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Assessment of an integrated pest mite and disease management program on Florida citrus utilizing 224°C or 235°C horticultural mineral oils (HMO)*

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Abstract

The objective of this work was to compare HMO-only foliar spray programs with grower´s usual practices for the control of the fungal pathogen greasy spot, *Mycosphaerella citri* Whiteside, and for suppression of arthropod pests, primarily the citrus rust mite, *Phyllocoptruta oleivora* (Ashmead), the pink citrus rust mite, *Aculops pelekassi* (Keifer), and the spider mites, *Eutetranychus banksi* (McGregor) and *Panonychus citri* (McGregor). Four cooperators with 2.38 to 5.22 hectare blocks of either 'Hamlin' or 'Valencia' oranges were switched to 224°C or 235°C horticultural mineral oil (HMO)-only foliar spray programs applied at 46.8 liters/hectare for four years. HMO applications varied from one to three applications in the test blocks per location at each year. Cooperating grower spray programs included various fungicides, acaricides, insecticides, and HMOs. First year transition from the standard fungicide-insecticide-acaricide programs resulted in active citrus rust mite development, and multiple HMO treatments were required in three of the four sites for their control. Subsequent rust mite populations in years two, three, and four did not develop in three of four sites using the HMO-only foliar spray programs. Spider mite densities in the four HMO blocks never reached levels of economic injury during any year of the study. One of the cooperators was dropped after the third (2002) season, as the test block in his property was sprayed sometime early in 2003 with a pesticide that eliminated beneficial mite populations. No secondary arthropod or disease problems developed in any of the remaining three HMO-only blocks through March 2004. The percentage of greasy spot infected leaves was significantly greater in each HMO block most years compared to the grower spray programs. However, there were no differences in leaf retention, tree canopy vigor, or yields between the HMO-only foliar spray program and the control pesticide programs. The severity of greasy spot on leaves averaged in the lowest rating category (e.g., 0 to 5%) in all treatment blocks in all years and ranged from 0.1 to 2.0% in the HMO blocks versus 0.2 to 1.5% in the control blocks. Greasy spot was effectively controlled with HMO-only treatments through the four years of this study in all orchard sites. Comparative effects between the HMO and grower spray programs on beneficial mites in the families Phytoseiidae, Stigmaeidae and Tydeidae are reported through 2002. All three mite families failed to re-establish in the four HMO-only foliar spray program blocks by the end of the third year.

Key words: *Mycosphaerella citri*, integrated pest management, petroleum oil, citrus, *Aculops pelekassi, Phyllocoptruta oleivora, Panonychus citri, Eutetranychus banksi*.

Introduction

Florida citrus provides 70% of the total United States production with 50% of the grapefruit and 5% of the oranges destined for fresh market and the remainder for processing (i.e., juice, sections, pulp) (Stelinski *et al*., 2010). Juice prices were declining prior to 2000 due to overproduction of citrus worldwide, and Florida growers were faced with increasing challenges to sustain profitability. Florida citrus growers spent 171 million US dollars annually for chemical control of mites in the late 1990s (Muraro & Hebb, 1997; Muraro *et al*., 1997a, b). Reducing production costs to the growers was one way to improve returns.

There is an extensive pest complex of arthropod species, diseases, weeds, and nematodes that attack citrus, and many of the arthropod pests are effectively controlled biologically. More than 12 species of phytophagous mites occur on Florida citrus, but only four are considered of economic importance for most varieties (Muma, 1975; Childers, 1994; Childers & Achor, 1999). These are the citrus rust mite, *Phyllocoptruta oleivora* (Ashmead) (Eriophyidae), the pink citrus rust mite, *Aculops pelekassi* (Keifer) (Eriophyidae), and to a much lesser extent the Texas citrus mite, *Eutetranychus banksi* (McGregor) (Tetranychidae), and the citrus red mite, *Panonychus citri* (McGregor) (Tetranychidae). The two rust mites were considered key pests of fruit, while the spider mites could be an occasional problem on leaves. Both rust and spider mite infestations tend to be greater during dry weather conditions in Florida. If citrus leprosis becomes re-established in Florida, then the tenuipalpid *Brevipalpus phoenicis* (Geijskes) would become an additional key pest due to its ability to vector the causal agent of this disease (Childers *et al*., 2003; Rodrigues *et al*., 2003).

In 2005, the bacterial disease, Huanglongbing (= citrus greening) was found in Florida (Brlansky *et al*., 2010). Its insect vector, *Diaphorina citri* Kuwayama (Hemiptera: Psyllidae), was discovered in 1998. This serious disease and insect vector are currently recognized as the key pests in Florida citrus (Rogers *et al*., 2010). Control of the citrus leafminer, *Phyllocnistis citrella* Stainton (Lepidoptera: Gracillariidae), also has become more of a problem as it facilitates the spread of the bacterium, citrus canker, *Xanthomonas axonopodis* (Rogers *et al.,* 2010).

