# Integration of Bifenazate and Western Predatory Mite (Acari: Phytoseiidae) for Control of Pecan Leaf Scorch Mite (Acari: Tetranychidae) in Pecan Orchards[1]

James D. Dutcher,[2] G. Esendugue Fonsah,[3] and William G. Hudson[4]

Department of Entomology, Coastal Plain Experiment Station, Tifton, Georgia 31793-0748 USA



J. Entomol. Sci. 44(2): 98-110 (April 2009)

**Abstract** A voluntary phase-out of the manufacture of dicofol, the principal miticide used for chemical control of pecan leaf scorch mite, *Eotetranychus hicoriae* McGregor (Acari: Tetranychidae), and the recent discovery and evaluation of western predatory mite, *Galendromus occidentalis* (Nesbitt), as a biological control of pecan leaf scorch mite have led to the registration of the selective miticide, bifenazate, as a possible replacement for dicofol for control of pecan leaf scorch mites in pecan orchards in the US. The impact of bifenazate on the pecan leaf scorch mite and phytoseiid predatory mites was studied in field trials conducted from 2003-2006. Bifenazate was an effective miticide and had the additional benefit over dicofol of conserving phytoseiid mites. The lowest effective concentration as a foliar spray application was 0.3 g actual bifenazate/l water. The effective residual activity of bifenazate at 0.3 g active ingredient/l applied at 1400 l/ha was 2-6 wks depending on the year and location. Bifenazate conserves a portion of the phytoseiid mite population as phytoseiid abundances were similar in the nontreated and bifenazate-treated trees for up to 4 wks after treatment. Treatment of pecan trees with bifenazate plus the release of phytoseiid mites was a more effective method for pecan leaf scorch mite control than the application of bifenazate alone. Among 8 chemical control treatment alternatives to dicofol, pecan trees treated with bifenazate had similar predatory mite abundance to the nontreated control.

**Key Words** integrated pest management, selective miticide, pest control, horticultural entomology

The pecan leaf scorch mite, *Eotetranychus hicoriae* McGregor (Acari: Tetranychidae), is an important mite pest of commercial pecan, *Carya illinoinensis* (Wangenhiem) K. Koch (Fagales: Juglandaceae), orchards in the southern US. Feeding damage can lead to early defoliation of the trees and may contribute to reduced fruit set during the spring following the season of the occurrence of the damage (Dutcher et al. 1984). Numerous species of phytoseiid mites are natural enemies of the pecan leaf scorch mite (Boethel 1978, Flechtmann and Davis 1971). Dicofol, the principal chemical control for pecan leaf scorch mite was voluntarily phased-out of manufacture by Dow AgroSciences in June of 2006 (Hogmire and Biggs 2006). Bifenazate, spirodiclofen,

[1]Received 28 May 2008; accepted for publication 23 July 2008.

[2]Address inquiries (email: dutch88@uga.edu).

[3]Cooperative Extension Service, Department of Agricultural and Applied Economics, University of Georgia, Rural Development Center, Tifton, GA 31793-1209.

[4]Cooperative Extension Service, Department of Entomology, University of Georgia, Horticulture Building, Tifton, GA 31793-0748.

hexakis, hexythiazox and flowable sulfur are the most commonly used registered alternatives to dicofol for chemical control of pecan leaf scorch mite (Guillebeau 2006). Releases of insectary-reared, predatory, phytoseiid mites were shown to be effective biological control alternatives in recent field experiments (Dutcher 2007). Bifenazate effectively reduced the abundance of plant feeding mites (Dekeyser et al. 2003) and conserved a portion of the predatory mites in apple orchards (Beers and Talley 2005, McDonald and Moore 2002). This paper reports the results of research over 4 seasons comparing the impact of bifenazate and dicofol on pecan leaf scorch mite abundance and phytoseiid abundance in pecan orchards. The objectives of the research were: (1) find the lowest effective concentration bifenazate in the field; (2) compare bifenazate and other alternative miticides to dicofol with respect to effectiveness against pecan leaf scorch mite and impact on abundance of phytoseiid mites; (3) determine the effectiveness of western predatory mites as a biological control of pecan leaf scorch mite when released in a bifenazate-treated commercial orchard, and; (4) discuss the practical aspects and economic impact of mite control on the pecan enterprise budget.

