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THE EFFECTS OF SULFUR DEFICIENCY ON CITRUS

H. D. CHAPMAN AND S. M. BROWN

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H. D. CHAPMAN[3] AND S. M. BROWN[4]

INTRODUCTION

IN A PRECEDING PAPER (*3*)[5] an account is given of the development of phosphorus deficiency in citrus trees growing in one of two soils potted in 55-gallon containers. In the other soil an acute deficiency of sulfur occurred. The purpose of this paper is to describe the effects of this sulfur deficiency on the growth, appearance, fruit characters, and inorganic composition of the orange trees of this experiment. To the knowledge of the authors, sulfur deficiency of citrus trees growing in the field has never been recognized or described. Haas (*7*) has given a very brief description of sulfur deficiency of young Valencia trees grown in sand cultures. He states that this deficiency caused a chlorosis of the leaves. Total sulfur determinations in the leaves, twigs, root bark, and rootlets showed less of this constituent in the plant grown without sulfate than in corresponding plants of the same age growing in an adjacent nursery. The leaf symptoms illustrated, however, are unlike those produced on the experimental plants described in this paper.

EXPERIMENTAL PROCEDURE

The technique used in these experiments, as regards culture, differential fertilization, number of containers, and preliminary cropping, has been given in the accompanying paper (*3*), and only such details as appear necessary to an understanding of this paper are set forth herein.

The soil in which sulfur deficiency developed was obtained from a sagebrush-covered hillside on the property of the University of California Citrus Experiment Station at Riverside. It was derived from granite and is classified as a Sierra loam. This soil was initially used for purposes of comparison with the phosphorus-deficient Hanford fine sandy loam. Previous pot tests on the Sierra soil, while showing a low supply of total and available nitrogen, had given no hint of other deficiencies.

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[1] Received for publication December 3, 1940.

[2] Paper no. 437, University of California Citrus Experiment Station, Riverside, California.

[3] Associate Professor of Agricultural Chemistry and Associate Chemist in the Experiment Station.

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[5] Italic numbers in parentheses refer to "Literature Cited" at the end of this paper.

As noted in the paper on phosphorus deficiency (*3*, table 1), enough soil was obtained to fill twelve 55-gallon containers. Six treatments in duplicate were accorded this soil, as follows: cultures 13 and 14, no treatment; cultures 15 and 16, calcium nitrate; cultures 17 and 18, calcium nitrate and dicalcium phosphate; cultures 19 and 20, calcium nitrate and potassium sulfate; cultures 21, 22, 23, and 24, calcium nitrate, dicalcium phosphate, and potassium sulfate. The dicalcium phosphate and potassium sulfate were mixed throughout the soil at the rate of 4,784 pounds of P_2O_5, and 1,185 pounds of K_2O per acre, save for cultures 23 and 24, which received P_2O_5 at the rate of 9,568 pounds per acre.[6] The calcium nitrate was applied in solution at the rate of 482 pounds per acre to the surface of the soil in the beginning, and frequent additions were made subsequently during the course of the experiment. No further applications of phosphate or potassium were made, but as noted later, subsequent additions of sulfur and of calcium sulfate were accorded to some of the cultures for diagnostic purposes. The cultures were watered with distilled water throughout.

After a preliminary cropping with oats, one-year-old budded navel-orange trees were planted in the containers on March 4, 1935.

DEVELOPMENT AND DIAGNOSIS OF SULFUR DEFICIENCY

While none of the orange trees in the Sierra loam grew quite so well as those in the Hanford fine sandy loam, little effect from fertilizer additions was evident for the first three years save for extreme nitrogen deficiency in cultures 13 and 14 and a very slight growth response from the potassium sulfate treatments in cultures 19, 20, 21, 22, 23, and 24. In the spring of 1938, however, the new growth on all the trees was distinctly yellowish. It was thought that this might be the result of insufficient aeration and failure of the plant roots to absorb adequate nitrogen; poor water penetration into this soil had been noticed almost from the beginning, free water often standing on the surface for several days after an irrigation.

To determine whether the physical state of this soil could be improved, 27 grams of sulfur per culture (equivalent to a rate of 946 pounds per acre on an area basis) was mixed into the top 2 or 3 inches of soil of half the replicated cultures of this series (nos. 16, 18, 20, 22, 24) on July 18, 1938. Within a few weeks, the yellow foliage of the sulfur-treated trees began to turn green; and shortly thereafter, healthy, vigorous new growth appeared. The untreated trees showed no improvement.

