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COPPER TOXICITY ON FLORIDA CITRUS—WHY DID IT HAPPEN?

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Abstract. **Copper has been commonly used on Florida citrus for both nutritional and disease control for about 80 years. About 30 years after its use began a widespread toxicity problem developed. In this paper I will discuss why that happened, who discovered it, and what was recommended to correct it.**

When copper is discussed in citrus production circles today, two things come to mind: 1) its use for disease control; and 2) the toxicity problem caused by an excess in the soil. Most people currently in citrus production have probably never seen copper deficiency, so the importance of copper use for nutritional purposes probably is not fully understood. The goal of this paper is to give the history for each of its uses and show how each impacted the toxicity problem.

Copper Deficiency

To understand the full range of copper deficiency symptoms the reader is referred to Camp and Fudge (1939). Before it was recognized as a deficiency it was referred to as "dieback", the name being derived from the dying back of the twigs; "ammoniation", derived from its frequent association with heavy application of nitrogen; and "exanthema", derived from the Greek and referring primarily to the excrescences on the surface of the twigs and fruit. Dieback was first described in Florida by Fowler in 1875.

In 1955, when I started working full time in south Lake county, copper deficiency was already rare. I can remember seeing it once in the late 1950s around the edges of a grove planted on a low hill surrounded by swamp. The soil around the perimeter was a "sand soak" area which meant it has a very low exchange capacity. Both fruit symptoms of excrescences of hardened gum and the typical angular s-shaped twigs were present. Since there wasn't any twig dieback I would classify this as a mild deficiency.

The only other time I have seen it was in a grove I planted in 1993 on a native pasture site. I had included copper in the young tree fertilizer and sprayed the young grapefruit trees with copper for scab control. However, by the time the trees were 6-8 feet tall some S shaped twigs were present. Because it was a mild deficiency, correction was obtained by the addition of copper to two fertilizer applications and the continuation of normal copper sprays for scab and greasy spot.

In 1917 B. F. Floyd wrote agricultural experiment station bulletin 140 titled "Dieback, or exanthema of citrus trees". In his summary he states "The absolute cause of dieback is not known. It is thought to be in some way connected with organic matter which has been added to the soil, or which is residual therein". He also states "The curative methods consist in the use of bluestone (copper sulfate) on the soil and beneath the bark of the trees; and of spraying the trees with Bordeaux mixture".

Floyd (1917) said the most popular curative method was "to apply bluestone to the soil, but the price of the chemical has recently become so great that its use in this manner is almost prohibited". He said bluestone is a strong poison and that a number of cases of injury to citrus trees by its use have been reported. While bluestone is evidently a preventative for dieback, it was not known how it prevents it.

Fudge (1934) reported that copper sulfate treatment of exanthema affected trees returned the sap composition of leaves and stems to normal. His work in 1935 showed that fruit from trees cured of dieback by copper sulfate contain ap-

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proximately the same amount of nitrogen and phosphorus as normal fruit whereas "ammoniated" pineapple oranges were found to be higher in nitrogen, phosphorus, and potassium.

Camp and Fudge (1939) decided to settle the discussion as to whether it was an excess of nitrogen or a deficiency of copper. They said the latter viewpoint is the more practical since it is relatively easy to supply a deficient element but difficult to remove an excess of an element.

Peech (1939, 1948) noted that prior to his studies no attempt had been made to correlate the occurrence of copper deficiency with the available copper content of the soil. In 1939 he reported that the amount of copper found in different soils, regardless of the exchange capacity, was less than 0.5 lb per acre in the surface layer which would explain why the trees were deficient. However, in 1948 one grove he surveyed was free from the usual copper deficiency symptoms, had never had copper applied, and the soil had only 0.36 lb copper per acre. At this time he decided that because of the widespread use of copper as a fungicide he would make no further attempt to correlate copper deficiency and soil copper content.

Reitz et al. (1954) recommended that soils that contain approximately 50 lb of copper per acre six inches need no further additions of copper in the fertilizer. Keep the figure of 50 lb in mind since you will see it later when toxicity is discussed.

Copper for Disease Control

While copper has been used to control melanose, scab, and greasy spot, the longest and most common use has been for melanose. Swingle and Webber (1896) published the first record of this disease after they observed it in November 1892 near Citra, Fla. Although they couldn't identify the cause, some spraying experiments they did in 1894 showed the disease was controlled by two applications of Bordeaux mixture, or ammoniacal solution of copper carbonate, the first made about two weeks after the flowers had fallen and the second a month later. Sound familiar?

Floyd and Stevens (1912) stated that melanose was caused by *Phomopsis citri* (Fawcett) which sporulates in deadwood. Since the fungus is active nearly the entire year, melanose may occur at any time when new growth is active. While they were able to produce the disease using spores, they couldn't recover the causal organism from melanose markings as Koch's postulates would require. Wolf (1926) found the perfect, or ascospore, stage growing saprophytically on decaying citrus twigs and named it *Diaporthe citri*. In 1928 Bach and Wolf isolated *Diaporthe citri* for the first time from the melanose lesions, thus establishing the standard proof of pathogenicity.