Because of high humidity and moderate to high rainfall conditions that occur in Florida, various foliar and rind blemish diseases are of considerable importance to citrus growers. The fungal pathogen *Mycosphaerella citri* Whiteside (Dothideales: Dothideaceae), called greasy spot, has been a key foliar disease (Whiteside, 1973a, b; Timmer *et al*., 2005). This disease affects fruit destined for processing or fresh market, including both grapefruit and the sweet orange varieties. Greasy spot causes premature leaf drop that can affect fruit yield as well. In recent years, there has been increasing attention to the threat of the bacterial disease, citrus canker, *Xanthomonas citri* (Dewdney & Graham, 2011). The only recommended products to reduce citrus canker infection are copper formulations. Historically, greasy spot control has also relied heavily on copper usage. Another exotic fungal disease of citrus, black spot, *Guignardia citricarpa,* was discovered infecting 'Valencia' orange fruit in Immokalee, Florida in March 2010 (Schubert *et al*., 2010). This serious disease will require additional fungicide sprays that will further exacerbate phytophagous mite control.

Copper formulations for fungal disease control have been used on Florida citrus for over 80 years (Childers, 1994; Timmer, 2002). Unfortunately, copper formulations stimulate citrus rust mites, spider mites, and false spider mite populations in both citrus and tea (Griffiths & Fisher, 1949; Venkata Ram, 1963; van Brussel, 1975; Oomen, 1982; Childers, 1994, 2002). This stimulatory effect occurs following exposure to copper formulations on citrus when mite populations are at low levels (Childers, 2002). The phenomenon does not occur every time copper is applied, but rather when conditions are optimal for mite increase. The citrus rust mite has seasonal population fluctuations due to a narrow range of restrictive environmental conditions that include temperature and water vapor concentration (Allen & Syvertsen, 1979). Because of widespread copper usage on Florida citrus, studies were initiated in 2000 to look for alternative products that would have minimal stimulatory effects on phytophagous mite populations while maintaining comparable disease control.

Horticultural mineral oils (HMO) with a mid-boiling point of 224°C or 235°C are effective in controlling various insect pests, rust and spider mites, as well as suppressing greasy spot infestations. The potential use of HMOs as foliar pesticides alone or in combination with other products is increasing throughout the world. Improvements in formulations, specifications, and emulsifiers provide continued opportunities to expand usage on citrus and other crops.

Some researchers have expressed doubt about the ability to successfully use HMOs year after year to maintain effective control of greasy spot within the same blocks of citrus trees. These arguments suggest that sustained use of HMOs would result in: (1) increased levels of greasy spot infection; (2) failure to control pest mites adequately; (3) development of other arthropod pests; and (4) negative effects on tree vigor or yields with continuous use of HMOs over time.

Therefore, a study was initiated in 2000 to determine if we can successfully use one or more applications of 224°C or 235°C HMO on citrus and effectively control greasy spot without disruption of pest mites, other pest arthropods, or diseases over an extended timeframe. Identifying the mid and long-term effects of HMO products on the beneficial mite complex is also needed. Results are reported from four locations in Florida on sweet orange varieties ('Hamlin' and 'Valencia') that were switched to HMO-only foliar spray programs for greasy spot and pest mite control beginning in 2000.

Materials and Methods

Four cooperators were selected in April 2000 to participate in changing their foliar spray programs from various fungicides including copper, HMOs, and other acaricides and insecticides to the use of only 224°C or 235°C HMO-foliar spray programs for processing oranges during four full seasons. The objectives of this study were to assess the impacts on: (1) pest mites, (2) secondary insect or mite problems, (3) greasy spot control using HMO-only foliar spray programs generally applied at 46.8 liters/ha, (4) fruit set or canopy vigor, and (5) beneficial mite populations, including the determination of the length of time required for their reestablishment.

Cooperator one was located in the Winter Garden vicinity, Orange County. The 'Hamlin' orange block of this grower was 5.22 hectares with trees averaging 3.3 m tall and set 430 trees/hectare. Cooperator two was located in Avon Park, Polk County. The "Valencia' orange block was 2.38 hectares with trees 1.4 to 5.2 m tall and set 430 trees/hectare. Cooperator three was located in Lake Wales, Polk County. The 'Valencia' orange block was 3.59 hectares with trees 1.4 to 3.7 m tall and set 430 trees/hectare. Cooperator four was located in the Arcadia vicinity, De Soto County, Florida. The 'Hamlin' orange block was 3.08 hectares with trees 3.4 m tall and set 390 trees/hectare. A comparable sized adjacent area with the same tree variety and age was designated as the standard (or control) treatment block for each grower. Each of the control blocks was also monitored and continued to receive the grower's original spray program. The foliar and herbicide spray programs for both test and control blocks are presented in Table 1.

Each test site was divided into five sections with three trees selected at random and sampled within each section (= 15 trees/site). Each block was monitored weekly to monthly for arthropod pests and fungal diseases throughout the year from 2000 through 2003. The procedures for monitoring pest and beneficial mites, rind blemish damage from citrus rust mites, greasy spot assessments, yield comparisons for 2002 and 2003, and monitoring of beneficial mite populations are presented. Fruit maturity requires 15 months for 'Valencia' oranges and ten or more months for 'Hamlin' oranges.

Citrus rust mites were not separated by species within any of the blocks over the four crop seasons. They were counted by examining 20 fruit individually on the tree and at random from each of 15 trees with a 10X handlens using a 1-cm^2 grid attachment to count the numbers of live motiles (Childers & Selhime, 1983). Two partially shaded fruit surfaces were examined, and the two counts of live rust mites were combined per observation. Twenty leaves were collected from each tree into separate labeled paper bags, placed in a cooler, and transported to the laboratory. A 4-cm^2 area was examined on both the upper and lower leaf surfaces of each leaf and the two counts per leaf were combined as one observation. The same leaves were examined for spider mites, and the numbers of live motile stages of each species were identified and recorded per leaf as one observation. In late fall, rind blemish damage due to citrus rust mite feeding injury was rated following published procedures by Childers (2002).

