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THE HISTORY OF SULFUR USE ON FLORIDA CITRUS AND ITS EFFECT ON SCALE POPULATIONS AND ENVIRONMENT

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Abstract. **The long history of heavy sulfur use to control mites on Florida citrus had detrimental effects both on the environment and by increasing scale populations. The transition to other mite control materials and the use of IPM greatly reduced the importance of scale insects in Florida citrus production. This subject is discussed as experienced by the author during his 50 plus years in the Florida Citrus industry.**

Scale insects have been important pests of Florida citrus since they were introduced in the 1830s. In the following 15 years scale spread throughout Florida groves, producing disastrous results and appearing likely to exterminate the industry. At that time, parasites were not present and scales thrived. Only years later when scale parasites had been naturally introduced and flourished, was the industry able to recover (Hubbard, 1885).

When he came to Florida in 1876, Ashmead (1880) "found orange culture the great industry of the state". It seems a small grove of one hundred trees on an acre of land, in full bearing condition, yielded annually an income of $1,000-$2,000. He also found scale insects which frequently killed trees or caused whole branches to die back.

Because the Florida red scale was only present on fruit and leaves, Ashmead (1880) reported that one grower successfully controlled this scale by spraying the trees with salt water in the fall after the fruit was picked. When the salt spray caused the leaves to fall off, the scale went with them. In the spring the trees responded with a "luxuriant new growth" that was scale free.

Scale populations. The author's first exposure to citrus scale infestation was in the summer of 1949 while employed as a lab assistant (flunky) at what is now known as the Indian River Research and Education Center (IRREC). The Center was in its second year of operation and Dr. Richard Voorhees, the only faculty member, was conducting parathion trials for scale control. In addition to applying parathion, as part of the field crew, it was my responsibility to collect leaf samples and check the percent kill for each scale species after applications were made.

While collecting leaves, it was obvious that close to 100% of the inside leaves were infested with numerous scales. The scale populations on the outside leaves were scattered and lighter in number. The main scale observed was purple scale, *Cornuaspis beckii* (Newman). Also present in smaller numbers were what we called long scale but which is properly known as Glover scale, *Lepidosaphes gloverii* (Packard). During my college years I observed similar scale infestation patterns in both the original and replacement teaching citrus groves at the University of Florida in Gainesville.

In 1955, I took my first full time job in the citrus industry when I was hired by Swift & Co. to be a fertilizer and spray sales representative. My territory was in the south part of Lake County, where the company had about 2,000 acres of business. As I became familiar with the groves, I saw that every tree in every grove had a scale population similar to that observed previously at IRREC.

I started work in September and the current salesman toured me through my new territory as part of my training. As we were driving through one extensive citrus area, he pointed to a grove on the side of a distant hill and stated that it was infested with Florida red scale, *Chrysomphalus aonidum* (L). When I challenged him to prove it, he drove to the grove. He was right, almost every leaf was a bright yellow color because of the large number of Florida red scale feeding on it. In addition, the fruit were covered with numerous, mostly female, scales. That fall and in several following falls, I saw a number of groves with a similar scale problem.

In groves where Florida red scale was present, the populations in the fall were always heavier than the more common purple scale. One reason was because the female Florida red scale produced more crawlers than the purple scale female. The average number of eggs produced by a Florida red scale female was 150, while the purple scale female only produced between 40 and 80. Also, purple scale had three generations per year while the Florida red scale had four (Metcalf and Flint, 1962).

Florida red scale crawlers were more active than purple scale crawlers, and they spread around the entire canopy of the tree rather than just in the shady areas like the purple scale. Purple scale are strongly repelled by light and seek the moderately shaded part of the tree and fruit before inserting their beaks and starting to feed (Metcalf and Flint, 1962).

Another reason Florida red scale was so destructive in the fall is that the recommended control period for purple scale was 15 June through 15 July, and the recommended control period for Florida red scale was 1 July until 1 Aug. This meant that when the summer oil spray was timed for purple scale control, a large number of Florida red scale crawlers escaped to produce the damage described above.

