in the checks, but only when stunted field grown seedlings of low vigor were used. This seems to indicate that root necrosis (rot) resulted when roots already weakened from other causes were attacked by weak parasites of citrus such as *Diplodia* sp. and *Fusarium* sp.

It is well known that water and dissolved nutrients are translocated from roots to the leaves by a system of tubes or vessels in the wood or xylem. These are made up of short sections or vessel elements joined end to end very much like drain tile, but with a constriction at each junction. Microscopic examination of sections cut from the roots of blighted trees reveals that the vessels are plugged by material (Fig. 1, C) of undetermined nature that collects at the constrictions. These plugs could retard or stop the flow of water and nutrients through the vessels. A species of actinomycetes (a group of organisms intermediate between fungi and bacteria) of the nocardia type has been isolated from such roots on several occasions. As yet it has not been established that the formation of plugs is related to a micro-organism although at times the plugs resemble masses of actinomycete hyphae (Fig. 1, D). Similar vessel plugging, often accompanied by brown staining of the wood, was found in the twigs of blighted trees and could account for the twig die-back which is conspicuous.

Treatment

After 62 years we still know very little about blight. We do not know what causes it, how to control it, or how to avoid it. However, experience has shown that blighted trees never recover and efforts in that direction appear to be futile. Thus it is suggested that blighted trees be removed as soon as the identity of the disorder is reasonably certain.

There seems to be no harm in replanting immediately. Young trees grow normally even when set out the same day the blighted trees were removed. Under such conditions blight symptoms rarely appear before the replant is 15 years old.

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COPPER OXIDE AS A SOIL AMENDMENT FOR CITRUS

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Practically all of the copper used in Florida citrus fertilizers has been in the water-soluble copper sulfate form. Recently a product containing a mixture of cupric and cuprous oxides, in which the copper is only slightly water soluble, has been offered for use in citrus fertilizers. The availability to plants of this form of copper already has been demonstrated for other crops on peat soils (1) but its value for citrus on mineral soils has not been demonstrated heretofore.

Most of the doubt concerning the availability of copper in oxide form centers around its low water solubility. While water solubility is a characteristic possessed by most fertilizer materials in use at present, a high degree of water solubility has not proved essential for availability of copper to plants. Numerous references can be found in the literature which describe the successful use of relatively insoluble compounds to overcome copper deficiency. Some of these have been copper refinery slag (6); oxidized copper ore, roaster residues from pyrite burners (9); copper pyrophosphate catalysts, tetra copper calcium oxychloride, copper hydroxide, metallic copper (2); and minerals such as chalcopyrite, chalcocite, cuprite, and malachite (8). Trials were run with these materials in some cases on organic and in other cases with mineral soils. In view of facts such as these, Steenbjerg (8)

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has proposed the theory that the availability of copper in any compound depends upon the copper content of the compound and on the fineness of grinding, that is, the surface exposed. This theory involves solubility only indirectly.

In addition to demonstrations that the copper in some insoluble compounds is available to plants, there is the consideration that even water soluble forms of copper become fixed in insoluble forms in the soil. According to Lucas (5), copper applied as copper sulfate to peat soils is precipitated as the hydroxide if the pH is above 4.7. It appears more generally believed that copper is fixed in combination with the soil organic matter in Florida (4).

With this background it appeared probable that finely divided copper oxide would be available to citrus unless, for some unexpected reason, the combination of citrus plants and Florida soils would prove to be an exception.

In order to determine the relative availability to citrus of copper from copper oxide, comparisons with copper sulfate were undertaken, both in the field and in pot cultures. Field trials established in young groves have so far been inconclusive because of failure to develop more than traces of copper deficiency under any conditions. Pot studies carried out in 1951 and 1952 have provided some information, which will be presented in this paper. Two general types of pot experiments were conducted. In one, relatively low soil copper conditions were established to determine comparative citrus seedling growth and copper uptake from copper sulfate and copper oxide. This was simply an attempt to demonstrate possible increased growth and copper content of plant tissues due to copper additions from the two sources. In the other, relative toxicity of equal high soil concentrations of copper from the two sources was determined. This experiment was undertaken simultaneously with the low copper experiment, since it was believed that with soil cultures, difficulty might be experienced in obtaining a differential due to copper deficiency. Development of copper toxicity might then provide an approximate, indirect measure of availability in the soil of copper applied in the two forms.