In April of each year, ten trees of similar size and canopy density were selected at random in both the test and control blocks at each cooperator site. Ten shoots with spring flush growth were

TABLE 1. Arthropod disease and weed control treatments of cooperating growers from 2000 through the 2003 season.

Grower	Test block	Control block	Material	Formulation	Rate per hectare	Application dates
1		Aldicarb (G)[1]	(A,I)	15 G	36.4 kg	11 Apr 00
	Glyphosate (G)	Glyphosate (G)	(H)	4 WSG	8.9 L	24 Apr 00
	HMO		(F,A,I)	224°C	46.8 L	10 Jul; 14 Aug 00
	Glyphosate (G)	Glyphosate (G)	(H)	4 WSG	8.9 L	28 Jul 00
		HMO	(F,A,I)	224°C	46.8 L	31 Aug 00
	Mefenoxam	Mefenoxam	(F)	2 EC	6.1 L	18 Sep 00
	Mefenoxam	Mefenoxam	(F)	2 EC	6.1 L	13 Feb; 16 Mar 01
	Glyphosate (G)	Glyphosate (G)	(H)	4 WSG	4.7 L	27 Apr 01
	+ 2,4-D (G)	+ 2,4-D (G)	(H)	1.8 kg/L	0.5 L	
	HMO	–	(F,A,I)	224°C	46.8 L	16 Jun 01
		Glyphosate (G)	(H)	4 WSG	4.7 L	16 Jun 01
		HMO	(F,A,I)	224°C	46.8 L	13 Aug 01
		+ Abamectin	(A)	0.15 EC	370 mL	
		+ Copper hydroxide	(F)	35% metallic	2.3 L	
	HMO		(F,A,I)	224°C	46.8 L	14 Aug 01
	Glyphosate (G)	Glyphosate (G)	(H)	4 WSG	4.7 L	30 Aug 01
	+ 2,4-D (G)	+ 2,4-D (G)	(H)	1.8 kg/L	0.5 L	
	Glyphosate (G)	Glyphosate (G)	(H)	4 WSG	4.7 L	26 Apr 02
		HMO	(F,A,I)	224°C	46.8 L	24 Jun 02
		+ Abamectin	(A)	0.15 EC	740 mL	
		+ Copper hydroxide	(F)	35% metallic	5.6 kg	
	HMO		(F,A,I)	224°C	46.8 L	24 Jun 02
		HMO	(F,A,I)	224°C	46.8 L	28 Aug 02
		+ Abamectin	(A)	0.15 EC	740 mL	
		+ Copper hydroxide	(F)	35% metallic	11.1 kg	
	HMO		(F,A,I)	224°C	46.8 L	28 Aug 02
	Glyphosate (G)	Glyphosate (G)	(H)	4 WSG	2.9 L	13 Sep 02
		HMO	(F,A,I)	224°C	46.8 L	12 May 03
		+ Pyraclostrobin	(F)	2.09 EC	647 mL	
		+ Abamectin	(A)	0.15 EC	500 mL	
	HMO		(F,A,I)	224°C	46.8 L	16 May 03
	HMO		(F,A,I)	224°C	52.9 L	17 Jul 03
		HMO	(F,A,I)	224°C	52.9 L	18 Jul 03
		+ Copper hydroxide	(F)	35% metallic	8.4 kg	
		+ Fenbuconazole	(F)	2 F	588 mL	
2		HMO	(F,A,I)	235°C	37.4 L	20 May 00
		+ HMO	(F,A,I)	224°C	0.95 L	
	HMO		(F,A,I)	224°C	46.8 L	26 Jun 00
		HMO	(F,A,I)	235°C	37.1 L	29 Jun 00
		+ Abamectin	(A)	0.15 EC	0.5 L	
		HMO	(F,A,I)	235°C	70.1 L	6 Aug 00
		+ Pyridaben	(A,I)	75 WP	0.7 kg	
		+ Copper hydroxide	(F)	50% metallic	5.6 kg	
	HMO		(F,A,I)	224°C	46.8 L	14 Aug 00
		Fenbutatin oxide	(A)	50 WP	2.2 kg	8 Nov 00
		HMO	(F,A,I)	224°C	58.5 L	19 Jun 01
		+ Azoxystrobin	(F)	2 F	0.9 L	
	HMO		(F,A,I)	224°C	58.5 L	11 Aug 01
		HMO	(F,A,I)	235°C	28.5 L	14 Aug 01
		+ Pyridaben	(A,I)	75 WP	0.7 kg	