Burger's (1923) eleven experiments on 1,255 acres in three counties proved without a doubt that Bordeaux 3-3-100 plus oil was an effective control of melanose. Oil was added to control the scale increase caused by the Bordeaux mixture. The fruit from the sprayed grapefruit groves graded 69% bright and 24% golden compared with the unsprayed groves where the fruit graded only 24.6% bright and 33.3% golden. Burger et al. (1923) concluded from both laboratory work and field observations that fruit becomes immune about 1 June.

Winston et al. (1927) published their bulletin on melanose that provided details about every aspect of this disease. Like many other old bulletins, it examines and presents the basic knowledge about its subject we use today. For example, they describe star melanose, and since they had observed it only on trees that had previously been sprayed with Bordeaux mixture they suggest it was due to spray injury. They also reported that in Florida melanose impairs the market value of more citrus fruit than all other active parasitic diseases combined.

In spite of Swingle and Webber (1896) reporting melanose control with Bordeaux mixture Winston et al. (1927) said few growers attempted to do so because of the injurious effects from the abnormally great increase in scale insects following application. Prior to 1920 no commercial spraying was done in Florida for melanose control, but that year several growers started spraying using a 3-3-100 Bordeaux plus 1 per cent oil to control both melanose and scale. From that year forward more growers started to spray for melanose control using the same mixture. They observed that one of the side benefits was that trees that received several applications corrected or reduced those symptoms we now know as copper deficiency.

The first Better Fruit Program (issued in 1937) recommended spraying Bordeaux mixture for melanose control plus oil with the concentration depending on the scale population. Sexton (1938), an Indian River grower, reported spraying with copper solution to control scab and melanose.

In 1939 Ruehle and Kuntz published Bulletin 349, Melanose of citrus and its commercial control. This bulletin added to our knowledge by proving 53% basic copper sulfate was as effective as Bordeaux mixture. This information eventually allowed the industry to stop using Bordeaux mixture. This work also gave us the rate of 7.5 lb of 53% basic copper sulfate per 500 gal which was used for many years until newer coppers came along.

The research to control citrus scab in Florida was done about the same time as that done for melanose and most of the early work was done by the same people. Although H. S. Fawcett published several reports on scab in Florida between 1907 and 1921 it was Winston (1923) who published Citrus scab: its cause and control, a work which was as inclusive as his melanose bulletin that was mentioned earlier.

The first report on citrus scab in America was made by Scribner (1886) who stated that the disease first made its appearance in 1885 on sour-orange stock in a citrus nursery near Ocala, Fla. Winston (1923) reported in detail about its severity in citrus nurseries and said "This disease is such consequence to rough-lemon and sour-orange nursery stock that nurserymen are in search of a desirable stock immune to citrus scab". Although we now know citrus scab by the scientific name *Elsinoe fawcetti* (Bitanc. and Jenk.), there was a lot of discussion about its correct name for many years.

Winston (1923) said very little spraying was done for scab control until Bordeaux oil mixtures were developed, again because of the problem of scale flaring. More spraying was done after he developed and published his spray schedules which varied with the amount of scab historically present.

Ruehle and Thompson (1939) published work with Bordeaux mixture and some of the proprietary copper spray materials for the previous 5-6 years. They stated that the proprietary copper spray materials controlled scab as well as Bordeaux mixtures, if equal amounts of metallic copper were used. As with melanose this gave the industry the freedom to stop using the scale causing Bordeaux mixtures.

Greasy spot, caused by the fungus *Mycosphaerella citri* (Whiteside), is the last of the diseases requiring copper to control to be discussed. The first mention of this disease I could find in Florida literature was by Thompson (1948) who suggested that there may be a relationship between the de-

gree of rust mite control and the intensity of greasy spot. However, in 1954 both he and Fisher reported copper would give control. Fisher's experiments were done with 3 lb of basic copper sulfate per 100 gal of water. Thompson reported that 1.5 lb basic copper sulfate per 100 gal reduced greasy spot even though the rust mite population was the same as where control was not obtained. He also reported that oil sprays were beneficial.

Griffiths (1955) stated that greasy spot was a leaf condition that had been recognized in Florida for many years but only in the past few years has it become a major problem. At the start of my working career in 1955 it was an important leaf disease and we planned control measures in our spray programs. The 1956 Better Fruit Program was the first one to recommend copper to control greasy spot on leaves.

During my first ten years, while working mostly in central Florida, we occasionally saw "pink pitting" on the fruit but it would occur as scattered specks that you had to look hard to find. I can remember only one or two crops where it was severe enough to cause fresh fruit grade problems.

In 1965, when I moved to the Indian River district, the 1,700 acres I managed was about half grapefruit which was intended for the fresh market. Two hundred acres were Burgundy grapefruit which were more susceptible to foliar and fruit greasy spot than other grapefruit varieties. Some of Dr. Cohen's original research on controlling greasy spot on leaves was done on this property. Dr. Whiteside did one of his few field experiments on this property to research the control of greasy spot rind blotch.

