EFFECT OF DIFFERENT COPPER FORMULATIONS TANK-MIXED WITH FENBUTATIN-OXIDE FOR CONTROL OF CITRUS RUST MITES (ACARI: ERIOPHYIDAE) ON FLORIDA CITRUS

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ABSTRACT

One or more rates of fenbutatin-oxide (= Vendex®) 4 L applied alone were compared with the same rates of Vendex tank-mixed with one or more formulations of copper and an untreated check for control of citrus rust mite, *Phyllocoptruta oleivora* (Ashmead) (Acari: Eriophyidae), in 4 citrus grove sites between 1988 and 1991. The copper formulations corresponded to recommended rates in the Florida Citrus Spray Guide and included: 99% GC basic copper sulfate (pentahydrate) with 53% metallic copper, a 77% WP copper hydroxide formulation containing 50% metallic copper and a 61.4% copper hydroxide DF formulation containing 40% metallic copper. Reduced effectiveness of Vendex occurred when combined with all 3 copper formulations. Both copper hydroxide formulations were more disruptive in reducing the effectiveness of Vendex in controlling citrus rust mite compared with the basic copper sulfate formulation. Increases in citrus rust mite numbers occurred in the copper-only treatments in 2 of the 3 field experiments. In both instances, population increases in the copper-only treatments occurred at the same time as those in the untreated check trees, suggesting a stimulatory effect by the copper compounds.

Key Words: Chemical control, *Phyllocoptruta oleivora*, miticides, spray tank-mixes

RESUMEN

Varias dosis de oxido de fenbutatina (Vendex) 4 L aplicadas solas fueron comparadas con mezclas en tanque de diferentes formulaciones de cobre mas fenbutatina a las mismas dosis y con un testigo no tratado, para el control del acaro tostador, *Phyllocoptruta oleivora* (Ashmead) (Acari: Eriophyidae), en cuatro localidades con huertas de citricos entre 1988 y 1991. Las formulaciones de cobre correspondieron a las recomendadas en la Guía de Aspersiones de los Cítricos de la Florida e incluyeron: 99% GC de sulfato de basico de cobre (pentahidratado) con 53% de cobre metalico, una formulación de hidroxido de cobre al 77% WP conteniendo 50% de cobre metalico y una formulación del 6l.4% de hidroxido de cobre DF con un 40% de cobre metalico. La efectividad del Vendex se redujo cuando este fue combinado con las tres formulaciones de cobre. Las formulaciones de hidroxido de cobre redujeron mas fuertemente la efectividad del Vendex que el sulfato basico de cobre en el control del acaro tostador. En dos de los tres campos experimentales se observaron aumentos en la mortalidad de los acaros tostadores. En ambos casos, la población en los tratamientos de cobre solo aumentó al mismo tiempo que en los arboles no tratados, sugiriendo un efecto estimulador por parte de los compuestos de cobre.

Copper compounds are recommended for use on Florida citrus to control several fungal diseases including greasy spot (*Mycosphaerella citri* Whiteside), melanose (*Di-*

aporthe citri Wolf) and citrus scab (*Elsinoe fawcettii* Bitancourt & Jenkins) (Timmer & McGovern 1993, Whiteside 1988). Several formulations of copper, that contain metallic copper, including copper sulfate and copper hydroxide, have been used by Florida citrus growers for many years. The materials are relatively inexpensive while providing fungicidal activity. Many citrus growers apply copper in the postbloom and summer sprays, in combination with a miticide or insecticide, for broad spectrum pest control and to minimize application costs.

The citrus rust mite, *Phyllocoptruta oleivora* (Ashmead), and the spider mites, *Eutetranychus banksi* (McGregor) and *Panonychus citri* (McGregor), can be serious pests during the postbloom and summer periods and thus may require a miticide application during one or both times, depending upon citrus variety, mite presence and risk of population increase (Childers 1987).

Thompson (1939) found that *P. citri* increased following copper sprays on citrus and Holloway et al. (1942) reported that this spider mite was more abundant following sprays containing compounds of copper, zinc and lime compared with untreated trees. Griffith & Fisher (1949) observed that *Phyllocoptruta oleivora* and *Panonychus citri* increased abnormally on citrus in Florida following the use of sprays containing copper, zinc, or lime or exposure to road dust or fertilizer residues on fruit and leaves. Johnson (1960a) evaluated 5 copper formulations, including basic copper sulfate, copper oxide, copper hydroxysulfate, copper sulfate, and tetra copper calcium oxychloride, in combination with zineb for control of *Phyllocoptruta oleivora*. All of the copper compounds and rates tested reduced the effectiveness of zineb in the summer spray but not in the postbloom spray. This supported earlier work by Johnson et al. (1957) that showed zineb provided less control of *P. oleivora* when combined with fixed copper compared with zineb alone.

