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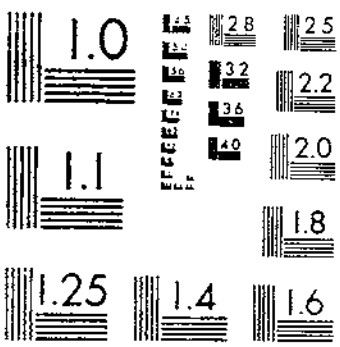

MICROCOPY RESOLUTION TEST CHART
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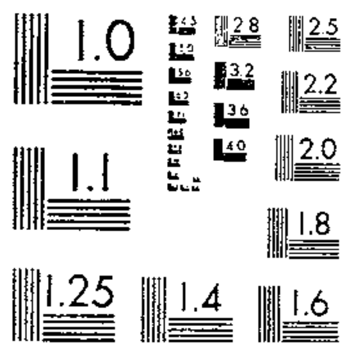

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THE CITRUS RUST MITE[1] AND ITS CONTROL

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INTRODUCTION

Several years prior to 1879, Florida orange growers were very much concerned about the cause of russet fruit. Some growers were of the opinion that it was of a fungous nature; others, that it resulted from adverse soil conditions. Perhaps the honor of discovering the real cause of russeting belongs to J. K. Gates, who was the first to find the mites on oranges and immediately ascribed russeting to their presence. His observation was probably made in 1878 or 1879. He conveyed the information to W. C. Hargrove, of Palatka, who in turn informed T. W. Moore (*8, p. 138*)[2] of their discovery. Mr. Moore knew that William H. Ashmead was studying the insects affecting the orange, so he took up the matter of the discovery of the pest with this entomologist. This led to the description of the species by Ashmead (*1*). Considerable experimenting was carried on by Moore

[1] *Phyllocoptes oleivorus* (Ashm.); order Acarina, family Eriophyidae.
[2] Italic numbers in parentheses refer to "Literature cited," p. 55.

and Ashmead for the elimination of the damage caused by this pest. Moore found that a decoction of tobacco and whale-oil soap was very effective if applied once a month from February to June. No reference is made in these experiments to the use of sulphur as a remedy.

In 1885 a report was published covering the most exhaustive study of orange-infesting insects that had been made up to that time. This was the treatise on Insects Affecting the Orange, by Hubbard (7). Much relating to the life history and habits of the rust mite was found out by Hubbard, and sulphur was mentioned for the first time as a most satisfactory remedy. From 1885 until the present investigation was begun very little of importance was added to our knowledge of the rust mite.

ORIGIN AND DISTRIBUTION

In all probability the original habitat of the citrus rust mite is southeastern Asia, where citrus trees are indigenous. It has probably accompanied its hosts from their original home to many other citrus-growing regions. It now occurs in Florida, Alabama, Louisiana, Texas, and California, and has been found on citrus trees growing in greenhouses in Philadelphia, Pa., and Marlboro and Niagara Falls, N. Y. There are also records of its occurrence in Cuba, Porto Rico, Jamaica, Bermuda, Venezuela, Yucatan, Hawaii, the Philippine Islands, Japan, and Australia.

There are no records of its presence in the citrus-growing districts of the Mediterranean. Penzig (*9, p. 551*) stated that up to 1887 it had never been found in Italy. F. Silvestri in 1923 wrote in a letter that he had never seen this mite there. It is not recorded as being present in South Africa. In fact, up to this time, it has not been recorded from India, although without doubt it is present there and has been overlooked owing to its small size.

SYSTEMATIC HISTORY

The rust mite was first described by Ashmead (*1*) in 1879 as *Typhlodromus oliioorus*. Pergande determined it the same year as a species of Eriophyes. The genus Typhlodromus does not occur in recent literature and, according to Ewing (*4*), is evidently a synonym of Phytoptus Dujardin (1851), which in turn is a synonym of Eriophyes Siebold (1851); consequently the rust mite has long been placed in the genus Eriophyes. Banks (*3*) first called the mite *Phyllocoptes oleivorius*, and other authors also refer to it as Phyllocoptes (a genus erected by Nalepa in 1889), and this classification according to Ewing is correct, since only half of the abdominal rings are complete rings.

The specific name has been referred to in various papers as *oliioorus*, *oleiiorus*, *oilivorus*, and *oil-livorus*. Although it was first described under the first-mentioned spelling Ashmead a year later (1880) in his Orange Insects (*2, p. 40*) speaks of it as *Typhlodromus oleivorus;* consequently this earliest emended spelling is accepted as the proper specific name.

ECONOMIC IMPORTANCE

In all probability the rust mite ranks third (*16, p. 3*) among the injurious pests on citrus in Florida, being exceeded in amount of damage done only by the purple scale (*Lepidosaphes beckii* Newm.) and the citrus white fly (*Dialeurodes citri* Ashm.), and the total loss sustained by the industry is very great. It is present over the entire citrus belt and no doubt occurs in greater or less numbers on every tree in the State, and when climatic conditions are favorable its rapid rate of reproduction enables it to cause great damage to the foliage and fruit in a very short time. In fact, in many instances fruit russets before the grower is aware of the presence of the rust mites in injurious numbers. On an average, more than 50 per cent of the fruit is more or less injured by rust mites. This lowers the grade, and such fruit brings from 25 to 50 cents a box less in the market than normally colored fruit. On the basis of a 16,000,000-box crop, 50 per cent of which would be russet and selling for 25 cents per box below the standard price, the loss would be $2,000,000 annually. To this must be added the loss due to the devitalization of the trees by the feeding of countless mites on the foliage.

HOST PLANTS

The citrus rust mite infests all commercial species and varieties of citrus grown in Florida. The host plants are here listed in the order of the severity of infestation, or as preferred host plants:

Lemon (*Citrus limonia*).
Lime (*C. aurantifolia*).
Citron (*C. medica*).
Grapefruit (*C. grandis*).
Sweet orange (*C. sinensis*).
Sour orange (*C. aurantium*).
Tangerine (*C. nobilis*, var. *deliciosa*).
Calamondin (*C. mitis*).
Satsuma (*C. nobilis*, var. *unshiu*).
Mandarin (*C. nobilis*, var. *deliciosa*).
Oval kumquat (*Fortunella margarita*).
Round kumquat (*F. japonica*).
Meiwa kumquat (*F. crassifolia*).

It has also been found on the following hybrids and other miscellaneous species of Rutaceæ:

Natsumikan 11184 11337.[3]
Siamelo 52007 1 8.
Tangor 539.
Tangelolo 47220.
Citrangequat 48010 D 5.
Faustrimedin 47431.
Faustrime 49806.
Eustis limequat.
Seedling orange Tample 11159.
Chaetospermum glutinosa 7138.
Cleopatra orange (*C. nobilis*, var. *deliciosa*) 11338.

No rust mites were found on the following species of Rutaceæ on any of the 34 examinations made during a period of more than two

[3] The numbers are those given to each variety by the Division of Crop Physiology and Breeding, Bureau of Plant Industry, U. S. Department of Agriculture.

years: *Severinia buxifolia*, *Chalcas exotica*, *Toddalia lanceolata*, *Glycosmis pentaphylla*, and *Aeglopsis chevalieri* (7633).

Only one mite each was found on *Citropsis schweinfurthii* (11260) and *Triphasia trifolia* throughout the entire two years, and it is only reasonable to suppose that these two rust mites were simply blown from some of the near-by infested trees and were merely resting on the foliage. All of the above species were planted near (less than 10 feet from) the other species which were infested with rust mites, and if the rust mite could maintain itself on them it certainly had an opportunity to do so.

The hybrids and species of Rutaceæ listed in Table 1 were growing on the laboratory grounds at Orlando, Fla., and examinations were made to determine the presence of rust mites thirty-four times from May 25, 1920, to August 3, 1922. The mites in the same number of half-inch squares[1] were counted for each species on each date. As a usual practice 5 squares on the upper surfaces of the leaves, 5 squares on the lower, and 5 squares on the fruit, if any were present, were counted. The numbers of rust mites found in the 34 examinations are given in Table 1.

TABLE 1.—*Number of rust mites found on the Rutaceæ growing in the laboratory grounds, Orlando, Fla., from May 25, 1920, to August 3, 1922*

Variety	1920									1921		
	May 25	June 23	Aug. 26	Oct. 16	Oct. 30	Nov. 13	Nov. 27	Dec. 11	Dec. 27	Jan. 8	Jan. 27	Feb. 8
Calamondin	8	80	10	53	316	0	1	0	0	0	0	0
Faustrime	3	23	135	17	80	0	0	0	6	1	0	0
Natsumikan	0	28	14	35	104	0	5	1	0	0	0	0
Siamelo	17	142	6	9	381	0	0	0	200	1	0	255
Tangor	4	238	33	8	223	0	0	0	0	0	0	0
Kumquat	22	204	21	1	97	0	0	0	1	0	3	0
Seedling orange	39	199	6	26	406	0	0	0	0	0	0	0
Chaitospermum glutinosa	6	18	0	1	1	0	0	0	2	0	1	0
Meiwa	-	-	-	-	-	-	-	-	-	-	-	-
P. Lolo R. L.	-	-	-	-	-	-	-	-	-	-	-	-
Cleo 11338	-	-	-	-	-	-	-	-	-	-	-	-
Total	108	932	225	150	1,608	0	6	1	209	2	4	255

Variety	1921											
	Mar. 1	Mar. 24	Apr. 15	May 2	May 17	June 1	June 14	July 5	July 15	Aug. 2	Aug. 15	Sept. 1
Calamondin	0	0	2	1	1	0	2	0	1	0	2	0
Faustrime	0	0	0	0	0	0	1	0	0	0	0	0
Natsumikan	0	0	0	0	0	48	0	7	32	0	33	1
Siamelo	4	0	0	2	5	4	150	0	2	0	0	28
Tangor	66	146	12	24	112	360	583	87	18	0	15	40
Kumquat	2	0	0	0	0	5	0	1	0	1	0	7
Seedling orange	3	1	0	0	0	31	113	1	5	104	12	4
Chaitospermum glutinosa	0	0	0	0	0	2	0	0	0	0	4	1
Meiwa	-	-	-	-	-	-	27	0	0	0	0	0
P. Lolo R. L.	-	-	-	-	-	-	14	1	0	0	0	0
Cleo 11338	-	-	-	-	-	-	89	0	0	0	211	59
Total	75	147	14	27	118	450	979	97	58	105	277	140

[1] The term "square" as used in this bulletin denotes an area one-half inch square and was used as the standard for determining the relative abundance of rust mites on the fruit and foliage of trees. In practice a piece of paper with an area one-half inch square cut out was placed over the leaf or fruit and all the mites within the square counted.

TABLE 1.—*Number of rust mites found on the Rutaceæ growing in the laboratory grounds, Orlando, Fla., from May 25, 1920, to August 3, 1922*—Continued

Variety	1921							1922			Total number of mites found May 25, 1920, to Aug. 3, 1922
	Sept. 15	Sept. 30	Oct. 15	Nov. 1	Nov. 16	Dec. 1	Dec. 15	Feb. 21	Apr. 3	Aug. 3	
Calamondin	0	0	5	7	26	44	28	0	9	4	602
Faustrime	0	6	2	0	0	0	0	0	0	0	274
Natsumikan	7	117	44	11	10	78	55	17	2	89	747
Siamelo	1	248	234	9	74	143	59	18	2	45	2,039
Tangor	85	84	72	95	404	270	94	78	1	77	3,229
Kumquat	4	135	131	82	173	103	196	11	1	16	1,217
Seedling orange	6	20	22	4	1	26	50	1	7	147	1,234
Chaitospermum glutinosa	0	0	0	0	0	1	0	0	0	0	37
Melwa	6	0	70	35	96	114	17	31	1	97	494
P. Lolo R. L.	52	4	90	63	27	18	27	21	2	115	434
Cleo 11338	76	19	15	10	2	6	9	0	0	41	537
Total	237	633	685	316	815	803	535	177	25	631	10,844

NOTE.—During the period covered by the examinations the trees were sprayed as follows: June 23, 1920, lime-sulphur solution, 1-66; Nov. 2, 1920, 1 per cent oil emulsion; June 15, 1921, 1 per cent oil emulsion; July 28, 1921, some trees were sprayed with 1 per cent oil emulsion.

The development of the rust mites on these plants was checked by the several sprayings. On June 23, 1920, a spraying was given with lime-sulphur solution, following which the mites did not get abundant in July, so no count was made. On October 30, however, the mites were quite abundant, but an application of lubricating-oil emulsion, made on November 2 for scale insects and white flies, was also effective in killing the mites. Another spraying with oil emulsion on June 15, 1921, for scale insects and white flies also greatly reduced the number of rust mites. During the spring of 1922 a very severe drought occurred from February until May, and the rust mites did not become abundant during this period.

The results of these examinations certainly indicate that the nearer the species and hybrids are to a true citrus, the more favorable the rust mite finds the food supply. The tangor, a cross between the tangerine and the sweet orange, was the most favorable host plant. The siamelo, which is a cross between the King orange and the grapefruit, was the second, and the seedling orange and kumquat were also favorable hosts. It is very doubtful whether *Chaitospermum glutinosa* should be considered a true host plant since so few mites were found on it.

SPECIFIC PREFERENCE

The citrus rust mite infests lemon more severely than any other host, and grapefruit much more severely than it does orange. From June 4 to 8, 1923, three counts were made of the rust mites in an equal number of half-inch squares on grapefruit and orange trees growing in adjoining rows. There were one and two-thirds times as many mites on the grapefruit as there were on the orange trees. The infestation records of rust mites on the check trees during the spraying work of several years, covering all seasons, show three and one-half times as many mites on grapefruit as on orange. Probably on an average, year after year, the infestation is about three times as severe on grapefruit as it is on orange. The infestation is much less severe on tangerine than it is on orange.

MITES MISTAKEN FOR THE CITRUS RUST MITE

In so far as is known there is only one species of rust mite attacking citrus in Florida, and consequently any Phyllocoptes mite found there is undoubtedly the rust mite which causes the enormous damage to the foliage and fruits. There are, however, several species of mites, some of them closely related, found on plants and shrubs growing in and near citrus groves, which could easily be mistaken for the citrus rust mite.

A mite that feeds on maiden cane resembles the citrus rust mite more closely, perhaps, than any other species observed thus far. It is lighter in color, more transparent, and considerably larger, but, like the citrus rust mite, it does not make a gall. The eggs, larvæ, and adults may be found on the host plant in May, June, and July. It could not be found, however, early in October. Both mites evidently reach their period of maximum infestation at about the same time. It was first observed in 1919 at Plymouth, Fla., and since that time in Orlando and south of Orlando, and about many other groves. Several attempts were made to transfer these mites to leaves of citrus trees under observation, but in all cases the mites remained only a day or two and then disappeared.

In 1914 a mite resembling the citrus rust mite was reported by the writer, on roses (*13*). It is pinkish or lavender in color and perhaps somewhat smaller than the citrus rust mite. It also does not make a gall. Eggs, larvæ, and adult mites are present on the foliage most abundantly about the 1st of June, but soon after that it largely disappears. While present in great abundance, it does not seem to cause serious injury to the plant beyond the crinkling of the young leaves in some cases. On the theory that these might be the same mites which infest citrus trees, some experiments were made to determine whether the citrus rust mite could live on rose foliage. Several mites were transferred to the rose bushes, and some of them lived for two or three days, but they were unable to maintain themselves there, and most of them disappeared within a day. Subsequent examinations have shown that the rose mite is distinctly different although superficially resembling the citrus rust mite.

Several of the gall-forming mites also resemble the rust mite very closely both in size and general appearance. Although gall forming is characteristic of the Eriophyidæ as a class, the citrus rust mite is one of the few exceptions in the family. Some of these gall-forming mites were observed on trees around citrus groves. A gall-making mite infesting persimmon is usually present in great abundance in late May, June, and July, but it is not known how it passes the winter, as the persimmon sheds its foliage. There is also a gall-forming mite found on sumac. This mite is present in great abundance in May and June crawling over the foliage. In August it appears to be only on the inside of the galls. In October the galls, of course, are present, but examinations showed no mites within.

Free-feeding mites have also been found on a briar, a bamboo, and a native plant resembling the rubber plant, but since only single specimens were observed no data relating to them are available.

Although little is known of the biology of these various species of mites it is most interesting and remarkable that they reach the period of maximum infestation at about the same time as does the citrus rust mite and then disappear. It may be that these species are attacked by the same fungus that attacks the citrus rust mite.

RUST-MITE INJURY

INJURY TO THE FRUIT

NATURE OF INJURY

The rust mite, being possessed of piercing mouth parts, punctures the epidermal cells of the rind of the fruit. This injury, when excessive, destroys the outer layers of cells, as shown in Figure 1, B. This

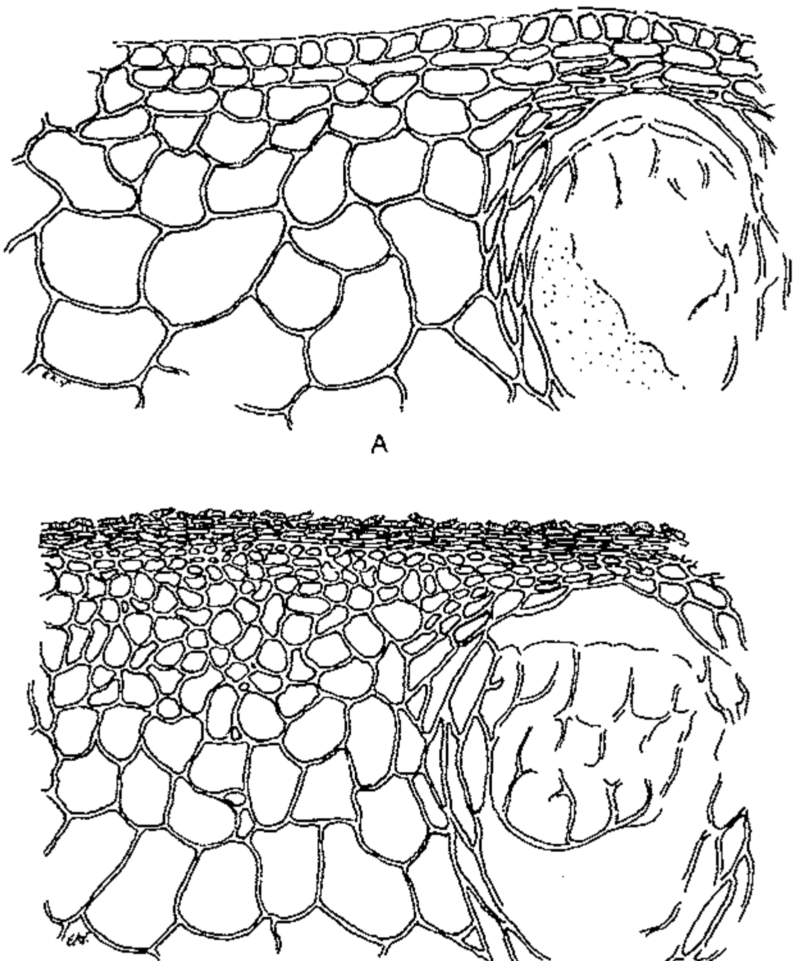


FIGURE 1. Magnified section of grapefruit rind: A, Normal cellular structure; B, cellular structure showing flattened epidermal cells after severe injury that has produced "shark skin"

illustration shows that the outer layers of epidermal cells have been largely flattened or destroyed. It will be noticed (fig. 1, A) that the epidermal cells of the normal grapefruit are more or less rectangular in shape and are much thicker than the cells of the injured fruit.

