soils with increasing depth. A knowledge of the soil conditions and the control of soil moisture is essential in the overcoming of chlorosis in citrus.

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