Residual control by chlorobenzilate or dicofol against the citrus rust mite was reduced when copper or methidathion was tank-mixed for use on citrus in Texas (Dean 1979). Densities of *Brevipalpus phoenicis* (Geijskes) (Acari: Tenuipalpidae) increased after frequent copper oxychloride applications on tea in Indonesia (Oomen 1982). Eger et al. (1985) evaluated tank mixtures of copper with chlorpyrifos or ethion applied in 2.338 or 4.676 kiloliters of water per hectare using an airblast sprayer. They found that residual control of the citrus rust mite was reduced with the copper + organophosphate combinations compared with the organophosphate compounds applied alone. *Hirsutella thompsonii* Fisher, a fungus pathogenic to citrus rust mite, was suspected of being adversely affected by the copper.

Vendex is not affected by differences in water pH because the organotin compound is extremely stable. The formulation forms a suspension, not a solution, in water (Seaman & Riedl 1986). This would suggest that a coating of the miticide by petroleum oil would reduce the efficacy of the contact miticide (Childers & Selhime 1983).

Grower complaints of poor citrus rust mite control with fenbutatin-oxide + copper tank mixes prompted the field evaluations reported in this paper. The residual activity of one or more copper formulations in combination with one or more rates of Vendex was evaluated between 1987 and 1991 and compared with the miticide applied alone at the same rates. Results of these studies are reported here.

Materials and Methods

One or more rates of Vendex, 4 pounds active ingredient per gallon liquid formulation (4 L) (479 g AI per liter) (E. I. DuPont de Nemours, Wilmington, DE), applied alone were compared with the same rates of Vendex tank-mixed with one or more for-

mulations of copper for citrus rust mite control and an untreated control in 4 citrus grove sites between 1988 and 1991 (Table 1). The rates of copper corresponded to recommended rates in the Florida Citrus Spray Guide. The copper formulations included 99% basic copper sulfate (pentahydrate) granular crystals (GC) with 53% metallic copper (Tennessee Chemical Co., Copperhill, TN), a formulation of 77% copper hydroxide WP containing 50% metallic copper (Kocide Chemical Corp., Houston, TX) and a 61.4% copper hydroxide dry flowable (DF) formulation containing 40% metallic copper (Griffin Corp., Valdosta, GA).

Experimental Sites

At grove site 1, plots consisted of 9 trees arranged in a 3 by 3 grid (Table 1). At sites 2 and 3, treatments were assigned to plots of 25 trees arranged in a 5 by 5 grid and at site 4, 36 trees arranged in a 6 by 6 grid. All treatments were arranged in a randomized complete block design based on motile numbers of citrus rust mites per tree taken during the pretreatment counts and replicated 5 times for each site (Childers & Selhime 1983).

The center tree was sampled from each plot in all of the sites except site 2 where 2 center trees were sampled from each plot. Each sample tree was a vigorous, healthy tree representative of the block and each plot was separated from adjacent plots by 2 trees within the row and 2 rows between treatments. Foliar spray treatments were applied in the listed volumes per ha with properly calibrated airblast sprayers on the dates listed in Table 1.

TABLE 1. LOCATIONS, CHARACTERISTICS OF CITRUS PLANTINGS, DATES OF MITICIDE APPLICATION, SPRAYERS, GALLONAGES AND TRACTOR SPEEDS.

	Citrus Grove Site			
Characteristic	1	2	3	4
Location	Baseball City Polk County	Mineola vic. Lake County	Lake Placid vic. Highlands County	Ft. Meade vic. Polk County
Cultivar	Valencia orange	Hamlin orange	Valencia orange	Hamlin orange
Tree height (meters)	4.57-5.49 m	2.13-3.35 m	4.27-5.18 m	2.44-3.66 m
Spacing (meters)	7.62 x 7.62 m (= 173 trees/ hectare)	7.62 x 9.14 m (= 240 trees/ hectare)	9.14 x 9.14 m (= 119 trees/ hectare)	4.57 x 7.62 m (= 287 trees/hectare)
Application dates	May 26-27, 1988	June 20-22, 1989	June 25-26, 1991	July 8-10, 1991
Type sprayer	FMC 4000 CP	Southwind pto	FMC 970	Swanson-Durand pto
Liters per hectare	1,169	1,169	1,403	720
Spray pressure	160 psi	200 psi	180 psi	100 psi
Tractor speed	2.4 kph	2.4 kph	2.4 kph	2.4 kph
Water pH	7.9	7.8	7.3	7.6

Mite Sampling

Twenty fruit were examined at random around the canopy perimeter of each sample tree at recorded time intervals before and after spraying of the treatments. Live motile citrus rust mites were counted using a 10x hand lens equipped with a 1 cm^2 grid subdivided into 4 mm^2 subunits (Childers & Selhime 1983). Two places on opposite sides of each fruit outside of the exposed sunspot were examined. Population density estimates of citrus rust mite were obtained by counting the number of living motile mites present within the combined 2 cm^2 area per fruit and recorded as one observation. In test 2, 10 fruit were examined at random around the canopy perimeter from each of 2 sample trees with a total of 20 fruit per plot.