My scale observations were not unique. Simanton (1976) put purple scale at the top of the list of citrus pests. He said that prior to 1958 it was the most prevalent, the most injurious, and therefore the most important pest species on citrus. In discussing my observations with John T. Moose, Jr., who began his career as a production manager in 1948, he confirmed seeing the same level of scale populations that I experienced.

In his 1934 survey of purple scale, Louis W. Ziegler (1949) reported that he found an average of 35.0 live scales on the upper surface and 33.5 live scales on the lower surface of leaves on the inside of trees. The outside leaves averaged 8.2 live scales on the upper surface and 4.5 live scales on the lower surface. Ziegler (1949) stated that the build-up of purple scale was due mostly to their preference for shade and the build up of scale-enhancing residues which were primarily

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from sulfur sprays for mites and road dust. This was true in south Lake County where most of the citrus roads were made from the orange clay found below the sand layer. When the roads were dry, every vehicle that passed created a cloud of dust. The scale infestations on the 2-3 rows adjoining the roads were so heavy that we would sometimes apply additional scale sprays to those rows.

Sulfur wasn't the only spray material that caused build up of purple scale. Rolfs (1913) reported that purple scale was on 69.6% of the trees sprayed with Bordeaux mixture but only 16.7% of the unsprayed trees. Ruehle and Kuntz (1935) reported "Scale increase was greater where Bordeaux mixture was used than where basic copper sulfate was used". According to the 1998 Farm Chemicals Handbook, Bordeaux is a mixture of copper sulfate and hydrated lime, usually a 1-1 ratio. It is named after the region of France where it was first used as a control for downy mildew. Bordeaux mixture was the only recommended copper material for melanose and scab control until 1939, when the Better Fruit Program listed Bordeaux 3-3-100 or its fungicidal equivalent in other forms of copper. By 1944, the Better Fruit Program no longer recommended use of Bordeaux mixture.

Spencer and Norman (1954) studied the number of sprays needed as well as the concentration of parathion needed to control purple scale on a Ruby grapefruit grove near Fort Pierce, FL. Prior to starting the experiment, a composite leaf sample had 734 living scale per 100 leaves. They rated this as a high infestation. At the end of the experiment, all the treated groups had infestations higher than the initial populations. This gives an indication of how difficult it was to control this scale.

Scale populations increased in the middle and late 1930s because of the increased vigor of the trees. More advanced cultural programs were being practiced by the average producer, resulting in healthier and more productive trees. During this time, minor element deficiencies were identified and treated. Some of the indirect factors influencing scale build-up, which resulted from increased tree vigor, were: increased shade; longer leaf life which, in turn, means less elimination of scale colonies from premature dropping of leaves; and the failure to obtain a thorough coverage with oil sprays on densely foliaged trees (Thompson, 1942).

Applying Sulfur

During this time, the main methods of spraying were by hand and by booms mounted on a pressure sprayer, neither of which resulted in good spray coverage. These methods were still around when I started working, and my experience with both was not good under the best of conditions. The approved method of hand spraying large trees (Thompson 1938) was to get under and inside them to spray the inside first. This meant the spray dripped on the applicator and in his eyes. My introduction to spraying sulfur in citrus groves was in 1949 during the time I was working at the IRREC. We used 50 lb of wettable sulfur per 500 gallon tank, and applied it by hand. Because most of the trees were large, a lot of the acreage was sprayed with more than one tank per acre.

After I sprayed sulfur and had to close my eyes, there was a burning sensation that did not want to go away. My fellow employees told me when I went home to fill the bathroom sink with water, put your face in it, and open your eyes. This felt good until you had to come up for breath. Another remedy that was supposed to help was to put condensed milk in your eyes to neutralize the sulfur. Sleep did not come easy no matter what you did.

The introduction of the air blast sprayer in the early 1950s didn't do anything to reduce the discomfort of the tractor driver who was always surrounded by a mist containing sulfur. The supply tank operator had to lift the 50 lb bag of sulfur to the top of the tank, cut it open, and slowly let it drop into the tank to make sure it mixed properly. As a result he was exposed to the sulfur dust.