When this injury, in the case of orange, is only slight the blemish results in a grade of fruit known as "golden." If it is very severe when

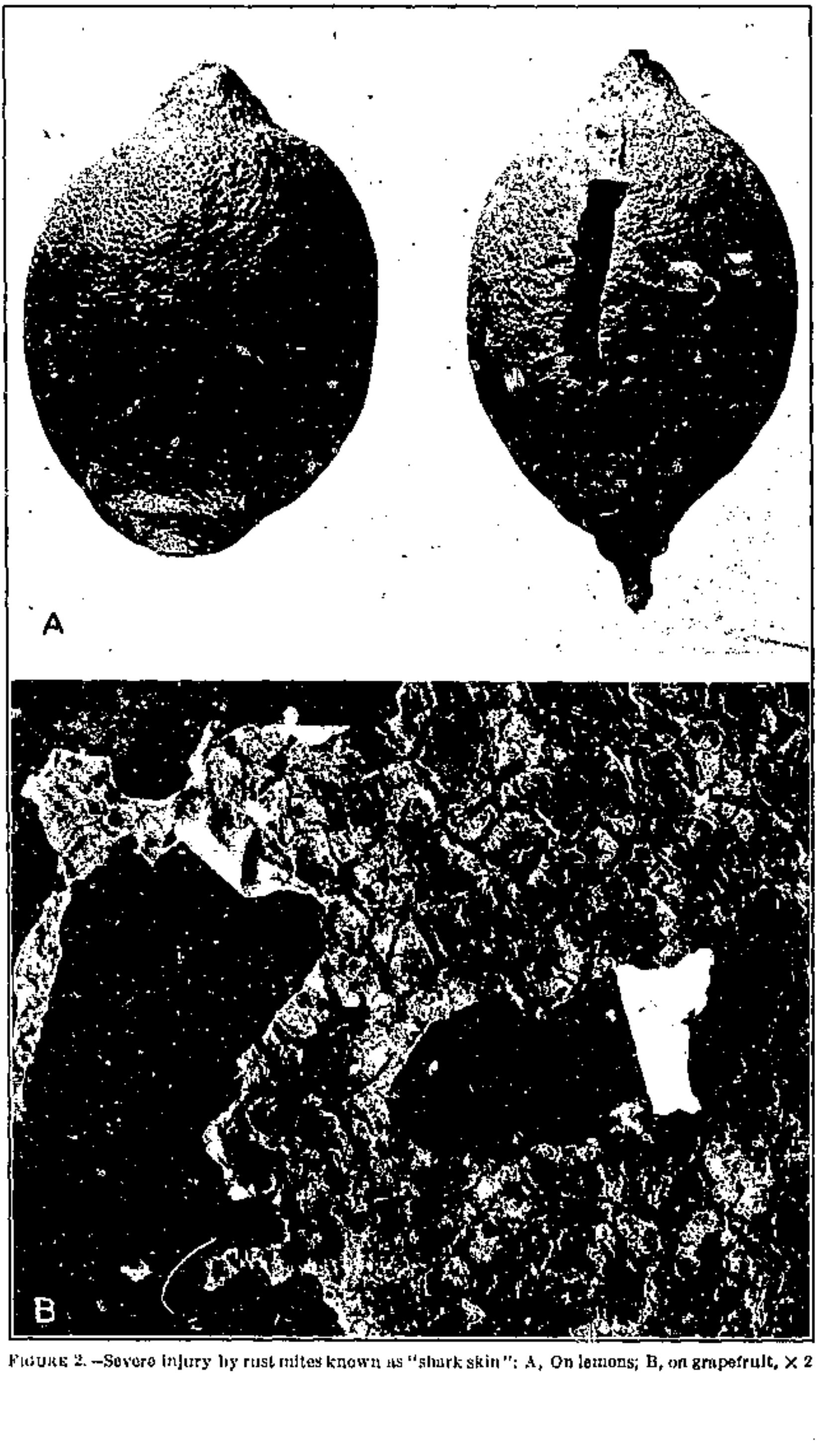
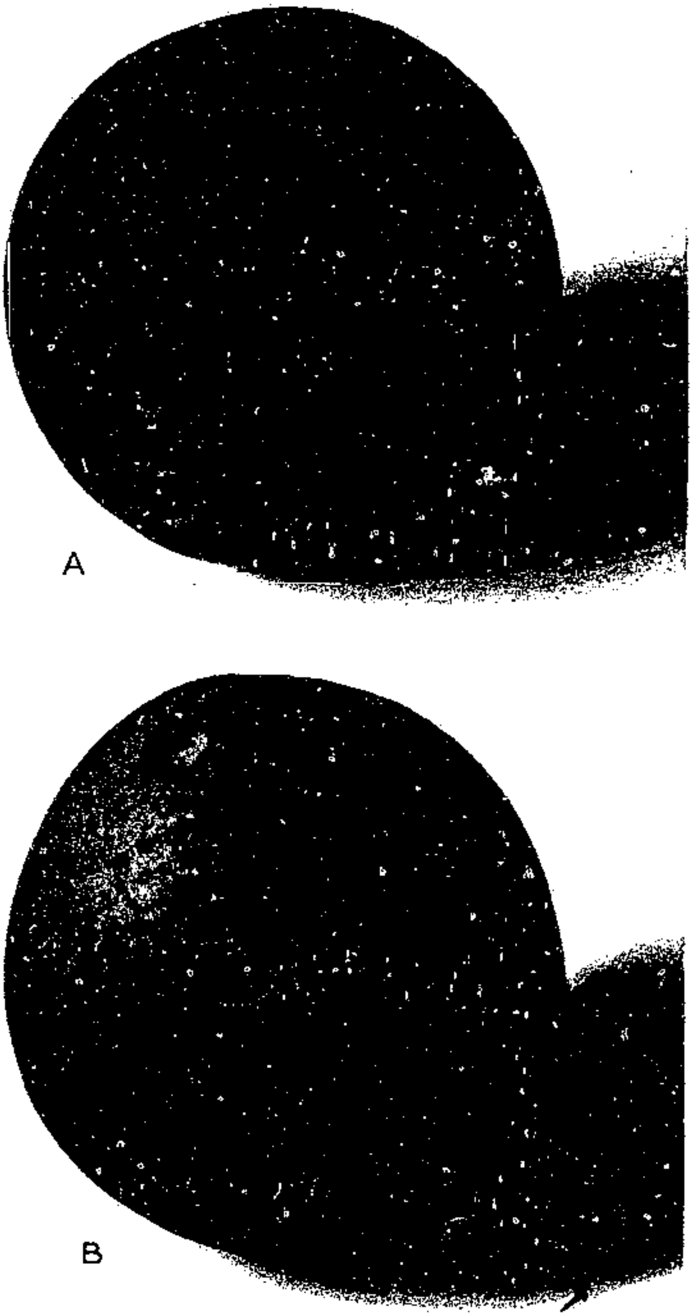


FIGURE 2.—Severe injury by rust mites known as "shark skin": A, On lemons; B, on grapefruit. × 2



ORANGES INJURED BY FEEDING OF RUST MITES

A, Type of severe injury known as "black russet."
B, Less severe injury known as "russet."

the fruit is young "black russet" develops. (Pl. 1, A.) When it is quite severe but does not cover all the rind it is known as "russet." (Pl. 1, B.) The same term can be applied with reference to injury on grapefruit excepting that when the rust-mite injury is excessive on young fruit it develops into what is known as "shark skin." (Fig. 2, B.) When grapefruit or lemons are thus injured, the epidermal cells can be turned back and peeled off. (Fig. 2.) In many instances the presence of thousands of rust mites on a single fruit stunts its growth and prevents it from developing into a normal fruit. These stunted fruits are very small and are practically all rind. The rind of both russet oranges and russet grapefruit and of shark-skin grapefruit is much thicker than it is on normal fruit; in fact, excessive injury from rust mites produces fruit which might be termed citrus galls. (Fig. 3.)

Until the last few years the blemish known as "tear stain" (fig. 4) was thought to be due to a fungous disease, but it is now known to be the result of rust-mite attack (*11*).

PROOF THAT THE INJURY IS CAUSED BY RUST MITES

Although it is universally believed by citrus growers that russeting is caused by rust mites, some experiments were carried on to furnish positive proof that such was the case. On July 5, 1919, several designs were painted with pure lime-sulphur solution on fruits heavily infested with the rust mite. The lime-sulphur solution killed the rust mites upon the surface of the orange where it was placed, leaving the rest of the fruit to be attacked by the mites. These fruits were picked on March 19, 1920. Some of the lime-sulphur designs showed very distinctly, while in other cases they appeared as bright spots. The lime-sulphur in some cases no doubt killed the mites at a considerable distance from the design, which accounted for the appearance of a bright spot instead of the distinctive design. In some cases, however, letters painted on the fruit showed very distinctly as bright lines on the russeted fruit. This experiment certainly shows that russeting follows the feeding by rust mites, and, further, that one part of an orange may be protected so as to be bright while the rest of it may become russeted.

ATTEMPTS TO PRODUCE ARTIFICIAL RUSSETING

Since rust mites puncture the skin of the orange it was thought that some artificial means could be used to imitate the work of the mite and thereby produce at will the russeting as well as the severe form of injury known as shark skin on grapefruit. On December 20, 1916, half of the several fruits were hit with the bristles of a stiff hairbrush. Over other fruit the hairbrush was rubbed quite vigorously. In both instances it was quite evident that several oil cells had been punctured, as the odor of the oil could be very readily detected. A heavy rain fell eight hours afterward. By February 8, 1917, no injury resembling in the slightest degree rust-mite injury had developed. Severe spots had resulted on some of the fruit. A freeze on February 2 had caused most of the fruit to fall, so a complete record was not available.

Again, on May 23, other experiments were conducted to imitate the rust-mite injury. The fruits were about 1 inch in diameter and were pricked with a hairbrush having stiff bristles. On June 8 these fruits

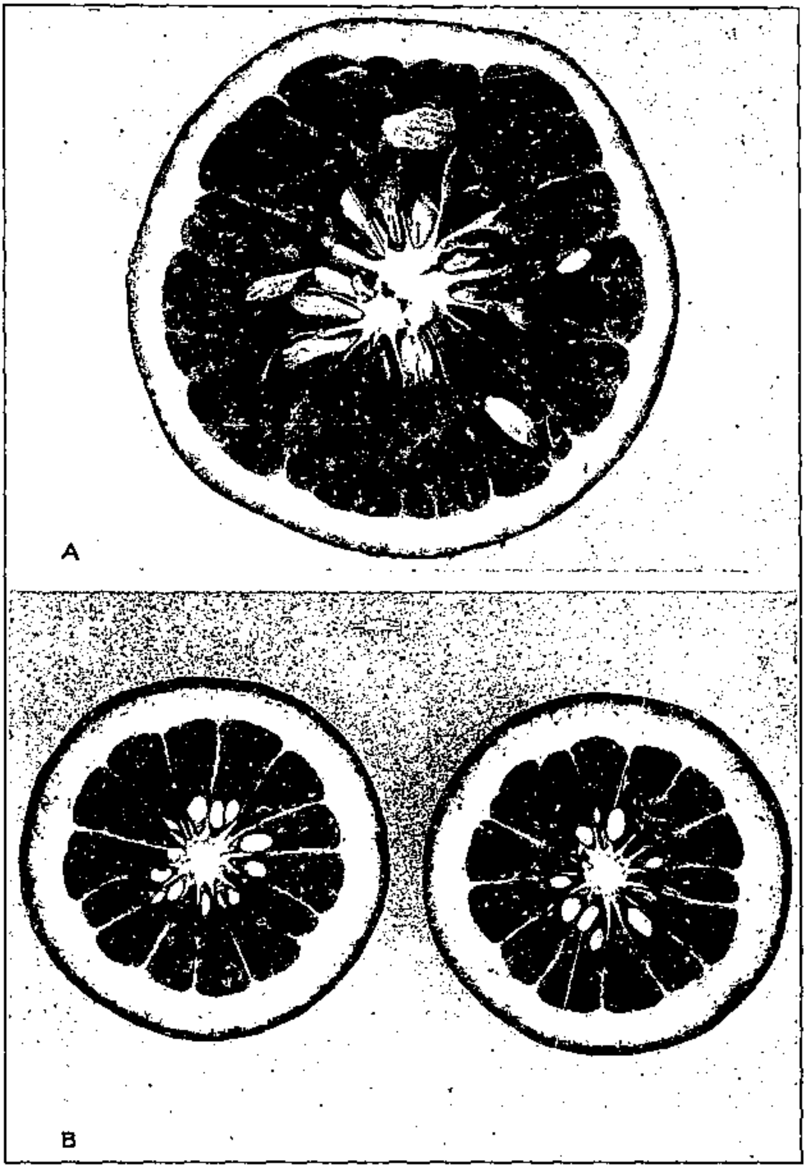


FIGURE 3.—Grapefruit cut open to show effect of rust-mite injury: A, A normal, uninjured fruit; B, injured fruit showing the thickened skin and the smaller size of the fruit which contains practically no juice

were showing rust wherever the oil cells of the skin were broken by the bristles. As a general thing the injury was coarse and in spots and did not in the slightest degree resemble that of rust mites. On June

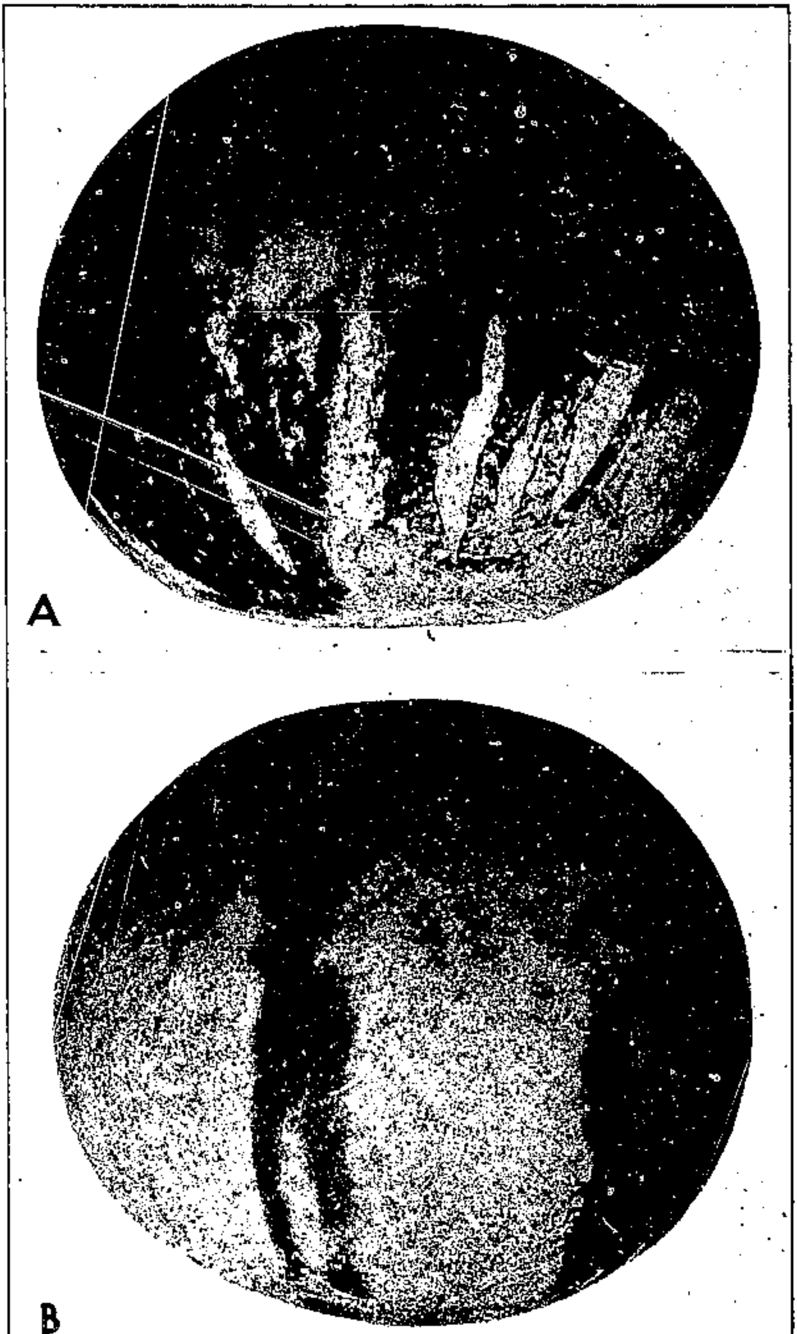


FIGURE 4.—Grapefruits showing the results of infestation by rust mites: A, An example of what may be termed "multiple tear stain"; B, a fruit showing a form more distinctly marked. These variant types of injury are frequently observed. One side of the fruit may be severely russeted and the other side bright or tear stained

5, 1918, the entire surface of 25 oranges and only half of the surface area of 25 additional fruits were struck with the bristles of a toothbrush. On December 1, 1918, 44 of these fruits were picked. Not a single one had a blemish resembling the rust-mite damage; in fact the injury was purely mechanical.