Twenty leaves from the spring flush were picked at random around the canopy perimeter of each sample tree at designated time intervals before and after spraying. Each leaf sample was placed in separately labeled paper bags and returned to the laboratory. A stereomicroscope was used to examine a 1 cm^2 area on both the upper and lower leaf surfaces in test 1, or a 2 cm^2 area on both leaf surfaces in tests 4 and 5. Live motile citrus rust mites were counted within each area on both the upper and lower leaf surfaces. The 2 counts were combined as 1 observation and equalled either 2 or 4 cm^2 area of leaf surface. In test 3, 10 leaves were collected from each of 2 trees in the center of each plot.

Cumulative citrus rust mite-days were determined for each treatment within a grove each year by calculating the area under the population growth curve over time (Allen 1976). Mite-days were calculated using the formula presented by Childers et al. (1987).

Fruit Damage Ratings

One hundred fruit were examined randomly around the perimeter of each sample tree following completion of a field experiment. The cumulative percentage of surface area with russeting from citrus rust mite feeding injury was recorded for each fruit. This was determined by estimating the percentage area of russeting on one side of each fruit and then turning the fruit 180° and repeating the estimate of russeted area again. The combined estimated russeted area of sides one and two for each fruit was then divided by two. A series of plates with line drawings of mature sized fruit with calculated proportional areas of surface injury were prepared to provide a consistent reference for the person determining rind blemish injury. A fruit was classified as rejected for the fresh market when rind blemish from citrus rust mite feeding exceeded 5% of the total surface area.

Statistical Analysis

In all experiments, data were subjected to analysis of variance; Duncan's (1955) multiple range test was used to separate treatment means when the ANOVA provided a significant F value ($P \leq 0.05$) (SAS Institute 1991). Motile citrus rust mite counts were subjected to Log_{10} $(X + 1)$ transformations for statistical analysis. Untransformed means are shown in all tables.

RESULTS

Site 1, 'Valencia' Orange

Sustained moderate numbers of citrus rust mites were present in the untreated check trees through August 2 following treatment applications on May 26 and 27. Cit-

rus rust mite densities on treated trees were significantly higher between August 2 and 25 in the Vendex + copper sulfate or hydroxide combinations compared with the Vendex only treatments at the same rate (Table 2). Cumulative mite-days were significantly higher with the 2.10 kg rate of Vendex + copper hydroxide and the 1.40 kg rate of Vendex + copper sulfate compared with the same rates of Vendex applied alone. The other combinations of copper + Vendex did not result in significantly higher cumulative mite-days than the corresponding rates of Vendex alone. Damage rating differences were not significantly different between the miticide treatments in this experiment (Table 2). Based on these data, all Vendex treatments performed well.

Site 2, 'Hamlin' Orange

Moderate to high densities of citrus rust mites were present on the untreated trees between July 27 and October 12 following treatment applications (Table 3). Vendex at 1.68 kg + copper hydroxide had a significantly higher citrus rust mite density on the fruit by September 20 compared with Vendex at 1.68 kg applied alone. Vendex at 1.68 kg + copper sulfate had a significantly higher citrus rust mite density by September 27 compared with Vendex at the same rate applied alone. These differences continued through October 18. Vendex at 2.24 kg + copper hydroxide had significantly higher citrus rust mite densities by September 27 compared with Vendex at 2.24 kg applied alone. Again, these differences continued through October 18. The Vendex at 2.24 kg + copper sulfate combination was not significantly different from Vendex at 2.24 kg until October 3. These differences in citrus rust mite densities continued to be significantly higher through October 12. Vendex at 2.80 kg combined with either copper hydroxide or copper sulfate had significantly higher citrus rust mite densities on the fruit by September 20 and 27 and October 18 compared with Vendex at 2.80 kg applied alone. These high rust mite densities occurred while the population was increasing in the untreated check trees.

Consistently higher citrus rust mite densities ranging from 1 to 4 times higher were present in both copper hydroxide and copper sulfate treated trees between August 17 and September 27 compared with the untreated trees.

Cumulative mite-day comparisons were significantly different between the Vendex at 1.68 kg + copper hydroxide treatment compared with Vendex at 1.68 kg applied alone (Table 4). Cumulative mite-day differences between the remaining miticide treatments were not significantly different although numerically higher densities of citrus rust mites were consistently obtained in the Vendex + copper treatments compared with the Vendex only treatments.

Significantly higher percentages of russeted and rejected fruit were obtained in the low rate of Vendex combined with either copper hydroxide or copper sulfate compared with the low rate of Vendex applied alone (Table 4). The highest percentages of russeted and rejected fruit were obtained in the copper-only treatments compared with all other treatments including the untreated check trees.

Site 3, 'Valencia' Orange

Low to moderate citrus rust mite densities were present on both fruit and leaves between July 11 and August 19 on the untreated check trees (Tables 5, 6). Low but significantly higher citrus rust mite densities were present on the Vendex + copper DF treatment by August 12 compared with Vendex applied alone. Significantly higher citrus rust mite densities on the fruit were consistently obtained on the Vendex + copper DF treatment between August 12 and September 17 compared with Vendex applied

TABLE 2. CONTROL OF CITRUS RUST MITE ON 'VALENCIA' ORANGE (SITE 1) IN POLK COUNTY, FLORIDA, 1988.