Methods

Large bulk samples of the surface layers of previously uncultivated soils of Lakeland, Ft. Meade, and Parkwood series were obtained, and each was mixed thoroughly. Some characteristics of the soils used are given in Table 1. The soil used in each pot was weighed out

Table 1

Some Characteristics of Soils Used in Pot Experiments

Soil Characteristic	Soil Series		
	Lakeland	Ft. Meade	Parkwood
Original pH	5.6	5.1	8.0
Natural Cu Content, ppm	4.5	2.0	5.1
Organic Matter, percent	1.21	3.33	4.11
Carbonates, percent	—	—	15.3
Total Phosphorus, ppm P	135.	52.	69.

into a small concrete mixer, the proper amount and form of copper was added, and the lot then mixed thoroughly. The copper sulfate used was sugar-sized crystals and the oxide was a very fine powder. Ten-inch clay pots were used in all experiments.

For the low copper series, sour orange, rough lemon, and Cleopatra mandarin seedlings were started in sand culture without adding copper. These seedlings were transplanted into the soil cultures when 3 to 4 inches high. Treatments, in addition to a no-copper check, included each source of copper used at 9.5 or 10 ppm, and 47.5 or 50.0 ppm metallic copper. Seedlings in the Lakeland series grew fifteen months outdoors except during midwinter while seedlings in the Ft. Meade and Parkwood series grew outdoors nine months.

Seedlings for the high copper series were planted in ordinary grove soil and transplanted into treatment pots when 4 to 5 inches tall. Sour orange and Cleopatra mandarin seedlings were used with Lakeland and Ft. Meade soils, but only Cleopatra mandarin was used with the Parkwood soil. Concentrations of copper added to the soil ranged from 0 to 1000 ppm. Each combination representing a different soil, seedling type, or copper level was duplicated with copper oxide and copper sulfate. After mixing the copper compounds with the soil, the pots were allowed to stand in the open in moist condition for six weeks. Seedlings were transplanted in March, 1952, and the trials were terminated in December, 1952. All pots were at first fertilized periodically with mixtures of pure chemicals containing most essential elements except copper, but later only sodium nitrate was applied.

Results

Low Copper Series. The plants in the Lakeland soil in July, 1952, had grown ten and one-half months. The sour orange and Cleopatra at this time appeared to show some increase in growth due to the 9.5 ppm copper treatment and a smaller increase in growth at the 47.5 ppm rate. Consequently in July, 1952, the tops of these plants were removed, the leaves were washed with an acidified solution of detergent, dry weights of the tops were obtained, and copper contents of the leaves were determined. The data obtained in this preliminary sampling were very similar to those obtained at the end of the experiment and hence are not presented here. These plants were allowed to grow new tops, and data presented below concern only the second growth of tops on these plants.

The experiment was terminated in December, 1952. At this time, the leaves were removed from the plants, washed in acidified detergent solution, dried, weighed and analyzed for copper. Stems and roots were washed free of soil, dried, and weighed. Average results for the four replications of each treatment are given in Table 2.

On all soils, growth was usually slightly increased by the 9.5 or 10 ppm rate of copper application. While similar trends were evident on all soils, the growth increase was of statistical significance only on the Ft. Meade soil, which had the lowest natural copper content.

Increase in copper application to 47.5 or 50 ppm did not result in greater growth than at the lower rate. In fact, some plants grew less than those in the no-copper pots. This slight restriction of growth at the higher rate may have been a mild expression of copper toxicity. No iron chlorosis was observed in any of these seedlings during the experimental period. Plants in soil treated with copper oxide were usually slightly larger than those in soil treated with copper sulfate, but the difference due to source was not statistically significant.

Copper content of leaves was very low in some individual cases, but no copper deficiency symptoms aside from restricted growth were observed. Copper content of leaves was significantly increased by the 9.5 or 10.0 ppm rates, and except in Cleopatra, somewhat further increased by the application of 47.5 or 50 ppm. The two sources of copper produced

Table 2

Growth and Copper Content of Citrus Seedlings in the Low Copper Series, Treated with Equal Amounts of Copper From Two Sources.