Additional experiments were carried on in 1922 with grapefruit which were about 4 inches in diameter, and some June-bloom fruits 1 inch in diameter were also used. Distilled orange oil was put on the fruit with an atomizer. Twenty minutes after this oil was sprayed on the fruits they showed brown spots where the oil had hit them. Those in the sun showed more pronounced burning than those in the shade. On the following day the fruit showed severe injury. The larger grapefruit, and lemons similarly treated, had dark-brown areas where the oil came in contact with the rind. Some of the leaves also were injured and had dead spots in them. The young grapefruit were black and deformed from the effects of the oil. On July 14, three days after the experiment was started, all the fruits were brown, and the injury very severe. On July 17 one fruit had turned yellow and had dropped off. The others were badly injured and were starting to decay. Gum exuded from the brown areas. On July 20 the fruits had all dropped or were yellow and badly deformed.

Another experiment was conducted to show the effects of oil on fruit. Six more fruits—lemons and grapefruit—were sprayed with the distilled orange oil, the atomizer being held 10 or 12 inches from the fruit and the oil sprayed into the air and allowed to drift on to the fruits. In this way only a very small quantity of spray hit the fruit. On the following day no injury whatever could be seen on the fruit. On July 17 some of the fruits were sprayed for the second time, and also some new fruits were sprayed. On the following day none of the fruit showed any effect whatever of the oil. As late as August 16 the fruit sprayed lightly with orange oil showed no injurious effects.

Several other methods were used in attempting to produce an injury similar to rust-mite injury. In June, 1921, green oranges were ground up with a meat grinder, and some of this pulp was bound on several oranges with oil paper and left for 24 hours. This produced no injury. Other oranges were dipped in the juice of these ground oranges for periods ranging from 10 seconds to 2 minutes, with no resulting injury. On August 15, 1922, a slice of black walnut was rubbed over several fruits, and no injury resulted. Fruits dipped in a dilution of 5 c. c. of sulphuric acid to 50 c. c. of water fell off without developing any russet. In another experiment the pulp of ground oranges was spread on the fruit and no damage resulted. On July 17, 1922, a great many designs were made on fruit by puncturing the oil cells with a very fine needle, so that the contents ran out over the surface of the fruit. After 24 hours the designs on the fruit showed up very distinctly, somewhat resembling rust-mite work, but they were very coarse. At the end of three days they were much more noticeable, but they were then entirely too coarse to resemble rust-mite work. Various substances, such as pumice stone or fine sandpaper, have been tried, but all these materials were so coarse that the injury resulting did not resemble rust-mite injury in the slightest degree.

EFFECT OF THE INJURY

LOWERING OF THE GRADE

The blemish caused by the presence of rust mites lowers the grade of the fruit. This has been discussed in considerable detail by the senior author (*15, p. 8*), who showed that during the winter of 1915–16 there was approximately 13 per cent of first-grade, 41 per cent of second-grade, and 46 per cent of third-grade fruit shipped from Florida. It was also shown that by controlling the rust mite with lime-sulphur solution the grade of fruit was raised in several groves, so that 35 per cent was shipped as first grade, 50 per cent as second, and the remaining as third and fourth grades.

REDUCTION OF THE SIZE OF FRUITS

The injury following rust-mite feeding prevents the fruit from attaining its normal size. In just what manner this is accomplished is not known, except that it is due to injury of the epidermal cells. This reduction in size has also been discussed by the senior author (*15, p. 8*). It was shown that the russet fruit is, on the average, about 12½ per cent, or one size, smaller than bright fruit.

INCREASE OF EVAPORATION OF THE WATER CONTENT

It is well known that russet fruit becomes wrinkled in appearance in a very short time after it has been taken from the trees. The results, so far as available, show that the percentage of evaporation of the water content from russet fruit is about twice as great as that from bright fruit (*15, p. 12*).

SUNBURN

It is well known that when russet oranges are left on the trees until late spring quite a large number of them are rendered unmarketable because of the effect of the sun on the rind. Since the normal protection of the rind has been destroyed by the rust mites, the hot sun breaks down the oil cells over a considerable area of the part turned toward the sun, and a large black spot develops. In some instances this affects a considerable portion of the crop, depending, of course, upon the time the fruit is picked. The later in the season the greater the damage.

MORE RAPID DECAY

Experiments which showed that russeted fruit decayed more rapidly than bright fruit were carried on by the senior author (*15*). In addition to these, other experiments were conducted from February 1 to April 15, 1919. One hundred bright fruit and one hundred russet fruit were put in pasteboard plates, which were then placed on shelves in the laboratory. The bright fruits were not what would be termed absolutely bright, and the russets were affected to a greater or less extent by other blemishes than those caused by rust mites, although an attempt was made to select fruit affected only with rust-mite injury. Careful examinations were made of all fruits used in the experiment so as to select only fruit free from mechanical injury.

This will account, perhaps, for the small quantity of blue mold which developed during the experiment. The results of the examinations which were made from time to time are given in Table 2.

TABLE 2.—*Rapidity of decay in russet fruit and bright fruit (100 of each) picked February 1, 1919*

Date of examination	Number of bright fruit decayed from—		Number of russet fruit decayed from—	
	Blue mold	Stem-end rot [1]	Blue mold	Stem-end rot [1]
Feb. 12 [2]	2	0	0	0
Feb. 19	3	0	0	0
Mar. 1	0	6	0	21
Mar. 10	5	6	0	12
Mar. 13	0	1	0	3
Mar. 18	0	3	0	4
Mar. 20	0	5	0	18
Mar. 27	0	4	0	6
Mar. 31	0	9	0	7
Apr. 5	0	12	0	10
Apr. 15	0	14	0	6
Total	10	60	0	87

[1] *Phomopsis citri.*
[2] All russet fruits were shriveled on this date.

At the end of one month only 6 per cent of the bright fruit had decayed from stem-end rot while 21 per cent of the russet fruit had decayed. At the end of two and one-half months 60 per cent of the bright and 87 per cent of the russet fruit had decayed from stem-end rot. It may be that some of this decay was brought about by the fruit being affected with melanose russet instead of rust-mite russet. Every possible effort, however, had been made to select only fruit that showed rust-mite injury instead of melanose russet. The russet fruit shriveled up much faster than did the bright fruit.

CHEMICAL ANALYSES OF BRIGHT AND RUSSET ORANGES

There is an almost universal belief that russet fruit is sweeter than the bright or natural-colored fruit. As to the origin of this belief, the writer has no explanation to offer other than that the russet fruit is seldom sold before the holidays; hence it is never eaten before it has had ample time to ripen, so no russet fruit is ever sour. Bright fruit is usually sold early in the season, and therefore may not have had time to mature fully.

As far as is known no analyses of bright and russet fruit had been previously made so that these could be compared. It was thought advisable therefore to make analyses of these two classes of fruit to determine if this belief had any foundation in fact.

The analyses were made by the division of drug, poisonous, and oil plants, Bureau of Plant Industry. The results, corrected for temperatures, are given in Table 3.

The bright and russet fruit in the first half of the table were taken from two seedling orange trees in the same grove, the former having been sprayed with lime sulphur the previous July and the latter left unsprayed throughout the entire season. The grove treatment was the same for both trees excepting that the tree of bright fruit had received some stable manure a year or more before the date of the analyses. The commercial fruits were taken from the packing house and had been graded by the packing-house grader. Twelve fruits were used for each test on each date.

TABLE 3.—*Difference in soluble solids and anhydrous citric acid in bright and russet oranges, Orlando, Fla.*

Date picked	Date analyzed	Anhydrous citric acid	Soluble solids	Ratio of anhydrous citric acid to soluble solids
BRIGHT FRUIT TAKEN FROM TREE				
1917	1917	*Per cent*	*Per cent*	
Nov. 1	Nov. 10	1.22	9.93	1- 8.14
Nov. 10	do	1.07	9.20	1- 8.60
Nov. 20	Nov. 23	1.19	10.50	1- 8.82
Nov. 30	Nov. 30	1.29	10.50	1- 8.14
Dec. 10	Dec. 20	1.22	11.52	1- 9.44
Dec. 20	do	1.19	11.27	1- 9.47
Dec. 30	Dec. 30	1.03	11.52	1-11.18
RUSSET FRUIT TAKEN FROM TREE				
Nov. 1	Nov. 10	1.39	10.50	1- 7.55
Nov. 10	do	1.26	9.93	1- 7.88
Nov. 20	Nov. 23	1.31	10.50	1- 8.01
Nov. 30	Nov. 30	1.44	10.50	1- 7.29
Dec. 10	Dec. 20	1.44	12.22	1- 8.48
Dec. 20	do	1.46	12.41	1- 8.50
Dec. 30	Dec. 30	1.10	11.52	1-10.47
BRIGHT FRUIT TAKEN FROM PACKING HOUSE				
Nov. 10	Nov. 12	0.97	8.82	1-9.09
Nov. 23	Nov. 23	1.50	11.90	1-7.93
Nov. 30	Nov. 30	1.43	11.68	1-8.17
Dec. 20	Dec. 20	1.22	11.52	1-9.44
RUSSET FRUIT TAKEN FROM PACKING HOUSE				
Nov. 10	Nov. 12	1.92	10.21	1-5.33
Nov. 20	Nov. 23	1.82	10.97	1-6.03
Nov. 30	Nov. 30	1.45	10.70	1-7.38
Dec. 20	Dec. 20	1.31	11.68	1-8.91
BRIGHT AND RUSSET FRUIT FROM THE SAME SEEDLING TREE				
BRIGHT				
Nov. 5	Nov. 5	1.73	10.72	1-6.20
RUSSET				
Nov. 5	Nov. 5	1.70	9.77	1-5.75

The total soluble solids in the bright fruit from trees were less than those in the russet fruit in four analyses and equal in three, and the anhydrous citric acid was less in the bright fruit in all tests. Owing to the larger quantity of acid in the russet fruit the proportion of acid was less in the bright fruit in every test. In the commercial bright fruit the total soluble solids were greater than they were in the russet in two tests and less in two tests. These russets also had a greater quantity of citric acid than the commercial brights, which caused every test to show a lower proportion of acid in the bright than in the russet fruit.

The russet fruit picked November 20, 1917, was much more tart than the bright. The commercial russets were extremely tart, very sour, and not fit for use.

The juice of the bright fruit taken from the packing house on November 30 was much better flavored and considerably sweeter than that of the russet. The same was true of the sprayed and unsprayed fruit.

On December 20 the same was found true of both the fruit from the grove and from the packing house.

Another analysis was made on November 5, 1919, by H. D. Poore of the then Bureau of Chemistry. The samples of fruit were picked from a seedling tree.

It will be seen that the russet fruit is not so sweet as the bright fruit even though from the same tree. The foregoing analyses show that the rust-mite injury retards the ripening to a considerable extent. Toward spring, after considerable of the water content has evaporated through the rind of the russet fruit, the ratio of the sugar content to acid content may be much greater and therefore such fruit may be really sweeter.

INJURY TO THE LEAVES AND BRANCHES

INJURY TO THE LEAVES

The rust mites when present on the upper surfaces (*5*) of citrus leaves cause a roughening or stippling effect that can be detected by touch. The leaves lose their glossy appearance and no doubt lose a large part of their waxy covering, which increases the rate of evaporation. The rust mites, when present in great abundance, also cause a bronzing of the lower surfaces of the leaves, but in some cases it is also present on the upper surfaces. In a number of instances rust mites have been so abundant in the spring that the size of the leaves was reduced. No doubt the devitalization caused by the presence of thousands of rust mites on citrus foliage is much greater than the average grower realizes.

INJURY TO THE BRANCHES

Rust mites are also found on the branches just after they have become reasonably mature, in some cases so abundantly as to cause russeting on the bark. This is especially true on lemon and grapefruit, and is also more frequently found on water shoots than on regular growth. Since an injury to wood is much more serious than an injury to foliage the devitalization caused by the presence of rust mites on the branches must be considerable.

LIFE HISTORY AND HABITS

METHODS OF REARING

Observations made both in the laboratory and in the field had given a general impression of the various stages, oviposition, metamorphosis, etc., of the rust mite, but because of its extremely small size as well as its wandering habits many difficulties were encountered when individual mites were reared in cages in order to determine the length of the various stages and other factors regarding their life history. Unless confined in a very small cell, the mites were easily lost or would get into a crevice or other place where it was impossible to find them. Their minute size always necessitated the use of a hand lens when working with them and many times the binoculars were needed when making examinations. Besides this, the mites have the habit of wandering around considerably and hence will not live long in confinement. This is especially true of the adults, which could usually be kept for only a few days. A fresh supply of food is always necessary since the mites failed to live on withered or dry fruit and leaves. This necessitated transferring them from one fruit to another, and many were lost or injured in this process. Many rearings, therefore, had to be started in order to carry through a few of them successfully.

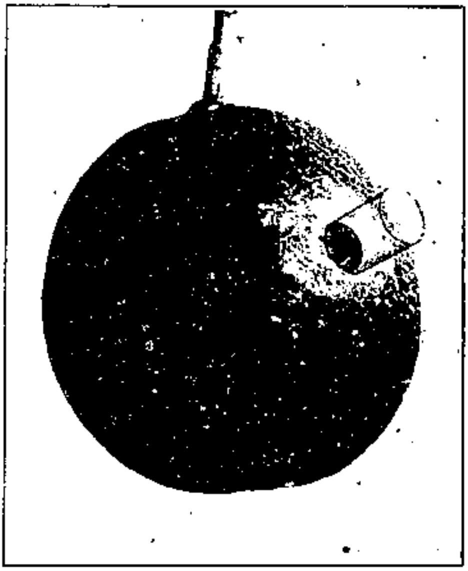


FIGURE 5.—Cage used for rearing rust mites. The cage consists of a gelatin capsule fastened on the surface of the orange with melted paraffin. This method causes no injury to the rind and prevents the exudation of juices detrimental to the mites under observation

Repeated efforts to raise the mites for observation purposes on very small trees or isolated portions of trees or leaves were unsuccessful since they could not be found when wanted. It was necessary, therefore, to devise a cage in which they would live and could be observed at regular intervals. Various types of cells made of felt and pasteboard, bone rings, etc., were devised, and attempts were made to rear the mites in these cells placed over the leaves and fruit. The cage finally adopted (fig. 5) as being the most satisfactory consisted of a No. 0 gelatin capsule secured on a fruit by means of hot paraffin placed around the outside and allowed to harden. In this cell the mites would sometimes live for several days or until the fruit began to dry, when they could be transferred to a fresh fruit. At first the entire half capsule was used, but it was later found that by cutting off the end and using only the gelatin cylinder more satisfactory observations could be made since the convex surface at the end of the capsule reflected the light and made it difficult to see inside. With the cylinder open, air was admitted, and the mites did not often attempt to crawl up the perpendicular sides.

These capsules could be placed on the fruits, and they made fairly satisfactory breeding cages. No injury was done to the surface of the orange, and the green fruit could be kept fresh and in good condition for several days by putting the stem in water. During the spring and early summer, when the mites were reproducing in greatest abundance, the fruits were of a convenient size to handle (one-half inch to 2 inches in diameter). Later in the fall, when the oranges began to color up, the mites could not readily be found on them since they were too nearly the color of the fruit. The leaves and stems were never successfully used since they soon withered and dried.

As already stated, confinement in the small cells lessened the normal activities of the mites to some extent and perhaps interfered with their regular life processes. It is believed, however, that the results obtained will at least approximate what occurs in natural life.

Detailed records of the various stages of the citrus rust mite are given in Table 4.

TABLE 4.—*Length of the various life stages of the rust mite for summer and winter, Orlando, Fla., 1922 and 1923*

Date deposited	Number of eggs	Date hatched	Duration of egg stage	Date molted	Duration of first larval stage	Date molted	Duration of second larval stage	Date of first oviposition	Duration of preoviposition period	Date died or lost	Length of adult life
			Days		*Days*		*Days*		*Days*		*Days*
May 26	1	May 29	3	......	......	......	......	......	......	May 30	......
26	2	May 30	4	June 1	2	June 3	2	June 4	1	June 7	4
26	1	May 29	[1] 3½	...do...	2½	June 2	1	......	......	June 6	4
26	1	May 30	4	...do...	2	...do...	1½	June 3	1	June 13	11
26	2	May 29	3	......	......	......	......	......	......	May 30	......
26	1	May 30	4	June 1	2	June 3	2	June 5	2	June 9	6
27	1	...do...	3	...do...	2	June 2	1	...do...	3	June 11	9
27	1	May 31	4	......	......	......	......	......	......	June 1	......
27	1	May 30	3	June 1	2	June 2	1	......	......	June 10	8
27	1	...do...	3	...do...	2	...do...	1	June 5	3	June 11	9
27	1	May 31	4	...do...	1	......	......	......	......	June 3	......
30	1	June 2	3	June 3	1	June 5	2	......	......	June 6	1
30	1	...do...	3	June 4	2	......	......	......	......	...do...	......
June 1	1	June 5	4	June 6	1½	June 7	1½	June 11	3½	June 20	13
1	1	...do...	4	...do...	1½	June 8	1½	......	......	June 9	1
1	1	June 4	3	June 5	1	June 7	2	June 10	3	June 14	7
1	1	...do...	3	...do...	1	June 8	3	......	......	June 8	......
2	1	June 6	4	June 7	1	...do...	1	......	......	June 18	10
2	1	...do...	4	...do...	1	...do...	1	......	......	June 22	14
2	1	...do...	4	...do...	1	...do...	1	......	......	June 8	......
5	1	June 7	2	June 9	2	June 10	1	......	......	June 11	1
5	2	...do...	2½	......	......	......	......	......	......	June 8	......
5	1	...do...	2	June 9	2	June 11	2	......	......	June 14	3
5	1	...do...	2½	......	......	......	......	......	......	June 7	......
5	3	June 8	3	......	......	......	......	......	......	June 8	......
6	1	June 10	4	June 12	2	June 13	1	......	......	June 16	3
6	1	June 9	3	June 11	2	June 12	1	......	......	June 19	7
6	1	...do...	3	...do...	2	...do...	1	......	......	June 12	......
7	2	...do...	2	......	......	......	......	......	......	June 9	......
7	1	June 10	3	June 12	2	June 13	1	June 15	2	June 17	4
7	3	June 9	2	......	......	......	......	......	......	June 9	......
7	1	June 10	3	June 12	2	June 13	1	June 15	2	June 20	7
7	1	...do...	3	......	......	......	......	......	......	June 10	......
8	1	...do...	2	June 12	2	June 13	1	......	......	June 22	9

[1] Observations were made twice daily. Where fractions of days occur the transformation was observed in the afternoon.