## Materials and Methods

**Experimental sites and biological resources.** The experiments were conducted each season from 2003-2006 in Georgia, USA, in an experimental pecan orchard planted to the cultivar 'Desirable' in Tift Co. and at a grower's farm planted to the cultivar 'Stuart' in Ware Co. The Tift Co. site was planted in 1986-87 at a tree density of 59 tree/ha. The Ware Co. site was planted in the 1920s, and the tree density at the time of the experiment was 18 trees/ha. Trees were managed following current recommendations (Goff et al. 1996, Guillebeau 2006). Mite abundance was sampled by collecting at least 20 compound leaves from each pecan tree. The leaves were processed by brushing the entire surface of each leaf with a mite brushing machine (Llanfair Orchards, Okanagan Falls, British Columbia, Canada). The machine brushed mites from the foliage onto a 12.7-cm diam glass plate covered with a thin film (~0.03 ml) of liquid dishwashing soap (Palmolive Original, Colgate-Palmolive Canada, Inc., Toronto, Canada). The number of mites was estimated by directly counting them on the glass plates under a dissecting microscope. After counting the mites and classifying them into 3 categories—"pecan leaf scorch mite adults and nymphs", "pecan leaf scorch mite eggs", and "phytoseiid mites"—the sample was washed from the plate into a 55-ml glass test tube with 5-10 ml of 70% ethanol. After the solution air dried, the sample was taken up in a solution of ~1.2 ml of 70% ethanol and placed on a glass-well slide. Predatory mites were recovered from the glass-well slide and placed in lactophenol for clearing for 2 d, then mounted on glass slides in a solution of glycerine and distilled water (4:1, v:v) and identified to family using the mouthparts, body shape and pattern of genual leg setae (Krantz 1978) with a compound microscope.

**Field experiments.** In 2003, the lowest effective concentration of bifenazate (Acramite 50WS, EPA Reg. No. 400-503, Chemtura Corp., Middlebury, CT) was determined in a field trial at the Tift Co. site with 5 concentrations (0.00, 0.1, 0.2, 0.3 and 0.4 g actual ingredient (a.i.)/l) and a standard concentration (1.6 g a.i./l) of dicofol (Dicofol 4E, EPA Reg. No. 66,222-56, Makhteshim-Agan N.A., New York, NY) in a completely randomized experimental design with 4 replications. Each replication was a plot of 3 pecan trees in a row. At least 1 row of nontreated trees separated each replication. Trees had been bearing nuts for 8 seasons. Sprays were applied with a

Durand-Wayland (LaGrange, GA) PTO-driven airblast sprayer fitted with a double volute for medium to large trees. The sprayer delivered 1400 L/ha at 5.62 kg/cm$^2$ at a tractor speed of 3.06 km/h. Treatment concentrations were applied on 20 August at 0, 140, 280, 420 and 560 g a.i./ha corresponding to the 5 concentrations listed above. Mite abundance was evaluated by sampling 20 leaves from the center tree of each replication at 1, 2 and 4 wks after treatment.

In 2004, at the Tift Co. site, 4 treatments were applied on a 5-ha orchard. Treatments were: nontreated control; dicofol at 2242 g a.i./ha; bifenazate at 280 g a.i./ha, and; bifenazate at 420 g a.i./ha. Sprays were applied with same equipment and methods as in 2003. Inclement weather intervened, and the treatments were applied 2 times. The first spray was applied on 1 September, the second spray was applied on 14 October, to an entirely new set of trees at the same farm. Treatments were applied to four 3-tree replications in a completely random experimental design. The 3 trees in each replication were in a straight row with a center tree and 2 adjacent trees. At least 1 row of untreated trees separated each replication. Due to the lower abundance of mites, the shoot (the leaves on the current season's stem growth and equal to ~6 leaves/shoot) was used as the sample unit. For the first spray application, mite counts were taken from 5 shoots/tree at 2 and 7 d post treatment from the center tree of each plot. For the second spray application, mite counts were taken from 5 shoots/tree at 2 d and 1 and 2 wks after treatment. Afterward, cold weather caused a ceasation of mite activity on the foliage, and no further samples were taken.