Treatment and Formulation		Rate per Hectare	Pre-treatment Means May 23	Citrus Rust Mite Post-treatment Means[1]							Cumulative Mite-days	% Russeted Fruit	% Rejected Fruit
				Jun 30	Jul 7	Jul 19	Jul 25	Aug 2	Aug 15	Aug 25			
Vendex	4 L	1.40 kg	3 a[2]	1 b	0 b	0 c	1 cd	0 d	1 d	3 d	196 cd	0.8 b	0.4 b
Vendex	4 L	2.10 kg	2 a	0 b	0 b	0 c	0 d	0 d	0 d	0 e	134 d	1.2 b	1.2 b
Vendex	4 L	2.80 kg	2 a	0 b	0 b	0 c	0 d	0 d	0 d	0 e	34 d	0.2 b	0.2 b
Vendex + Copper hydroxide	4 L 77 WP	1.40 kg 7.96 kg	1 a	0 b	0 b	0 bc	2 bc	6 b	6 bc	4 b	258 bc	0.6 b	0 b
Vendex + Copper hydroxide	4 L 77 WP	2.10 kg 7.96 kg	2 a	0 b	2 b	1 b	4 b	6 b	11 a	12 a	506 b	3.4 b	1.4 b
Vendex + Copper sulfate	4 L 99 GC	1.40 kg 7.96 kg	1 a	0 b	0 b	0 bc	2 bcd	3 c	3 cd	4 c	239 c	0.4 b	0 b
Vendex + Copper sulfate	4 L 99 GC	2.10 kg 7.96 kg	1 a	0 b	0 b	0 c	0 cd	1 d	2 d	2 d	91 cd	0 b	0 b
Untreated	–		1 a	82 a	63 a	46 a	58 a	34 a	8 ab	3 c	2761 a	30.6 a	19.2 a

[1]Citrus rust mite per 2 cm^2 of fruit surface.
[2]Means within columns followed by the same letter are not significantly different [P > 0.05; Duncan's (1955) multiple range test].

TABLE 3. CONTROL OF CITRUS RUST MITE ON 'HAMLIN' ORANGE (SITE 2) IN LAKE COUNTY, FLORIDA, 1989.

Treatment and Formulation		Rate per Hectare	Pre-treatment Means June 16	Citrus Rust Mite Post-treatment Means[1]							
				Jul 5	Aug 17	Aug 24	Sep 20	Sep 27	Oct 3	Oct 12	Oct 18
Vendex	4 L	1.68 kg	12 a[2]	0 c	0 c	0 e	7 fg	6 f	4 d	20 fg	15 d
Vendex	4 L	2.24 kg	38 a	0 c	0 c	0 e	3 gh	33 de	3 d	36 de	16 d
Vendex	4 L	2.80 kg	14 a	0 c	0 c	10 d	2 h	1 g	3 d	27 h	2 e
Vendex + Copper hydroxide	4 L 77 WP	1.68 kg 7.85 kg	30 a	0 c	0 c	0 de	16 d	75 b	30 a	99 a	53 a
Vendex + Copper hydroxide	4 L 77 WP	2.24 kg 7.85 kg	20 a	0 c	0 c	0 de	4 efg	76 c	22 c	98 ab	33 b
Vendex + Copper hydroxide	4 L 77 WP	2.80 kg 7.85 kg	21 a	0 c	0 c	0 e	7 fg	14 ef	2 d	25 ef	10 d
Vendex + Copper sulfate	4 L 99 GC	1.68 kg 7.85 kg	42 a	0 c	0 c	0 e	9 ef	21 de	27 c	60 abc	47 a
Vendex + Copper sulfate	4 L 99 GC	2.24 kg 7.85 kg	26 a	0 c	0 c	1 de	11 e	29 cd	10 c	36 de	24 bc
Vendex + Copper sulfate	4 L 99 GC	2.80 kg 7.85 kg	21 a	0 c	0 c	0 e	5 fg	16 ef	7 d	20 gh	35 b
Copper hydroxide	77 WP	7.85 kg	32 a	7 b	67 a	124 a	192 b	158 a	20 bc	48 bcd	14 cd
Copper sulfate	99 GC	7.85 kg	18 a	7 b	44 a	114 b	202 a	164 a	28 ab	35 cde	15 d
Untreated	–	–	22 a	8 a	43 b	34 c	74 c	94 b	30 a	49 cd	11 cd

[1]Citrus rust mite per 2 cm^2 of fruit surface.
[2]Means within columns followed by the same letter are not significantly different ($P > 0.05$; Duncan's [1955] multiple range test).