[6] Rate per acre calculated on an area basis. The soil-surface area in oil drums was 2.74 square feet.

Since the effects of sulfur on soils are diverse, and the results noted could have been caused by the improved physical condition of the soil or by the effects on nutrient availability, further experiments were undertaken.

To determine the characteristic effects of sulfur deficiency, a sand-culture experiment of the automatically operated type (*4*), using sweet-orange and grapefruit seedlings and lemon plants grown from cuttings, was begun in the greenhouse. One sand-culture unit was provided with a complete nutrient solution of a type known to be suitable for good citrus growth, and another with a sulfate-deficient nutrient solution in which the sulfate-carrying salts were replaced by nitrates. After a growing period of about six months, the terminal foliage of all plants in the cultures lacking sulfate became yellow, the affected leaves being more or less uniformly yellow, as in nitrogen deficiency. The older green leaves, however, retained their green color to a somewhat greater degree than when nitrogen is lacking. The appearance of these sulfur-deficient plants at this stage was strikingly similar to that of the navel-orange trees in the soil cultures, especially at periods following the emergence of new-cycle growth.

Soil samples taken from the soil cultures in September, 1938, were extracted with water, and tests for sulfate were made on the filtered solution. Substantial quantities were found in those soils which had been treated with sulfur, but only a trace in the untreated soils.

In the spring of 1939, the new-cycle growth on the non-sulfur-treated trees was again very yellowish, as in the previous year.

On June 21, 1939, several clusters of such yellowed leaves from tree 19 were sprayed with a 2-*N* solution of sodium sulfate. Within a few weeks some green spots appeared on these leaves, whereas there was no change in the untreated yellowed leaves.

On July 9, 1939, 28 grams of calcium sulfate (equivalent to a rate of 981 pounds per acre applied on an area basis) was applied to the surface of the soil of one of the chlorotic tree cultures (no. 19). In the course of the summer, the yellowish leaves of the tree in this culture became green, while the leaves of the untreated trees remained essentially unchanged.

In order to further verify the belief that the malnutrition of these trees was sulfur deficiency, total sulfur and nitrogen determinations were made on terminal yellow leaves and old green leaves picked from the affected navel-orange trees (no. 15), as well as on corresponding leaves from the sulfur-deficient sweet-orange seedlings grown in the greenhouse. For comparison, leaves of comparable age from one of the now healthy, sulfur-treated trees (no. 16), growing in Sierra loam, from one of the nitrogen-deficient trees (no. 14) growing in this soil, and from control cultures growing in the greenhouse were also analyzed. The results are presented in table 1. The sulfur and nitrogen contents of the leaves of the navel-orange trees suspected of sulfur deficiency were very similar to those of the leaves of known sulfur-deficient plants grown under controlled conditions in the greenhouse. Despite the nearly identical appearance of leaves affected by lack of nitrogen and those affected by lack of sulfur, it will be noted that the nitrogen content of the sulfur-deficient leaves is a little higher than that of healthy green leaves, whereas the sulfur content is, roughly, one half that of leaves from healthy plants.

TABLE 1

SULFUR AND NITROGEN CONTENTS OF LEAVES FROM HEALTHY AND YELLOWED CITRUS PLANTS

Source, age, and character of leaves tested	Composition of leaves, in percentage of dry matter	
	Total sulfur	Total nitrogen
	per cent	*per cent*
Sulfur-deficient sweet-orange seedlings grown in greenhouse:		
Young terminal yellow leaves	0.075	3.88
Old green leaves	.120	3.31
Healthy sweet-orange seedlings grown in greenhouse:		
Young terminal green leaves	.260	3.46
Old green leaves	.220	3.15
Chlorotic navel-orange trees grown in Sierra loam soil:		
Young terminal yellow leaves	.096	2.54
Old green leaves	.129	2.44
Nitrogen-deficient navel-orange tree grown in Sierra loam soil:		
Young terminal yellow leaves	.189	1.12
Old yellow leaves	.320	1.13
Healthy sulfur-treated navel-orange tree grown in Sierra loam soil:		
Young terminal green leaves	.202	2.15
Old green leaves	0.320	1.66

In the spring and summer of 1940, the non-sulfur-treated trees (that is, those which had received neither sulfur nor calcium sulfate) again produced an extremely yellowish cycle of growth which was even more marked than in the two preceding years. On May 29, 1940, 100 grams of calcium sulfate was incorporated into the soil surface of another of the sulfur-deficient tree cultures (no. 17). In one month's time, the yellow leaves of this tree had become green. Subsequently, healthy new-cycle growth emerged, and this tree now stands in sharp contrast to the untreated trees.