Grower	Test block	Control block	Material	Formulation	Rate per hectare	Application dates
		+ Copper hydroxide	(F)	35% metallic	3.7 kg	
	HMO		(F,A,I)	224°C	5.9 L	11 Sep 01
		Norflurazon (G)	(H)	80 DF	3.4 kg	14 Mar 02
	Simazine (G)		(H)	1.8 kg/L	8.9 kg	15 Mar 02
		HMO	(F,A,I)	235°C	39.4 L	1 May 02
		+ Abamectin	(A)	0.15 EC	225 mL	
		+ Azoxystrobin	(F)	2 F	390 mL	
	HMO		(F,A,I)	224°C	64.5 L	11 Jun 02
		HMO	(F,A,I)	235°C	64.5 L	18 Jun 02
		+ Abamectin	(A)	0.15 EC	225 mL	
		+ Azoxystrobin	(F)	2 F	390 mL	
		Norflurazon (G)	(H)	80 DF	2.2 kg	11 Jul 02
	Diuron (G)		(H)	80 DF	5.6 kg	12 Jul 02
	Paraquat (G)		(H)	20 SL	3.0 L	12 Jul 02
		HMO	(F,A,I)	235°C	64.5 L	12 Aug 02
	HMO		(F,A,I)	224°C	56.3 L	13 Aug 02
		HMO	(F,A,I)	224°C	64.5 L	12 May 03
		+ Pyraclostrobin	(F)	2.09 EC	647 mL	
	HMO		(F,A,I)	224°C	64.5 L	16 May 03
	HMO		(F,A,I)	224°C	56.3 L	17 Jul 03
		HMO	(F,A,I)	224°C	56.3 L	18 Jul 03
		+ Copper hydroxide	(F)	50% metallic	8.4 kg	
		+ Fenbuconazole	(F)	2 F	0.56 kg	
3	Diuron (G)	Diuron (G)	(H)	80 DF	2.8 L	10 Mar 00
	+ Norflurazon (G)	+ Norflurazon	(H)	80 DF	2.2 L	
	+ Glyphosate	+ Glyphosate (G)	(H)	4 WSG	231 mL	
	Glyphosate (G)		(H)	4 WSG	4.7 L	17 Apr 00
		HMO	(F,A,I)	235°C	48.6 L	9 Jun 00
		+ Abamectin	(A)	0.15 EC		
		+ Copper hydroxide	(F)	50% metallic		
	HMO		(F,A,I)	224°C	37.1 L	10 Jun 00
	HMO		(F,A,I)	224°C	46.8 L	28 Jun 00
	HMO		(F,A,I)	224°C	28.1 L	10 Aug 00
		HMO	(F,A,I)	235°C	48.6 L	15 Aug 00
	Diuron (G)		(H)	80 DF	2.8 L	5 Sep 00
		Diuron (G)	(H)	80 DF	2.8 L	6 Sep 00
		+ Glyphosate (G)	(H)	4 WSG	231 mL	
	Diuron	Diuron	(H)	80 DF	2.8 L	1 Jun 01
	+ Glyphosate	+ Glyphosate	(H)	80 DF	3.7 L	
	HMO		(F,A,I)	224°C	50.6 L	29 Jun 01
		HMO	(F,A,I)	235°C	50.6 L	29 Jun 01
		+ Copper hydroxide	(F)	50% metallic	4.0 kg	
		HMO	(F,A,I)	235°C	50.6 L	30 Jul 01
		+ Abamectin	(A)	0.15 EC	600 mL	
	HMO		(F,A,I)	235°C	56.4 L	31 Jul 01
	HMO		(F,A,I)	224°C	93.9 L	29 Oct 01
	Glyphosate	Glyphosate	(H)	80 DF	3.0 L	13 May 02
	HMO		(F,A,I)	224°C	51.0 L	31 May 02
		HMO	(F,A,I)	224°C	46.9 L	31 May 02
		+ Abamectin	(A)	0.15 EC	370 mL	
		HMO	(F,A,I)	224°C	46.9 L	18 Jul 02
		+ Copper hydroxide	(F)	50% metallic	2.25 kg	
	HMO		(F,A,I)	224°C	46.9 L	19 Jul 02

