COMPARATIVE RESIDUAL TOXICITIES OF PESTICIDES TO THE PREDATOR *EUSEIUS MESEMBRINUS* (ACARI: PHYTOSEIIDAE) ON CITRUS IN FLORIDA

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ABSTRACT

Residual toxicities of registered and selected experimental pesticides used on citrus against *Euseius mesembrinus* (Dean) (Acari: Phytoseiidae) were compared. A tractor-drawn airblast sprayer calibrated to deliver 2,338 liters/ha was used to apply pesticides at one or more recommended rates on mature 'Ruby Red' grapefruit trees. Pesticides rated as highly toxic were: azinphos-methyl 50WP at 4.48 kg/ha, dicofol 4EC at 7.01 liters/ha, formetanate 92SP at 5.84 kg/ha, dimethoate 4EC at 5.85 liters/ha, malathion 57EC at 5.85 liters/ha, propargite 6.55EC at 3.51 liters/ha, benomyl 50WP at 1.68 kg/ha + ferbam 76GF at 5.60 kg/ha, ferbam 76GF at 16.81 kg/ha, carbaryl XLR plus at 18.7 liters/ha + FC435-66 petroleum oil at 46.8 liters/ha, pyridaben 75WP at 462 g/ha + FC435-66 petroleum oil at 46.8 liters/ha, carbaryl 80S at 11.21 kg/ha, ethion 4EC at 7.01 liters/ha + FC435-66 petroleum oil at 46.8 liters/ha, benomyl 50WP at 3.36 kg/ha, chlorfenapyr 2SC at 1.46 liters/ha, and pyridaben 75WP at 462 g/ha. Pesticides that were moderately to slightly toxic were: sulfur 80DF at 16.81 kg/ha, abamectin 0.15EC at 731 ml/ha + FC435-66 petroleum oil at 46.8 liters/ha, chlorfenapyr 2SC at 971 ml/ha + FC435-66 petroleum oil at 46.8 liters/ha, FC435-66 petroleum oil at 93.5 liters/ha, and chlorpyrifos 4EC at 5.85 liters/ha. Pesticides that were considered non-toxic were: FC435-66 petroleum oil at 46.8 liters/ha, carbaryl 80S at 4.48 kg/ha, chlorfenapyr 2SC at 971 ml/ha, chlorpyrifos 4EC at 5.85 liters/ha, fenbuconazole 2F at 292 ml/ha + FC435-66 petroleum oil at 46.8 liters/ha, copper hydroxide 77WP at 4.48 kg metallic/ha, benomyl 50WP at 3.36 kg/ha, and fenbuconazole 2F at 584 ml/ha. Ferbam 76GF at 16.81 kg/ha, benomyl 50WP + ferbam 76GF, carbaryl 80S at 11.21 kg/ha, carbaryl XLR Plus + FC435-66 petroleum oil, and benomyl 50WP at 3.36 kg/ha had significantly higher numbers of missing females from treated leaf surfaces suggesting these products were repellent, irritating, and/or excitatory to the gravid females.

Key Words: Acaricides, fungicides, insecticides, integrated pest and disease management, toxicity, non-target arthropods

RESUMEN

Toxicidad residual de pesticidas registrados y experimentales selectos usados en cítricos contra Euseius mesembrinus (Dean) (Acari: Phytoseiidae) fueron comparados. Una asperjadora de aire a presión y halada por un tractor, calibrada para entregar 2,338 litros/ha fue usado para aplicar pesticidas a una o mas dosis recomendadas en árboles de toronja 'Ruby Red'. Pesticidas clasificados como altamente tóxicos fueron: azinphos-methyl 50WP a 4.48 kg/ha, dicofol 4EC a 7.01 litros/ha, formetanate 92SP a 5.84 kg/ha, dimethoate 4EC a 5.85 litros/ha, malathion 57EC a 5.85 litros/ha, propargite 6.55EC a 3.51 litros/ha, benomyl sowr a 1.68 kg/ha + ferbam 76GF a 5.60 kg/ha, ferbam 76GF a 16.81 kg/ha, carbaryl XLR plus a 18.7 litros/ha + FC435-66 aceite de petróleo a 46.8 litros/ha, pyridaben 75WP a 462 g/ha + FC435-66 aceite de petróleo a 46.8 litros/ha, carbaryl 80S a 11.21 kg/ha, ethion 4EC a 7.01 litros/ha + FC435-66 aceite de petróleo a 46.8 litros/ha, benomyl 50 WP a 3.36 kg/ha, chlorfenapyr 2SC a 1.46 litros/ha, y pyridaben 75WP a 462 g/ha. Pesticidas que fueron moderadamente o levemente tóxicos eran: azufre 80DF a 16.81 kg/ha, abamectin 0.15EC a 731 ml/ha + FC435-66 aceite de petróleo a 46.8 litros/ha, chlorfenapyr 2SC a 971 ml/ha + FC435-66 aceite de petróleo a 46.8 litros/ha, FC435-66 aceite de petróleo a 93.5 litros/ha, y chlorpyrifos 4EC a 5.85 litros/ha. Pesticidas considerados no tóxicos fueron: FC435-66 aceite de petróleo a 46.8 litros/ha, carbaryl 80S a 4.48 kg/ha, chlorfenapyr 2SC a 971 ml/ha, chlorpyrifos 4EC a 5.85 litros/ha, fenbuconazole 2F a 292 ml/ha + FC435-66 aceite de petróleo a 46.8 litros/ha, hidróxido de cobre 77WP a 4.48 kg metalico/ha, benomyl 50WP a 3.36 kg/ha, y fenbuconazole 2F a 584 ml/ha. Ferbam 76GF a 16.81 kg/ha, benomyl 50WP + ferbam 76GF, carbaryl 80S a 11.21 kg/ha, carbaryl XLR Plus + FC435-66 aceite de petróleo, y benomyl 50WP a 3.36 kg/ha tuvieron números significativamente mas altos de hembras ausentes de superficies de hojas tratadas sugiriendo que estos productos fueron repelentes, irritantes, y/o excitatorio a las hembras grávidas.