In 2005, the effects of treatments of pecan trees with 2 concentrations of bifenazate were compared with a standard dicofol and a nontreated control treatment in the 'Desirable' orchard in Tift Co. Sprays were applied with the same equipment and by the same methods in the same experimental design as the 2003 and 2004 experiments. Bifenazate was applied at 420 and 560 g a.i./ha and dicofol was applied 2242 g a.i./ha whereas the control was not treated. The treatments were applied one time on 22 August. Mites were counted on 20 leaves per replication, once per week, for wks after treatment from the center tree of each 3-tree plot.

In 2004, western predatory mites, *Galendromus occidentalis* (Nesbitt) (Acari: Phytoseiidae) formulated as live adult mites on dry corncob grit by BioControl Network (Brentwood, TN) were released at a rate of 1000 adult mites per tree in a 4.4-ha plot of 88 'Stuart' cultivar pecan trees in a field experiment at the Ware Co. site. Eight trees were randomly selected from nonadjacent trees in the orchard and treated with the release of predatory mites. That is, a constraint was imposed on the selection of trees where adjacent trees could not be selected as trees for predator release. The predatory mites were released on 25 July, at the beginning of an outbreak of pecan leaf scorch mite in a 2-step process. First, the foliage of each entire tree was sprayed with 38 L water using a Durand Wayland (LaGrange, GA, Model AF500G) engine-powered, airblast sprayer that was fitted with a double volute for large trees. Second, the predatory mites were sprinkled onto the wet foliage, in a corn cob grit formulation. The formulation temporarily adhered to the wet foliage and predatory mites crawled from the formulation to the pecan leaf surface before the foliage dried. The entire plot was treated with bifenazate at 420 g a.i./ha on 26 July. The formulation of bifenazate was Acramite 75WG (EPA Reg. No. 400-519, Chemtura Corp., Middlebury, CT). The miticide was applied with the same equipment and methods that were used to wet the foliage. Mite activity was monitored by sampling 20 leaves per tree at 1, 2, 3, 4, 16 and 52 wks post treatment from 8 trees with predatory mites and 8 trees without predatory mites. Trees were too valuable in this

**Table 1. Abundance of pecan leaf scorch mite adults and nymphs (mites), pecan leaf scorch mite eggs (eggs) in pecan trees treated with a series of increasing concentrations of bifenazate, Tift Co. 2003**

| Sample Date (wk*) | Treatment | Rate (g a.i./ha) | Number per Leaf** | |
|---|---|---|---|---|
| | | | Mites | Eggs |
| 1 | nontreated | 0 | 40 a | 90 a |
| | dicofol | 2242 | 0 b | 3 c |
| | bifenazate | 140 | 21 a | 26 b |
| | bifenazate | 280 | 3 b | 4 c |
| | bifenazate | 420 | 0 b | 2 c |
| | bifenazate | 560 | 0 b | 0 c |
| 2 | nontreated | 0 | 68 a | 123 a |
| | dicofol | 2242 | 9 bc | 19 b |
| | bifenazate | 140 | 12 b | 20 b |
| | bifenazate | 280 | 17 b | 17 b |
| | bifenazate | 420 | 8 bc | 6 c |
| | bifenazate | 560 | 2 c | 2 c |
| 4 | nontreated | 0 | 27 a | 25 a |
| | dicofol | 2242 | 2 b | 3 b |
| | bifenazate | 140 | 3 b | 4 b |
| | bifenazate | 280 | 2 b | 3 b |
| | bifenazate | 420 | 2 b | 2 b |
| | bifenazate | 560 | 2 b | 2 b |

* Sample date indicates the number of weeks after treatment on Aug. 20, 2003.

** Means in the same sample date and same mite category and followed by the same letter are not significantly different (ANOVA, df $_{4,15}$, LSD Test $P < 0.01$).

commercial orchard to leave a nontreated control where serious defoliation could potentially send them into a nonproductive alternate nut-bearing mode for several seasons afterward.