All these observations prove that the malnutrition which developed in these trees was acute sulfur deficiency.[7]

EFFECT OF SULFUR DEFICIENCY ON TREE GROWTH AND FOLIAGE

As already mentioned, the onset of sulfur deficiency was shown by the appearance of a decidedly yellowish type of new growth. The typical appearance of young terminal leaves and of older leaves on the same

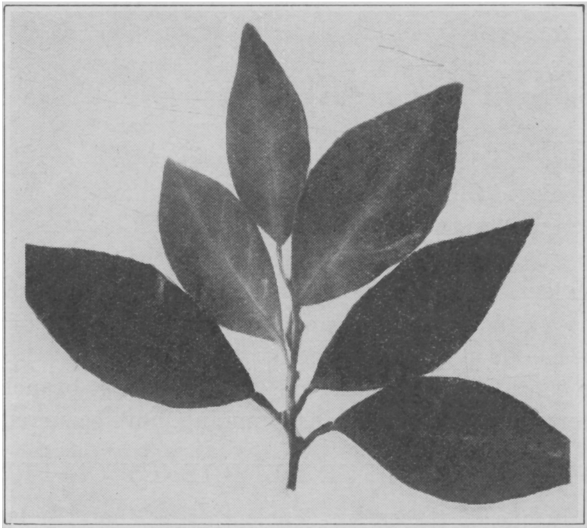

Fig. 1.—Shoot from a sulfur-deficient navel-orange tree (no. 15), showing yellow new-cycle leaves which stand in sharp contrast to the green older leaves. This type of growth is especially prominent in the earlier stages of sulfur deficiency. The yellow sulfur-deficient leaves are similar in appearance to nitrogen-deficient leaves. In many instances the midrib is somewhat more yellow than the rest of the leaf.

shoot, at the time when this disorder first became manifest, is shown in figure 1. The terminal growth was distinctly yellow, though there was no leaf pattern other than a tendency for the midrib to be a little more yellow than the mesophyll tissues. The chlorotic terminal growth stood in sharp contrast to the older green leaves during the first month or so

[7] It is curious that sulfur deficiency should have developed at the same time and to the same degree in cultures 19, 20, 21, 22, 23, and 24, which received potassium sulfate initially. One explanation is that most of the sulfate had been leached out of the surface by the frequent additions of distilled water before the trees were planted in this soil. As noted previously, a preliminary crop of oats was grown in these soils prior to planting the trees. Another possibility is that some of the sulfate may have been reduced and disappeared as hydrogen sulfide in the periods following an irrigation, when water often stood in these soils for several days at a time.

after the appearance of the new-cycle growth. As the yellow leaves aged, they gradually became somewhat greener, and the contrast with subsequent new cycles of growth was less conspicuous. The leaves became leathery and thickened and finally attained a dull-green color; the midribs on many were more yellow than the rest of the leaf.

The new growth which appeared in 1939 and 1940 was more yellow than that of the preceding year, and the leaves were smaller. The appearance of the sulfur-deficient tree no. 23, in June, 1939, is shown in plate 1, *A*. The dull-green color of the old leaves, many of them with a somewhat more yellowish midrib, is shown in plate 1, *C*, in contrast with leaves from a healthy tree (plate 1, *B*). The spring-cycle growth in 1940 consisted essentially of an exceedingly profuse though weak bloom, scarcely any leaves accompanying this bloom (plate 1, *D*). No fruit was set, and considerable dieback of these twigs subsequently took place. The cream-colored June-cycle growth which followed is shown in plate 1, *E*. The leaves were small and immature. Subsequently, with hot weather, considerable burn took place, both at the leaf tips and in other parts of the leaf. Such burn is not uncommon with citrus leaves which, for one cause or another, are lacking in chlorophyll. Many of these June-cycle leaves had dropped by September.

Save for considerable dieback, no abnormal twig, branch, trunk, or root symptoms, such as splitting or gumming, have occurred.