Citrus is a multi-billion dollar agricultural business in Florida that annually provides 70-80% of the total United States production (Anonymous 1996). Of this, 85% of the Florida crop is used in processing (i.e., juice, sections, pulp) with the balance for fresh market. The pest mite complex on Florida citrus is diverse and includes species in four acarine families: Eriophyidae, Tetranychidae, Tarsonemidae, and Tenuipalpidae (Childers 1994). The citrus rust mite *Phyllocoptruta oleivora* (Ashmead), the pink citrus rust mite *Aculops pelekassi* (Keifer) (Eriophyidae), and several spider mite species, primarily the Texas citrus mite, *Eutetranychus banksi* (McGregor) are important. Approximately 171 million dollars are spent annually by farmers in Florida for chemical control of these mites including the combined costs of chemicals and application equipment, based on estimates for Central, East Coast and Southwest Florida (Muraro & Hebb 1997, Muraro et al. 1997a, Muraro et al. 1997b). Historically, this has been one of the largest commodity markets for acaricide usage within the United States with 2-3 applications per hectare per year on 346,823 hectares of trees (Childers 1994). Citrus rust mites and the fungal pathogen greasy spot, *Mycosphaerella citri* Whiteside, are recognized as key fruit and foliar pests on Florida citrus, respectively. Control recommendations currently rely solely on pesticides for both key pests (Childers et al. 2000a, Roberts & Timmer 2000). Increasing urbanization, the public's concern over pesticide use on food products, increased application and chemical costs, sustaining competitive food exports to foreign markets and compliance with the Food Quality Protection Act of 1996 dictate the need for alternative control strategies.

Because of climatic conditions that exist in Florida, the fungal pathogens: e. g., greasy spot, melanose, *Diaporthe citri* Wolf, citrus scab, *Elsinoe fawcettii* Bitancourt and Jenkins, alternaria brown spot, *Alternaria* sp. and postbloom fruit drop disease, *Colletotrichum acutatum* J. H. Simmonds, are important disease problems for many citrus growers. Current fungicides recommended for these diseases are limited to ferbam, benomyl, ferbam + benomyl, copper formulations applied alone or in combination with petroleum oil, or petroleum oil applied alone (Roberts & Timmer 2000, Timmer 2000a,b,c, McMillan et al. 2000).

Arthropod predators and parasitoids are the most important naturally occurring biological control agents of arthropods in most agroecosystems (Croft 1990). Predacious mites are recognized as highly important in regulating phytophagous mites on citrus worldwide (Keetch 1972, Ferragut et al. 1987, Papacek & Smith 1992, McMurtry & Croft 1997) and Florida citrus has a rich fauna of both predacious and other beneficial mites (Muma 1975). On-going research has identified species within several mite families that have potential in suppressing citrus rust mites and spider mites (Childers 1994, Childers & Abou-Setta 1999; C. C. C., unpublished data). However, little information on comparative toxicities of registered or experimental pesticides to predacious mites on Florida citrus has been available. Such information is essential in developing an effective integrated pest and disease management program.

This study was initiated to assess direct and indirect residual toxicities of different pesticides either registered for use on Florida citrus or being developed for registration as insecticides, acaricides or fungicides. The pesticides were applied and weathered in the field against the predacious mite, *Euseius mesembrinus* (Dean), a prevalent phytoseiid species that feeds on spider mites and other mite species on Florida and Texas citrus (Abou-Setta et al. 1991; C. C. C., unpublished data). Different pesticides were applied and weathered in the field to assess their impact on gravid females, oviposition, and survival of eclosing larvae.

Materials and Methods

Field Application

Four series of field applications were completed between August and September 1997 in a 4 hectare block of 'Ruby red' grapefruit located at the Citrus Research and Education Center in Lake Alfred, Florida. The treatment trees were healthy, vigorous and measured 3.2 to 3.9 m tall and 3.9 to 5.2 m in diameter. Trees were spaced 7.47 m within the row and 8.11 m between rows (= 187 trees/ha). Different trees were selected for each of the series of pesticide treatments with a minimum of four trees separating single tree treatments within the row and with two buffer rows between treatment rows.