TABLE 4.—*Length of the various life stages of the rust mite for summer and winter, Orlando, Fla., 1922 and 1923*—Continued

Date deposited	Number of eggs	Date hatched	Duration of egg stage	Date molted	Duration of first larval stage	Date molted	Duration of second larval stage	Date of first oviposition	Duration of preoviposition period	Date died or lost	Length of adult life
			Days		*Days*		*Days*		*Days*		*Days*
June 8	1	June 10	2	June 12	2	June 13	1			June 13	
9	1	June 12	3	June 14	2	June 15	1	June 24	9	June 26	11
9	1	do.	3	do.	2	do.	1	June 17	2	June 19	4
10	1	June 13	3½	June 15	2	June 16	1			June 17	1
13	1	June 16	3	June 18	2	June 19	1	June 22	3	June 27	8
13	1	do.	3	do.	2	do.	1			June 19	
15	1	June 18	3	June 19	1	June 20	1			June 25	5
15	1	do.	3	do.	1	June 21	2			do.	4
16	1	June 19	3	June 21	2					June 21	
17	1	June 20	3	June 22	2	June 23	1			June 24	
17	1	do.	3	do.	2	do.	1			June 25	
19	1	June 22	3	June 23	1	June 24	1			do.	
27	1	June 30	3							July 1	
28	1	do.	2½							June 30	
28	3	July 2	4							July 3	
28	1	do.	4							July 2	
28	1	do.	4							do.	
28	1	July 1	3	July 3	2	July 5	2			July 17	12
28	1	do.	3	do.	2	do.	2	July 7	2	July 14	9
29	2	July 2	3	July 4	2	do.	1			July 7	2
30	1	July 3	3							July 3	
30	1	do.	3	July 4	1	July 5	1	July 7	2	July 13	8
30	3	do.	3	do.	1	do.	1			July 5	
30	1	do.	3½							do.	
July 1	1	July 4	3							July 4	
1	1	do.	3½	July 6	2	July 7	1	July 11	4	July 20	13
1	1	do.	3							July 5	
7	1	July 10	3	July 12	2	July 14	2			July 25	11
7	1	do.	3	do.	2	do.	2			July 14	
7	1	do.	3	do.	2	do.	2			July 18	4
7	1	do.	3½	do.	2	do.	2	July 15	1	July 20	6
7	1	do.	3	do.	2	do.	2	July 18	4	July 19	5
7	2	do.	3	do.	2	do.	2			July 20	
7	1	do.	3	do.	2	do.	2			July 14	
7	1	do.	3	do.	2	do.	2			July 18	
8	1	July 11	3	do.	1	do.	2			July 19	
8	1	do.	3½	July 13	2	do.	1			July 31	17
9	1	July 12	3	July 14	2	July 15	1	July 17	2	July 20	5
10	2	do.	2	do.	2	July 16	2			July 25	9
10	2	July 14	4	July 16	2	July 17	1			July 17	
10	1	July 12	2							July 12	
10	1	do.	2½	July 14	2	July 16	2			Aug. 2	17
10	1	do.	2½	July 15	3					July 15	
11	2	July 14	3	July 16	2	July 17	1			July 25	8
12	1	July 15	3	July 18	3	July 19	1			do.	6
12	1	do.	3							July 15	
14	1	July 16	2	July 19	3	July 20	1			July 26	6
14	1	do.	2							July 16	
14	1	July 17	3	July 19	2	July 20	1			July 27	7
Average for summer			3.05		1.82		1.34		2.66		6.89
	1	Jan. 5		Jan. 10	5	Jan. 23	13			Jan. 30	7
	1	do.		Jan. 9	4	Jan. 15	6	Jan. 22	7	do.	15
Jan. 2	1	Jan. 6	4	do.	3	Jan. 14	5	Jan. 17	3	Jan. 26	12
2	1	Jan. 8	6								
2	1	do.	6	Jan. 12	4	Jan. 16	4				
5	1	Jan. 9	4								
6	3	Jan. 10	4								
9	1	Jan. 15	6								
10	2	Jan. 16	6								
17	1	Jan. 25	8	Jan. 29	4	Feb. 2	4				
21	1	Jan. 26	5	Jan. 30	4						
22	1	Jan. 29	7								
26	4	Jan. 30	4								
	1	Jan. 26		Feb. 1	6						
Average for winter			5.07		4.3		6.4		5		11.3

THE EGG

DESCRIPTION

The eggs (fig. 6, B) of the rust mite are found on the fruit and leaves, usually in the pits or depressions of the surface. Although laid singly, several usually occur together in a group but never so close as to touch one another. They are very minute, and it is almost impossible to see them without the aid of a hand lens unless they are present in groups. The egg is spherical with a smooth regular surface and semitransparent or pale translucent yellow. In spite of their small size the eggs are relatively large for the size of the female, and only one or two developed eggs occur in the abdomen at one time.

INCUBATION PERIOD

The incubation period of the egg is of brief duration during hot weather. One hundred eggs under observation during the months of

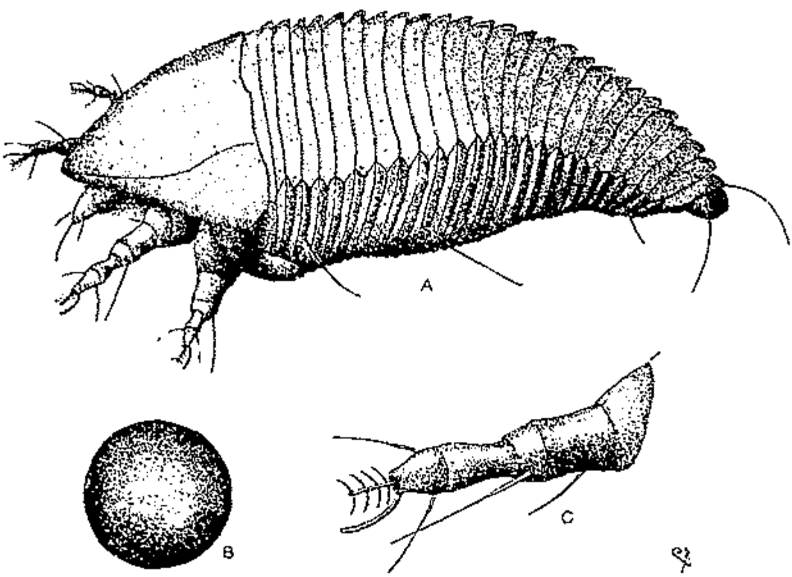


FIGURE 6.—The citrus rust mite: A, Adult, × 700; B, egg, × 825; C, one leg showing appendages, × 1,500

May, June, and July, 1922, at Orlando, Fla., as shown in Table 4, ranged in the length of the developmental period from 2 to 4 days with an average of 3.01 days. In these months the mites increase in greatest numbers on the trees and cause the most injury to the green fruits. The temperatures recorded during this period were as follows: For May the maximum temperature ranged from 80° to 99° F., with a mean of 90.9° and a mean minimum of 65.9°, and a total precipitation of 5.88 inches; for June the maximum ranged from 88° to 99°, with a mean of 92.9°, and a mean minimum of 70°, and a total precipitation of 9.75 inches; for July the maximum ranged from 87° to 101°, with a mean of 93.4°, and a mean minimum of 71.4°, and a total precipitation of 4.84 inches.

During the winter months the period of incubation is considerably extended. In January, 1923, the time ranged from 4 to 8 days, with an average of 5.53 days. The maximum temperature during this month ranged from 64° to 88° F., with a mean of 77.2°, and a mean minimum of 48.1°, total precipitation 0.56 inch. Doubtless this time would be considerably lengthened for eggs deposited during very cold spells. Hubbard (*7, p. 115*) states that the incubation period seldom exceeds two weeks.

HATCHING

During the last few hours of the incubation period the young mite can be seen inside of the egg, curled up to fit into the spherical shell. When the time for hatching arrives the shell cracks, and the mite crawls out. This may take place at any time of the day, but by far the largest percentage hatch out in the early morning. Bright, sunny, warm mornings will cause the eggs to hatch in greater numbers, and cloudy or cool weather retards their development.

THE LARVA

The young mites undergo two molts before becoming adult, the two larval stages being of about equal duration. When first emerged from the egg the larva is of a very pale straw color or semitransparent. Feeding begins at once on the cell contents of the leaf or fruit. Although at first not very active, the young mite begins to wander around within a few hours. This stage lasts for only a very few days, whereupon the mite takes a short rest preliminary to molting. The mite becomes motionless for a few hours until the skin cracks, and it crawls out. The second-stage mite is slightly larger and has a more decidedly yellow color, but otherwise it is very little changed. After a brief period of feeding, about equal in duration to that of the first stage, the mite again enters a quiescent state and prepares to molt. The skin again splits, and the adult mite emerges. The white cast skin remains attached to the surface of the leaf or fruit and contributes to the dusty appearance of the tree caused by the presence of the mites.

During the summer the first larval stage lasted from 1 to 3 days, with an average of 1.82 days, but in winter it was increased to from 3 to 6 days, with an average of 4.3. The second stage also lasted from 1 to 3 days in summer but averaged 1.34 days. In winter it was increased to from 4 to 13, with an average of 6.4 days. (Table 4.)

THE ADULT

DESCRIPTION

The citrus rust mite (fig. 6, A) is among the smallest of the pests of economic importance. When occurring singly on the tree, it is difficult to distinguish, and the russeting resulting from the feeding of the mites was for many years attributed to other causes. When occurring in large numbers, they give the leaves and fruit a dusty or powdery appearance, each individual mite appearing as a speck of dust. Close examination with a hand lens, however, will reveal a minute vermiform mite, light yellow or straw colored. Some specimens become a darker yellow or nearly brown a few days after reaching maturity. This is particularly true of those which are attacked by the fungous disease described later. Instead of having the spiderlike or crab-shaped appearance of many of the other mites the rust mites are elongate and wedge shaped, being about three times as long as wide. The body is composed of a cephalothorax, or fused head and thorax, and a slender, tapering abdomen. The mite ranges from 0.11 to 0.14 mm. in length, with an average of 0.12 mm. The cephalothorax at its widest part averages 0.046 mm., ranging from 0.041 to 0.054 mm. If placed under the microscope, the abdomen will be found to be transversely striated and have the appearance of being made up of a number of rings each of which grows smaller toward the posterior end. There are usually 28 rings appearing on the dorsal surface, but on the ventral surface there are twice as many. The anterior end tapers bluntly off to the head, which is rounded and curved downward. It is supplied with a pair each of maxillary palpi and mandibles used for piercing the cell walls. On the ventral side and placed closely together are two pairs of short rather weak legs (fig. 6, C) which are used in crawling. The creature is assisted in moving about and clinging to the trees by a pair of lobes, or false feet, located on the last abdominal segment. By means of these it is able to raise the entire body and turn around in various directions. It also rears up in this manner when disturbed.

LENGTH OF LIFE

The length of life of the adult mite is difficult to estimate and could not be accurately determined in the breeding jars since the mites failed to live long in confinement. The longest period recorded for an adult mite was 23 days. Another was kept alive 17 days, and a number lived for about two weeks, while many others died or were lost in less than a week. The average length of life for all adults kept in confinement was 7.6 days. It is not thought that the rust mites live for any great length of time, even under ideal conditions, or that the number of eggs deposited is excessive. On the other hand the mites owe their great numbers and extremely rapid increase to the brief length of time required to reach maturity.

OVIPOSITION

Oviposition begins shortly after the mite reaches maturity. When mites were confined in the cells there was often a preoviposition period of from 1 to 4 or 5 days (an average of 2.66 days in summer), but it is not thought that this would be so long under natural conditions. Eggs are probably deposited within a day or two after the mites reach maturity. Table 4 shows that some of the specimens in the breeding cages deposited eggs on the day following the last molt. Egg laying continues throughout the life of the mite.

The eggs are deposited, both singly and in groups, on the leaves, fruit, and small limbs. The favorite places for oviposition seem to be the pits on the surface of the green fruits. This is especially true in May and June when the oranges are from 1 to 2 inches in diameter, and the mites are increasing most rapidly. The adult female rests with her ovipositor extending down into a pit or depression on the surface and deposits the egg at the bottom. Although single eggs are sometimes seen in these cavities, there are usually from 5 or 6 to 10 or more. Several hundred eggs can be seen at times on a single green fruit when it is well infested with mites. On the leaves also the mites seek the small depressions on the surface, and eggs can often be found there in large numbers. No preference is shown for either side of the leaf, as many eggs occurring on the top as on the bottom. The leaf petioles and limbs are rarely selected for oviposition, though a few eggs can be found on the smaller limbs of heavily infested trees. As far as is known oviposition does not take place on any plants other than citrus. The morning hours seem to be the time of greatest activity in egg laying.

NUMBER OF EGGS

The number of eggs which a female mite is capable of laying can only be estimated, since they could be kept alive in the cells for only a limited time. The greatest number obtained from a single female was 29, deposited over a period of 20 days. A second mite deposited 19 eggs in 9 days, and others deposited from 8 to 14 eggs each over periods of about a week. The number actually laid under natural conditions would be somewhat greater.

As many as five eggs have been deposited by a female in a day, although it was seldom that more than one or two were produced. There were many days during which no eggs were laid, and some mites reared to maturity in the cells and kept for several days died without ovipositing. This was undoubtedly abnormal, for it is believed that mites under favorable conditions will deposit a few eggs every day. Warm weather seems to stimulate oviposition to some extent. Following the egg-laying stage there usually was a postoviposition period of a day or two preceding death.

PARTHENOGENESIS

Reproduction appears to be entirely by parthenogenesis. No sexual differences have ever been distinguished in the rust mites, nor has copulation ever been observed. The rearing work was carried on with single individuals in isolated cells, and in all cases where eggs were obtained they seemed to be fertile. Several mites reared separately from egg to adult deposited eggs which in all cases hatched out in due time. Several generations were reared in this way. There may be times during the year when males occur in nature, but no evidence has been obtained to substantiate such a supposition.

NUMBER OF GENERATIONS

From the results obtained it will be seen that the mites reproduce at an exceedingly rapid rate. From 7 to 10 days only are required for a generation during warm weather, while in winter this time is increased to 14 days or more, depending upon the temperature. In several instances an entire generation from egg to egg was produced in 7 days. This will allow for several generations per month and accounts for the enormous number of the mites on the trees at some seasons of the year.

MOVEMENTS AND MIGRATIONS

On August 13, 1913, about 7.30 a. m., the mites on an orange were noticed to behave in a remarkable manner. They were jumping or flip-flopping around in a ludicrous way. As well as could be seen, this was done by bringing the head and rear ends together and then suddenly straightening out. This action would sometimes throw the mite a half inch or even more from the starting point. This is, no doubt, one of the means of distribution.

It was thought that the rust mites possibly have a diurnal migration, going from the tops of the leaves to the lower surfaces for the night and returning to the upper surfaces to spend the day. On May 24, 1920, the trees on the laboratory grounds were examined at 9 p. m., and mites were found on both sides of the leaves—more, perhaps, on the upper surfaces than on the lower. There are indications, however, that the mites may crawl to the lower surfaces of the leaves to protect themselves from heavy rains.

REACTION TO LIGHT

Having noticed that occasionally the mites on some oranges gather in bunches in the direct sunlight, apparently at times when attacked by a fungous disease, the senior writer thought it advisable in June, 1920, to study the reaction of the mites to light.

Several branches with infested fruit were set in water on the laboratory table for observation. On some of the fruits the mites congregated on the side toward the window. One fruit that had a large group of mites on it was turned around at 4 p. m., but on the following morning there was no marked movement toward the side now turned toward the window. Another fruit infested with mites was placed in a parasite-breeding box with the only opening turned toward the light. The mites quickly gathered on the light side, but on the following morning they were scattered all over the fruit. During the second day many reassembled on the light side, but the next morning found them scattered again. This was repeated the next day.

From the foregoing experiments it appears that the rust mites gather to the light during the day and scatter during the night. The early morning light does not seem to attract them.

Unless infected with a fungous disease (see p. 34), mites appear to avoid direct sunlight.

PARTS OF THE TREE INFESTED

On June 4, 1920, several trees were examined to determine the relative number of mites on the limbs, trunk, foliage, and fruit. They were very abundant on the fruit and foliage and very nearly as abundant on the smaller green limbs, where there was russeting similar to that found on the leaves and fruit. There was also a considerable infestation on the larger limbs, but none could be seen on the trunks, as the bark was rough and brown. Wherever the bark was green, however, mites were present. Limbs up to 2 inches in diameter were infested, but the numbers seemed to decrease as the size of the limbs increased.

There were no mites found nearer to the ground than 1 inch. They were present on foliage growing near the ground, and also close to the trunk under the trees, where the sun would never reach them. There were not so many in such locations, however, as on the foliage near the tops of the trees.

On June 7, several trees were examined in the morning, and rust mites were found on the limbs of all of them. The leaves in the center of the tree, which were always in the shade, and the small limbs growing near the trunk also had many mites on them.

The data given in Table 5 were collected to determine whether the rust mites were mostly on the lower or the upper surfaces of the leaves at different times of the year. The results were about the same on orange and grapefruit.

TABLE 5.—*Comparative number of rust mites on the upper and lower surfaces of spring flush leaves of oranges and grapefruit, Orlando, Fla., 1920*

Fruit and date	Upper side		Lower side		Remarks
	Number	*Per cent*	*Number*	*Per cent*	
Orange:					
Feb. 6	0	0	4	100	
June 4	219	24.4	678	75.6	Counted between 10 and 11 a. m.[1]
June 5	426	38.8	671	61.2	Counted between 8 and 9 a. m.
June 8[2]	111	16.0	583	84.0	Counted between 9 and 10 a. m.
Grapefruit:					
Feb. 6	0	0	1	100	
June 4	203	23.3	668	76.7	Counted between 10 and 11 a. m.
June 5	495	24.3	1,530	75.7	Counted between 8 and 9 a. m.
June 8[2]	257	16.1	1,336	83.9	Counted between 9 and 10 a. m.

[1] The relative abundance of mites on the upper and lower surfaces may be entirely different at some other time of day.
[2] A total of 2.42 inches of rain fell on June 6 and 7.

In making examinations throughout a period of more than two years in another grove the rust mites found on the tops of the leaves and those found on the lower surfaces were counted. In only 3 out of 59 examinations were more rust mites found on the tops of the leaves than on the lower surfaces. In one of these instances only 7 mites were found in all, so its record is of little importance. The results of the 59 examinations are given by months in Table 6. It is seen in this table that 20.2 per cent were found on the tops and 79.8 per cent on the lower surfaces.