In 2006, a field trial was established at the Tift Co. site to compare the effects of miticide treatments on the abundance of pecan leaf scorch mites, pecan leaf scorch mite eggs, and phytoseiid mites for the duration of the late-season population peak of the pecan leaf scorch mite. The miticides tested were: two formulations of bifenazate - Acramite® 50WS (560 g a.i./ha) and Acramite® 4SC (560 g a.i./ha) (EPA Reg. No. 400-514, Chemtura Corp., Middlebury, CT), Dicofol 4E (2242 g a.i./ha), Microthiol® Disperss® (4,487 g a.i./ha, 80% sulfur, EPA Reg. No. UPI, Inc., King of Prussia, PA), Desperado™ (9.35 l/ha; this is equal to 6,210 g sulfur/ha and 506 g pyridaben/ha)

**Table 2. Abundance of pecan leaf scorch mite adults and nymphs (mites), pecan leaf scorch mite eggs (eggs) in bifenazate, dicofol treated and nontreated pecan trees Tift Co., 2004**

| Spray Date | Sample Date | Treatment | Rate (g a.i./ha) | Number per Shoot* | |
|---|---|---|---|---|---|
| | | | | Mites | Eggs |
| Sept. 1 | Sept. 3 | nontreated | 0 | 87 a | 46 a |
| | | dicofol | 2242 | 1 b | 13 b |
| | | bifenazate | 280 | 7 b | 5 b |
| | | bifenazate | 420 | 6 b | 7 b |
| Sept. 1 | Sept. 8 | nontreated | 0 | 0 a | 0 a |
| | | dicofol | 2242 | 0 a | 0 a |
| | | bifenazate | 280 | 0 a | 0 a |
| | | bifenazate | 420 | 0 a | 0 a |
| Oct. 14 | Oct. 16 | nontreated | 0 | 31 a | 17 a |
| | | dicofol | 2242 | 0 b | 4 b |
| | | bifenazate | 280 | 6 b | 11 ab |
| | | bifenazate | 420 | 3 b | 9 ab |
| Oct. 14 | Oct. 21 | nontreated | 0 | 84 a | 24 a |
| | | dicofol | 2242 | 0 b | 0 b |
| | | bifenazate | 280 | 5 b | 0 b |
| | | bifenazate | 420 | 0 b | 0 b |
| Oct. 14 | Oct. 28 | nontreated | 0 | 91 a | 32 a |
| | | dicofol | 2242 | 0 b | 0 b |
| | | bifenazate | 280 | 0 b | 0 b |
| | | bifenazate | 420 | 0 b | 0 b |

* Means in the same mite category and on the same sample date and followed by the same letter are not significantly different (ANOVA, df $_{3,12}$, LSD Test ($P < 0.05$).



(aqueous suspension of 49.5% sulfur and 4.03% pyridaben, EPA Reg. No. 7,969-225-2935, Wilbur-Ellis Fresno, CA), Zeal™ (151 g a.i./ha) (72% active ingredient, EPA Reg. No. 59,639-138, Valent U.S.A. Corp., Walnut Creek, CA), and Envidor® 2SC (two concentrations 245 and 316 g a.i./ha) (EPA Reg. No. 264-831, Bayer CropScience, Research Triangle Park, NC). The miticides were applied to the foliage as water solutions with the same equipment, methods and experimental design as used in the 2003, 2004 and 2005 Tift Co. experiments. Mites were counted from 20 leaf samples from the center tree of each replication at 7, 14, 24 and 29 d after treatment.