Treatments were applied using a tractor-drawn FMC 352 airblast sprayer beginning each morning after the citrus leaves had dried. The sprayer was calibrated to deliver 2,338 liters of spray/ha. Each single tree treatment was sprayed while traveling at 2.4 km/h. Tractor speed was properly adjusted several tree spacings ahead of the sample tree before engaging the sprayer on either side within the rows. The pesticides, application dates, water pH, formulations, and rates per hectare are shown in Table 1. FC435-66 represents a medium, narrow-range petroleum oil with a mid-distillation temperature of 224°C (= 435°F) that meets the designated Florida citrus standards established by Simanton & Trammel (1966). T-Mulz (Harcros Chemicals, Inc., Kansas City, KS), a non-ionic surfactant, was mixed at 10 ml per liter of petroleum oil as the emulsifier. Pesticides tested are registered for use on Florida

TABLE 1. SERIES OF PESTICIDES, APPLICATION DATES, WATER PH, FORMULATIONS, AND RATES PER HECTARE.

Series	Date of application and water pH	Pesticide common name and use[a]		Manufacturer	Pesticide trade name	Formulation[b]	Rate used in 2.34 k liters/ha
I	11 August—pH 7.5	1. Copper hydroxide	F	Griffin Corp. Valdosta, GA	Kocide 101	77WP (50% metallic)	4.48 kg metallic
		2. Copper sulfate	F	Cuproquim Corp. Memphis, TN	Copper 53	98% (53% metallic)	4.48 kg metallic
		3. Fenbuconazole (RH-7592)	F	Rohm and Haas Co. Philadelphia, PA	Enable	2F	584 ml
		4. Fenbuconazole (RH- 7592) + petroleum oil	F F, A, I	 Exxon Co., Houston, TX	Enable Orchex 796	2F FC435-66	292 ml 46.8 liters
		5. Benomyl	F	E. I. DuPont de Nemours Wilmington, DE	Benlate	50WP	3.36 kg
		6. Ferbam	F	UCB Chemical Smyrna, GA	Ferbam	76GF	16.81 kg
		7. Benomyl + ferbam	F F		Benlate + Ferbam	50WP 76GF	1.68 kg 5.60 kg
		8. Chlorpyrifos	I	Dow Elanco Indianapolis, IN	Lorsban	4EC	5.85 liters
		9. Sulfur	A	BASF Research Triangle Park, NC	Kumulus	80DF	16.81 kg
		10. Untreated		—	—	—	—
II	18 August—pH 7.3	1. Pyridaben	A	BASF	Nexter	75WP	462 g
		2. Pyridaben + petroleum oil	A F, A, I		Nexter + Orchex 796	75WP FC435-66	462 g 46.8 liters
		3. Abamectin + petroleum oil	A, I F, A, I	Novartis Greensboro, NC	Agri-mek + Orchex 796	0.15EC FC435-66	731 ml 46.8 liters
		4. Chlorfenapyr	A,I	American Cyanamid Co. Princeton, NJ	Alert	2SC	971 ml
		5. Chlorfenapyr + petroleum oil	A,I F, A, I		Alert + Orchex 796	2SC FC435-66	971 ml 46.8 liters
		6. Petroleum oil	F, A, I		Orchex 796	FC435-66	46.8 liters
		7. Petroleum oil	F, A, I		Orchex 796	FC435-66	93.5 liters
		8. Untreated	—	—	—	—	—
III	19 August—pH 7.5	1. Carbaryl	I	Rhone Poulenc Research Triangle Park, NC	Sevin	80S	4.48 kg

[a]A = acaricide, F = fungicide, I = insecticide.

[b]WP = wettable powder, F = flowable, GF = granular flowable, EC = emulsifiable concentrate, SC = soluble concentrate, S, SP = soluble powder, FC 435-66 = Florida citrus 435 oil (Simanton and Trammel 1966), DF = dispersible flowable.

TABLE 1. (CONTINUED) SERIES OF PESTICIDES, APPLICATION DATES, WATER PH, FORMULATIONS, AND RATES PER HECTARE.

Series	Date of application and water pH	Pesticide common name and use[a]		Manufacturer	Pesticide trade name	Formulation[b]	Rate used in 2.34 k liters/ha
		2. Carbaryl	I		Sevin	80S	11.21 kg
		3. Azinphos-methyl	I	Bayer Corp. Kansas City, MO	Guthion	50WP	4.48 kg
		4. Formetanate	A, I	Agro Evo, Wilmington, DE	Carzol	92SP	1.12 kg
		5. Carbaryl + petroleum oil	I F, A, I	Rhone Poulenc	Sevin + Orchex 796	XLR Plus 41.2% AI FC435-66	18.7 liters 46.8 liters
		6. Dimethoate	I	Platte Chemical Co. Fremont, NE	Dimethoate	400	5.85 liters
		7. Malathion	I	Platte Chemical Co. Fremont, NE	Malathion	57EC	5.85 liters
		8. Dicofol	A	Platte Chemical Co. Fremont, NE	Dicofol	4EC	7.01 liters
		9. Propargite	A	Uniroyal Chemical Co., Middlebury, CT	Comite	6.55EC	3.51 liters
		10. Untreated	—	—	—	—	—
IV	8 September — pH N/A	1. Benomyl	F		Benlate	50WP	3.36 kg
		2. Ferbam	F		Ferbam	76GF	16.81 kg
		3. Chlorpyrifos	I		Lorsban	4EC	5.85 liters
		4. Ethion + petroleum oil	A, I	FMC Corp. Philadelphia, PA	Ethion	4EC	7.01 liters
		5. Chlorfenapyr	A, I		Alert	2SC	1.46 liters
		6. Chlorfenapyr + petroleum oil	A, I F, A, I		Alert + Orchex 796	2SC FC435-66	971 ml 46.8 liters
		7. Formetanate	A, I		Carzol	92SP	1.12 kg
		8. Dicofol	A	Platte Chemical Co. Freemont, NE	Dicofol	4EC	7.01 liters
		9. Untreated	—		—	—	—

[a]A = acaricide, F = fungicide, I = insecticide.