To prevent phytotoxicity, sulfur and oil are not supposed to be applied within three weeks of each other. Scheduling rust mite control was difficult in the summer months when the rust mite populations were high. Rust mite populations increased dramatically as higher temperatures accelerated their life cycle. A duster could cover acreage faster and more cheaply than a sprayer, so dusting was used more often. Dusting was done as early as possible in the morning before the dew dried and the wind came up. In the summer, it was often necessary to dust throughout the day, even when trees were dry, to cover the acreage fast enough to prevent rust mite damage. We followed the three week rule when sulfur was applied as a spray, but we felt we could apply oil two weeks after dusting. If it rained after the dust application, we would use even shorter intervals. I don't ever remember having a fruit burn when following these guidelines.

One duster commonly used was made by Pounds Motor Company of Winter Garden, Fla. It was pulled by a tractor and was a steel-bodied, two-wheeled trailer which had a platform to carry the sulfur dust which came in 50 lb bags. Some were built using a gasoline motor to power the pump which provided the air pressure which flowed through two large fixed fan-shaped air ducts from which the dust was directed at each tree row. When sparks from the gasoline engines started igniting sulfur fires, the power source was changed to PTO driven. A man rode on the trailer and kept the hopper filled with sulfur dust, a difficult job on a moving trailer. Needless to say, the loader and tractor operator were constantly covered with sulfur dust.

After World War II, airplanes that had been used for pilot training were modified for aerial application. They were equipped to apply either liquid or dust materials. Where grove conditions were favorable, aerial application was used to apply sulfur dust. Some growers used wettable sulfur instead of dusting sulfur because they felt the wetting agents would help stick the sulfur to the moist leaves.

After several accidents destroyed airplanes and killed pilots, it was discovered that static electricity would sometimes cause the sulfur to ignite as it neared the ground. The flame would follow the dust up to the airplane, which would explode in flames. This stopped aerial sulfur dusting in the center of the state where the humidity was low. Because of the higher humidity present on the East Coast, aerial sulfur continued until about 1990 (Chuck Stone, Southeastern Aerial Spray Service, pers. comm.).

Spray Materials

In 1955, the main spray materials the industry had to work with were spray oil, basic copper sulfate, and the three forms of sulfur: wettable, dusting, and lime-sulfur. DN dry mix No. 1 was also available for purple mite control, but could not be applied when the temperature was above 88 °F. In essence, we had what closely resembles an organic spray program today.

I used these spray materials from the time I went to work in September 1955, through 1956, and until the summer of 1957. Although the 1954-55 Better Fruit Programs listed Ovetran and Aramite as spider mite materials they were expensive and were used sparingly.

In May of 1957, Fisher (1957) reported that one of the materials she was screening for greasy spot control, Zineb, gave good rust mite control. Because the industry desperately needed something beside sulfur to control rust mite, most growers mixed Zineb with their oil spray that summer. The results were excellent and the industry felt it had an effective new spray material.

Miller (1957) stated "Florida has produced the brightest crop of citrus fruit most free of russeting during the past summer ever grown" and credited Zineb as the reason. It was so widely used he said "It was actually difficult to find groves for checks where Zineb was not used."

Although Zineb continued to be listed in the Better Fruit Program through 1973, its use dropped after its poor performance in 1960-61. Griffiths (1962) reported that the poor control these two years was the result of differences in population development rather than resistance. In the three years when good control was obtained, 1957-59, rust mite populations peaked sharply at the end of July and then had a rapid decline. Since the spray oil commonly applied in June and July killed the adult rust mites, this combination resulted in very low populations for the rest of the summer. In 1960-61 there was no sharp increase in July but rather a prolonged period of relatively high populations throughout the summer.

Acaraben (chlorobenzilate) replaced sulfur in the post-bloom spray after it was listed in the Better Fruit Program in 1959, and was rapidly adopted by the industry. For the fall spray other miticides such as Delnav, Trithion, and Kelthane became available shortly thereafter and, since they controlled both rust mites and spider mites, it was no longer necessary to use sulfur.

This change was especially welcomed by Murcott growers, since sulfur application resulted in a lot of fruit burn, mostly on the blossom end which was exposed to the sun. At the time, most of the Murcott groves were young and the fruit was located on the sides and at the end of the upright branches. This placed it in direct sunlight all day, and the spray droplets acted as magnifying glasses to heat the sulfur enough to burn the fruit. The bright yellow burn would be so severe that a large interior area of the fruit under it would be dry, eliminating it from being of fresh fruit quality.