EFFECT OF SULFUR DEFICIENCY ON FRUIT

While only one of the sulfur-deficient trees (no. 21) bore fruit in 1940–41, most of them produced a few fruits each during the year 1939–40. All of these fruits had definite color characteristics in common. In place of the deep-green color of healthy immature fruits, those on the sulfur-deficient trees were of a light yellowish-green color throughout their early development, in this respect paralleling the chlorotic appearance of leaves (see plate 2, *A*). Maturing fruits started to turn color at about the same time as those on the healthy trees but failed to develop the orange color of the healthy fruit. Instead, they were of a distinctly lemon-yellow hue. Some of the fruits were small and misshapen; many of them attained normal size, however.

Examination of the interiors of affected fruits revealed, in many, an incomplete development of the juice vesicles and, in some, a distinct gelatinization of the contents. Most of such fruit had a somewhat thickened rind. Cross sections of healthy and sulfur-deficient fruits are shown in figure 2. Not all the fruits were so seriously affected as the one illustrated, but nearly all showed more or less rind thickening and some gelatinization of the juice-vesicle contents. The exterior appearance of immature fruits and the exterior and interior of mature healthy and sulfur-deficient fruits are shown in plate 2. The similarity of some of these characters to the condition known as "granulation" (*2*) is rather marked. Whether there is any necessary connection is unknown.

Determinations of the acid and soluble-solids content of the juice of

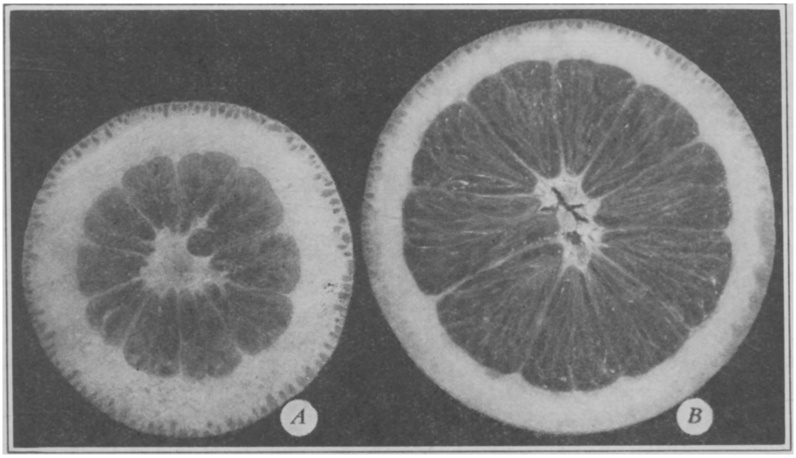

Fig. 2.—Cross sections through center of mature (*A*) sulfur-deficient and (*B*) healthy navel oranges. Note thickened rind and shriveled juice vesicles of sulfur-deficient fruit. This is a somewhat extreme case; not all the fruit from the sulfur-deficient trees was so adversely affected (see plate 2).

mildly affected fruit revealed a low sugar content but no significant difference in acid, in comparison with healthy fruit of like age. There was a noticeable lack of oil in the rind of the sulfur-deficient fruit.

INORGANIC COMPOSITION OF SULFUR-DEFICIENT ORANGE TREES

In July, 1940, one of the sulfur-deficient trees (no. 15) was removed from the culture, and inorganic analyses were made. The methods of sampling and analyzing were identical with those described in the preceding paper (*3*). The results, compared with those obtained from analyses of similar parts of a healthy tree, are presented in table 2.

All parts of the sulfur-deficient tree were lower in sulfur than corresponding parts of the healthy tree. The greatest contrast in total sulfur in the two trees was found in the bark and wood of the twigs, trunk, and coarse roots. The younger leaves showed a lower sulfur content than the older leaves.

Total nitrogen of all parts of the tree lacking sulfur was higher than that of the healthy tree. This difference was especially marked in the old leaves. Since there is a decided similarity in the appearance of sulfur- and nitrogen-deficient leaves, analysis affords a decisive means of distinguishing between them: the leaves of nitrogen-deficient trees, as