Soil Type	Copper Source	Copper Added ppm	Cleopatra		Sour Orange		Rough Lemon		Avg. - All Species	
			Dry Weight gm/plant	ppm Cu in Leaves	Dry Weight gm/plant	ppm Cu in Leaves	Dry Weight gm/plant	ppm Cu in Leaves	Dry Weight gm/plant	ppm Cu in Leaves
Lakeland	—	0	13.3	6.3	17.8	4.1	10.2	12.8	13.8	7.7
	CuO	9.5	15.8	8.8	19.5	12.4	11.6	15.2	15.6	12.1
	$CuSO_4$	9.5	14.0	8.0	16.4	11.6	9.8	15.5	13.4	11.7
	CuO	47.5	11.8	8.0	21.4	19.2	9.8	21.6	14.3	16.3
	$CuSO_4$	47.5	14.0	9.5	14.7	17.7	9.2	18.1	12.6	15.1
LSD*									NS	3.9
Ft. Meade	—	0	3.2	4.7	7.6	5.2	6.1	9.3	5.6	6.4
	CuO	10.0	6.6	8.8	11.7	14.3	8.9	13.3	9.1	12.1
	$CuSO_4$	10.0	6.4	8.3	11.5	13.4	9.0	12.8	9.0	11.5
	CuO	50.0	8.0	8.5	10.7	17.6	7.1	15.6	8.6	13.9
	$CuSO_4$	50.0	5.7	11.6	9.3	16.8	8.6	16.1	7.9	14.8
LSD*									2.6	2.6
Parkwood	—	0	3.6	5.0	10.3	5.1	7.1	10.3	7.0	6.8
	CuO	10.0	4.2	10.0	15.3	11.9	7.5	15.6	9.0	12.5
	$CuSO_4$	10.0	3.9	9.8	12.2	12.2	7.6	14.0	7.9	12.0
	CuO	50.0	4.7	11.0	12.1	17.6	8.6	16.8	8.5	15.1
	$CuSO_4$	50.0	3.7	11.2	7.9	19.2	9.4	17.7	7.0	16.0
LSD*									NS	1.6
Avg. - All Soils	—	0	6.7	5.3	11.9	4.8	7.8	10.8	8.8	7.0
	CuO	10.0	8.9	9.2	15.5	12.9	9.3	14.7	11.2	12.2
	$CuSO_4$	10.0	8.1	8.7	13.4	12.4	8.8	14.1	10.1	11.7
	CuO	50.0	8.2	9.2	14.7	18.1	8.5	18.0	10.5	15.1
	$CuSO_4$	50.0	7.8	10.8	10.6	17.9	9.1	17.3	9.2	15.3

LSD = Least significant difference at 5% level.
NS = Nonsignificant.

nearly identical copper content of leaves.

It is believed that this experiment demonstrated the adequate availability to citrus of copper applied in oxide form at low soil copper levels.

High Copper Series. In the Lakeland soil series, observable effects of the high copper levels appeared within a few weeks and became accentuated as time went on. At the end of the experimental period some restriction in growth of the sour orange seedlings had occurred at 100 ppm copper, but no restriction in growth of Cleopatra mandarin had occurred. Growth at higher levels was progressively reduced by increasing copper concentrations up to about 350 ppm and above this level little or no growth occurred. No leaf symptoms of any type developed on the plants in the no copper treatment. At 100 ppm copper, very slight yellowing of the foliage was observed. At 250 ppm copper and above, the leaves of most plants turned yellow soon after planting, and thereafter appeared as though affected by drought and nitrogen deficiency. Some iron chlorosis developed at 250 to 500 ppm copper, particularly in Cleopatra seedlings. As time went on, the plants at the highest copper levels became partially defoliated from the base upward.

While the severe toxic effects described above were occurring, only minor differences due to copper source appeared. At the beginning of the experiment, several plants at the higher levels in the sulfate series died, but few plants died in the oxide series. This difference presumably is due to temporary residual soluble copper from the sulfate source. Toward the end of the experiment no difference appeared to exist between the two copper sources.

Growth and development of symptoms in the corresponding plants in Ft. Meade soil was generally similar to that in Lakeland soil, except that slightly higher copper levels were required to produce equal effects. Growth was not obviously affected by 100 ppm of copper but generally severely retarded by 250 ppm copper and over. Leaf color was usually dark green at 0 and 100 ppm, pale green at 250 ppm and generally yellow at 350 ppm and over. Iron chlorosis was produced in Cleopatra by copper oxide at 100 to 350 ppm and by copper sulfate at 250 to 750 ppm. Iron chlorosis was appreciably less common in sour orange seedlings than in Cleopatra. Yellowing, wilting, and sometimes basal defoliation were prominent at 500 ppm and over.

Source of copper made little difference in the results except that, as in the Lakeland series, several plants died in the high copper sulfate series at the beginning of the trial, and as noted above, some difference appeared in the occurrence of iron chlorosis.