TABLE 4. CUMULATIVE CITRUS RUST MITE-DAYS AND DAMAGE RATING COMPARISONS OF FRUIT INJURY ON 'HAMLIN' ORANGE (SITE 2) IN LAKE COUNTY, FLORIDA 1989.

Treatment and Formulation		Rate per Hectare	Cumulative Mite-days Oct 18[1]	% Russeted Fruit[1]	% Rejected Fruit[1]
Vendex	4 L	1.68 kg	729 d	12 ef	9 cd
Vendex	4 L	2.24 kg	1271 cd	10 ef	6 cd
Vendex	4 L	2.80 kg	710 d	5 f	3 d
Vendex +	4 L	1.68 kg			
Copper hydroxide	77 WP	7.85 kg	2561 c	52 bc	32 b
Vendex +	4 L	2.24 kg			
Copper hydroxide	77 WP	7.85 kg	2007 cd	31 cde	20 bc
Vendex +	4 L	2.80 kg			
Copper hydroxide	77 WP	7.85 kg	843 d	10 ef	5 cd
Vendex +	4 L	1.68 kg			
Copper sulfate	99 GC	7.85 kg	1753 cd	40 bcd	31 b
Vendex +	4 L	2.24 kg			
Copper sulfate	99 GC	7.85 kg	1261 cd	22 def	11 cd
Vendex +	4 L	2.80 kg			
Copper sulfate	99 GC	7.85 kg	932 d	17 ef	8 cd
Copper hydroxide	77 WP	7.85 kg	6431 a	86 a	70 a
Copper sulfate	99 GC	7.85 kg	6056 a	85 a	71 a
Untreated	–	–	3573 b	58 b	42 b

[1]Means within columns followed by the same letter are not significantly different (P>0.05; Duncan's [1955] multiple range test).

alone. All 3 Vendex + copper treatments had significantly higher citrus rust mite densities on both fruit and leaves between August 19 and September 10 compared with Vendex applied alone.

P. oleivora densities on fruit in the 3 copper-only treatments were significantly higher between July 11 and September 10 compared with the untreated check tree counts. Populations of citrus rust mites ranged from 2 to 36 times higher on copper treated fruit compared with the untreated check trees.

The 4 miticide treatments provided comparable control of the citrus rust mite on leaves through July 18 (Table 6). Low, but significantly higher, citrus rust mite densities on leaves were present on the Vendex + copper DF and Vendex + copper hydroxide treatments by August 12 compared with Vendex applied alone. These differences increased dramatically between August 26 and September 10. The Vendex + copper sulfate treatment was less disruptive to rust mite control compared with the other 2-Vendex + copper treatments. However, leaf counts in this treatment were significantly higher compared with those in the Vendex only treatment between August 19 and September 17.

TABLE 5. CONTROL OF CITRUS RUST MITE ON 'VALENCIA' ORANGE FRUIT (SITE 3) IN HIGHLANDS COUNTY, FLORIDA, 1991.

Treatment and Formulation		Rate per Hectare	Pre-treatment Means June 19	Citrus Rust Mite Post-treatment Means[1]							
				Jul 18	Jul 24	Aug 12	Aug 19	Aug 26	Sep 3	Sep 10	Sep 17
Vendex	4 L	2.24 kg	4 a[2]	0 c	0 d	0 e	0 e	0 f	3 e	3 d	1 b
Vendex + Cooper hydroxide	4 L DF	2.24 kg 8.97 kg	4 a	0 c	1 d	2 d	15 c	18 c	58 a	23 a	7 a
Vendex + Copper sulfate	4 L 99 GC	2.24 kg 8.97 kg	4 a	0 c	0 d	0 e	4 d	9 e	15 c	5 cd	1 b
Vendex + Copper hydroxide	4 L 77 WP	2.24 kg 8.97 kg	4 a	0 c	0 d	1 de	10 c	18 cd	35 b	10 bc	1 b
Copper hydroxide	DF	8.97 kg	4 a	53 a	61 b	142 a	57 a	47 a	18 c	26 a	1 bc
Copper sulfate	99 GC	8.97 kg	4 a	49 a	75 a	167 a	40 b	19 cd	9 d	4 d	0 d
Copper hydroxide	77 WP	8.97 kg	4 a	51 a	67 ab	97 b	57 a	36 b	26 c	3 d	0 cd
Untreated	–	–	4 a	22 b	14 c	27 c	7 c	1 f	1 f	1 e	0 d

[1]Citrus rust mite per 2 cm^2 of fruit surface.
[2]Means within columns followed by the same letter are not significantly different ($P > 0.05$; Duncan's [1955] multiple range test).

TABLE 6. CONTROL OF CITRUS RUST MITE ON 'VALENCIA' ORANGE LEAVES (SITE 3) IN HIGHLANDS COUNTY, FLORIDA, 1991.