My first trial of chlorobenzilate was with a hand application on a young Murcott grove. Inspecting the grove about a week after it was sprayed I found a lot of fruit with live rust mites on them. My first impression was that the material didn't kill the rust mites, but I quickly realized the problem was poor coverage.

When ethion was listed in the Better Fruit Program in 1961 for rust mite control, the industry had another miticide to mix with oil. This happened just when the industry was looking for something to replace Zineb. With miticides available for sprays the other times of the year, it meant we could stop using sulfur. This gave the industry many advantages as we were about to find out in the next few years.

Where Did the Scales Go?

In the mid 1950s, other production mangers and I started noticing small round holes in the backs of female purple scales, and their population levels began to decline. The mystery was solved when Muma and Clancy (1959) reported finding a new parasitic wasp, *Aphytis lepidosaphes* (Compere) throughout the state. The widespread distribution of the wasp indicated it had been here for some time. This wasp had been imported into California from China in 1948-49 and had been distributed to Texas and Mexico. However, there had been no known introductions into Florida.

The reason this parasitic wasp reduced the purple scale population when it did was because we had stopped using sulfur. Simanton (1960) reported "A study of 97 spray treatments in 22 groves disclosed that of commonly used pesticides, only sulfur inhibited effective control of purple scale by *Aphytis*." Other reasons for the success of *A. lepidosaphes* include a short life cycle, which results in several generations of the parasite to each generation of the host, and adult feeding on non-parasitized scales, which results in additional scale mortality (Clausen, 1956).

The 1955 Better Fruit Program stated that purple scale was present in all citrus groves. By the time the 1961 Better Fruit Program was published, it said they were of minor importance. Both editions considered Florida red scale to be potentially dangerous. Because of the success of biological control of purple scale, researchers decided to try the same thing for Florida red scale. Clancy et al. (1963) introduced *Aphytis holoxanthus* (DeBach) as a parasite for Florida red scale in 1960. The parasite soon became established, and in one year had dispersed to most of the citrus growing area of the state. As a result, Florida red scale is rarely seen today.

Sulfur Use

The earliest reference that I could find for controlling rust mite with sulfur was from Hubbard (1885) who stated "Flowers of sulfur must therefore be regarded as one of the cheapest and most effective remedies for rust mite". The 1998 Farm Chemicals Handbook defines flowers of sulfur as the normal form of sulfur used for dusting. It is doubtful that use of sulfur for rust mite control existed before the 1880s since Mr. J. H. Gates made the first recorded find of rust mite occurred around this time (Ashmead 1880). Ashmead (1880) studied this pest and gave it a scientific name, *Phyllocoptruta oleivora* (Ashmead). Ashmead also reports that a Mr. T. W. Moore attributed the rusty color of many oranges to the rust mite and Ashmead's studies confirmed this.

Youthers (1914, 1920) discussed controlling rust mite by spraying with various sulfur compounds. He stated that "It has been known for thirty years that the sulfur sprays were very satisfactory to control this pest". He mentions that Mr. Thompson at Winter Haven had purchased a new dusting machine which they were going to use in mite control experiments.

Youthers (1918) illustrated the importance of controlling rust mites. When they were controlled, he reported that 19 fruit would fit in a fruit tray. When they were not controlled, 27 fruit would fit in the same tray because the rust mite damage reduced the fruit size. Allen (1993) confirmed the reduction in size caused by rust mites, which resulted in overall volume loss.

In 1930, Youthers and Mason published "The Citrus Rust Mite and Its Control." Its 56 pages report the detailed research they did in every area concerning rust mites. Reading through it, I recognized it was the basis for what I had been taught about rust mite in my college classes. In the summary, they stated that "Sulfur has been found the best agent for use against the rust mite."

When the first Better Fruit Program was published in 1937, it recommended all three forms of sulfur for rust mite control. Although the name of the publication changed over the years, some form of sulfur has continued to be recommended throughout the years. However, the latest guide recommends fewer pounds and contains a caution against frequent use.