TABLE 6.—*Number and percentage of rust mites on tops and lower surfaces of citrus leaves at Orlando, Fla., for each month, as shown by 59 examinations*

Month	Rust mites found on—			
	Upper side		Lower side	
1920	*Number*	*Per cent*	*Number*	*Per cent*
January	39	4.1	921	95.9
February	79	4.9	1,547	95.1
March	154	11.8	1,151	88.2
April	86	36.4	150	63.6
May	48	36.9	82	63.1
June	36	4.6	750	95.4
July	899	30.5	1,847	69.5
August	68	42.0	94	58.0
September	52	27.2	139	72.8
October	358	53.2	315	46.8
November	361	29.6	858	70.4
December	75	9.5	716	90.5
Total	2,165	20.2	8,570	79.8

An examination of all the results, covering both grapefruit and orange, indicates that approximately 75 per cent of the rust mites are found on the lower surfaces of the foliage. These results of course indicate nothing as to the number of mites on the upper or lower surfaces of the fruits. It is also seen that these results vary somewhat for the winter and summer months, more mites being on the lower surfaces during the dry season, which lasts from November to April, than during the rainy season.

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Rust mites leave the old leaves some time in late spring and migrate to the new foliage. On May 12, 1922, there were only 11 mites in 50 squares on the old foliage, whereas there were 47 mites in 25 squares on the new foliage. It was evident for some time previous to this date that the rust mites were moving to new leaves.

SEASONAL HISTORY

The rust mite is present on citrus trees throughout the entire year. Even in unsprayed groves the mites, as a usual thing, are not present in great abundance during January and February, although in exceptional cases great numbers may be present on grapefruit and lemon. During March and April their numbers increase rapidly. During May and the first part of June the rate of increase is much more rapid than at any other time of the year. Figure 7 shows the curve of abundance. The period of maximum infestation usually occurs during late June or early July, at which time the rust mites are present in countless hordes, in some cases a single grapefruit being infested with half a million or more mites.

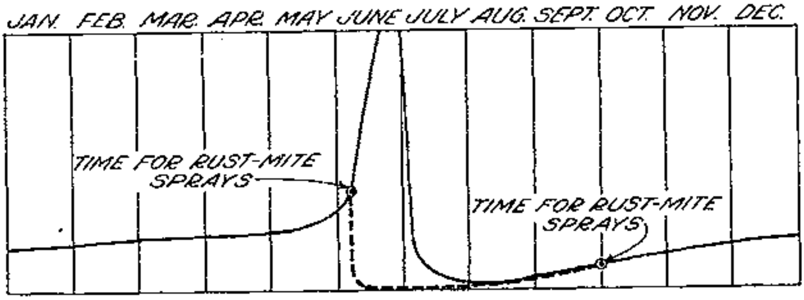

FIGURE 7.—Curve showing the abundance of mites on orange throughout the year and the proper times for spraying. The broken line indicates the abundance of mites on sprayed trees

Though the period of maximum infestation usually occurs during the middle of June, it occasionally comes as early as May. In 1911 the rust mites were present in the greatest abundance about May 10, and much russeting was done as early as May 1. On the other hand, in 1917 the period of maximum infestation did not appear until late in July, owing, no doubt, to the effect of the freeze of the previous February which reduced their numbers. During the rainy season their numbers diminish, as if by some magical force, almost to the point of extinction. No doubt this disappearance is caused by an entomogenous fungus which is discussed on page 34. After this they very slowly and gradually increase until the following June.

The period of maximum infestation occurs first on lemon and then on grapefruit and about one month later on orange.

Table 7 gives a summary of the counts of rust mites made on the check trees used for the control experiments over a period of several years. It is obvious from the table that there is a much larger population of rust mites during May, June, and July than during the remainder of the year. It is the writers' opinion from general observations that the figures given do not represent so great a difference as often exists. It will be seen also that there are many more mites on grapefruit than there are on orange.

TABLE 7.—*Summary, by months, of the counts of rust mites on the check trees over a period of several years at Orlando, Fla.*

ON ORANGE

Month	Upper surface of leaves		Lower surface of leaves		Fruit		Total		Average
	Squares	Mites	Squares	Mites	Squares	Mites	Squares	Mites	
January	110	47	110	677			220	724	3.29
February	115	0	115	320			230	320	1.43
March	170	59	170	98	10	0	350	157	.45
April	100	70	100	212	10	0	210	282	1.34
May	514	2,694	514	2,443	243	3,380	1,271	8,526	6.71
June	425	3,783	425	2,992	310	12,692	1,160	19,467	16.78
July	155	2,102	155	758	145	7,146	455	10,006	21.99
August	130	942	130	334	130	4,377	390	5,653	14.49
September	110	128	110	40	110	552	330	720	2.18
October	20	3	20	1	37	17	77	21	.27
November	5	5	5	41			10	46	4.60
December	173	657	173	2,209	10	43	356	2,909	8.17
Total	2,027	10,490	2,027	10,134	1,005	28,216	5,059	48,840	
Average		5.1		5.0		28.0		9.6	

ON GRAPEFRUIT

Month	Upper surface of leaves		Lower surface of leaves		Fruit		Total		Average
	Squares	Mites	Squares	Mites	Squares	Mites	Squares	Mites	
January	10	35	10	27			20	62	3.10
February	45	0	45	1			90	1	.01
March	20	0	20	0			40	0	0
April									
May	170	3,477	170	2,614	100	13,290	440	19,390	44.07
June	120	1,014	120	3,578	30	4,553	270	9,145	33.87
July	10	42	10	4	10	923	30	969	32.30
August									
September									
October									
November	15	2	15	102	10	10	40	114	2.85
December									
Total	390	4,570	390	6,320	150	18,785	930	29,681	
Average		11.7		16.2		125.2		31.9	

No reliable statements can be made as to conditions in the sprayed groves other than to say that the rust mite becomes quite abundant by late December and January, when control measures may be necessary during the winter.

METHODS OF SPREAD

DISTRIBUTION ON NURSERY STOCK

It is probable that the rust mites were introduced on nursery trees years ago when these were first brought into Florida for propagation. Little or no attempt was made in those early days to eliminate pests which might infest the plant when it was being introduced.

It is well known that rust mites can be found on the first flush of growth which appears after nursery trees have been planted in grove formation. Heavy infestation has been found on the first flush of growth of young trees that were at least 40 rods from the nearest older trees from which any possible infestation could spread. In all probability the rust-mite eggs are present in the tiny crevices of the bark and hatch out after the trees are planted, and the spread of the rust mite over Florida has been principally through infested nursery stock.

DISTRIBUTION BY INSECTS AND BIRDS

Since rust mites are present on citrus trees at certain times of the year in great abundance, often covering the surface of the fruit and leaves, it is only natural to suppose that several species of insects crawling over the trees would collect rust mites in the hairs of their bodies and legs. On June 9, 1920, a coccinellid larva was taken from a tree and examined in the laboratory. Three rust mites were found on its body and also the dried skin of a purple mite. On July 15, 1920, another coccinellid larva was examined, and several living mites were found on its back and legs. On August 2, 1922, six rust mites were found on the ventral side of the abdomen, near the tip, of a large female katydid. There were also a few mites on the legs. Rust mites were also found on this same date on trash bugs (chrysopid larvæ). None were found, however, on an adult Chrysopa, several ants, a spider, a lady beetle, and some mealy bugs. A year later, however, two were found on an adult lady beetle taken from an orange tree. Another coccinellid, however, showed no mites.

Birds also may be largely instrumental in spreading mites from tree to tree. Since the mites are easily detached, large numbers, when the mites are numerous on the leaves or fruit, are undoubtedly swept off by the tail feathers and feet of birds and transported to other trees.

DISTRIBUTION BY WIND

The wind no doubt causes a more or less local spread of rust mites. In August, 1922, spider webs stretched from one orange tree to another were examined, and four rust mites were found on the webs. No doubt these rust mites had been carried to them by the wind. Floating spider webs are very numerous in the groves at some seasons and they may carry mites for long distances. Hubbard (*7, p. 111*) is also of the opinion that spider webs and wind are important factors in spreading mites.

In order to test the effect of winds in spreading rust mites, three fruits heavily infested with mites were placed 1 foot in front of an electric fan. A black tray 7½ by 9 inches was placed immediately back of the fruits. This tray had been given a thin coat of glycerine jelly, to which the rust mites would adhere in case they were blown from the fruit to the tray. After the fan had been run for 30 minutes the tray was ruled off in small squares and the mites counted in each square; 26 mites were found after two hours of examination. No eggs were seen, but several may have been overlooked in the examination. Other tests to blow mites from the fruit with less power or at a greater distance from the fruits were unsuccessful.

DISTRIBUTION BY CRAWLING

Several experiments were conducted to determine the rate at which rust mites distributed themselves locally. On May 24, 1920, at 4 p. m., a small fruit and some leaves heavily infested with rust mites were tied into each of four small trees on which only a very few mites could be found. The following day at 4 p. m. the old fruits were still covered with mites, and some were also present on the old leaves. Only a very few had crawled off on to the fresh leaves. One tree had 5 mites; another, 35, of which 25 were touching the old fruit;

another had 10 mites; and the fourth tree, none; making a total of 50 mites. Check trees had only a very few mites. On June 7 there were still mites living on the old fruit introduced May 24, and also many on the fruit touching the old fruits. On June 9 rust mites were found all over the young grove, and the experiment was of little value from this time on. On June 2, however, four additional fruits had been tied on other young trees on which very few mites could be found at that time. On June 7 the 40 squares counted had 128 mites, whereas on the trees adjoining there were only 17 mites on 40 squares. There were living mites still on the old fruits, however.

On July 2, 1919, a branch having two oranges covered with rust mites was cut off and hung beneath another orange tree. Three days later the branch and fruit were quite wilted, but the mites were still alive and covered the fruit. On July 10 all leaves were brown and the fruit wilted, but the mites appeared as numerous as when the fruit was hung up. On July 15 mites were still very abundant on the oranges, which were very badly wilted. On July 24 only two or three living and a few dead mites were found on the fruit cut off July 2. This shows that rust mites will live on fruit until it no longer furnishes a food supply rather than crawl up the stem to other parts of the tree.

NATURAL CONTROL

CLIMATIC FACTORS INFLUENCING THE NUMBER OF RUST MITES

FROST

Abnormally low temperatures in Florida in February, 1917, furnished an opportunity to note the effect of freezing on the rust mites. From December 25, 1916, until February 1, 1917, the weather had been very warm. On many days the temperature reached 85° F. at Orlando, and on February 1 it was 1 degree higher. Owing to this prolonged period of warm weather, citrus trees were in a growing condition in every part of the State, and there were present many more rust mites than is ordinarily the case at that season of the year.

The following minimum temperatures were recorded for February 2 to 4, at localities where examinations were made to determine the conditions of mites:

	°F.
Crescent City, Putnam County	19
De Land, Volusia County	15
Ocala, Marion County	18
Eustis, Lake County	20
Orlando, Orange County	22
Winter Haven, Polk County	25
Frostproof, Polk County	27
Pinellas Park, Pinellas County	27

As a result of these low temperatures many of the rust mites were frozen, and many died because of the shedding of the foliage.

Examinations *(14)* were made at Orlando on February 3, or after the first cold night, and before the second one. No mites could be found on a small sour orange tree located in an exposed situation on which many thousands had been present previous to the frost. Examinations of green leaves still on the trees on February 7 showed that the mites were very scarce, as compared with the number present before the frost.

The rust mite can not live on dead, fallen leaves. Green leaves were picked up from the ground on February 10 and examined, but only 1 living mite was found, and that was on a leaf from a protected location where 17 living mites and 3 eggs were found on 10 leaves taken from a tree. There is no doubt that the rust mites present on the trees and fruit the following October were the progeny of those that survived on the leaves uninjured by the frost.

In the northern counties, where defoliation was complete, the rust mites were nearly exterminated. Those that were not actually frozen perished with the falling of the leaves. In an examination of six groves at Crescent City early in May only two mites were observed in two days. In a normal infestation there would have been literally billions present. In Marion County, on May 24, they were also extremely scarce.

In the counties where the defoliation amounted to from 90 to 95 per cent the rust mite also received a serious setback. A conservative estimate of the mortality would be more than 99 per cent; in fact not until June 1, or more than four months after the frost, had they become as abundant as they were before the cold wave. Following the freeze the weather was extremely favorable for the reproduction of the mites, and this pest was so abundant in this section in late June that spraying was necessary in order to get bright fruit. The only result of the reduction of the mites by the freeze was the postponement of the time of maximum infestation in these counties about a month or six weeks.

In the more southern localities they were also greatly reduced in numbers, but the reduction was not sufficient to be of any great economic importance. Spraying had to be resorted to at about the same time as in an ordinary season.

By late July and early August the rust mites had become so abundant that it was generally believed that a heavier infestation followed the freeze than had occurred for many years. The almost complete extermination of this species by the freeze and its reproduction to billions in six months is a most remarkable biological fact. It is difficult for the human mind to conceive of such a rate of reproduction. Many single grapefruits during August were infested with at least a half million mites. On October 3, however, the species was very scarce. Several groves were examined, and only a very few mites were found.

DROUGHT

The drought of the spring of 1922 was the worst since that of 1906–7. Observations made during this period indicated that rust mites did not multiply at all. There seemed to be no more mites present on May 4, the date of the first rain, than there were three months before. Not long after the rain of May 4, and subsequent rains, the rust mites developed at a very rapid rate.

HEAT OF SUN

It has been observed for many years that rust mites do not attack the outer surfaces of the fruit on the outside of the tree. They are usually found on the side of the fruit which is in semishade. Of course they attack the entire surface of fruit on the inside of the tree.

It is supposed that the rust mites are not able to endure the direct rays of the hot sun and therefore feed mostly on the sides of the fruit in semishade.

RAIN

For many years it has been thought by citrus growers that the heavy rains of summer are directly responsible for the scarcity of rust mites during the rainy season. They have thought that the heavy rains washed the mites from the foliage and fruits. As noted elsewhere, this scarcity of rust mites is due to a fungous disease.

Observations were made, however, to determine whether heavy driving rains did wash mites from foliage and fruit. On May 17, 1920, the rust mites were extremely abundant on both the upper and lower surfaces of the leaves, on the stems, and on the fruit of the trees around the laboratory. On May 18 it rained all day and practically all night, the total precipitation being 1 inch. An examination was made in the afternoon during the rain, and the mites were all found on the lower surfaces of the leaves. On May 19 an examination made at noon showed that the mites were very abundant on both the upper and lower surfaces of the leaves. There appeared to be no fewer mites present on the 19th than there were on the 17th. It is only reasonable, however, to suppose that some of the mites had been washed off.

On May 25, between 6 p. m. and 8 p. m., 2⅛ inches of rain fell. At 9 p. m. an examination indicated that though many of them might have been washed off, there were still countless numbers of mites present. There were many more on the lower surfaces of the leaves than on the upper surfaces. Those leaves which were somewhat protected from the most direct downpour had many mites on the upper surfaces. The mites seemed to have the power of sticking to the foliage in spite of the rains. On May 26 observations made as soon as the leaves became dry indicated that mites were still present by countless millions, and they seemed to be crawling back to the upper surfaces of the leaves.

On June 5 rust mites were found covered by drops of water on the fruit and also on both sides of the leaves which were wet on both surfaces. Apparently the mites were not affected by the water.

In 1923 it rained practically every day from May 3 to June 1, all the night of June 1, and all the forenoon on June 2. After such a period of wet weather it was thought advisable to note the location of the mites. At 10 a. m. on June 2, while it was still raining, an examination showed that the rust mites on plots which had been sprayed with Bordeaux mixture alone were mostly on the lower surfaces of the leaves. Not more than 5 per cent of the mites on all the foliage were on the upper surfaces. A large number of the mites on the fruit were on those areas which were not wet. In several instances mites, which were probably alive, were observed beneath drops of water. Around the edges of several drops of water were lines of mites which appeared to be drinking the water.

While no doubt the heavy driving rains did wash a few mites from the foliage and fruit this diminution in numbers was not appreciable and had little or no bearing either on methods of control or on subsequent abundance of the mites. It was apparent, however, that rust mites crawl to the lower surfaces of the leaves to protect themselves to a certain extent from the rains.

RELATION TO SITE

It has been known for many years by growers and shippers that fruit grown in hammock lands, both on the Florida east coast and elsewhere, does not become russet to a degree amounting to injury. The term "hammock" is applied in Florida to land having a deeper soil and supporting a greater variety of hardwood growth than the surrounding flatwoods. As many people believe that the rust mite is not present in such groves, it was thought desirable to make a special effort to determine the status of the rust mite throughout the year in several hammock groves. To do this, counts were made, monthly with a few exceptions, of the rust mites in one grove at Hawks Park, now Edgewater, in two groves at Mims, and in one grove on Merrits Island. In most of these groves there was considerable shade from cabbage palmettos, as illustrated in Figure 8. The results of these examinations are given in Table 8.

FIGURE 8.—Citrus grove shaded by cabbage palmettos. The partial shade is conducive to the development of the fungous disease of the rust mites

TABLE 8.—*Counts of rust mites on oranges in unsprayed groves on hammock land*

Date	Squares examined	Mites counted	Average mites per square	Date	Squares examined	Mites counted	Average mites per square
1922	*Number*	*Number*	*Number*	1922	*Number*	*Number*	*Number*
Mar. 8	100	1	0.010	Nov. 7	540	121	0.224
Apr. 7	200	5	.025	Dec. 7	600	20	.033
May 10	220	1	.005				
June 7	250	3	.010	1923			
July 5	600	123	.205	Jan. 11	330	126	.420
Aug. 8	600	330	.550				
Sept. 13	600	62	.103	Total or average	4,580	923	.202
Oct. 11	540	131	.242				

Rust mites were present on every date when examinations were made, but the infestation was so slight that in the entire four groves not more than a dozen oranges became russeted during the year. Adjoining the grove at Hawks Park, in a grove with no shade or palmettos, there was a considerable infestation of rust mites. Here, on August 8, there were 20 mites on as many squares, and numerous cast skins and dead mites were found on one leaf which was slightly tinged with rust.

As lemon is a preferred host plant for the citrus rust mite, examinations were made in a lemon grove of about an acre in extent growing in the Mims hammock. This was very low hammock, and during parts of the year there was considerable water around the trees. Table 9 gives a detailed account of the examinations and notes made.