On Parkwood soil, only Cleopatra mandarin seedlings were used. For the first three months of the trial these plants grew slowly and no differences appeared. At the end of this period considerable growth occurred at the lower copper levels and noticeably less growth occurred at the higher levels. No yellowing, wilting or basal defoliation was observed in any part of this series.

Where copper sulfate was the source of copper, growth was moderately but regularly reduced by increasing amounts of copper in the soil. No iron chlorosis was observed at any time in this series. Where copper oxide was the copper source, growth was fairly good up to 350 ppm copper, but was reduced at this level and above. At all copper levels higher than 500 ppm severe and persistent iron chlorosis symptoms developed on all plants, greatly retarding growth. Thus copper from oxide appeared to be more toxic than copper from sulfate in the Parkwood soil. Possibly this difference was due to the more uniform mixing of the finely divided oxide throughout the soil, so that everywhere roots came in contact with toxic copper concentrations.

The toxicity experiment was terminated on December 8, 1952, at which time all the symptoms described above were present. Average weights of the plants in these series of pots are given in Table 3. These data support the observations presented above, indicating that copper supplied as oxide is generally as toxic as copper supplied as sulfate, and hence, as available.

Copper contents of the leaves of these plants are given in Table 3. Few of the values presented are low, partly at least because the seedlings were started in ordinary grove soil, moderately high in copper. In Lakeland and Ft. Meade soils, extremely high values were found associated with plants which were severely stunted by copper toxicity. In spite of the washing procedure it is difficult to believe that in the case of severely stunted plants the copper analyses actually represent internal leaf copper. Under nutrient solution conditions

Table 3
Growth and Copper Content of Citrus Seedlings in the Copper Toxicity Experiments

Form of Copper	ppm Cu Added to soil	Lakeland				Ft. Meade				Parkwood	
		Sour Orange		Cleopatra		Sour Orange		Cleopatra		Cleopatra	
		Dry Weight gm/plant	ppm Cu in Leaves	Dry Weight gm/plant	ppm Cu in Leaves	Dry Weight gm/plant	ppm Cu in Leaves	Dry Weight gm/plant	ppm Cu in Leaves	Dry Weight gm/plant	ppm Cu in Leaves
$CuSO_4$	0	23.2	16.6	8.5	10.7	27.0	9.7	12.2	8.5	19.9	3.1
	100	7.8	25.6	8.9	12.7	21.9	30.7	14.0	17.4	19.0	6.3
	250	2.3	39.3	4.1	19.0	10.9	27.5	10.3	19.6	17.6	7.9
	350	1.8	46.6	1.7	36.8	3.9	43.2	6.3	35.0	18.4	7.6
	500	2.0	49.8	3.5	23.0	3.8	41.7	4.7	22.2	17.6	10.0
	600	*	*	2.0	37.6	2.1	28.1	2.3	33.3	15.6	9.6
	750	*	*	2.0	47.5	3.7	40.1	3.9	26.5	16.4	10.1
	850	2.5	57.2	2.2	22.3	*	*	*	*	13.6	9.2
	1000	2.3	72.6	1.5	55.8	*	*	*	*	13.7	12.9
CuO	0	20.0	12.5	7.7	9.3	15.6	14.3	16.1	9.0	15.7	4.0
	100	13.7	25.8	13.2	11.8	22.2	26.7	20.3	19.1	19.2	8.3
	250	4.8	34.8	3.7	21.9	19.9	36.1	8.9	25.9	19.5	9.2
	350	2.8	38.0	1.5	46.8	10.2	38.0	4.4	28.2	11.7	12.5
	500	1.8	34.6	2.2	34.6	3.4	48.6	2.5	30.1	10.1	10.1
	600	1.7	31.4	1.4	39.6	0.5	33.3	0.8	37.1	7.1	13.1
	750	2.1	55.4	2.0	43.0	0.7	36.7	1.6	33.4	12.9	11.2
	850	1.6	46.2	2.4	43.4	2.0	33.2	1.4	42.6	6.9	26.1
	1000	1.6	50.8	1.8	44.1	1.9	31.2	5.1	33.0	10.0	11.8

* All plants in these pots died in the early stages of the experiment.

where contamination presumably was under better control, high leaf copper contents have not been obtained (7).