Treatment and Formulation		Rate per Hectare	Pre-treatment Means June 19	Citrus Rust Mite Post-treatment Means[1]								
				Jul 18	Jul 24	Jul 31	Aug 12	Aug 19	Aug 26	Sep 3	Sep 10	Sep 17
Vendex	4 L	2.24 kg	1 a[2]	0 d	0 e	0 d	0 e	0 e	0 d	1 e	2 e	2 c
Vendex + Cooper hydroxide	4 L DF	2.24 kg 8.97 kg	1 a	0 d	0 e	1 c	5 d	7 c	22 a	51 a	26 a	7 a
Vendex + Copper sulfate	4 L 99 GC	2.24 kg 8.97 kg	2 a	0 d	0 e	0 d	0 e	2 d	5 c	11 d	8 c	6 b
Vendex + Copper hydroxide	4 L 77 WP	2.24 kg 8.97 kg	1 a	0 d	3 d	0 d	1 d	5 c	15 a	25 b	15 b	4 b
Copper hydroxide	DF	8.97 kg	2 a	6 b	19 b	18 a	21 a	15 a	10 b	11 cd	2 de	1 c
Copper sulfate	99 GC	8.97 kg	1 a	12 a	30 a	16 a	17 b	15 b	7 c	10 d	3 de	1 c
Copper hydroxide	77 WP	8.97 kg	3 a	15 a	18 b	18 a	19 a	18 a	7 c	12 c	3 d	1 c
Untreated	–	–	1 a	3 c	12 c	9 b	9 c	7 c	1 d	1 e	0 f	0 d

[1]Citrus rust mite per 4 cm^2 of leaf surface.
[2]Means within columns followed by the same letter are not significantly different (P > 0.05; Duncan's [1955] multiple range test).

Cumulative mite-day comparisons on fruit and leaves showed that the Vendex + copper DF treatment was significantly higher than Vendex alone or Vendex combined with copper sulfate. Cumulative mite-days on fruit were not significant between Vendex combined with either copper hydroxide or copper sulfate while the cumulative mite-day differences were significantly higher on leaves between the 2 treatments. Also, the Vendex + copper sulfate cumulative mite-day value on leaves was significantly higher compared with Vendex applied alone while those on the fruit were not (Table 7).

Cumulative mite-day values on fruit and leaves for the Vendex + copper DF and Vendex + copper hydroxide treatments were not significantly different. Corresponding percentages of russeted and rejected fruit were not significantly different between the same 2 Vendex + copper treatments compared with the untreated check trees. This demonstrates the negative effect of tank-mixing either copper hydroxide formulation at the rates tested with Vendex.

P. oleivora densities on leaves in the 3 copper-only treatments were somewhat variable until July 31. Between that date and September 10, all 3 copper-only treatments had consistent and significantly higher citrus rust mite densities on leaves that ranged from 2 to 12 times higher than those on the untreated check trees. Both copper DF and copper hydroxide tank-mixes with Vendex resulted in significantly higher percentages of russeted fruit compared with Vendex applied alone. Only the Vendex + copper DF combination had a significantly greater percentage of rejected fruit compared with Vendex applied alone (Table 7). Percentages of both russeted fruit and rejected fruit were significantly higher in the 3 copper-only treatments compared with the untreated check trees (Table 7).

TABLE 7. CUMULATIVE CITRUS RUST MITE-DAYS AND DAMAGE RATING COMPARISONS OF FRUIT INJURY ON 'VALENCIA' ORANGE (SITE 3) IN THE LAKE PLACID VICINITY, HIGHLANDS COUNTY, FLORIDA, 1991.

Treatment and Formulation	Rate per Hectare	Cumulative mite-days[1]		% Russeted Fruit[1]	% Rejected Fruit[1]
		Leaves	Fruit		
Vendex 4 L	2.24 kg	43 d	77 e	14 d	0.4 c
Vendex + 4 L Copper hydroxide DF	2.24 kg 8.97 kg	865 b	912 bc	55 b	18.8 b
Vendex + 4 L Copper sulfate 99 GC	2.24 kg 8.97 kg	231 c	271 de	25 cd	2.6 c
Vendex + 4 L Copper hydroxide 77 WP	2.24 kg 8.97 kg	501 b	594 cd	31 bc	6.6 bc
Copper hydroxide DF	8.97 kg	1080 a	3930 a	89 a	63.8 a
Copper sulfate 99 GC	8.97 kg	1410 a	4540 a	97 a	79.8 a
Copper hydroxide 77 WP	8.97 kg	1303 a	3930 a	93 a	66.6 a
Untreated	–	507 b	756 b	33 bc	6.4 bc

[1]Means within columns followed by the same letter are not significantly different ($P > 0.05$; Duncan's [1955] multiple range test).

Site 4, 'Hamlin' Orange

Low to moderate citrus rust mite densities on fruit in the untreated check trees were recorded between July 15 and September 10 following treatment applications on July 8, 9 and 10. Population development of *P. oleivora* was evident on the back sides of fruit by August 8 with no citrus rust mites present on the front sides of the same fruit in the Vendex treatments. Poor spray coverage resulted from inadequate penetration of pesticide spray through the canopy since only 720 liters of finished spray were applied per hectare.