TABLE 9.—*Counts of rust mites in an unsprayed lemon grove, Mims, Fla.*

Date	Squares examined	Mites on foliage and fruit	Remarks
1922	*Number*	*Number*	
Mar. 6	80	0	
Apr. 7	80	0	
May 10	80	0	Foliage only examined.
June 7	60	1	Some shark skin present; 6 mites were found on branches.
July 5	150	0	A few mites on branches.
Aug. 8	150	24	No russeting or shark skin; clean fruit.
Sept. 13	150	24	3 or 4 shark-skin fruit; some dead mites.
Oct. 11	150	0	A few on stems; 3 rusty fruit.
Nov. 7	150	0	A few on stems.
Dec. 7	150	0	No rusty fruit.
1923			
Jan. 10	45	514	Practically all mites were on one fruit.
Total	1,215	563	

Several shark-skin fruits were observed, but only a few fruits in the entire grove showing the presence of excessive numbers of rust mites could be found on any date. On several occasions dead mites were observed on the fruit, and on several other occasions living rust mites were observed on the branches. The fruit with few exceptions remained entirely bright throughout the year.

Numerous examinations have been made in other hammock groves, and only a very few rust mites could ever be found. In some groves Valencia oranges remained bright until late spring.

Russet fruit was found in every grove visited on the east coast, but in some cases only one or two were discovered. Shark skin on lemons was observed in the Mims hammock, and fruit literally covered with rust mites was found also in this lemon grove. Dead rust mites were also observed on several occasions. The appearance of these dead mites was identical with that of those found in central Florida, and they were no doubt killed by the same fungous disease that caused the death of rust mites in other parts of the State. Probably the reason why the rust mites do not become more abundant on the east coast is that the excessive humidity is conducive to the development of the entomogenous fungus on rust mites throughout the greater part of the year.

INSECT ENEMIES

No internal parasite has ever been found attacking the citrus rust mite.

Adults of the lady beetle *Stethorus nanus* Lec. have been observed to feed upon rust mites, and on August 29, 1922, J. R. Springer found two larvæ of this beetle so feeding. These were put in a breeding jar, and one adult emerged September 5. The feeding of the larva of this beetle on rust mites may be of very rare occurrence, as the above is the only instance on record. This species is of little or no importance in holding the mites in check.

It is very probable that several other species of Coccinellidæ which inhabit citrus trees feed to some extent, in both the larval and adult stages, on rust mites. The mites, however, are so small that they would not prove attractive to the lady beetle when other food was available. The same is true of the trash bugs or larvæ of the golden-eyed lacewing, *Chrysopa oculata* Say, and of a species of Hemerobius. These trash bugs when very small undoubtedly feed to some extent on rust mites, as the dead mites are often seen on their backs along with the remains of other insects.

Hubbard (*6, p. 11*) was the first to observe that cecidomyiid larvæ ate rust mites. These are coral red maggots with yellowish or transparent heads and a band of the same color near the posterior end, although the last segment is red. This feeding was observed by the writers in 1913 and has been observed many times since, though the larvæ appear only when the mites are very abundant. Although they have been seen to eat mites at the rate of four or five per minute for several minutes their feeding does not reduce the number of mites to any appreciable extent. These larvæ are very small and extremely delicate, and all attempts to rear them to maturity have failed. They fed on mites when placed in small cages, but always died without pupating.

FUNGI

Though it has not been established as a scientific fact, there is considerable evidence to show that an entomogenous fungus attacks rust mites (*10*).

It has been observed annually since 1912 that the citrus rust mite reaches the point of maximum infestation just after the beginning of the rainy season. In some instances a single grapefruit may be infested at this time with more than half a million mites. Shortly after the point of maximum infestation is reached the mites disappear as if by magic so that by the middle or end of September more than an hour of diligent search is sometimes required to find a single specimen. This diminution of numbers is not due to a lack of food since on an average only about 50 per cent of the unsprayed fruit is seriously attacked by the rust mites.

There is considerable evidence to show that this disappearance of the citrus rust mite is due to a fungous disease. In many instances since 1920 the mites have been seen to congregate on a small area of the fruit which is in the most direct sunlight. When so herded together, the area occupied by them becomes yellow, and it is impossible to see the rind of the fruit. The mites in this mass seem to be stuck to one another like numerous angleworms. They are a writhing, wriggling mass and crawl around without any apparent object or sense of direction. Shortly after this the mites are seen to be dead, or more brownish in color than when alive, and occupying the same spot in the direct sunlight. This congregating habit is contrary to the habits of the species, for they normally seek partial shadow and are not found in great abundance on the part of the fruit in direct sunlight.

It has been also observed that most of the adult mites change color from a lemon yellow to a darker or orange yellow. They also become somewhat sluggish in their movements.

An examination of the dead mites usually shows that certain fungal filaments protrude from their bodies. In most instances also there are fungous bodies on the inside of the dead mites; in fact these bodies have been observed in mites which were still alive but which had changed color and become sluggish.

The use of copper sprays also gives strong circumstantial evidence that the limiting factor in the reproduction of rust mites is an entomogenous fungus. Winston, Bowman, and Yothers (*12, p. 12*) proved beyond the possibility of a doubt that the rust mites always become much more abundant following the use of copper sprays or compounds than on unsprayed trees and fruit. They are also abundant for a considerable length of time after the beginning of the rainy season when scarcely any mites are present on the trees not sprayed with copper sprays. The use of such fungicides evidently eliminates the fungous disease which in all probability, under normal conditions, would have attacked the rust mites. This same disease very likely attacks the species wherever the climatic conditions permit.

ARTIFICIAL CONTROL

Numerous experiments and observations extending over many years show that the blemish or injury following rust-mite feeding can not be removed. This damage to the fruit must be prevented by killing the rust mites before any appreciable injury takes place (*16, p. 28*). As a general rule rust mites are present in great abundance from one to two weeks before extensive injury appears.

INEFFECTIVE INSECTICIDES

LEAD ARSENATE

As the rust mites have piercing mouth parts, lead arsenate would not be expected to be an effective insecticide for their control. Nevertheless it was thought advisable to make some actual tests to determine this point. On June 10, 1914, powdered lead arsenate in the proportions of 1 and 2 pounds, respectively, to 50 gallons of water were sprayed on citrus trees infested with rust mites. Observations made on several later dates showed that no rust mites had been killed. They were still present in great abundance. Another test was made in 1922. Trees were sprayed twice, April 17 and June 23, with 1½ pounds of powdered lead arsenate to 50 gallons of water. There were, of course, thousands of rust mites present before the spraying on June 23. On June 27 living rust mites were present on the fruit and foliage in great numbers. Some grapefruit were quite rusty, and mites were present on these fruits by the millions. There was not the slightest evidence that any mites had been killed by the spray.

TOBACCO SPRAYS

Tobacco sprays perhaps should be classed as only partially effective against rust mites since the ordinary tobacco decoctions used at 1 to 1,600 will kill the adults and young mites, but the strength necessary to prevent the eggs from hatching is so great that the cost would be prohibitive. On June 28, 1915, several trees were sprayed with a tobacco extract, 1 to 1,600, but a rain fell immediately after the last tree was sprayed, and on June 1 there were both adult and young mites and also eggs present. In all probability the rain prevented the insecticide from producing its full effect. An experiment was tried with a solution made by soaking a quantity of tobacco stems in water. This solution was sprayed on the trees, and it was strong enough to kill mites and also to prevent practically all the eggs from hatching.

NICOTINE DUST

In order to determine the effect of nicotine sulphate in the form of a dust preparation on rust mites, an entire grove was dusted on March 15, 1922. Over most of the grove the machine went on only one side of each row, but there was a gentle breeze, and the dust drifted in good shape. Part of the grove, however, was dusted on both sides, and another plot was dusted twice on each side. The results of the various examinations are given in Table 10. The rust mites in 25 squares on the upper surfaces and 25 on the under sides of the leaves were counted for each treatment and for each date.

TABLE 10.—*Counts of rust mites surviving after dusting on March 15, 1922, with various strengths of nicotine sulphate in an orange grove at Orlando, Fla.*

Date of examination	Number of mites found on 25 squares on foliage dusted with nicotine sulphate of stated concentration								Number of mites found on check trees		
	2.2 per cent		5 per cent		10 per cent		10 per cent, 2 dustings on each side		Squares counted	Upper surface	Lower surface
	Upper surface	Lower surface	Upper surface	Lower surface	Upper surface	Lower surface	Upper surface	Lower surface			
Mar. 16	1	9	0	2	3	13	0	9	140	48	82
Mar. 21	0	0	0	0	0	0	0	2			
Mar. 30	3	2	0	0	12	2	18	8	50	1	2
Apr. 17	42	1	0	0	5	2	28	7	100	30	8
Total	46	12	0	2	20	17	46	26	290	79	92

For all treatments combined it was found by computation that 80 per cent of the rust mites were killed at the expiration of 24 hours. This is not at all a satisfactory mortality. There were a few left at the expiration of 6 days, but there were a considerable number present at the expiration of 15 days, and on June 16 there were just as many rust mites present as if no dusting had been done, a condition which was to be expected.

FUMIGATION WITH HYDROCYANIC-ACID GAS

From 1906 to 1910 much experimental work was done in fumigation with hydrocyanic-acid gas for the control of white flies and scale insects. A. W. Morrill, who had charge of the work, except during the last year, observed that the rust mites which were present on the trees at the time of fumigation were killed, but that there was reinfestation later. The senior author, working with him at that time, also observed that groves which were fumigated had the usual percentage of russet fruit. In the fall of 1918 additional experimental work was carried on at three or four places in the State. Although the main object was to determine the value of this process in the control of white flies and scale insects, it was deemed advisable to obtain as extensive data as possible on the effect of the fumigation on mites, both immediately afterwards and at monthly intervals throughout the spring until the period of maximum infestation had occurred. In most experiments regular white-fly and scale dosages were used. The results are given in Table 11.

TABLE 11.—*Effect of fumigation with hydrocyanic-acid gas on rust mites in Florida*

Time of examination	Squares counted	Mites found	Average mites per square	Remarks
	Number	*Number*	*Number*	
November and December before fumigation (check).	196	1,866	9.52	
First examination immediately after fumigation.	220	1	.01	
Second examination (January)	282	5	.02	
Third examination (February)	320	21	.07	
Fourth examination (March)	265	3,688	13.92	Practically all mites from 1 grove.
May examination	311	1,757	5.65	
June condition				Rust mites abundant and all groves required treatment.

On December 13, 1918, a count was made to determine the abundance of rust mites on foliage that had been fumigated the night before. In 50 squares not a single mite was found. On the row adjoining the fumigated row 50 squares had 441 mites, or 8.8 mites per square.

An examination of the foregoing data proves that fumigation with hydrocyanic-acid gas kills rust mites and in all probability a majority of the eggs present. It is also indicated that however complete the killing may be at the time of fumigation, which is usually before February 1, the rust mites will be just as abundant in late May and June as if no fumigation had been done. The same is usually true if spraying for rust mites is done in the late winter or early spring. If fumigating were done in either May or June, using such dosages as have been found effective for the killing of white flies and scale insects, it is evident that it would be an effective rust-mite control.

OIL EMULSIONS

Since emulsions made of lubricating oils are extensively used in Florida for the control of white flies and scale insects on citrus trees, it was considered advisable to determine the effect of these emulsions on rust mites and their eggs. In 1910 and 1911 several groves sprayed with them had fruit reasonably free from rust-mite injury, and it was thought by some growers that these emulsions were very effective in killing rust mites and therefore favored the production of bright fruit. Other groves sprayed with them did not produce satisfactory fruit. Experiments conducted in 1912 showed that 0.25 per cent of oil [5] did not kill rust mites; that 0.5 per cent killed nearly all mites; that 0.75 per cent killed still more; and that after the use of 1 per cent only a very few mites survived. To be a satisfactory spray for

[5] Analysis of oil No. 1:

Specific gravity at 27° C	0.898.
Flash point	184° C.
Fire point	207° C.
Viscosity	305.3 Saybolt seconds.
Volatility	4.9 per cent.

rust mites, not a single mite should be observed in the entire grove for at least a period of from three weeks to a month after spraying. The fact that a few rust mites were observed where 1 per cent of oil was used indicates that it is not an entirely satisfactory spray. There was much less russet trees in each test, except that of the one-fourth of 1 per cent, than on the unsprayed trees, and the fruit from the trees sprayed with 1 per cent was reasonably free from rust-mite injury. A commercial lubricating-oil emulsion applied on a large scale in 1913 with 1 per cent of oil in the diluted spray material gave reasonably satisfactory results, but not so good as was given by lime-sulphur solution at 1 to 75.

On June 28, 1915, several seedling sweet orange trees abundantly infested with rust mites were sprayed with 1 per cent of oil No. 1.[6] On July 1 all adult mites were dead, but there were literally thousands of very young mites present. On July 10 there was still an abundant infestation, and on August 26 rust mites were abundant, but no russeting had taken place.

On May 20, 1916, a row of seven large seedling trees abundantly infested with rust mites was sprayed with 0.67 per cent of oil No. 1. On June 3 the rust mites were exceedingly abundant, and by July 3 millions were present and much russeting had taken place.

On May 20, 1916, a row of trees was likewise sprayed with a dilution of 1 per cent of a commercial miscible oil.[7] On June 3 rust mites were present in considerable abundance. On July 3 many more mites were present than in the following test, where 2 per cent of oil was used, and on August 2 much russeting had developed and the row was sprayed for the second time. On January 17 there were 1 bright fruit (0.53 per cent), 54 goldens (28.9 per cent), and 132 russets (70.6 per cent).

On May 20, 1916, seven large seedling trees were sprayed with an emulsion containing 2 per cent of oil No. 1. A heavy rain fell two days later, which in all probability did not interfere with the effectiveness of the spray. On June 3 living rust mites were present. On July 3 there were millions of them, eggs were abundant on both leaves and fruit, and russeting had just begun to appear. After an average spraying with lime-sulphur solution practically no rust mites would have been present. Up to this time no injury had resulted from the spraying. On August 2 the same trees were sprayed for the second time, 2 per cent of the same emulsion as was used for the first application being used. On September 9 it was quite noticable that some of the fruit on the trees sprayed twice showed considerable injury from the oil; i. e., the shadows were very pronounced on the fruit. On January 17 the fruit was picked, and there were 24 bright fruit (3.9 per cent), 265 goldens (43.4 per cent), and 321 russets (52.6 per cent).

On May 13, 1922, a row of heavily infested young trees having no fruit was thoroughly sprayed with 1 per cent of oil No. 1. On May 17 a careful examination of 10 leaves was made, and not a single rust mite or egg was found. On May 20 no rust mites could be found after the trees had been examined for over 15 minutes, and no rust mites were found on June 1.

Although the above experimental work appears somewhat contradictory, it certainly is evident that the oil emulsions are generally

[6] See footnote 5 on p. 37.

[7] No analysis available.

only partially effective against rust mites and their eggs. They can not be relied upon to produce bright fruit. It is probable that any dilution of oil emulsion of 1 per cent or stronger kills practically all mites actually hit by the spray, but none are killed that are not hit. As a consequence, owing to imperfect spraying, many mites are left, and all the eggs are not prevented from hatching, and these provide for rapid reinfestation. The past experience of Florida growers bears out the conclusion that oil sprays are only partially effective against rust mites.

EFFECT OF SULPHUR ON RUST MITES

WHEN NOT IN IMMEDIATE CONTACT

Rust mites are extremely sensitive to sulphur. This was reported by Hubbard (*7, p. 117*), who found that rust mites were killed by the fumes resulting from its oxidation when the mites were not in immediate contact with the sulphur. Additional experimental work was undertaken to determine further the effect of sulphur on rust mites.

On June 23, 1921, a pound of sulphur was sprinkled over the bottom of an air-tight box of 25 cubic feet capacity, with shelves 8, 16, and 24 inches, respectively, from the bottom. This was done some time in the forenoon so that the sulphur would have time to settle before the fruit was placed inside. In the afternoon five recently picked oranges, heavily infested with rust mites, were placed on each of the three shelves in the box, and the box was then closed. On the next day an examination showed that there were living mites on all the fruit and a faint odor of sulphur was present. There may have been some dead mites also, but not enough to be noticeable. At the expiration of 48 hours the odor of sulphur was quite pronounced, and it seemed that most of the mites on the fruit were dead, though there were some living mites on each fruit. No difference could be detected in the number of dead mites on the fruit on the three shelves. On June 27, four days after the beginning of the experiment, not a single living mite could be seen with a hand lens on any of the fruit. On June 28, the fifth day, a very careful examination was made with the binocular microscope, and a very few living mites were observed on each of the fruits. The living mites were all old ones; the eggs which were present at the beginning of the experiment evidently had hatched, but the young mites had been killed by the sulphur fumes. On July 2 all mites were dead, and the fruits had shriveled up and dried out. The average maximum temperature from June 23 to June 28 was 93° F., which no doubt was conducive to a more rapid oxidation of the sulphur. As a check on the above test, five fruits heavily infested with rust mites had been placed on each of the shelves in the box on June 21, and after 48 hours no mites had been killed by the confinement in the box. Under the binoculars they were seen to be moving about and appeared exactly as they did when the fruit was first put in the box.

AT VARIOUS TEMPERATURES

On January 22, 1923, experiments were started to determine the effect on rust mites of oxidation of sulphur at different temperatures. The temperature box had five compartments holding constant temperatures of 10°, 15°, 20°, 25°, and 30° C. The warmest compartment was regulated with a thermostat so that a constant temperature of 30° C. (86° F.) was maintained. The temperature of the coldest compartment was maintained at 10° C. (50° F.) by ice in an adjoining chamber. Fifteen grams of flour of sulphur was placed on the bottoms of each of five clean tin cans of about 3-pint capacity, and an orange heavily infested with rust mites was put into each can. A small glass beaker was placed in each can, which supported the orange and kept it from coming in contact with the sulphur. Five other cans were prepared in the same way except that the sulphur was omitted, and these were used as checks. Two cans, one with sulphur and one without, were placed in each compartment. Tightly fitting lids were placed on the cans, and all were handled most carefully so as not to disturb the sulphur.

Several examinations were made to determine the effect of the sulphur on the mites in the cans. At the end of the third day the mites in the cans without the sulphur were, in so far as could be told, normal in numbers and in appearance. There were practically no mites killed in any of the compartments with sulphur except the warmest two. Only a few mites were killed in the second-warmest compartment, with a temperature of 25° C. (77° F.), and most of the mites were killed in the hottest compartment, where the temperature was 30° C.

A grove experiment was also conducted in which two large, heavy paper sacks were placed over branches each having about six fruits heavily infested with mites. In one a fairly large quantity of sulphur was placed so that it was at least 6 or 8 inches from the fruits. The other sack did not contain any sulphur. The average maximum temperature for the following three days was about 90° F. At the end of this time no mites had died in the sack without sulphur, whereas nearly all were dead in the sack containing the sulphur. The fruits in the treated sack were reasonably bright at picking time but there was much rust on those fruits in the sack without sulphur.