Grower	Test block	Control block	Material	Formulation	Rate per hectare	Application dates
4	Glyphosate (G)	Glyphosate (G)	(H)	4 WSG	4.7 L	18 Jan 00
	+ Simazine (G)	+ Simazine (G)	(H)	90 WDG	7.0 L	
		Aldicarb (G)	(A,I)	15 G	16.8 kg	20 Feb 00
	Glyphosate (G)	Glyphosate (G)	(H)	4 WSG	4.7 L	23 May 00
		Fenbutatin oxide	(A)	50 WP	2.2 kg	28 Jun 00
		+ Copper hydroxide	(F)	50% metallic		
	HMO		(F,A,I)	224°C	46.8 L	11 Jul 00
	Glyphosate (G)	Glyphosate (G)	(H)	4 WSG	4.7 L	25 Jul 00
	HMO		(F,A,I)	224°C	46.8 L	10 Aug 00
		HMO	(F,A,I)	224°C	74.8 L	
		+ Abamectin	(A)	0.15 EC	600 mL	
	Glyphosate (G)	Glyphosate (G)	(H)	4 WSG	4.7 L	15 Oct 00
	+ Diuron (G)	+ Diuron (G)	(H)	80 DF	7.0 L	
		Aldicarb (G)	(A,I)	15 G	16.8 kg	5 Feb 01
	Glyphosate (G)	Glyphosate (G)	(H)	4 WSG	4.7 L	10 Feb 01
		+ Simazine (G)	(H)	90 WDG	7.0 L	
	Aldicarb (G)	Aldicarb (G)	(A,I)	15 G	16.8 kg	20 Mar 01
	Glyphosate (G)	Glyphosate (G)	(H)	4 WSG	4.7 L	12 May 01
		Diflubenzuron	(A)	25 WS	1.4 kg	22 Jun 01
		+ Copper hydroxide	(F)	50% metallic	5.6 kg	
	Glyphosate (G)	Glyphosate (G)	(H)	4 WSG	4.7 L	1 Jul 01
	Diuron (G)	Diuron (G)	(H)	80 DF	7.0 L	
	HMO		(F,A,I)	224°C	46.8 L	1 Jul 01
		HMO	(F,A,I)	224°C	74.8 L	1 Jul 01
		+ Abamectin	(A)	0.15 EC	600 mL	
		Aldicarb (G)	(A,I)	15 G	16.7 kg	27 Jan 02
	Glyphosate (G)	Glyphosate (G)	(H)	4 WSG	3.5 L	4 Mar 02
	+ Simazine (G)	+ Simazine (G)	(H)	90 WDG	7.0 L	
	Glyphosate (G)	Glyphosate (G)	(H)	4 WSG	4.7 L	15 Apr 02
	HMO		(F,A,I)	224°C	46.8 L	4 Jun 02
	Glyphosate (G)	Glyphosate (G)	(H)	4 WSG	4.7 L	7 Jun 02
		Diflubenzuron	(A)	80 WS	463 mL	2 Jul 02
		+ Copper hydroxide	(F)	50% metallic	5.6 kg	
		HMO	(F,A,I)	224°C	65 L	28 Aug 02
	HMO		(F,A,I)	224°C	46.8 L	15 Sep 02
	HMO		(F,A,I)	224°C	46.8 L	28 May 03
		HMO	(F,A,I)	224°C	65 L	28 May 03
		+ Copper hydroxide	(F)	50% metallic	4.6 kg	
		HMO	(F,A,I)	224°C	65 L	29 Jul 03
		+ Copper hydroxide	(F)	50% metallic	3.4 kg	
		+ Abamectin	(A)	0.15 EC	700 mL	
	HMO		(F,A,I)	224°C	46.8 L	30 Jul 03

Type of application in test and control blocks: (F)= Foliar; (G)= Ground.
Materials: (A)= Acaricide; (F)= Fungicide; (H)= Herbicide; (I)= Insecticide.

selected, tagged, and the leaves counted on each of ten trees. Five shoots were selected on each of two sides of each sample tree and numbered. The following winter, each of the ten trees was examined for remaining leaves on each tagged flush per tree. The numbers of remaining leaves were recorded as well as the numbers of infected leaves with greasy spot disease from each tagged tree. Infected leaves were also rated for severity of greasy spot infection following unpublished guidelines showing percentages of surface areas on greasy spot infected leaves. The lowest level of severity was listed as trace, that ranged from 0 to 5%.

Fruit set differences between treatments were determined in each test site during the 2002 and 2003 seasons by using a 1-m^3 frame constructed of 12.5-mm diameter PVC pipe with an attached vertical PVC pipe of 1.37 m in length (Childers, 1992). This supported the frame at a fixed height (Fig. 1). The frame was placed into the canopy at approximately 45° angles from the tree row on opposite sides of each sample tree (Childers, 1999). All of the fruit were counted within this frame area, and the replicated series of counts were compared between the test and control blocks.

FIGURE 1. One cubic meter pvc pipe frame used for measuring fruit set (Childers, 1992, 1999).

Each sample tree was inspected monthly for various pest insects including fire ant, *Solenopsis invicta*, various scale insects, citrus root weevils, citrus psyllids, whiteflies, and aphids. Each insect was identified to species, and rating levels were assigned per species based on the infestation.

Fifty inner canopy leaves were collected at random directly into 80% ethanol from each of eight randomly selected trees within the test and control blocks at each grower site at designated times. Beneficial mites were counted, separated, and identified to family within each sample through 2002. In this paper, only the totals per family were recorded for the Phytoseiidae, Stigmaeidae, and Tydeidae on the sample dates.

Waller-Duncan k-ratio procedures were used to separate treatment means when the ANOVA provided a significant F value ($p \leq 0.05$) (SAS Institute, 1991).

Results and Discussion

Grower 1 had a maximum of five motile rust mites per 2 cm^2 on fruit during July and a maximum of 7.4 rust mites per 8 cm^2 on leaves in December 2000. Rust mite numbers never exceeded 2.5 per 2 cm^2 on fruit during the remaining three growing seasons. Grower 2 had a maximum of 18 motile rust mites per 2 cm^2 on fruit and 12.4 per 8 cm^2 on leaves during May 2000 compared with 10 per 2 cm^2 on fruit and 3.4 per 8 cm^2 on leaves during May 2001 and 6.4 per 2 cm^2 on fruit and 1.2 per 8 cm^2 on leaves during 2002 and 2003. The magnitude of rust mite infestation was substantially reduced in years three and four. Grower 3 had a maximum of five motile rust mites per 2 cm^2 on fruit during September–October 2000 and a maximum of 7.4 per 8 cm^2 on leaves during December 2000 compared with 31.8 motile rust mites per 2 cm^2 on fruit and 0.4 per 8 cm^2 on leaves during 2001. The late season rust mite infestation on fruit that developed during 2001 required a third HMO application. Maximum densities during 2002 were 8.3 per 2 cm^2 on fruit and 3.1 per 8 cm^2 on leaves for Grower 3. The grower was dropped during the 2003 season for over spraying the test area with a non-reported pesticide that eliminated all beneficial mites in both the HMO- and control blocks. Grower 4 had a maximum of 19.0 motile rust mites per 2 cm^2 on fruit and 12.0 per 8 cm^2 per leaf during May 2000 compared with 10.8 motile rust mites per 2 cm^2 on fruit in June and 3.0 per 8 cm^2 on leaves in May 2001. Motile rust mite numbers were less than one per 2 cm^2 on fruit or one per 8 cm^2 on leaves during 2002 and 2003. Again, there was a substantial decline in citrus rust mite pressure in the test block of Grower 4 during the third and fourth years.