All Vendex treatments provided comparable control of citrus rust mite on the fruit through August 13 (Table 8). The Vendex + copper hydroxide and Vendex + copper DF combinations generally had significantly higher citrus rust mite densities on the fruit between August 21 and September 10 compared with Vendex applied alone and the Vendex + copper sulfate treatments. As in the previous field experiment (site 3), the amount of metallic copper applied per hectare was highest in the copper sulfate formulation followed by copper hydroxide WP and copper hydroxide DF. The 3 copper-only treatments did not have higher rust mite densities on fruit during this experiment compared with the untreated check trees (Table 8).

All 4 Vendex treatments had significantly lower cumulative mite-day values on fruit compared with the untreated check trees (Table 9). Only the Vendex + copper hydroxide 77% WP treatment had significantly more russeted fruit compared with the other Vendex treatments in this experiment. Numerically higher percentages of rejected fruit were found in the Vendex + copper DF and Vendex + copper hydroxide treatments. However, they were not significantly different compared with the other 2 Vendex treatments.

P. oleivora densities on leaves were low in all treatments throughout this experiment (Table 10). However, significantly higher citrus rust mite densities were recorded on the Vendex + copper DF and Vendex + copper hydroxide treatments on August 27 and September 5 compared with Vendex applied alone or Vendex + copper sulfate. The 3 copper-only treatments did not have consistently higher citrus rust mite densities on the leaves compared with the untreated check trees. Cumulative mite-day differences between the copper-only and untreated check treatments were not significantly different in this experiment (Table 9).

DISCUSSION

Results from this study show that the different copper formulations tested are incompatible with Vendex when applied at the rates tested. The copper hydroxide DF formulation demonstrated the greatest degree of incompatibility followed by copper hydroxide WP. The copper sulfate formulation in combination with Vendex showed the least disruption in residual rust mite control of the 3 formulations tested. The amount of available metallic copper applied per hectare in tests 3 and 4 differed between the 3 formulations as follows: copper DF = 1.45 kg, copper hydroxide = 1.81 kg and copper sulfate = 1.93 kg. This would suggest that one or more other components of the copper DF formulation were involved in creating increased antagonism in combination with the organo-tin miticide compared with the metallic copper content alone. This phenomenon is not unique and has been reported with other tank mixtures. For example, Venkata Ram (1963) found that nickel chloride hexahydrate controlled the fungal pathogen, *Exobasidium vexans*, on tea as effectively as copper oxychloride without increasing purple mite, *Calacarus carinatus* (Green) (Acari: Eriophyidae).

TABLE 8. CONTROL OF CITRUS RUST MITE ON 'HAMLIN' ORANGE FRUIT (SITE 4) IN THE FT. MEADE VICINITY, POLK COUNTY, FLORIDA, 1991

Treatment and Formulation		Rate per Hectare	Pre-treatment Means Jul 27	Citrus Rust Mite Post-treatment Means[1]								
				Jul 23	Jul 30	Aug 8	Aug 13	Aug 21	Aug 27	Sep 5	Sep 10	Sep 18
Vendex	4 L	2.24 kg	4 a[2]	0 b	0 c	2 d	0 c	4 d	4 c	3 c	3 d	1 a
Vendex +	4 L	2.24 kg										
Copper hydroxide	DF	8.97 kg	5 a	0 b	0 c	8 c	0 c	4 cd	7 b	8 c	14 bc	2 a
Vendex +	4 L	2.24 kg										
Copper sulfate	99 GC	8.97 kg	4.a	0 b	0 c	1 d	0 c	1 e	2 c	5 c	3 d	1 a
Vendex +	4 L	2.24 kg										
Copper hydroxide	77 WP	8.97 kg	5 a	0 b	0 c	2 d	2 c	7 c	9 b	10 b	12 c	5 a
Copper hydroxide	DF	8.97 kg	4 a	6 a	9 a	40 b	11 b	16 b	20 a	43 a	29 a	2 a
Copper sulfate	99 GC	8.97 kg	5 a	4 a	6 b	6 c	10 ab	20 b	27 a	40 a	22 ab	2 a
Copper hydroxide	77 WP	8.97 kg	4.a	3 a	4 b	13 c	17 ab	32 a	29 a	39 a	10 bc	2 a
Untreated	–	–	7 a	15 a	7 ab	47 a	19 a	34 a	30 a	26 a	21 abc	1 a

[1]Citrus rust mite per 2 cm^2 of fruit surface.
[2]Means within columns followed by the same letter are not significantly different ($P > 0.05$; Duncan's [1955] multiple range test.

TABLE 9. CUMULATIVE CITRUS RUST MITE-DAYS AND DAMAGE RATING COMPARISONS OF FRUIT INJURY ON 'HAMLIN' ORANGE (SITE 4) IN THE FT. MEADE VICINITY, POLK COUNTY, FLORIDA, 1991.