[b]WP = wettable powder, F = flowable, GF = granular flowable, EC = emulsifiable concentrate, SC = soluble concentrate, S, SP = soluble powder, FC 435-66 = Florida citrus 435 oil (Simanton and Trammel 1966), DF = dispersible flowable.

citrus except chlorfenapyr (4-Bromo-2-(4-chlorphenyl)-1(ethoxymethyl)-5-(trifluoromethyl) pyrrole-3-carbonitrile), an experimental acaricide of American Cyanamid Co., Princeton, NJ and fenbuconazole (RH-7592), alpha [2-(4-chlorophenyl) ethyl]-alpha-phenyl-1H-1,2,4-triazole-1-propanenitrile, an experimental fungicide of Rohm and Haas Co., Philadelphia, PA. The acaricides, insecticides, or fungicides are used to control one or more arthropod or fungal disease pests included in the Florida Pest Management Guide (Childers et al. 2000a, b; Browning et al. 2000; Roberts & Timmer 2000). Daily maximum-minimum air temperatures and rainfall data during the test intervals between application and completion of leaf sampling for each series of pesticides are listed in Table 2.

Field Sampling

Sixteen or more hardened spring flush leaves were collected at random from the outer exposed canopy around each sample tree at waist to chest height (1.2 to 1.6 m) one and 4 days after each series of pesticide treatments was applied during 1997. Leaves were always collected first from the unsprayed check trees for each treatment series. Disposable rubber gloves were changed between treatments both in the field and laboratory to avoid potential contamination. Individual dry leaves were collected into a paper bag by picking the leaf at the base of the petiole without touching the leaf surface. Each paper bag was then placed on the floor of the air conditioned vehicle out of direct sunlight. Sampling in the field and travel time required less than 1 h before returning to the laboratory for processing.

TABLE 2. MAXIMUM-MINIMUM AIR TEMPERATURES AND RAINFALL DURING THE TEST INTERVALS IN 1997.

Series	Date	Temperature °C		Rainfall (mm)
		Max	Min	
I	11 August	34	22	35
	12	34	22	
	13	36	24	
	14	37	23	6
	15	34	23	
	16	35	22	25
	17	34	22	
II	18	36	22	
III	19	36	23	
	20	36	26	
	21	35	24	
	22	36	22	6
	23	34	19	
	24	34	21	
	25	36	20	
IV	8 September	33	17	
	9	33	17	
	10	34	20	
	11	34	20	3
	12	33	21	
	13	34	19	
	14	36	20	

Laboratory Preparation

Untreated check leaves were always processed first. Leaves from each treatment were removed from a paper bag and briefly placed on a clean paper surface. Leaves for that treatment were then individually selected and prepared for single whole leaf arenas. Contact with treated leaf surfaces was avoided as much as possible. Six leaves (= 6 treatment replicates) were selected per treatment based on size, vigor and minimal leaf blemishes. Individual leaf arenas were prepared with the lower leaf surface facing up based on established methods for rearing phytoseiid mites (Abou-Setta & Childers 1987a). An aluminum foil sheet was placed beneath the foam padding to prevent contact of water with the plastic container and to avoid potential contamination. A filter paper was placed over the foam pad and the leaf arena was then placed over the filter paper. The sides and petiole areas of each whole leaf were covered with absorbent cotton stripping to keep the leaf in position and provide a non-toxic wet barrier to minimize escape of the gravid females. Treated leaf arenas were maintained in the laboratory between 26 and 28°C and held in open boxes to assure adequate ventilation.

Mite Cultures

Euseius mesembrinus was collected from Central Florida citrus groves in the Winter-Spring of 1997, maintained in culture on leaf arenas and fed ice plant, *Malephora crocea* (Jacquin) pollen (Abou-Setta & Childers 1987b).

Large numbers of both *E. mesembrinus* males and females were transferred to several new untreated rearing leaf arenas and held for 24 h to deposit a cohort of eggs ± 12 h old. The following day, all motile mites were removed from the leaf arenas and the eggs were allowed to develop. Gravid *E. mesembrinus* females were then collected from the arenas after 9-10 days (Abou-Setta & Childers 1987b). Cotton fibers were placed on the surface of each leaf for use as an oviposition substrate along with a piece of black construction paper about 4 mm wide by 8-10 mm long that served as a refuge for aggregation. A total of 10 gravid females were transferred individually using a 5-0 sable brush directly onto the black construction paper of each replicated arena to avoid contaminating the brush with pesticides.

The mites were checked to ensure that they were not injured during transfer and any that appeared injured were immediately replaced.

Laboratory Assessment

Each arena was examined 72 h after infestation to determine mortality of gravid females. Three categories were recorded for adults: dead, alive, or missing. A mite was considered dead if it was unable to move forward. In addition, number of live eggs per arena was recorded after 72 h. Eggs were recorded as live when their size, opaque color and oblong-oval shape were consistent. Live larvae or protonymphs per arena were recorded after 72 h.