TABLE 2

COMPARATIVE INORGANIC COMPOSITION OF PARTS OF SULFUR-DEFICIENT AND HEALTHY NAVEL-ORANGE TREES

Part of tree and condition	Constituents of dry matter, at 105° C								
	Ash	Ca	Mg	K	Na	Cl	N	P	S
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Young leaves:									
Sulfur-deficient......	16.02	3.56	0.22	3.40	0.210	0.35	4.90	0.50	0.050
Healthy..............	14.23	4.34	.12	1.55	.020	.39	3.38	.18	.230
Old leaves:									
Sulfur-deficient......	15.40	5.05	.18	0.81	.100	.42	5.30	.34	.130
Healthy..............	22.80	8.17	.09	0.80	.040	.35	1.70	.11	.260
Twig bark:									
Sulfur-deficient......	12.25	4.32	.13	0.34	.010	.12	3.03	.10	.010
Healthy..............	15.47	5.22	.12	0.62	.005	.14	1.65	.28	.270
Twig wood:									
Sulfur-deficient......	5.31	1.89	.06	0.15	.010	.09	0.85	.01	.004
Healthy..............	4.12	1.26	.08	0.24	.004	.14	0.72	.22	.120
Trunk bark:									
Sulfur-deficient......	12.83	4.23	.25	0.29	.005	.07	2.12	Trace	.010
Healthy..............	13.15	4.40	.35	0.66	.005	.11	1.64	.24	.180
Trunk wood:									
Sulfur-deficient......	3.32	1.10	.07	0.17	.004	.12	0.73	Trace	.010
Healthy..............	2.49	0.69	.08	0.21	.003	.14	0.60	.16	.110
Root bark:									
Sulfur-deficient......	8.75	2.56	.12	0.61	.006	.35	2.66	.22	.040
Healthy..............	11.00	3.26	.18	0.75	.020	.40	2.15	.24	.200
Root wood:									
Sulfur-deficient......	1.78	0.52	.09	0.09	.009	.14	0.70	.06	.008
Healthy..............	2.64	0.73	.09	0.18	.005	.12	0.66	.16	.080
Fine roots:									
Sulfur-deficient......	13.73	4.04	.21	0.54	.010	.39	2.81	.30	.080
Healthy..............	28.23	4.46	0.22	0.59	0.040	0.32	1.95	0.25	0.140

shown in table 1, are distinctly subnormal in nitrogen content and somewhat higher in total sulfur, whereas the reverse is true when the yellowing results from lack of sulfur.

With other mineral elements, results were not always consistent in different parts of the tree. The leaves and fine roots of the sulfur-deficient plant were distinctly higher in phosphorus content, than those of the healthy plant. The condition was reversed, however, in the bark and wood of twigs, trunk, and coarse roots, the phosphorus content being distinctly lower in the sulfur-deficient than in the healthy plant parts, that of the trunk being as low as in phosphorus-deficient trees. The potassium content of the young sulfur-deficient leaves was abnormally high; but in the bark and woody tissue it was lower than in corresponding parts of the healthy tree. The calcium and total-ash content were, for the most part, lower in the sulfur-deficient than in the healthy tree.

In general, there is a decided parallelism in the nitrogen, potassium, calcium, and total-ash contents of these sulfur-deficient trees and the phosphorus-deficient trees discussed in a previous paper (*3*). One point of difference is the relatively lower sulfur content of young leaves as compared with old leaves of the sulfur-deficient tree. Under conditions of phosphorus deficiency, the young leaves are higher in phosphorus than the old leaves. This is in harmony with the observation that in sulfur deficiency the young growth is the first to be affected, whereas in phosphorus deficiency the older leaves are the first to show the effect.

DISCUSSION

The external effects of sulfur deficiency on bearing citrus trees agree in many respects with those described by other investigators on a wide range of plants. General yellowing of the foliage, especially of the terminal growth, and a resemblance to nitrogen deficiency are the more prominent characters emphasized. The similarity of symptoms of sulfur deficiency of citrus to those of tea plants, as reported by Storey and Leach (*10*), is marked: the undersized, yellow, uprolled, tipburned young leaves and their premature abscission followed by twig dieback, as seen on tea plants, are also characteristic of citrus trees. These investigators found that absorption of potassium sulfate, magnesium sulfate or sodium sulfate by cut shoots brought about prompt recovery. While this treatment has not as yet been tried with citrus trees, leaves sprayed with a solution of sodium sulfate developed green spots. Recovery after soil application of sulfate was rapid.

McMurtrey (*8*) noted on sulfur-deficient tobacco plants a yellowing of the leaf midrib and veins analagous to that seen on the citrus trees here described. In connection with vein yellowing, however, it should be noted that this frequently occurs in citrus leaves from other causes. Substantial root or bark destruction due to disease, gopher, or mechanical injury are common causes. The sulfur-deficient leaves which show this symptom, while of shorter life than healthy leaves, do not fall so early or abruptly as do leaves which become affected with the vein chlorosis caused by root rot or other troubles.