Citrus rust mite populations were potentially damaging during the first year in the HMO-only blocks, and control measures were needed in three of the four locations. No significant problems occurred in three of the four HMO blocks with citrus rust mites during years two, three, and four. However, citrus rust mite required treatment in the fall of 2001 in the control block of Grower 3.

All four HMO-only treatments had higher levels of fruit russeting on 'Hamlin' and 'Valencia' oranges compared with the control spray programs during 2000 (Table 2). Grower 1 had higher

TABLE 2. Proportions (%) of fruit russeting caused by citrus rust mite feeding injury on the HMO-only versus the Control (CON) spray programs.

2000 Treatment	1 Hamlin	2 Val	3 Val	4 Hamlin
HMO	0.7	6.0	17.9	3.0
CON	0.3	0.8	11.0	1.4
F	4.82	38.58	14.95	11.66
df	1,998	1,998	1,998	1,998
p	0.028	0.0001	0.0001	0.0007
2001 Treatment	**1**	**2**	**3**	**4**
HMO	0.03	0.07	1.0	0.1
CON	1.34	0	0.1	0.3
F	12.6	1.55	11.40	1.89
df	1,998	1,998	1,998	1,998
p	0.0004	0.213	0.0008	0.169
2002 Treatment	**1**	**2**	**3**	**4**
HMO	2.0	<1.0	<1.0	<1.0
CON	2.0	0	<1.0	<1.0
F	–	–	–	–
df	–	–	–	–
p	–	–	–	–
2003 Treatment	**1**	**2**	**3**	**4**
HMO	0.22	0.63	DROPPED	0,21
CON	1.37	0.43		1.05
F	12.63	0.90		6.12
df	1,798	1,998		1,798
p	0.0004	0.3426		0.0135

fruit russeting in his program versus the HMO treatment during 2001. Grower 3 had significantly greater fruit russeting in the HMO block during 2001. However, the differences were minor. None of the growers had significant differences in rind blemish problems on fruit between the treatment and control blocks during 2002. Growers one and four had greater rind blemish levels in the control blocks versus the HMO treatments during 2003 but these differences were minor. Both 'Valencia' orange blocks had higher percentage levels of russeting compared with the two 'Hamlin' blocks during 2000, although none of the blocks had sufficient damage to affect the value of the fruit for processing. Numbers of rejected fruit due to rust mite feeding were significantly greater in the control block of Grower 2 during 2000 and in the HMO block of Grower 3 during 2001 (Table 3). Fruit with rind blemish exceeding 5% of the surface area are considered rejected for only the fresh fruit market. All four growers had higher numbers of rejected fruit during 2000 than they did in the following three years.

TABLE 3. Mean numbers of rejected fruit that exceeded 5% russeting from citrus rust mite feeding injury [50 fruits examined from each of ten trees in both the HMO (T) and Control (C) blocks].

	2000		2001		2002		2003	
Grower	**T**	**C**	**T**	**C**	**T**	**C**	**T**	**C**
1	1.5	1.0	<1	1.8	<1	<1	<1	<1
2	0.5	6.4*	<1	0	0	0	0	0
3	14.9	11.0	2.1*	<1	<1	0	–	–
4	6.4	2.8	<1	<1	<1	<1	<1	<1

*$p \leq 0.05$

The Texas citrus mite was the prevalent spider mite species found in all test blocks during 2000 and 2001 with frequencies between 95 and 99%. The remainder consisted of citrus red mite, *Panonychus citri* (McGregor). The maximum spider mite density per leaf at Grower 1 was 0.37 in April 2000 and 0.42 per leaf in April 2001. During 2002 and 2003, spider mite numbers never exceeded 0.05 per leaf. Grower 2 had maximum spider mite numbers that ranged from 1.25 per leaf in mid-March 2000, 1.5 mites per leaf on 7 March 2001, and then remained well below 0.1 per leaf during 2002 and 2003. The maximum spider mite density at Grower 3 was 2.11 per leaf in late April 2000 and then 1.5 per leaf during May, while the maximum spider mite density was 0.4 per leaf in March 2001. During 2002 and 2003, spider mite densities remained relatively constant between 0.25 and 0.4 per leaf between March and mid-May followed by collapse of the population each year. Spider mite densities were very low in Grower 4 during all four years and never exceeded densities of 0.014 per leaf.

Treatment effects for greasy spot control are presented in Tables 4 and 5. There were high percentages of leaves that remained on tagged flushes in both treatments at Grower 1 during December (Table 4). However, leaf retention dropped to 84% and 92% in the HMO and control blocks, respectively, by 5 March 2001. High leaf retention remained in both the HMO and control blocks of Growers two and three through February–March 2001. There were 94% of the leaves remaining in the HMO treatment in Grower 4 compared with 82% for the control on 27 February 2001. However, the control block of Grower 4 was hedged prior to February. Otherwise, all four blocks had good leaf retention over the 4-year period.