We don't have any direct evidence of how fast Florida citrus growers implemented the recommendation of using sulfur to control rust mites, but we can estimate its use by reviewing what happened to leprosis in the state. Leprosis was sometimes known as scaly bark because of its effect on branches and nailhead rust from its symptoms on leaves and fruit. Leprosis was first thought to be caused by a fungus, but it was later discovered to be a virus-like disease vectored by Brevipalpus mites (Garnsey et al., 1988). Knorr and Thompson (1954) proved that these mites could be controlled by a single pre-bloom application of wettable sulfur.

Knorr and Thompson (1954) reported that in 1917, the State Plant Board tried to control leprosis by quarantine in nine of the leading Florida citrus counties. However, the disease continued to spread and by 1925, it was known to be present in 17 counties. During the late 1920s, leprosis ceased to be a problem. In the years that followed, it was seen less and less frequently, until today it is not known in the state. It seems likely that this resulted from widespread use of sulfur for rust mite control.

Since its introduction as a miticide in Florida, large volumes of sulfur have been used. It was not possible to find sales records of actual use, but we can come up with a close estimate by using acres of citrus and average use per acre over a 12 month period.

The last season sulfur was used at maximum rates was 1956-57. The Florida Agricultural Statistics Service indicates there were 527,000 acres of Florida citrus that year. From my experience, the industry was applying an average of three sulfur sprays a year using 50 pounds of sulfur per 500 gallon tank. While some young groves would not require a tank per acre, most of the groves with larger trees were using more than one tank per acre. If we use an average of one tank per acre and round off the final figure, we arrive at 40,000 tons per year for 1956-57. Although I don't know how they arrived at their number, my figure is close to the 45,000 tons estimated by Knorr and Thompson in 1954.

Sulfur and the Environment

Sulfur's effect on the environment can be separated into three areas. First, is the utilization of natural resources to produce a usable sulfur product. It must be mined, dried, ground, bagged, transported, and applied in large volumes.

Second, when large amounts are repeatedly applied to citrus trees occupying considerable land area, the potential environmental effects are significant. Of the 200 pesticides they studied, Kovach et al. (1992) gave sulfur the highest environmental impact quotient of any of the citrus pesticides commonly used today. Each pesticide was evaluated by giving it a toxic or harmful rating for each of ten environmental factors and totaling the rating given each factor to determine an impact quotient. Since sulfur is acceptable in an organic spray program, this should help answer criticism from the environmentalists about newer "man-made chemicals" versus organic programs.

Third, additional natural resources are needed to neutralize sulfur's detrimental effects on soil pH. We used a guideline of 5 lb of liming material needed to neutralize each pound of sulfur applied. To neutralize the amount of sulfur estimated above in 1956-57, it would have required 200,000 tons of liming material. This had to be mined, transported to a central site, dried, ground, stored, loaded, transported to the user's site, and applied. During the early 1950s the liming industry was driven by sulfur use, acid fertilizer, the copper toxicity problem, and the recognition that many native soils needed a higher pH for tree health. All of these increased the demand for liming materials, which resulted in the expansion of the industry.

In 1952, Dolomite Products, Inc. opened two new plants with a capacity of 400,000 tons per year. In 1963, West Coast Dolomite, Inc. opened a new plant in the southern end of the deposits in the state. Now that sulfur use is greatly reduced, and there are fewer new agricultural operations requiring substantial soil pH adjustment, the number of lime-producing companies and volume of lime produced in Florida is down significantly from the high 40 years ago. This likely reduced use of fuel and other resources needed for lime production, processing, and application and reduces the environmental damage resulting from continued mining.

Someone once said if you don't know history you are doomed to repeat it. While the occasional use of a sulfur spray probably won't upset the balance between scale and their parasites, understanding what has happened in our industry in the past will help prevent this problem from reoccurring in the future, and may help provide guidance in avoiding similar problems. It is clear that we can never again look at control of a single pest, such as rust mite, in isolation from the effects on other pests and aspects of citrus production. Examining use of sulfur from an integrated perspective, and implementing appropriate strategies, has largely eliminated scale insects as pests of Florida citrus. It has also likely provided extensive environmental benefits to the state of Florida and its citizens. This must be one of the greatest success stories in integrated pest management (IPM).

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