Though no studies of organic composition were made on the affected citrus trees, Nightingale, Schermerhorn, and Robbins (*9*) and Eaton (*5*), in studies of the metabolism of sulfur-deficient plants, found accumulations of carbohydrates, nitrates, and proteolytic products. Eckerson (*6*) noted that lack of sulfur decreases the reductase of soybean and tomato plants.

A thickening of cell walls of sulfur-deficient plants was found by Nightingale, Schermerhorn, and Robbins (*9*) and by Eaton (*5*). The thickened and leathery leaves which developed on the citrus plants may be a reflection of excessive lignin formation.

The parallelism between sulfur and phosphorus deficiencies, noted by the aforementioned workers as manifest in carbohydrate and nitrate accumulations, is also apparent in the inorganic composition of citrus plants affected by the two deficiencies. The promptness of the recovery of sulfur-deficient plants when sulfur is supplied is noteworthy and is no doubt owing, in part, to the accumulations of carbohydrate and nitrate, which are important foundation materials for the synthesis of proteins and other vital plant constituents.

The development of sulfur deficiency in citrus grown in Sierra loam cultures has raised the question whether commercial citrus orchards in any part of California might be lacking in this element. Considerable areas in certain parts of Oregon, Washington, and California are low in sulfur, and crops respond to additions of this element. Few citrus groves are likely to benefit by sulfate fertilization, however, for the following reasons. In the first place, all irrigation waters carry more or less dissolved sulfate; and while those waters derived from the runoff of the essentially granitic-type mountainous areas are low in sulfate content, the renewal is frequent, and citrus-tree requirements for sulfur are rather low.[8] Also, a certain amount of sulfur is brought down annually by rainfall. And Alway, Marsh, and Methley (*1*) have shown that air, even in regions remote from industrial centers, contains a small amount of sulfur dioxide, part of which is absorbed by the soil and by growing crops. In addition, any organic matter added to the soil in the form of manures, straws, and so forth, will furnish available sulfur, as will ammonium sulfate or mixed fertilizers carrying potassium sulfate or superphosphate. Pest-control operations employing dusting sulfur or sulfur-containing insecticides add to the sulfur supply of soil. Hence, even on citrus soils low in sulfur, deficiencies are not likely to develop under California conditions, except perhaps in isolated instances where waters of low-sulfate content prevail and no sulfur or sulfur-containing

[8] Computations based on analyses of whole fruits show that a yield of 20,000 pounds of fruit per acre would remove about 25 pounds of sulfur.

compounds are used in the commercial production of citrus. In conclusion, it should be noted that many California citrus soils and irrigation waters, for example, those of Imperial, Orange, and Ventura counties, are high in sulfate content.

SUMMARY

A condition of malnutrition which developed gradually in young navel-orange trees growing in a granitic-derived soil in large 55-gallon containers was found to be sulfur deficiency. This disorder was characterized by an abnormal yellowing of the new-cycle growth, similar to the more or less uniform yellowing caused by nitrogen deficiency. In many of the leaves, the midrib was somewhat more yellowish than the rest of the leaf.

In contrast to nitrogen-starved leaves, sulfur-deficient leaves had a higher nitrogen content than is normal for healthy green leaves and a lower sulfur content, whereas nitrogen-deficient leaves had a subnormal nitrogen content and a slightly higher sulfur content. Thus it is possible by leaf analysis to differentiate definitely between sulfur and nitrogen deficiency.

With the exception of considerable dieback, no abnormal twig or bark symptoms developed on the trees lacking sulfur. While growth was limited, as with phosphorus-deficient trees, a profuse, though weak, bloom was a characteristic feature. This may be a result of carbohydrate accumulation, since different workers have shown that one of the effects of sulfur deficiency in a number of plants is an accumulation of starch and other forms of carbohydrate.

In place of the deep-green color of healthy immature fruits, those produced on the sulfur-deficient trees were of a light yellowish-green color; and maturing fruits failed to develop the orange color characteristic of fruit produced on healthy trees. They were, instead, distinctly lemon yellow in color. Most of the sulfur-deficient fruit showed abnormally thick rinds and reduced juice content. In many of the fruits, the juice vesicles were shriveled; in the less severely affected fruit, the contents of many of the juice vesicles were gelatinized, as in granulation.