Statistical Analysis

All data on surviving or missing adults, oviposition and surviving immatures were analyzed in each experiment by analysis of variance (ANOVA) and means were separated using LSD (GLM procedures, SAS Institute 1991). Means and standard errors reported here were calculated using non-transformed data.

Results and Discussion

Maximum air temperatures in the field during the 1997 experiment ranged from 33 to 37°C and two significant rains of 35 and 25 mm occurred on 11 and 16 August, respectively, during evaluation of series I pesticides (Table 2). The 11 August rain occurred about 2 h after the last treatment applications (treatments 3 and 4 in series I).

Gravid Females

Pesticides that resulted in less than 30% survival of gravid female *E. mesembrinus* included: azinphos-methyl, dicofol, malathion, propargite, formetanate, dimethoate, propargite, benomyl + ferbam, ferbam, carbaryl XLR + petroleum oil, pyridaben + petroleum oil, cabaryl 80S at 11.21 kg/ha, ethion + petroleum oil, benomyl, chlorfenapyr and pyridaben (Table 3). Pesticides that remained highly toxic to gravid females when exposed to 4-day-old field treated leaves were: azinphos-methyl, dicofol, formetanate, ferbam and pyridaben + petroleum oil. Use of formetanate in three different treatment regimes in a field experiment on 'Tahiti' limes significantly reduced populations of *Typhlodromalus peregrinus* (Muma) (Acari: Phytoseiidae) for over 2 months following the last applications (Childers & Abou-Setta 1999). Subsequent feeding injury from elevated populations of citrus red mite, *Panonychus citri* (McGregor) in this experiment resulted in economic loss to the grower. Most of the same pesticides were shown to be toxic to *Euseius hibisci* (Chant) in California by Jeppson et al. (1975).

Pesticides listed in Table 4 had significantly higher numbers of missing *E. mesembrinus* females from treated leaf surfaces compared to the untreated checks and other treatments tested. Mites could not be found on the treated leaf arenas, cotton pad strips surrounding each treated leaf surface or on the water saturated sponge beneath the leaf. The gravid females were presumed to have escaped the arena since no visible cadavers or injured mites remained. We suspect that these products were repellent, irritating, and/or excitatory to gravid females.

Fecundity

Pesticides that were not toxic to gravid females but resulted in a 50% or greater reduction in egg production after one day post treatment included: sulfur and benomyl (Table 3). The untreated check from series I had low numbers of eggs produced in the 4 day post spray evaluation. Egg production was significantly lower compared to several other treatments in that series except copper hydroxide, chlorpyrifos, or copper sulfate. None of these treatments had significantly lower egg production in the 1 day postspray series (Table 3).

Larval Survival

Pesticides that were not toxic to gravid females but resulted in a 50% or less reduction in larvae included: abamectin + FC435-66 petroleum oil after one day and benomyl or chlorfenapyr + FC435-66 petroleum oil after 4 days compared with the untreated checks.

Comparative Toxicities

Our data often showed differential toxicity to various life stages of *E. mesembrinus*. Therefore, a simple method to compare toxicities between pesticides was used where ($\bar{x}$ number of surviving gravid females) × ($\bar{x}$ number of live eggs produced/arena) × ($\bar{x}$ number of live larvae) were multiplied. The lower the value obtained the more toxic was the pesticide. Based on these criteria, pesticides evaluated in this study were determined to be highly toxic with values below 200, moderately toxic with values between 200 and 400 and slightly to non-toxic with values greater than 400 (Table 5).

Phytoseiid mites in the genus *Euseius* are recognized as facultative pollen feeders (McMurtry 1992). However, *E. hibisci* (Chant) was shown to feed on avocado leaf sap but not on lemon using radioactive phosphoric acid (Porres et al. 1975). Subsequent studies failed to indicate whether this feeding was restricted to the larval stage or all motile stages of the mite. Abou-Setta & Childers (1987b) reported that *E. mesembrinus*

TABLE 3. *EUSEIUS MESEMBRINUS* GRAVID FEMALE SURVIVAL, EGG PRODUCTION AND LIVE IMMATURES ($\bar{X}$ ± SE) 72 H AFTER INFESTATION ON LEAVES 1 AND 4 DAYS FOLLOWING SPRAY APPLICATION.