When I left this property in 1985 I don't remember greasy spot rind blotch being a major problem except for the Burgundy variety. Maybe it was because I was including copper in my summer oil spray to control greasy spot on leaves. However, it was becoming a problem in the state because the 1974 Better Fruit Program recommended copper as a control for pink pitting which later became known as greasy spot rind blotch.

Copper Toxicity

Peech (1941) gave us the solution to this problem before it was ever identified as a toxicity. He stated that copper was fixed by liming to a comparatively low pH level in light sandy soils. Westgate (1952) reported copper toxicity was a problem in old vegetable fields that had received years of copper sprays. He described symptoms of copper toxicity as plants having brown, stubby roots, iron chlorosis of the leaves, and a general stunting. Ford (1953) reported that where there were high copper concentrations and a pH below 5.0 citrus feeder roots of severely iron deficient trees were ashy gray, rather shriveled, and highly corked with no visible evidence of an actively growing root tip.

Leonard and Stewart (1952) reported that where copper was high, liming was more effective in preventing iron chlorosis than other means of correcting this deficiency. Stewart and Leonard (1952) stated that copper is less available to plants on limed than unlimed soils. They found that grapefruit leaves from the 4.0 pH plots had 76 ppm copper but where the pH was 5.6 the leaves contained only 14 ppm. Smith and Specht (1952) concluded that the main cause of the recent increase in acid soil chlorosis in Florida citrus groves was the accumulation of copper in the soil. Reuther and Smith (1953) found that a high percentage of the copper applied to field plots during a 7 year study was retained in the topsoil.

Reuther et al. (1953) studied copper levels in relation to different soil types as well as virgin versus old grove soils of the same type. They concluded that the toxicity effect of high copper content on soils of high exchange capacity was not as great as on soils with a low exchange capacity. They also found that the negative effect of high copper was not as great on old grove soils as the same amount of copper on a virgin soil of the same type. In the old grove soils they felt that heavy phosphate concentrations reduced copper toxicity. However, the phosphate factor was not as effective in correcting the problem as liming to pH 7 so they recommended the latter be used.

How Much Copper is Too Much?

Reuther et al. (1953) stated that when a Lakeland sand contains 96 lb of copper per acre six inches it was definitely unfavorable for normal growth and at copper levels about one-half of these concentrations a slight to no toxicity might be expected. Driscoll (1955) studied the effect on orange seedlings of five levels of copper at two different pHs, 4.5 and 6.5, in a virgin Lakeland sand. At pH 6.5 there was no statistical difference in amount of fresh weight produced. At pH 4.5 the maximum amount of fresh weight was produced at the 50 lb copper per acre rate. At the 200 lb rate the fresh weight produced was only 58% of the 50 lb rate and at the 400 lb rate the seedlings lost their foliage and were dying at the conclusion of the experiment.

Where Did the Copper Come From?

From our experience today we know some came from our sprays for disease control. However, Reuther and Smith (1953) point out that the copper accumulation in commercial groves was caused by the practice, common for more than a decade, of applying mixed fertilizers containing sufficient copper sulfate to add 10 to 25 lb of copper per acre annually to mature groves. They estimated that during that time fungicidal sprays added 5 to 15 lb an acre per year also.

By the time I went to work in 1955 growers had stopped using copper in their mature grove fertilizer. One of my customers told me when they first applied copper in the 1930s they applied several pounds of bluestone per tree by hand. The results were so great that they continued to apply more the same way.

Although they no longer used copper in their old tree fertilizer, most growers were not aware of how much copper toxicity was affecting them. One of my services as a fertilizer salesman was to take pH samples for our customers. Once there was evidence of a low pH in the grove it then became a matter of explaining the existence of copper toxicity and recommending liming materials to correct it. Since I had studied this problem while working on my masters I had pictures of citrus seedlings to show the results of why a higher pH was needed. This made my job much easier, created satisfied customers, and a happy boss.

However, it wasn't only citrus growers who created copper toxicity in citrus groves. One of my customers had a 30 acre Orlando tangelo grove in which the northwest corner 10 acres did not look as good as the rest of the grove. Since the difference in tree condition on the two sides facing the other trees was in a straight line it was apparent it was a man made problem, but what? We talked about it almost from the first time I met the grower. Several years after meeting him he happened

to mention that as a boy he remembered seeing that 10 acres planted in grapes. Since I estimate he was at least 60 years old when we were talking about 1959 he must have seen the vineyard around 1915. As soon as he told me about the grapes a light went off in my head. We applied 20 tons of dolomite to the 10 acres and a year later the tree condition had greatly improved. The problem was copper toxicity caused by the Bordeaux mixture used to control fungus diseases on the grapes. It seems there was a grape industry in Lake County around that time and I later talked to others who had groves planted on old vineyards who benefited by raising the pH.

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