These experiments show that the rust mites are killed by the fumes resulting from the oxidation of sulphur if the temperature is high enough.

Numerous experiments have been conducted to determine the effect of sulphur fumes on rust mites in the open. Several cigar boxes containing a pound each of sulphur were placed 6 inches beneath foliage heavily infested with rust mites, but no mites were killed. As many as 12 paper bags containing sulphur have been hung in a single tree without producing any mortality whatever. Sulphur has likewise been put on the ground, but it is doubtful if any mites were killed by it.

WHEN IN CONTACT WITH THE MITES

Leaves heavily infested with rust mites were placed under the microscope. With the eyes protected, sulphur was blown from a hand duster over the leaves. There was on the whole no unusual activity among the mites as the grains of sulphur settled near them. A few reared themselves on the anal end, and a few crawled very short distances, but the majority remained motionless and died without any movement visible through the microscope. A large percentage were dead at the end of 5 minutes, nearly all at the end of 10 minutes, and no life could be detected at the end of 20 or 25 minutes. These results show that the effect of the sulphur is extremely rapid.

To determine whether the mites were dead, they were touched very gently with a needle, and if the legs did not move the mite was considered to be dead. The temperature ranged from 90° to 92° F. The observations were made outdoors in the shade, but the sun was shining brightly.

EFFECT OF WEAK DILUTIONS OF LIME-SULPHUR SOLUTION ON RUST MITES

LABORATORY TESTS

In order to get additional data on the sensitiveness of rust mites to sulphur and also to obtain information as to what dilution of lime-sulphur solution might be used for spraying purposes, a series of dipping tests were carried on in the laboratory from June 14 to 27, 1920. Small twigs from seedling trees were cut off, each twig having one orange and a few leaves heavily infested with rust mites, and were immersed in lime-sulphur solution at a wide range of dilutions. Each twig was then placed in a bottle of water to keep it fresh.

In all dilutions from 1–50 to 1–275 all the mites present at the time of dipping were instantly killed, and in 24 hours their bodies had dried up. No eggs hatched; they seemed to collapse or were eaten by the caustic nature of the insecticide. In the dilutions from 1–300 to 1–325 all the mites were killed by the dipping, but a few eggs hatched out on the third and fourth days. In 13 dilutions ranging from 1–400 to 1–8,000, all of the rust mites were killed, and their bodies were dried up on the following day. The eggs, however, did not seem to be injured in any way, and an abundance of young mites hatched on each of the days following the tests. In the dilutions 1–400 and 1–500 most of the hatching took place after the second day, showing, perhaps, that if the egg was ready to hatch the sulphur was effective in killing the embryo mite. It would appear from the tests that 1–8,000 is the critical dilution. At 1–10,000 most of the mites present were killed, but a few of the older ones remained unharmed; 1–20,000, 1–30,000, and 1–40,000 did not seem to hurt them at all.

The mites on three check twigs lived normally for over a week, or throughout the experiment. Eggs hatched normally. Two other checks were dipped in water, but the mites were not killed, and the eggs hatched in normal numbers. The water, however, seemed to make the mites crawl around more than they did on the dry checks.

In the main the experiments were repeated from June 15 to 20, 1921. That year the dilutions 1–200, 1–225, and 1–250 killed all mites present, and no eggs hatched. With the 1–275 dilution, however, three young mites appeared on the second day. Also for the dilutions 1–300, 1–325, 1–350, and 1–500 from one to four were present after two days. None appeared after the use of the 1–400 dilution. The 1–5,000 was the weakest dilution that killed all the mites present. A few adult mites were present on the day following the tests with 1–6,000 and 1–7,000. With the strengths 1–8,000 and 1–9,000 about 50 per cent of the mites were killed, but 1–10,000, 1–12,000, and 1–15,000 did not affect the mites at all.

On the whole the experiments conducted in 1920 and 1921 agreed. In 1920 the dilution 1–275 killed all mites, and no eggs hatched; whereas in 1921 the dilution 1–250 produced the same results. In 1920 the weakest dilution to produce a complete mortality of mites was 1–8,000, but in 1921 it was 1–5,000.

FIELD SPRAYING TESTS

For field tests with various dilutions of lime-sulphur solution five lots of 50 gallons each were sprayed on trees heavily infested with rust mites and eggs on June 26, 1920. The temperature during the spraying was 80° to 84° F., and the trees were very thoroughly sprayed, but about one and one-half hours after the last lot had been applied a shower (0.45 inch) fell. The first count was made on June 28, two days after the spraying, so that the effect of various dilutions could be determined upon both the adult mites and the eggs. The results of the test are shown in Table 12.

TABLE 12.—*Number of rust mites surviving field tests with weak dilutions of lime-sulphur solution*

[Sprayed June 26, 1920; counted June 28, 1920]

Dilution	Number of mites found on 10 squares			Total
	Upper surface of leaves	Lower surface of leaves	Fruit	
1-2,000	124	51	247	422
1-1,500	172	62	152	386
1-1,000	47	27	137	211
1-500	29	15	68	112
1-250	1	3	7	11

Practically all of the rust mites found on June 28 were young mites and no doubt had hatched from the eggs which had been deposited before the trees were sprayed. The 1–2,000 dilution left twice as many mites as the 1–1,000, and the 1–1,000 dilution left approximately twice as many mites as the 1–500, whereas the 1–250 left very few mites alive. The above results were obtained by counting the same number of squares from each plot, 10 on the upper and 10 on the lower surface of the leaves, and 10 on the fruit. There were present thousands of dead mites. It was also noticed that more than twice as many mites were found on the upper surfaces as on the lower surfaces. No doubt this was due to the effect of the rain in the afternoon, which washed off the sulphur from the top surfaces of the leaves more thoroughly than from the lower surfaces.

Another count was made of the 1–250 dilution plot on June 30. There were 16 mites on the upper surfaces and 2 on the lower surfaces of the leaves, and 64 on the fruit. Practically all of these mites were young ones which had hatched since the spraying on June 26. The results of this spraying certainly indicate that, so far as field work is concerned, not even the dilution of 1–250, the strongest spray used in this experiment, is strong enough to give perfect results or commercial control with one application.

EFFICIENCY OF VARIOUS SULPHUR COMPOUNDS FOR RUST-MITE CONTROL

It has been shown (*18*) that certain sulphur compounds, when used so that the diluted spray material contains equal quantities of sulphur in solution, produce equally satisfactory results. In order to further test several forms of sulphur recommended by the manufacturers as substitutes for lime-sulphur solution, additional experimental work was conducted June 9 and 10, 1921, in a grove near Orlando where there was an abundant infestation of rust mites. Each material was applied at such a dilution that the quantity of sulphur present in each spray material was the same. The trees were very thoroughly sprayed, in fact drenched. No rains fell during the spraying or until June 15, at 8 p. m., when a heavy downpour occurred. To obtain the records given in Table 13 the mites were counted in 75 squares for each material and check on June 16 and 30, and on July 14, and in 30 squares for each material and check on July 30 and September 2, an equal number being counted on the lower surfaces and upper surfaces of the foliage, and on the fruit.

The examination made on June 16, six days after the spraying, showed that all of the materials were efficient in preventing the eggs from hatching. Of the 16 mites found, 8 were young ones which had hatched since the spraying. Considering the millions of eggs present at the time of spraying, the results were most satisfactory. As stated before, the trees were thoroughly drenched, and it is the writers' opinion that this may account for the uniformity of the results obtained with the several materials and dilutions.

Many more mites were present on the unsprayed checks on June 16 and 30 and July 14 than on the sprayed plots. On July 30 and September 2 this condition was reversed. This is probably due to the presence of an entomogenous fungus which developed on the unsprayed check during the rainy season. No doubt this fungus was responsible for fewer mites being present September 2 on the sprayed trees on which the materials were used at the weakest dilution. The stronger dilutions may have acted to prevent the development of this fungus whereas the weaker dilutions were not so effective.

TABLE 13.—*Number of rust mites counted following the use of several sulphur compounds on trees in a grove near Orlando, Fla., June 9 and 10, 1921*

Material used	Dilution	Number of rust mites present on—				
		June 16	June 30	July 14	July 30	Sept. 2
Lime-sulphur solution	1-66	4	0	27	277	205
Dry lime-sulphur	3 pounds to 50 gallons	1	0	22	309	344
Dry soda-sulphur (lime added)	3¾ pounds to 50 gallons	0	4	105	210	217
Dry soda-sulphur (no lime)	do	0	11	148	176	185
Liver of sulphur	do	1	2	178	424	152
Barium tetrasulphide	4¼ pounds to 50 gallons	0	5	10	[1] 102	425
Commercial sulphur spray (substitute for self-boiled lime-sulphur solution).	3⅜ pounds to 50 gallons	0	5	56	459	753
Total		6	27	555	1,957	2,321
Check		1,072	2,527	3,660	615	64
Lime-sulphur solution	1-200	3	6	66	258	232
Dry lime-sulphur	1 pound to 50 gallons	1	15	120	382	64
Dry soda-sulphur (lime added)	1¼ pounds to 50 gallons	0	2	89	792	132
Dry soda-sulphur (no lime)	do	1	22	151	164	212
Liver of sulphur	do	5	11	91	184	418
Barium tetrasulphide	1½ pounds to 50 gallons	0	13	27	243	49
Commercial sulphur spray (substitute for self-boiled lime-sulphur solution).	1⅛ pounds to 50 gallons	0	0	18	231	281
Total		10	69	562	2,254	1,388
Check		1,072	2,527	3,660	615	64

[1] No fruit on this plot. Mites counted on 50 squares of foliage.

In 1922 the same materials were again used on the sulphur-content basis. Two strengths of each material, based on lime-sulphur solution 32° Baumé 1-66 and 1-132, were applied. The spraying was done June 13, 14, and 15, when the rust mites were present in great abundance, and the first rain (1.28 inches) fell June 19 at 7 p. m. The results were identical with those obtained in 1921. No one material gave evidence of having been more effective than the others.

Dry lime-sulphur and barium tetrasulphide (*19, p. 9*) should be used according to the quantity of sulphur they contain, or on the sulphur-equivalent basis. There is no indication in any of the experiments recorded in this bulletin that the sulphur is any more effective in either of these forms than it is in lime-sulphur solution. In fact, in every experiment conducted lime-sulphur solution proved to be equal to or superior to any other form of sulphur. Dry soda-sulphur or soda-sulphur solution should perhaps not be used alone for rust-mite control, since these materials if used on the sulphur-equivalent basis of lime-sulphur 1-50 will produce some injury to the foliage. They have a distinct place, however, when mixed with an oil emulsion to make a combined white-fly, scale, and rust-mite spray. If this combination is used, the oil emulsion should be diluted to the strength usually prescribed for the insects it is intended to control, and 3 or 4 pounds of dry soda-sulphur or 1½ gallons of soda-sulphur solution to 100 gallons of water should be used.

As mentioned before, the trees sprayed in 1918, 1919, 1921, and 1922 were most thoroughly sprayed, which may account for the remarkable uniformity of the results obtained. An opportunity was presented in 1921 for determining the results of spraying under the average grove conditions, using dry lime-sulphur and lime-sulphur solution. The spraying was done April 23, and an abundant infestation of rust mites was present. The results are given in Table 14.

TABLE 14.—*Number of rust mites per 75 squares following application of sprays made with dry lime-sulphur and lime-sulphur solution, April 23, 1921*

Date of examination	Number of rust mites per 75 squares following application of—						
	Spray made with dry lime-sulphur			Spray made with lime-sulphur solution			Check
	2 pounds to 50 gallons	3 pounds to 50 gallons	4 pounds to 50 gallons	½ gallon to 50 gallons	¾ gallon to 50 gallons	1 gallon to 50 gallons	
May 18	805	59	43	8	3	15	1,765
June 15	(1)	264	175	659	481	110	9,979

1 Too many to count.

It will be seen from the table that dry lime-sulphur is much less efficient than lime-sulphur solution when applied under average grove conditions. When 2 pounds to 50 gallons of water was used, the results were little better than where no spraying had been done.

SULPHUR COMPOUNDS COMBINED WITH OIL EMULSIONS FOR RUST MITES

It is often necessary, and many times advisable, to spray for rust mites, white flies, and scale insects at the same time. Since the lubricating-oil emulsions designed for white-fly and scale control are only partially effective against rust mites, it is necessary to add sulphur in order to obtain satisfactory results. For many years soda sulphur in both the dry and liquid forms has been used for this purpose.

In 1912 an attempt was made to determine the strength of soda-sulphur solution [8] that should be used with oil emulsion to produce satisfactory results. The results obtained are given in Tables 15 and 16. The adults were killed in every test, and examinations had reference only to young mites which hatched out after the tests were made.

The results of the tests made by dipping branches and spraying trees agreed reasonably well, and if 1 per cent of oil is used for the control of scale insects the strength of soda-sulphur solution should not be less than 1-100, and 1-75 would make a perfect mortality more certain. From 3 to 4 pounds of the dry form of soda-sulphur (analyzing 56 per cent of sulphur) to 100 gallons of water produces satisfactory results when combined with 1 per cent of oil as emulsion.

TABLE 15.—*Dipping tests to determine the strength of soda-sulphur solution most effective in combination with oil emulsion for the killing of eggs of the rust mite*

[Twigs dipped July 27, 1912, Orlando, Fla.]

Composition of insecticide used		Results of examinations made—		Remarks
Oil emulsion	Soda sulphur	July 29	Aug. 7	
Per cent oil	*Gallons to gallons of water*			
0.25	1-75	15 young mites	Very few mites, eggs numerous.	
.25	1-50	Young mites present	No living mites, but eggs appear normal.	Nearly perfect.
.50	1-100	6 young mites present	1 young mite	
.50	1-75	Young mites present	Young mites present	
.50	1-50	No young mites	No mites	Perfect.
.75	1-150	Young mites present	No examination	
.75	1-100	1 young mite	No mites found, but may not be conclusive.	Nearly perfect.
.75	1-75	Killed no eggs. No young mites present.	1 young mite	Do.
1.00	1-150	Young mites present, eggs appear normal.	No examination.	
1.00	1-75	2 young mites.	No living mites	Perfect.
1.00	1-100	4 young mites present.	4 young mites	Nearly perfect.

TABLE 16.—*Spray tests to determine the strength of soda-sulphur solution most effective in combination with oil emulsion for the killing of rust-mite eggs*

[Trees sprayed July 19, 1912, Orlando, Fla.]

Composition of insecticide used		Results of examinations made—		Remarks
Oil emulsion	Soda sulphur	July 23	Aug. 6	
Per cent oil	*Gallons to gallons of water*			
0.25	1-150	Living mites abundant	Mites abundant, same as check.	
.25	1-100	Many living mites present	Mites abundant, about same as check.	
.25	1-75	Living mites present	Very few present	
.25	1-50	One young mite living	Mites fairly abundant	Eggs appear abnormal. Perfect.
.50	1-100	Living mites present.	do	
.75	1-100	Very few living mites present.	do	Perfect.
1.00	1-100	None present	Few living mites present	Do.

[8] The solution used in all the experiments was made according to the formula given on p. 22 of Farmers Bulletin 933 (*16*).

The simple oil emulsions can be treated with glue or other stabilizers to make them mix with lime-sulphur solution (*21*), dry lime-sulphur, or barium tetrasulphide. Several commercial oil emulsions are so made that they will readily mix with these sulphur compounds. These combination sprays have been used by the writers experimentally and in most cases produced satisfactory results, as shown in Table 17.

All of the tests produced a satisfactory mortality.

In 1922 a small grove was sprayed with 3 quarts of lime-sulphur solution combined with 1 per cent of oil as emulsion in 50 gallons of water, and satisfactory results were produced.

TABLE 17.—*Results of spraying with 7 per cent oil emulsions combined with varying quantities of lime-sulphur solution, dry lime-sulphur, and barium tetrasulphide*

Composition of spray	Number of rust mites present on 75 squares			
	Before spraying	May 12	May 31	July 6
Barium tetrasulphide 1½ pounds, plus oil-emulsion paste	589	0	2	--------
Barium tetrasulphide 2½ pounds, plus oil emulsion with glue	589	0	0	--------
Barium tetrasulphide 4½ pounds, plus oil-emulsion paste	56	0	0	[1] 210
Dry lime-sulphur 1½ pounds, plus oil emulsion with glue	589	[2] 1	[3] 4	--------
Dry lime-sulphur 1½ pounds, plus oil-emulsion paste	589	0	[4] 2	--------
Dry lime-sulphur 3 pounds, plus oil emulsion with glue	56	0	0	107
Lime-sulphur solution 1–130, plus oil emulsion with glue	589	0	0	[5] 1
Lime-sulphur solution 1–66, plus oil emulsion with glue	56	0	0	96
Check	--------	--------	332	--------

[1] 175 on 1 fruit may not have been hit by spray.
[2] 1 young mite.
[3] 2 young mites.
[4] 2 young mites.
[5] 1 young mite.

In 1923 considerable injury followed the use of oil-emulsion paste made by using kaolin as the emulsifying agent and lime-sulphur solution. In several other cases injury has followed the use of soda-sulphur solution combined with the oil emulsions. It is not known why the oil emulsion and sulphur sprays cause injury in rare instances only, and this combination has gradually been discarded in recent years.

THOROUGHNESS IN SPRAYING NEEDED

In spraying for white flies and scale insects it is necessary to hit every insect with the spray material in order to kill it. This requires most thorough application and the skillful use of a spray rod. Since rust mites are killed by the oxidation of sulphur not necessarily in immediate contact, the necessity for such thorough work is not imperative to produce satisfactory rust-mite control. Spraying, however, should not be carried on in a haphazard or disinterested manner. Every fruit on a tree should be thoroughly wet, and an attempt should be made to hit foliage on the lower surfaces. In so doing a large part of the upper surfaces of the foliage will likewise be wet by the spray. Abundant observations indicate that the more thoroughly spraying for rust mites is done the more lasting are the results.