			1 day			4 days		
Series	Pesticide formulation	Rate per ha	Surviving ♀♀	Live eggs	Live immatures	Surviving ♀♀	Live eggs	Live immatures
I	1. Copper hydroxide 77WP	4.48 kg metallic	9.6 ± 0.2 a	12.3 ± 1.9 bc	6.3 ± 0.9 abcd	7.5 ± 0.6 ab	2.3 ± 1.0 d	4.0 ± 0.3 bc
	2. Copper sulfate 98%	4.48 kg metallic	9.1 ± 0.4 a	13.5 ± 0.9 bc	6.9 ± 0.7 ab	7.9 ± 1.7 a	3.4 ± 1.6 cd	3.5 ± 0.6 bc
	3. Fenbuconazole 2F	584 ml	8.8 ± 0.4 a	21.3 ± 2.4 a	7.1 ± 0.5 a	9.0 ± 0.5 a	13.8 ± 2.9 a	7.4 ± 1.0 a
	4. Fenbuconazole 2F + petroleum oil FC435-66	292 ml 46.8 liters	8.9 ± 0.4 a	14.8 ± 1.0 abc	5.5 ± 1.2 abcde	8.6 ± 0.7 a	13.8 ± 1.9 a	3.4 ± 0.9 bc
	5. Benomyl 50WP	3.36 kg	9.6 ± 0.2 a	10.6 ± 2.3 c	7.6 ± 1.0 a	9.8 ± 0.2 a	2.0 ± 1.1 d	4.8 ± 0.8 b
	6. Ferbam 76GF	16.81 kg	2.6 ± 1.3 b	2.8 ± 1.7 e	3.8 ± 0.9 e	2.4 ± 1.1 c	1.5 ± 0.8 d	2.9 ± 0.9 c
	7. Benomyl 50WP + ferbam 76GF	1.68 kg 5.60 kg	2.9 ± 1.2 b	1.9 ± 1.0 e	3.9 ± 0.9 de	5.9 ± 1.4 b	4.3 ± 2.0 cd	4.4 ± 0.4 bc
	8. Chlorpyrifos 4EC	5.85 liters	9.4 ± 0.3 a	15.4 ± 2.5 abc	4.4 ± 0.7 bcde	8.1 ± 0.5 a	7.4 ± 1.9 bc	3.8 ± 0.8 bc
	9. Sulfur 80DF	16.81 kg	8.5 ± 0.6 a	5.9 ± 2.0 d	4.1 ± 0.8 cde	9.5 ± 0.3 a	11.4 ± 1.3 ab	5.0 ± 0.7 ab
	10. Untreated	—	9.0 ± 0.5 a	15.8 ± 1.1 ab	6.9 ± 1.2 abc	8.1 ± 0.4 a	3.6 ± 1.3 cd	3.9 ± 0.7 bc
II	1. Pyridaben 75WP	462 g	7.1 ± 0.9 ab	6.4 ± 1.8 bc	3.6 ± 0.7 ab	9.3 ± 0.3 a	3.0 ± 0.7 bc	6.4 ± 1.1 d
	2. Pyridaben 75WP + petroleum oil FC435-66	462 g 46.8 liters	5.4 ± 1.5 b	4.8 ± 1.7 c	1.3 ± 0.6 c	8.4 ± 0.5 a	0.4 ± 0.4 d	7.6 ± 0.8 cd
	3. Abamectin 0.15EC + petroleum oil FC435-66	731 ml 46.8 liters	8.8 ± 0.3 a	11.1 ± 1.8 ab	2.5 ± 0.6 bc	9.5 ± 0.2 a	3.8 ± 0.6 ab	6.4 ± 0.8 d
	4. Chlorfenapyr 2SC	971 ml	8.3 ± 0.8 a	14.6 ± 2.5 a	4.9 ± 1.1 ab	9.1 ± 0.5 a	6.0 ± 0.7 a	12.3 ± 1.0 ab
	5. Chlorfenapyr 2SC + petroleum oil FC435-66	971 ml 46.8 liters	7.0 ± 1.4 ab	11.0 ± 2.3 ab	4.0 ± 1.3 b	9.0 ± 0.2 a	3.0 ± 0.7 bc	10.1 ± 0.7 abc
	6. Petroleum oil FC435-66	46.8 liters	8.5 ± 0.9 a	17.1 ± 2.9 a	3.4 ± 0.8 b	8.9 ± 0.3 a	4.6 ± 0.8 ab	7.9 ± 0.6 cd
	7. Petroleum oil FC435-66	93.5 liters	8.9 ± 0.4 a	12.4 ± 2.2 a	3.4 ± 1.0 b	9.5 ± 0.2 a	4.9 ± 1.0 ab	9.5 ± 1.0 bc
	8. Untreated	—	9.1 ± 0.2 a	12.6 ± 1.1 a	6.3 ± 0.6 a	9.6 ± 0.2 a	4.4 ± 0.7 ab	3.9 ± 0.8 e
III	1. Carbaryl 80S	4.48 kg	9.3 ± 0.4 a	10.0 ± 1.7 a	6.0 ± 0.8 a	8.8 ± 0.3 a	13.0 ± 1.9 a	4.9 ± 0.4 bc
	2. Carbaryl 80S	11.21 kg	4.5 ± 0.8 b	2.1 ± 1.1 b	4.9 ± 0.7 a	8.0 ± 0.6 ab	7.0 ± 1.5 a	4.1 ± 0.6 c
	3. Azinphos-methyl 50WP	4.48 kg	0 ± 0 d	0 ± 0 c	0 ± 0 c	0 ± 0 d	0 ± 0 d	0 ± 0 e
	4. Formetanate 92SP	1.12 kg	0 ± 0 d	0 ± 0 c	0 ± 0 c	0 ± 0 d	0 ± 0 d	0 ± 0 e
	5. Carbaryl-XLR plus 41.2% ai + petroleum oil FC435-66	18.7 liters 46.8 liters	3.8 ± 0.8 b	2.9 ± 0.9 b	2.8 ± 0.8 b	9.3 ± 0.3 a	13.8 ± 1.6 a	4.9 ± 0.4 bc

Means within each column within each series followed by the same letter are not significantly different ($P \geq 0.05$).