**Table 3. Abundance of pecan leaf scorch mite adults and nymphs (mites), pecan leaf scorch mite eggs (eggs) and predatory phytoseiid mites (phytoseiids) in bifenazate, nontreated control and a standard dicofol treatment, Tift Co. 2005**

| Sample Date (wk*) | Treatment | Rate (g a.i./ha) | Number per Leaf** | | |
|---|---|---|---|---|---|
| | | | Mites | Eggs | Phytoseiids |
| 1 | nontreated | | 13.91 a | 21.68 a | 1.09 a |
| | dicofol | 2242 | 1.35 c | 2.24 b | 0.15 b |
| | bifenazate | 420 | 4.31 b | 4.32 b | 0.59 a |
| | bifenazate | 560 | 8.60 b | 7.35 b | 1.03 a |
| 2 | nontreated | 0 | 8.12 a | 2.37 b | 1.05 a |
| | dicofol | 2242 | 0.90 c | 2.95 b | 0.06 b |
| | bifenazate | 420 | 14.48 a | 7.25 a | 0.71 a |
| | bifenazate | 560 | 5.12 b | 3.63 b | 0.71 a |
| 3 | nontreated | 0 | 3.26 a | 2.19 a | 0.74 a |
| | dicofol | 2242 | 2.89 a | 2.62 a | 0.05 b |
| | bifenazate | 420 | 7.89 a | 3.23 a | 0.69 a |
| | bifenazate | 560 | 5.85 a | 7.20 a | 0.48 a |
| 4 | nontreated | 0 | 7.29 ab | 14.63 a | 0.89 a |
| | dicofol | 2242 | 3.63 b | 15.91 a | 0.00 b |
| | bifenazate | 420 | 14.33 a | 6.83 b | 0.84 a |
| | bifenazate | 560 | 3.80 b | 4.14 b | 0.36 ab |
| 5 | nontreated | 0 | 21.47 a | 10.92 a | 0.71 a |
| | dicofol | 2242 | 4.58 b | 11.40 a | 0.12 b |
| | bifenazate | 420 | 4.39 b | 2.72 b | 0.53 ab |
| | bifenazate | 560 | 5.84 b | 4.50 b | 0.36 ab |
| 6 | nontreated | 0 | 16.99 a | 11.28 a | 1.02 a |
| | dicofol | 2242 | 8.12 b | 12.60 a | 0.09 b |
| | bifenazate | 420 | 3.61 b | 4.87 b | 0.66 ab |
| | bifenazate | 560 | 10.28 ab | 10.44 a | 0.39 ab |

* Sample date indicates weeks after treatment application on Aug. 22, 2005.
** Means on the same sample date and in the same mite category and followed by the same letters are not significantly different (ANOVA, df $_{3,12}$, LSD Test $P < 0.05$).

**Table 4. Abundance of pecan leaf scorch mite adults and nymphs (mites), pecan leaf scorch mite eggs (eggs) and predatory phytoseiid mites (phytoseiids) 1, 2, 3, 4, 16 and 52 weeks after application of two mite control treatments, in a commercial pecan orchard where pecan trees. Ware Co. 2004**

| Sample Date (wk*) | Treatment** | Number per 20 Leaves† | | |
|---|---|---|---|---|
| | | Mites | Eggs | Phytoseiids |
| 1 | bifenazate | 1.7 a | 3.3 a | 0.17 b |
| | bifenazate plus WPM | 3.5 a | 4.2 a | 1.0 a |
| 2 | bifenazate | 56 a | 6.2 a | 0.42 b |
| | bifenazate plus WPM | 6.8 b | 2.1 b | 1.2 a |
| 3 | bifenazate | 119 a | 129 a | 2.2 b |
| | bifenazate plus WPM | 88 b | 104 b | 3.5 a |
| 4 | bifenazate | 10 a | 13 a | 0.34 b |
| | bifenazate plus WPM | 68 b | 24 a | 1.1 a |
| 16 | bifenazate | 0.0 a | 0.0 a | 14 a |
| | bifenazate plus WPM | 0.0 a | 0.0 a | 12 a |
| 52 | bifenazate | 141 a | 367 a | 15 a |
| | bifenazate plus WPM | 92 a | 308 a | 11 a |

* Date indicates the weeks after treatment was applied on July 25, 2004.

** bifenazate = bifenazate at 420 g a.i./ha alone; and, bifenazate plus WPM = bifenazate at 420 g a.i./ha plus 1000 live adult western predatory mites.

† Means in the same sample date and same mite category and followed by the same letter are not significantly different (ANOVA, df $_{1,14}$, LSD Test, $P < 0.05$).