Significantly greater numbers of leaves were infected with greasy spot in the HMO treatments in three of the four HMO blocks by February–March 2001 (Table 4). All four HMO blocks had higher percentages of infected leaves during January–February 2002 compared to the control blocks, while two of the three HMO blocks had significantly greater percentages of infected leaves by January 2003. There were no significant differences in percentages of leaves remaining on the trees or leaves infected with greasy spot in the three grower sites in January 2004. Leaf infection rates

TABLE 4. Comparisons of treatment effects on greasy spot, *Mycosphaerella citri,* on *Citrus sinensis* leaves in four grower locations.

		2000-2001				2001-2002				2002-2003		2003-2004	
		% leaves present		% leaves infected		% leaves present		% leaves infected		% leaves present	% leaves infected	% leaves present	% leaves infected
Grower	**Treatment**	**Dec 20**	**Mar 5**	**Dec 20**	**Mar 5**	**Nov 13**	**Jan 23**	**Nov 13**	**Jan 23**	**Jan 7**	**Jan 7**	**Jan 7**	**Jan 7**
1	HMO	98 a[1]	84 a	4 a	16 a[2]	96 a	87 a	5 a	23 a	95 a	9 a	87 a	2 a
	CON	97 a	92 a	2 a	3 b	99 a	85 a	1 a	19 a	96 a	10 a	81 a	4 a
		Dec 18	Feb 22	Dec 18	Feb 22	Nov 16	Jan 24	Nov 16	Jan 24	Jan 14	Jan 14	Jan 7	Jan 7
2	HMO	96 a	96 a	8 a	16 a	100 a	95 a	16 a[2]	12 a[3]	100 a	19 a[3]	95 a	15 a
	CON	98 a	95 a	3 a	9 a	100 a	91 a	6 b	1 b	99 a	1 b	91 a	11 a
		Dec 18	Mar 1	Dec 18	Mar 1	Nov 16	Feb 6	Nov 16	Feb 6				
3	HMO	98 a	95 a	8 a	22 a[2]	100 a	97 a	15 a[3]	44 a[3]	DROPPED		DROPPED	
	CON	98 a	94 a	6 a	9 b	100 a	98 a	4 b	15 b				
		Dec 13	Feb 27	Dec 13	Feb 27	Nov 14	Feb 5	Nov 14	Feb 5	Jan 6	Jan 6	Jan 8	Jan 8
4	HMO	98 a	94 a[2]	1 a	47 a[3]	–	88 a	4.0 a[2]	9 a[2]	99 a	19 a[3]	88 a	10 a
	CON	97 a	82 b	9 a	18 b	–	95 a	0.2 b	3 b	100 a	6 b	95 a	8 a

[1] Paired means within each column per grower followed by the same letter are not significantly different; [2] $p \geq 0.05$; [3] $p \geq 0.01$

TABLE 5. Comparisons of greasy spot severity ratings.

Grower	Treatment	2001 Mar 20	2002 Jan 23	2003 Jan 7
1	HMO	1.0%[1]	>0.1%	0.4%
	CON	0.6%	0.5%	0.2%
		2001 Mar 1	2002 Jan 24	2003 Jan 14
2	HMO	0.8%	0.2%	2.0%
	CON	1.1%	0.2%	0.8%
		2001 Mar 1	2002 Feb 6	
3	HMO	0.8%	0.5%	Dropped
	CON	1.5%	0.6%	
		2001 Feb 27	2002 Feb 5	2003 Jan 6
4	HMO	2.0%	2.0%	0.3%
	CON	1.0%	0.8%	0.4%

[1]The lowest level of infection is trace that ranges from 0 to 5%

increased as readings were taken from November through March each year. However, greasy spot ratings never exceeded 2% levels within any of the locations over four years (Table 5). These values or scores fell within the lowest category of greasy spot infection ratings (e.g., trace= 0 to 5%).

There were no apparent differences in tree canopy vigor between the HMO and control blocks in three of the four sites by January 2004. There were no significant differences between fruit set in the test versus the control blocks at any of the four locations based on frame counts taken in July 2002 and in two sites during December 2003 and January 2004 (Table 6). Grower 1 had already harvested the test blocks in late 2003. Both 'Hamlin' blocks had higher fruit densities compared with the two 'Valencia' blocks during 2002.

Results of this study have demonstrated that the use of HMO-only foliar spray programs can effectively provide comparable control of both pest mites and greasy spot disease to the more conventional programs. Neither yield nor tree vigor was negatively impacted by the use of HMO-only foliar spray programs. No other secondary insect or disease problems developed within any of the HMO-only blocks. This HMO-foliar spray program can work where citrus greening, citrus canker, and black spot do not occur on citrus.

TABLE 6. Mean numbers of fruits/m^3 of canopy volume for the HMO-only versus the Control (CON) spray programs.