TABLE 3. (CONTINUED) *EUSEIUS MESEMBRINUS* GRAVID FEMALE SURVIVAL, EGG PRODUCTION AND LIVE IMMATURES ($\bar{X}$ ± SE) 72 H AFTER INFESTATION ON LEAVES 1 AND 4 DAYS FOLLOWING SPRAY APPLICATION.

			1 day			4 days		
Series	Pesticide formulation	Rate per ha	Surviving ♀♀	Live eggs	Live immatures	Surviving ♀♀	Live eggs	Live immatures
	6. Dimethoate 400	5.85 liters	0 ± 0 d	0 ± 0.1 c	0.6 ± 0.6 c	9.0 ± 0.3 a	12.5 ± 0.6 a	7.1 ± 1.0 ab
	7. Malathion 57EC	5.85 liters	2.3 ± 1.1 c	0 ± 0 c	0 ± 0 c	9.8 ± 0.2 a	17.8 ± 1.0 a	7.5 ± 0.7 a
	8. Dicofol 4EC	7.01 liters	1.0 ± 0.7 cd	0.1 ± 0.1 c	0.5 ± 0.5 c	2.6 ± 1.5 c	2.9 ± 1.9 cd	2.1 ± 1.1 d
	9. Propargite 6.55EC	3.51 liters	0 ± 0 d	0 ± 0 c	0.5 ± 0.4 c	6.3 ± 1.3 b	6.6 ± 1.9 b	6.0 ± 0.6 abc
	10. Untreated	—	9.5 ± 0.3 a	12.5 ± 2.0 a	4.9 ± 0.9 a	9.5 ± 0.3 a	17.3 ± 0.8 a	5.6 ± 0.5 abc
IV	1. Benomyl 50WP	3.36 kg	6.3 ± 1.0 bcd	5.9 ± 2.9 e	3.9 ± 1.2 ab	9.4 ± 0.3 ab	11.8 ± 2.6 cd	4.3 ± 0.6 bc
	2. Ferbam 76GF	16.81 kg	5.8 ± 0.9 cd	7.3 ± 1.9 cde	4.3 ± 0.4 a	3.6 ± 0.9 d	6.3 ± 2.3 e	5.4 ± 0.9 b
	3. Chlorpyrifos 4EC	5.85 liters	7.8 ± 0.4 abc	12.5 ± 1.5 abc	4.1 ± 0.8 ab	8.9 ± 0.2 ab	16.3 ± 1.1 bc	4.8 ± 0.8 b
	4. Ethion 4EC + petroleum oil FC435-66	7.01 liters 46.8 liters	5.4 ± 1.3 cd	6.8 ± 3.0 de	2.4 ± 0.7 b	7.1 ± 1.1 bc	7.9 ± 2.2 de	2.3 ± 0.8 d
	5. Chlorfenapyr 2SC	1.46 liters	5.3 ± 1.5 d	9.3 ± 3.4 cde	3.1 ± 0.9 ab	6.0 ± 1.6 cd	7.5 ± 1.9 de	4.1 ± 1.0 bcd
	6. Chlorfenapyr 2SC + petroleum oil FC435-66	971 ml 46.8 liters	7.8 ± 1.2 abc	11.1 ± 2.4 bcd	3.3 ± 0.8 ab	8.9 ± 0.4 ab	11.0 ± 1.2 cd	2.8 ± 1.2 cd
	7. Formetanate 92SP	1.12 kg	0 ± 0 e	0 ± 0 f	0 ± 0 c	0 ± 0 e	0 ± 0 f	0 ± 0 e
	8. Dicofol 4EC	7.01 liters	0 ± 0 e	0 ± 0 f	0 ± 0 c	0 ± 0 e	0 ± 0 f	0 ± 0 e
	9. Untreated	—	9.0 ± 0.3 ab	15.9 ± 1.7 ab	4.8 ± 0.6 a	9.9 ± 0.1 a	23.8 ± 2.5 a	10.8 ± 0.9 a

Means within each column within each series followed by the same letter are not significantly different ($P \geq 0.05$).

TABLE 4. PESTICIDES WITH SIGNIFICANTLY GREATER NUMBERS OF MISSING *EUSEIUS MESEMBRINUS* GRAVID FEMALES ($\bar{X}$ ± SE) AFTER 72 H EXPOSURE ON TREATED LEAF SURFACES 1 AND 4 DAYS AFTER SPRAY APPLICATION 1997.

				Missing females	
Series	Pesticide	Formulation	Rate per ha	1 day post spray	4 days post spray
I	Ferbam	76WP	16.81 kg	6.3 ± 1.2 a	4.5 ± 1.1 a
	Benomyl	50WP	1.68 kg		3.3 ± 1.2 a
	+ ferbam	76WP	5.60 kg	5.1 ± 1.2 a	
	Untreated	—	—	0.9 ± 0.5 b	0.5 ± 0.2 b
III	Carbaryl	80S	11.21 kg	1.4 ± 0.6 a	0.4 ± 0.2 a
	Carbaryl	XLR Plus	18.7 liters		
	+ petroleum oil	FC435-66	46.8 liters	2.3 ± 0.9 a	0 ± 0 a
	Untreated	—	—	0.3 ± 0.3 b	0.3 ± 0.2 a
IV	Benomyl	50WP	3.36 kg	1.4 ± 0.4 a	0.5 ± 0.3 bc
	Ferbam	76WP	16.81 kg	1.3 ± 0.6 ab	4.4 ± 0.9 a
	Chlorpyrifos	4EC	5.85 liters	0.8 ± 0.4 abc	1.0 ± 0.3 b
	Untreated	—		0.4 ± 0.2 bc	0.1 ± 0.1 c