Treatment and Formulation	Rate per Hectare	Cumulative Mite-days[1]		% Russeted Fruit[1]	% Rejected Fruit[1]
		Leaves	Fruit		
Vendex 4 L	2.24 kg	100 c	157 b	16 e	9 d
Vendex + Copper hydroxide 4 L DF	2.24 kg 8.97 kg	203 bc	361 b	25 de	13 cd
Vendex + Copper sulfate 4 L 99 GC	2.24 kg 8.97 kg	76 c	117 b	14 e	7 d
Vendex + Copper hydroxide 4 L 77 WP	2.24 kg 8.97 kg	224 bc	379 b	32 cd	18 cd
Copper hydroxide DF	8.97 kg	399 a	1367 a	55 ab	38 ab
Copper sulfate 99 GC	8.97 kg	408 ab	1057 a	56 ab	38 ab
Copper hydroxide 77 WP	8.97 kg	418 a	1136 a	43 bc	29 bc
Untreated	–	449 a	1558 a	68 a	53 a

[1]Means within columns followed by the same letter are not significantly different (P > 0.05; Duncan's [1955] multiple range test).

Citrus rust mite populations increased in 2 of the 3 field experiments in which copper-only treatments were included. In both instances, population increases in the copper-only treatments occurred at the same time as those occurring in the untreated checks. However, the mite densities were significantly higher suggesting a stimulatory effect by the copper compounds. Johnson (1960b) found that copper compounds had no effect on the percentage of fruit infested with *P. oleivora* when the population was increasing on unsprayed trees. However, copper sprays prolonged high citrus rust mite populations, or caused an increase, if applied when unsprayed populations were declining. This situation did not develop in 2 of the 3 field experiments in this study. Adverse effects caused by copper compounds on the pathogenic fungus, *Hirsutella thompsonii* Fisher, have been proposed (Eger et al. 1985, McCoy 1979, Griffith & Fisher 1949, Spencer 1939, Thompson 1939).

In many instances, the use of copper on Florida citrus is essential for effective disease control. Great care must be exercised by citrus growers when selecting pesticides for control of pest complexes. Oftentimes, tank-mixes are designed to minimize application costs and to optimize efficiency. The use of such tank-mixes requires sound assurance of both physical and chemical compatibility. Potential risks of pesticide failure or acceleration of pesticide resistance dictate the need for such information.

Vendex is a highly effective miticide with broad spectrum activity against various phytophagous mite pests in the families Eriophyidae, Tetranychidae, Tenuipalpidae, and Tarsonemidae. Studies presented here demonstrate that copper DF and copper hydroxide formulations result in reduced residual effectiveness of Vendex, especially at lower rates, i.e., 2.24 kg of 50 WP or 2.34 liters of 4 L per hectare (University of Florida 1993 Spray Guide recommendations). In a single field experiment by Lye et al. (1990), Vendex 4 L was applied at the rate of 3.34 liters per hectare in combination

TABLE 10. CONTROL OF CITRUS RUST MITE ON 'HAMLIN' ORANGE LEAVES (SITE 4) IN THE FT. MEADE VICINITY, POLK COUNTY, FLORIDA, 1991

Treatment and Formulation		Rate per Hectare	Pre-treatment Means Jun 27	Citrus Rust Mite Post-treatment Means[1]							
				Jul 15	Aug 9	Aug13	Aug 21	Aug 27	Sep 5	Sep 10	Sep 18
Vendex	4 L	2.24 kg	1 a[2]	1 cd	0 c	0 c	0 d	2 e	2 d	2 de	2 a
Vendex + Copper hydroxide	4 L DG	2.24 kg 8.97 kg	1 a	1 cd	0 c	1 c	1 d	6 cd	7 c	4 cd	5 a
Vendex + Copper sulfate	4 L 99 GC	2.24 kg 8.97 kg	2 a	0 d	0 c	0 c	0 d	1 e	2 d	1 e	3 a
Copper + copper hydroxide	4 L 77 WP	2.24 kg 8.97 kg	3 a	0 cd	0 c	0 c	2 d	3 d	5 c	4 c	5 a
Copper hydroxide	DF	8.97 kg	1 a	2 a	2 ab	3 b	8 bc	9 bc	11 b	12 a	5 a
Copper sulfate	99 GC	8.97 kg	0 a	0 cd	6 b	3 b	6 c	12 ab	16 a	3 cd	6 a
Copper hydroxide	77 WP	8.97 kg	0 a	1 bc	5 a	2 b	8 ab	12 a	12 ab	12 a	4 a
Untreated	–	–	1 a	4 ab	2 ab	7 a	8 a	10 ab	10 b	7 b	6 a

[1]Citrus rust mite per 4 cm^2 of leaf surface.
[2]Means within columns followed by the same letter are not significantly different ($P > 0.05$; Duncan's [1955] multiple range test).

with copper hydroxide. No reduction in miticidal activity was recorded. However, this rate exceeds that which is recommended in the Florida Citrus Spray Guide.

Additional studies are needed to identify those miticides currently recommended for use during the postbloom and summer sprays that have minimal compatibility problems with specific available copper formulations.

ENDNOTE

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