July 2002 Treatment	**1 Hamlin**	**2 Val**	**3 Val**	**4 Hamlin**
HMO	48	29	20	41
CON	48	30	21	41
F	0.006	0.046	1.348	0.010
df	1,28	1,28	1,28	1,28
p	0.9395	0.8316	0.2554	0.9197
December 2003 - January 2004 Treatment	1 Hamlin	2 Val	3 Val	4 Hamlin
HMO	–	29	D	32
CON	–	28	R O	38
F	–	0.32	P	2.88
Df	–	1,38	P E	1,30
p	–	0.5724	D	0.0998

[1] Harvested

Originally, it was intended to inoculate each of the HMO-treatment sites with substantial numbers of beneficial mites in the beginning of field trials. Because of the presence of citrus canker and ongoing eradication efforts at the time, it was not possible to move plant materials from one orchard site to another for fear of spreading infection.

There were no sustained differences in populations of Phytoseiidae, Stigmaeidae, or Tydeidae between the HMO- and the control spray programs over the first three years of this study (Table 7). Mite densities within these families did not increase over time within any of the four locations. Suppression of beneficial mite numbers on citrus has been demonstrated following HMO foliar spray applications (Childers, 2002). Use of multiple HMO applications within one season may have contributed to delaying reestablishment of beneficial mite numbers. Also, repeated usage of herbicides could have contributed to substantial reductions in phytoseiid numbers (Childers &

TABLE 7. Comparative numbers of beneficial mites in the HMO-only and Control (CON) spray programs of four cooperators.

		Grower 1[a]			**Grower 2[a]**			**Grower 3[a]**			**Grower 4[a]**		
Date	**Treatment**	**Phytos[b]**	**Stigs[b]**	**Tydeids[b]**	**Phytos**	**Stigs**	**Tydeids**	**Phytos**	**Stigs**	**Tydeids**	**Phytos**	**Stigs**	**Tydeids**
Feb/Mar	HMO	17 a	4 a	50 b	0 a	0 a	3 b	42 a	1.8 a	25 a	10 a	0.1 a	56 a
2000	CON	31 a	8 a	152 a	0 a	0 a	11 a	28 a	0.3 a	30 a	11 a	0.4 a	77 a
Mar	HMO	21 a	13 a	17 a	43 a	11 a	60 a	68 a	4 a	91 a	37 a	3 a	4 b
2001	CON	29 a	5 a	19 a	22 b	3 b	19 b	33 a	5 a	81 a	29 a	3 a	53 a
Apr	HMO	31 a	0.5 a	33 a	59 a	2.6 a	59 a	95 a	0.1 a	127 a	29 a	1 a	21 b
2001	CON	26 a	0.6 a	54 a	38 a	1.4 a	20 a	94 a	0.3 a	58 a	33 a	1 a	70 a
Jun	HMO	20 a	1 a	213 a	12 a	0.8 a	948 a	26 a	0.5 a	486 a	37 a	1.8 a	125 a
2001	CON	13 a	2 a	220 a	11 a	0.4 a	682 a	23 a	0.9 a	413 a	32 a	0.3 b	76 b
Sep	HMO	5 a	0 a	1 a	0.3 a	0 a	0.1 a	0.4 a	0 a	2 a	12 a	2.0 a	16 a
2001	CON	1 a	0 a	1 a	0.1 a	0 a	0.3 a	0.1 a	0.1 a	1 a	4 b	0.1 b	1 b
Oct	HMO	7 a	1 a	0.3 a	1 a	0 a	0.1 b	1.1 a	2.4 a	12.3 a	18 a	4.3 a	20 a
2001	CON	3 a	2 a	0.6 a	0 a	0.4 a	44.3 a	0.1 a	0.1 b	0.4 b	2 b	0.4 b	4 b
Jan	HMO	13.4 a	3.6 a	11.3 a	4.8 a	0.1 a	0.4 a	1.5 a	1.6 a	0.4 a	11.9 a	1.0 b	6.3 a
2002	CON	8.0 a	1.5 b	17.1 a	5.4 a	0.4 a	4.9 a	4.3 a	3.6 a	1.0 a	9.9 a	4.1 a	2.9 b
Mar	HMO	23 a	0.9 a	15 a	15 a	2 a	2 a	2 a	2 a	1 a	83 a	1 a	4 a
2002	CON	17 a	0.3 a	18 a	8 a	3 a	5 a	2 a	4 a	1 a	40 b	2 a	2 a
May	HMO	10.8 a	0.6 a	43.0 a	8.6 a	1.8 a	38.6 a	12.3 a	0.3 b	6.5 b	18.5 a	0.1 a	60.1 a
2002	CON	10.4 a	0.5 a	69.9 a	13.5 a	0 a	23.3 a	13.5 a	1.4 a	37.6 a	14.6 a	0.1 a	75.8 a

[a] Paired means followed by the same letter within each column set are not significantly different ($p > 0.05$).
[b] Phytos= Phytoseiidae; Stigs= Stigmaeidae; Tydeids= Tydeidae

Denmark, 2011). In laboratory assays trials, Rock & Yeargan (1973) showed that herbicides used in apple orchards were toxic to phytoseiid mites. Comparative assessments of potential direct toxicity or indirect negative effects to beneficial mites, such as loss of pollen sources and alternate prey by herbicides used in citrus, are needed. Recent studies by Childers *et al*. (2001a, b) showed that copper in combination with HMOs was highly toxic to the predatory stigmaeid mite *Agistemus industani* Gonzalez, but not to the phytoseiid *Euseius mesembrinus* (Dean).

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