It is more likely that the high leaf copper contents are due in considerable part to contamination with high copper soil through splash erosion of the coarse textured soil by raindrops over all the leaf surface of the smaller plants. It is the senior author's experience that leaves contaminated by copper-containing residues cannot be washed in any way to completely differentiate between surface residues and internal leaf copper. In addition, some of the copper found in these samples may have been absorbed through the leaves. In the finer textured Parkwood soil, less splash erosion of soil occurs than in the sandier soils. Also, the plants in Parkwood soil were much taller throughout the higher copper levels, thus reducing the chance for contamination from this source. Therefore, only the copper data for Cleopatra on Parkwood soil and for the lower copper levels in the acid sands seem reliable.

Copper content of leaves of Cleopatra mandarin seedlings in Parkwood soil was relatively low and did not increase consistently with soil copper concentrations above 350 to 500 ppm. Apparently copper is not translocated into leaves of Cleopatra as readily as into sour orange and rough lemon. Also the toxicity of any soil copper level was very much lower in this soil than in the acid sands. Leaf copper values are slightly higher with copper oxide than with sulfate, indirectly indicating at least equal availability of copper from the oxide.

Discussion

Since the results presented above indicate that copper applied as either sulfate or oxide is approximately equal in effect, a high degree of water solubility apparently is not an essential characteristic of copper sources for soil amendments. On the basis of the experiments described above it appears reasonable to believe that copper oxide can be expected to prevent the occurrence of copper deficiency in groves if used in amounts equivalent in metallic copper content to amounts recommended for the sulfate. This should be regarded as a tentative recommendation pending the outcome of field trials now in progress.

In view of the recent interest in copper induced iron chlorosis, it may be useful to point out that iron chlorosis is only one phase of plant behavior in relation to copper supply. In the plants described here, a range of symptoms from slight deficiency to extreme toxicity was observed. Extreme deficiency symptoms (as exanthema, gum pockets, and dieback (3)) were not observed, but at slight deficiency levels, sub-optimum growth occurred. Also, at only slightly toxic copper levels, the first symptom was reduced growth. This effect may well be injurious in the field but difficult to detect. Iron chlorosis appeared at higher levels, sometimes only transiently, together with still further reduced growth. Finally at even more highly toxic levels, growth was completely arrested, and general yellowing of foliage was induced. This series of symptoms re-emphasizes the fact that copper-induced iron chlorosis appears after some decrease in growth already has occurred. While copper-induced iron chlorosis rightfully deserves study, another general need is an accurate criterion to use in determining whether groves have proper copper supplies for optimum growth of both tops and roots.

SUMMARY

Relative availability and toxicity to citrus seedlings of copper supplied as oxide or sulfate was studied in pots of Lakeland, Ft. Meade, and Parkwood soils. Soil copper levels ranged from less than 5 ppm to 1,000 ppm.

With previously uncultivated soils, copper additions of 9.5 or 10 ppm copper slightly increased seedling growth, and increased copper content of leaves significantly. Differences due to source were minor and not statistically significant.

Generally at high copper levels, the oxide and sulfate forms were about equally toxic. However, the sulfate form was somewhat more toxic than the oxide on acid sands in early stages of the experiment, presumably due to temporary residues of soluble copper. Copper oxide was more toxic in Parkwood soil, possibly because of more uniform distribution of the finer particles throughout the soil.

Cleopatra mandarin showed iron chlorosis more commonly than did sour orange and accumulated less copper in leaves than did sour orange and rough lemon.

Soil toxicity level of copper was demonstrated to be slightly higher for Ft. Meade than for Lakeland, and much higher for Parkwood.

Copper oxide can be tentatively recommended as a soil amendment for citrus, and may be used at rates equivalent in metallic copper to those recommended for copper sulfate.

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DEGREENING CONDITIONS FOR FLORIDA CITRUS

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Ethylene degreening of Florida citrus is commonly carried out at 85° F., which is the maximum temperature allowed by State regulations when heat is applied in the degreening process (2). This temperature is considerably higher than is used in most other citrus growing countries, or even in other parts of the U. S. A. (6).

Approximately eleven years ago (in the season of 1941-42) C. K. Clark at the Citrus Experiment Station, Lake Alfred, initiated an investigation into the optimum degreening conditions for Florida-grown citrus fruits (3, 4). The preliminary experiments were conducted with Hamlin oranges and, to a lesser extent, with Duncan grapefruit. Temperatures used ranged from 80° to 100° F. The degreened fruit was graded visually into three grades. Grade I showed no green at all. Grade II was commercial No. 2 as far as color was concerned and showed some green cast. Grade III contained all fruit too green to fall in the other two classes. The degree of "color break" was expressed by a color index calculated by means of the relation:

Color Index = % No. I + ½ (% No. II).

These results were presented in tabular

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