Means within each column within each series followed by the same letter are not significantly different ($P \geq 0.05$).

was able to develop to the protonymph stage when no food sources were available except the citrus leaf substrate. In this study, chlorfenapyr + FC435-66 oil, abamectin + FC435-66 oil, or FC435-66 oil applied alone at 46.8 or 93.5 liters/ha had lower larval survival rates compared with the other treatments (Table 3). These data suggest that reduced larval survival was caused by either interference with larval feeding attempts through the petroleum oil film covering the leaf surface or by direct or indirect toxicity of the pesticides or combinations with acaricides. It is known that penetration of abamectin into the wax layers of both citrus leaves and fruit increases considerably when combined with petroleum oil under field conditions (Dybas 1990). The use of petroleum oil provided substantial extension of residual activity of abamectin versus abamectin applied alone in controlling citrus rust mite (C. C. C., unpublished data).

Understanding the toxic effects of field weathered pesticides against key predacious mite species is important for all commodities. Climatic conditions in Florida are characterized by warm temperatures, high humidity, and moderate to high annual rainfall. During the summer (i.e., May through October), humidity conditions at night approach 100% and result in long hours of leaf and fruit wetness that often extend into early to mid-morning. In addition, afternoon rain showers frequently occur, especially between May and October. Because of these conditions, accelerated degradation of many pesticides has been shown (Nigg et al. 1983). For example, organophosphate pesticide residues on citrus degrade much more quickly on Florida citrus compared with residues in California (Nigg et al. 1977, Thompson et al. 1979, Nigg & Stamper 1981). Despite such harsh environmental conditions, several of the pesticides evaluated in this study maintained relatively long-termed residual toxicities to *E. mesembrinus* either directly by reducing female survival or indirectly by impacting fecundity rates or larval survival as shown in this study. This study showed the potentially disruptive effects of using ferbam and benomyl on Florida citrus by adversely affecting the predacious mite *Euseius mesembrinus*.

The results of this study provide a comparison of direct and indirect toxic effects by various pesticides to *E. mesembrinus* under field conditions. This information is step one in a process of identifying the possible disruptive impact of specific pesticides used on Florida Citrus. Previous studies have shown that toxicity of certain pesticides to populations of predacious mites and consequent reductions in their effectiveness against phytophagous mite pests (Childers & Enns 1975; Childers & Abou-Setta 1999). Longer term field studies are in progress to identify possible subtle or delayed negative effects of one or more pesticides used in citrus for arthropod and fungal disease control.

ENDNOTE

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TABLE 5. HIGHEST TO LOWEST COMPARATIVE TOXICITIES OF VARIOUS PESTICIDES AND UNTREATED CHECKS TO EUSEIUS MESEMBRINUS ON 24 H POST-TREATED PESTICIDE LEAVES.

Treatment	Series	Calculated ratings	Toxicity rating
Azinphos-methyl	III	0	Highly toxic
Dicofol	IV	0	Highly toxic
Formetanate	III	0	Highly toxic
Formetanate	IV		Highly toxic
Dimethoate	III	0	Highly toxic
Malathion	III	0	Highly toxic
Propargite	III	0	Highly toxic
Dicofol	III	0.05	Highly toxic
Benomyl + ferbam	I	21	Highly toxic
Ferbam	I	28	Highly toxic
Carbaryl XLR + petroleum oil	III	31	Highly toxic
Pyridaben + petroleum oil	II	34	Highly toxic
Carbaryl (11.21 kg)	III	46	Highly toxic
Ethion + petroleum oil	IV	88	Highly toxic
Benomyl	IV	145	Highly toxic
Chlorfenapyr	IV	153	Highly toxic
Pyridaben	II	164	Highly toxic
Ferbam	IV	182	Highly toxic
Sulfur	I	206	Moderately to slightly toxic
Abamectin + petroleum oil	II	244	Moderately to slightly toxic
Chlorfenapyr + petroleum oil	IV	286	Moderately to slightly toxic
Chlorfenapyr + petroleum oil	II	308	Moderately to slightly toxic
Petroleum oil (93.5L)	II	375	Moderately to slightly toxic
Chlorpyrifos	IV	400	Moderately to slightly toxic
Petroleum oil (46.8L)	II	494	Non-toxic
Carbaryl (4.48 kg)	III	558	Non-toxic
Untreated (III)	III	582	Non-toxic
Chlorfenapyr	II	594	Non-toxic
Chlorpyrifos	I	637	Non-toxic
Untreated (IV)	IV	687	Non-toxic
Untreated (II)	II	722	Non-toxic
Fenbuconazole + petroleum oil	I	724	Non-toxic
Copper hydroxide	I	744	Non-toxic
Benomyl	I	773	Non-toxic
Copper sulfate	I	848	Non-toxic
Untreated (I)	I	981	Non-toxic
Fenbuconazole	I	1331	Non-toxic

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