Inorganic analyses of leaves, twigs, trunk, and roots of a sulfur-deficient tree were made. The sulfur-deficient leaves showed, in general, a higher nitrogen, phosphorus, potassium, and magnesium content and a lower calcium and sulfur content than the leaves from a healthy tree of like age. Except for the young leaves, the ash content of all parts of the tree was less in the sulfur-deficient tree. A certain degree of parallelism in the composition of sulfur-deficient and phosphorus-deficient orange trees is apparent.

Though many western soils are low in total sulfur, it does not appear probable that, except in isolated instances, commercial citrus orchards would benefit by sulfate fertilization. Not only do irrigation waters carry more or less dissolved sulfate, but small increments are also brought down by rains; these supplies added to the sulfur or sulfur-bearing compounds used incident to fertilization and pest control probably more than meet citrus-tree requirements.

ACKNOWLEDGMENTS

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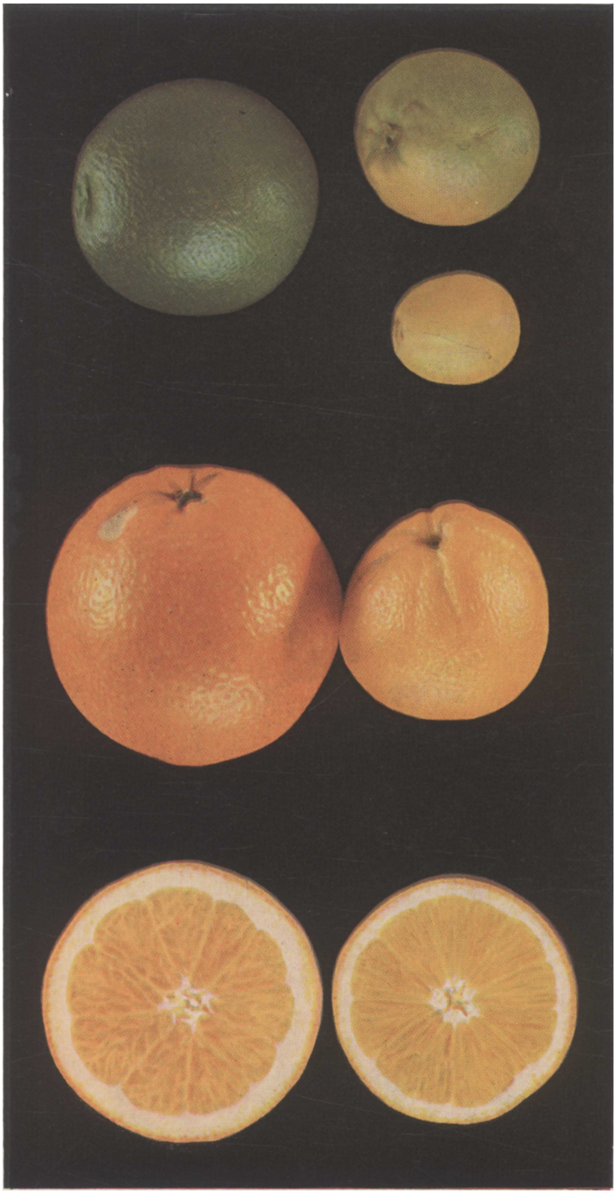
PLATES

Plate 1.—Sulfur deficiency of navel-orange tree: *A*, four-year-old tree showing chlorotic new-cycle growth and dull-green old leaves (June, 1939); *B*, healthy shoot; *C*, sulfur-deficient shoot showing dull-green leaves with yellowish midrib and weak new-cycle spring growth; *D*, spring-cycle growth (1940) showing profuse but weak bloom; *E*, extremely chlorotic sulfur-deficient June-cycle growth which emerged after the spring bloom. (Note upright position on stem, small leaves, and tipburn.) These yellow leaves showed progressive burning on the tips and margins and, in some leaves, brown necrotic spots in mesophyll areas. Many of these June-cycle leaves had fallen by September.



A *B* *C* *D* *E* *F* *G*

Plate 2.—Sulfur-deficient and healthy navel oranges. Immature (six-month-old) fruit (*A*) from healthy tree and (*B*, *C*) from sulfur-deficient tree. The lemon-yellow color of mature sulfur-deficient fruit (*E*) is shown in contrast with the orange color of mature healthy fruit (*D*). Cross sections show gelatinization of contents of juice vesicles of sulfur-deficient fruit (*F*) in comparison with healthy fruit (*G*).