TIME TO SPRAY

The opportune time for spraying for rust-mite control is when the mites are present in great abundance and yet before little or any blemish to the fruit has been caused. Since the rust mite reaches its period of maximum abundance between the middle and the last of June, it is obvious that the opportune time to spray should be some time between the 1st and the 15th of June. Rust mites also become abundant in December and January, and as it is desired to keep fruit from becoming even slightly russeted it is often necessary to spray or dust. If winter spraying in December and January for white flies and scale insects is given, it is advisable to use soda-sulphur if rust mites are present. Where shark skin is present on grapefruit the opportune time to spray is in April, with a second application in June. Numerous experiments show that spraying done in February or March is of value in preventing shark skin and rust-mite abundance during the spring months, but in no instance has this spraying resulted in such a degree of rust-mite control as to make the June spraying unnecessary. On figure 7, which shows the curve of abundance of rust mites on oranges, is indicated the opportune time to spray to obtain the maximum results with the minimum expenditure of money. Spraying for grapefruit should be done a month or six weeks before that required for oranges

EFFECT OF RAIN FOLLOWING SPRAYING WITH LIME-SULPHUR SOLUTION

Since the opportune time to spray for rust mites in order to obtain the maximum results for the least cost often comes at the season of the year when heavy rains may take place, it is important to know the results to be expected under such conditions. Many experiments and observations have been made, extending over a long period, to determine this point, and the more striking of these are here discussed.

On July 3, 1916, spraying experiments for the control of rust mites with lime-sulphur solution were being conducted. There was a gentle rain about 30 minutes after some of the trees had been sprayed and before the material had dried on the foliage. Other trees were sprayed during the rain. An examination made on the following day of trees sprayed with 1–25 and also with 1–50 strength showed that all the mites had been killed. A tree sprayed with the 1–50 strength during the rain was quite white. On July 8 trees that had been sprayed during the rain had no rust mites on them, and in August they were just as free from rust mites as those trees sprayed a half hour before the rain.

Again on May 24, 1920, a grove was sprayed using lime-sulphur solution 1–50 applied most thoroughly. The work was finished at 4.30 p. m., and between 6 and 7.30 p. m. 2⅓ inches of rain fell. On June 2 the fruit and leaves were examined for about 30 or 40 minutes, and no living mites were found. As it had been nine days since the adult mites were killed, there had been plenty of time for the eggs laid prior to the spraying to have hatched. This large-scale experiment certainly indicated that the eggs of the rust mites were killed by the spray even though a heavy rain fell shortly afterwards. The spray was thoroughly effective and protected this crop from rust mites until late fall.

Perhaps the most severe test of the effect of lime-sulphur solution when followed by excessive rains was carried on in May, 1923. On May 21, at about 11 a. m., some sweet lemon and grapefruit trees, very heavily infested, were sprayed with lime-sulphur solution 1–66. A heavy rain fell one hour after the spraying was done, and considerable rain continued to fall until late in the afternoon. It rained for three hours on the night of May 22, and a heavy rain fell on May 23, from 4 to 4.30 p. m. Another heavy rain occurred May 24 (p. m.). On May 25 an examination of 30 squares (15 on upper surfaces and 15 on the lower surfaces of the leaves) gave only one young mite. No adult mites were present. Another heavy rain fell the night of May 25. An examination of 20 squares on May 26 showed no living mites. On both dates there was an abundance of dead rust mites killed by the spray. On June 13 these trees were again examined, and 50 squares (half on the upper and half on the lower surfaces) gave no mites.

INJURY FOLLOWING THE USE OF LIME-SULPHUR SOLUTION

Considering the quantity of lime-sulphur solution used in Florida the injury resulting therefrom is very slight indeed, although instances do appear where extensive and serious damage follows its application. This injury in nearly every instance is on the side of the fruit on which the sun was shining when the spraying was done, and is never found on the lower side of the fruit, where the drops of spray material would collect. In some cases the damaged area is an inch and a quarter in diameter (fig. 9), and of course such fruit has no commercial value.

FIGURE 9.—Orange injured apparently by sunburn following the use of lime-sulphur solution

Some time during the last week in April, 1919, a citrus grower of Bradenton sprayed, by mistake, his entire grove with commercial lime-sulphur solution 1–9, or according to directions on the barrel for dormant spray on deciduous trees. Such dilutions are usually applied for the San Jose scale. The trees were sprayed on the following day with water, which may have washed off some of the lime-sulphur solution. On May 19 very little injury was apparent, not nearly so much as would be expected. Many old leaves and a very few new ones had fallen. Only a small percentage of fruit had fallen off, and only a very small percentage of that left had been damaged at all. The trees were still quite white on the date of the examination.

Experiments have been carried on to determine, if possible, what factors are responsible for this damage. On July 18, 1912, one tree without fruit was thoroughly sprayed with lime-sulphur solution 32° Baumé, 1 to 9. Little or no injury had been done to the foliage up to August 6. Only the most recent growth had been injured.

Some time during 1914, with the temperature at 95° F., a sweet-orange seedling tree was sprayed with lime-sulphur solution 1–25. On February 5, 1915, there were 44 fruits injured and 195 uninjured, or 18.4 per cent damaged. A row of trees including one sour-orange tree was sprayed with 1–25 lime-sulphur solution during the spring of 1914. When the fruit was picked 13.8 per cent of it was damaged. The fruit on the sour-orange tree in the row was very seriously damaged. In 1911, however, a row of 20 seedling trees was sprayed three times—on May 15, July 1, and August 15—with lime-sulphur solution 1–25. The spraying was most thoroughly done, and not the slightest injury developed. On June 9, 1917, a tree was sprayed at 2 p. m. (temperature 95° F.) with lime-sulphur solution 1–25, and no injury developed. On the same day some large trees were sprayed with lime-sulphur solution 1–50, and no injury resulted.

On November 26, 1912, four trees were sprayed, half of each with lime-sulphur solution 1–75 and half with 1–33. No injury apparently developed, except that on the lower side of each fruit sprayed with 1–33 a very tiny reddish spot developed. This injury did not seem to be at all serious, and the fruit appeared normal except for this tiny spot on January 23. A great deal of spraying has been done with lime-sulphur solution 1–50, and only rarely does it cause injury, and 1–75 does not cause injury except in extremely rare cases. Just what the factors involved in causing this injury are, the experiments have not shown. The writers think, however, that it is largely a case of sun damage hastened or intensified by the lime-sulphur solution.

DUSTING WITH SULPHUR FOR RUST-MITE CONTROL

It has been known since 1885 that sulphur when applied to citrus trees and fruit as a dust was extremely effective in killing rust mites (*7, p. 116*). This method of application owes its value to the extreme sensitiveness of the mites to sulphur. (See p. 39.) Considerable field experimental work was carried on in 1919 (*17*), 1922, 1923, 1924, and 1925. Several other groves dusted by commercial concerns were under observation, and the results then obtained were utilized in forming conclusions on the several points connected with dusting. Practically all of the writers' experimental work was carried on with a large power duster. (Fig. 10.)

MATERIALS AND QUANTITIES

FLOUR OF SULPHUR

A large part of the experimental work was done with flour of sulphur, which is perhaps the cheapest grade of sulphur that can be used for dusting purposes. It is 99.5 per cent pure, is somewhat coarse and heavy, the screen test being 56 per cent through 170 mesh, but it comes out of the machine in fairly good shape and reaches the tops of the highest seedling trees. It required from two-thirds of a pound to one pound to cover a tree. The results were entirely satisfactory, a complete mortality having been produced.

FIGURE 10.—Power duster applying sulphur dust: (A) To low citrus trees and (B) to tall citrus trees

FLOWERS OF SULPHUR OR SUBLIMED SULPHUR

A considerable portion of the experimental work was done with flowers of sulphur. It is a very fine bulky and fluffy material, the screen test being 84 per cent through 170 mesh, and it comes out of the machine in fine shape, producing a cloud of sulphur particles that envelopes the trees. Owing to the great bulk of this form of sulphur, it requires only a little more than one-half pound per tree. The results were highly satisfactory, a complete mortality having been produced.

SULPHUR AND LIME MIXTURE

There are a great number of dust mixtures on the market in Florida. Most of these are mixtures of sulphur and hydrated lime in various proportions and depend for their effectiveness on the sulphur content. The writers used in part of one grove a mixture of 80 per cent sulphur and 20 per cent hydrated lime. It came out of the machine satisfactorily, and the mortality was complete. Mixtures containing 90 per cent of sulphur and 10 per cent of hydrated lime have also been used with satisfactory results. If the percentage of lime in the mixture is much more than 20 per cent the results are not so satisfactory. The hydrated lime itself has no value in killing mites. Trees were dusted in 1922 and 1923 with hydrated lime alone and, in so far as could be determined, no mortality whatever was produced.

No injury to the fruit or foliage has ever resulted from the use of any form of sulphur dust. Even parts of the trees which received large quantities of sulphur when the dusting machine was standing still showed no injurious effect. In several instances trees were dusted so heavily that they were coated with sulphur, but not the slightest injury developed.

TIME OF APPLICATION OF DUST

Dusting for rust-mite control may be done at any time during the day at the convenience of the operator. Sulphur applied during the hottest and dryest part of the day produced results as satisfactory as that applied in the early morning. In a grove dusted between 11.30 a. m. and 2 p. m. a complete mortality of mites was obtained. In another grove dusted between 7 and 9 a. m., when the foliage was wet with dew, similar results followed. The sulphur, however, adheres to the leaves better if it is applied when they are wet and therefore may be effective over a longer period. In the grove dusted in the early morning some of the sulphur remained on the leaves and branches after almost daily rains for a month. In all probability enough sulphur to kill mites remained on the leaves and fruit after several rains. In all cases when the sulphur was applied when the leaves were dry the first drenching rain washed it all off. If the dusting can conveniently be done when the foliage is wet it is advisable to do it then, but operations should not stop if the dusting is unfinished when the leaves become dry. If extensive work is done the dusting should begin in the morning and continue until night or until the work is finished.

RELATION OF TEMPERATURE TO MORTALITY OF MITES

The efficiency of dusting presumably depends upon the oxidation of the sulphur. The higher the temperature the more rapidly this process takes place, and consequently the earlier the results are effected. In every case when dusting was done when the temperature was 90° F. or above, a complete mortality followed in a very few minutes. The writers have never found any living mites in a grove one hour after dusting when the temperature was 90° F. or above. When dusting is done during the winter with the temperature ranging from 70° to 80° the effect is not so immediate. Sometimes it is several days before all the mites are killed. In a grove dusted January 8, 1923, with a temperature ranging from 75° to 80° in the middle of the day it was two or three days before a satisfactory mortality was obtained, and even after a week a few mites were still present. The records of the Weather Bureau show that the average temperatures prevailing in May, June, and July, when the greater part of the dusting for rust-mite control is done, are highly conducive to a complete mortality of mites.

RELATION OF RAINS TO EFFECTIVENESS OF DUSTING

Experiments and observations made in all field tests show that a large part of the sulphur which adheres to the foliage at the time of dusting will remain there until it is washed off by a drenching rain. In one case the sulphur remained on the foliage for more than two weeks, apparently in undiminished quantity. In another grove, dusted in January, 1923, more than two weeks elapsed after the dusting before a drenching rain fell The heavy dews and breezes had caused a considerable portion of the sulphur to disappear, but there was a sufficient quantity present to kill the rust mites. In two groves dusted in 1919 practically all the sulphur remained until it was washed off by a drenching rain. Before the rain it was not possible to determine that any less sulphur was present on the foliage than there was immediately after the dusting. After the rain, however, there was practically none present. In one of the groves it remained 4½ days and in the other it remained 2½ days. In a grove dusted in 1922 the sulphur remained for 5 days, when practically all of it was washed off by a drenching rain. In another grove dusted in 1922 a drenching rain came a day after the dusting. The grove was dusted again on the fourth day after the first dusting. The foliage was wet when the second dusting was given, and the sulphur adhered much better than when it was dry. Though it is true that perhaps enough sulphur remained on the trees after one or two rains to cause death to rust mites, a greater part of it was washed off within the period of a week. Although sulphur adheres to the smooth citrus leaves much better than would be supposed, it is exceedingly doubtful whether under average conditions enough sulphur will be left on the trees to kill mites after one drenching rain.

Since the presence of sulphur on leaves and fruit produces the almost immediate death of all rust mites it would appear from a superficial standpoint that rains would have little or no bearing on the effectiveness of dusting for their control. This, however, is not the case. In June, when most of the dusting should be done, there is a large number of eggs present which require from two to four days to hatch. It is reasonably certain that sulphur will not prevent many of these eggs from hatching, but it is a certainty that the young mite will be killed by the sulphur just as soon as it emerges from the eggshell.

ADHESIVES

As sulphur is washed from the trees by drenching rains it occurred to the writers that some adhesive might be mixed with the sulphur to make it adhere to the trees indefinitely. If such an adhesive could be procured it would be a decided advantage to the citrus grower, and rust-mite control would be placed on a simple and inexpensive basis. Plaster of Paris, Portland cement, powdered glue, rosin, and tripoli were used, but without any success. The sulphur was washed from the trees whether these were used or not.

NUMBER OF APPLICATIONS

The number of times a grove should be dusted depends entirely upon the length of time after dusting before a drenching rain falls. Though the results obtained from dusting when followed immediately by drenching rains were much better than could be expected, young mites were usually found in more or less abundance under such conditions. If no rain falls for four or more days after the dusting all the rust mites as well as all the young mites which have hatched from the eggs present at the time of dusting will be killed, and a complete mortality thus effected. In case of rain it may be advisable to repeat the dusting before the expiration of the eighth day after the first dusting. This will reach all young mites before they are old enough to deposit eggs. Some groves no doubt will be able to get along with one dusting in June, and, if the fruit is to be held late, another dusting in January. Other groves will require two dustings in May and June and perhaps another one in December, or at any rate during the winter. Dusting for mites should be given when they are reasonably numerous on the fruit but before the faintest tinge of russeting has appeared.

EFFECTS OF DUSTING WITH SULPHUR FOLLOWING AN OIL SPRAY

It was deemed advisable (*20*) to test out the effect of dusting with sulphur following an oil-emulsion spray. On May 9, 1926, two rows of Valencia orange trees were sprayed with a so-called red oil that has been commonly used for spraying citrus trees for many years. Two rows were also sprayed with a good grade of so-called white oil. The red oil was used at 1.25 per cent actual oil and the white oil at the rate of 1.5 per cent. The maximum temperature was above 92° F. every day. Five days later the entire four rows were dusted with commercial dusting material containing about 92 per cent of sulphur and 8 per cent of hydrated lime. An excessive quantity of dust was used. Examinations were made on May 21 and June 6 and 14, and no evidence whatever was present to indicate that any injury had been done. There had been no rain until June 5, when 0.13 inch fell.

On May 19, 1926, two rows of Valencias were sprayed with the same red oil as was used on May 9, and also two rows with a high-grade white oil. Both oils were used at exactly 1.5 per cent of oil in the spray material. Within 20 minutes after the spraying, a sulphur-dust application was made to one row each of the trees sprayed with the red oil and to one sprayed with the white oil. Although the temperature was not excessive on the day the materials were applied, it reached a maximum of 102° F. before June 14, the date of the last examination. On May 21, the fruit was covered with a film of oil overlaid with a layer of sulphur. There was not the slightest indication of injury. On June 6 and 14 there was evident severe injury to the fruit on the rows dusted with sulphur. The side of the fruit facing the direct sunlight showed yellow spots or large yellow areas. Some of these spots were scarcely visible, but showed up as very light yellow areas. The injury was very slow in developing. There was no injury whatever to the fruit sprayed with either oil and not dusted with sulphur.

The injury was of commercial importance, and the writers would advise growers to wait two or three weeks after the application of an oil spray before dusting with sulphur.

SUMMARY

The familiar russeting of citrus fruit was first ascribed, about the year 1878, to the feeding of a mite. This insect was described by Ashmead, and is now known as *Phyllocoptes oleivorus*, or the citrus rust mite. It is found in most of the citrus regions of the world, but so far as known is absent from the Mediterranean and South African areas. It probably ranks third among the injurious pests on citrus trees in Florida, injuring more or less about 50 per cent of the fruit.

The mite is found on all the commercial species and varieties of citrus grown in Florida, being most severe on lemon and about one and two-thirds times as numerous on grapefruit as on orange. There are no other species of Phyllocoptes found in Florida, but other mites are sometimes confused with the citrus rust mite, especially one that feeds on maiden cane and one found on roses, and several species of gall-forming mites.

The injury is apparent on the exterior of the fruit in the form of a more or less severe russeting of the rind. The grade of the fruit is lowered, and the infested fruits are smaller and lose further by evaporation much more quickly than normal fruit. The keeping quality is impaired and, contrary to the somewhat prevalent idea, the russeted fruit is not so sweet as the uninjured fruit. The leaves and branches are also injured by the feeding of the rust mite.

On account of the small size of the mites, studies of the individual mites were difficult to make, but a small gelatin capsule fastened by paraffin to the rind of a fruit provided a cell or cage in which they could be observed. The incubation period was found to last from 2 to 4 days during the hot months and to extend to 8 or more days in the winter. The larval stage is of about the same duration as the egg stage. The longest life period recorded for an adult was 23 days, and the maximum number of eggs deposited by any female under observation was 29. No male has been observed. The rapid increase of this mite may be due more to the fact that in the summer a generation may be completed in 7 days than to a large reproductive capacity of the individual.

The mites are continuously present in the trees throughout the year, but the numbers rise to injurious proportions about the middle of June and, probably because of an entomogenous fungus, suddenly decrease a short time after the beginning of the summer rains. They are probably distributed on nursery stock, by insects and birds, and by the wind.

The weather factors that affect adversely the abundance of the rust mites are the occasional visitations of freezing weather in the citrus belt and seasons of dry weather. Hot sunshine and rains seem only to drive them to the more protected surfaces of the fruit and leaves. Insect enemies are unimportant, but a fungous disease seems to be responsible for the almost complete disappearance of the mites, usually in the first half of July. They are never abundant in the more humid sections near the coast.

Insecticides that would control leaf-eating insects are of no value against the mites. Tobacco, nicotine dust, and oil sprays have not given sufficient control to prove profitable. Sulphur has been found the best agent for use against the rust mite. Its action is through the fumes from the oxidation of the sulphur, which does not have to be in actual contact with each mite to cause its death. Sprays and dusts containing sulphur seem to be about equally effective when compared on the basis of the sulphur content. When used in the form of a lime-sulphur solution at a dilution of from 1–50 to 1–100, it should kill all adults and larvæ present at the time and remain effective under any weather conditions for a sufficient time to kill all larvæ subsequently emerging from the eggs that had been deposited prior to the spraying. Dusting with sulphur or sulphur and lime mixtures is also effective and may be carried on at any time of the day, but the dust will remain on the trees longer if applied while the foliage is wet with dew. If a drenching rain falls within four days it may be necessary to repeat the dusting before the eighth day after the first application.

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