**Statistical analyses.** All data were analyzed by analysis of variance (Steele and Torrie 1980) and calculated with Poptools© (Hood 2006). The mean square error term was used to estimate the variance and calculate the least significant difference for mean separation (Steele and Torrie 1980) whenever the analysis of variance indicated a significant difference between treatments. Results of the statistical analysis are provided as mean separations in the tables. The test used, degrees of freedom (df $_{\text{treatment, error}}$) and level of significance in each experiment are provided in the footnotes of the tables. The level of significance after each mention of the statistics indicates that the statement is significant ($P < 0.05$) or highly significant ($P < 0.01$).

## Results

An application rate of 280 g a.i./ha of bifenazate provided control of pecan leaf scorch mites similar to dicofol in the minimum application rate experiment in 2003. Applications of bifenazate at 420 and 560 g a.i./ha were significantly more effective in controlled pecan leaf scorch mite eggs than dicofol and the 140 and 280 g a.i./ha rates

**Table 5. Miticide treatments were a significant factor in the abundances of pecan leaf scorch mites (mites), pecan leaf scorch mite eggs (eggs) and predatory mites (phytoseiids) on the foliage of pecan trees treated with various miticides in comparison with a nontreated control and a standard dicofol treatment at Tift Co. GA 2006**

| Mite Category | Treatment | Rate (g a.i/ha) | Number per Leaf on Indicated Days after Treatment (DAT)* | | | |
|---|---|---|---|---|---|---|
| | | | 7 DAT | 14 DAT | 24 DAT | 29 DAT |
| mites | nontreated | 0 | 10 a | 89 a | 126 a | 3.3 a |
| | Acramite 50WS | 560 | 0.55 b | 3.8 b | 4.5 b | 1.7 a |
| | Acramite 4SC | 560 | 2.0 b | 0.00 b | 0.63 b | 3.2 a |
| | Dicofol 4E | 2242 | 0.00 b | 0.00 b | 1.2 b | 1.53 a |
| | M. Disperss | 4487 | 0.00 b | 0.00 b | 0.11 b | 0.25 b |
| | Desperado[†] | | 0.25 b | 0.00 b | 0.01 b | 0.01 b |
| | Zeal | 151 | 0.05 b | 0.00 b | 0.04 b | 0.01 b |
| | Envidor 2 SC | 245 | 0.15 b | 0.00 b | 0.00 b | 0.04 b |
| | Envidor 2 SC | 316 | 0.00 b | 0.00 b | 0.00 b | 0.01 b |
| eggs | nontreated | 0 | 9.7 a | 28 a | 21 a | 4.4 a |
| | Acramite 50WS | 560 | 1.4 b | 6.5 b | 1.5 b | 2.3 a |
| | Acramite 4SC | 560 | 1.6 b | 2.0 b | 0.35 c | 5.2 a |
| | Dicofol 4E | 2242 | 0.00 c | 0.00 c | 3.5 b | 3.0 a |
| | M. Disperss | 4487 | 0.00 c | 0.00 c | 0.20 c | 0.29 b |
| | Desperado[†] | | 0.00 c | 0.00 c | 0.03 c | 0.00 b |
| | Zeal | 151 | 0.00 c | 0.00 c | 0.24 c | 0.00 b |
| | Envidor 2 SC | 245 | 0.00 c | 0.00 c | 0.00 c | 0.11 b |
| | Envidor 2 SC | 316 | 0.00 c | 0.00 c | 0.00 c | 0.00 b |
| phytoseiids | nontreated | 0 | 1.5 a | 1.0 a | 3.0 a | 0.20 b |
| | Acramite 50WS | 560 | 0.00 b | 0.75 a | 2.5 a | 2.8 a |
| | Acramite 4SC | 560 | 0.00 b | 0.50 a | 0.18 b | 0.08 b |
| | Dicofol 4E | 2242 | 0.00 b | 0.00 b | 0.00 b | 0.00 b |
| | M. Disperss | 4487 | 0.00 b | 0.00 b | 0.05 b | 0.15 b |
| | Desperado[†] | | 0.00 b | 0.00 b | 0.01 b | 0.00 b |
| | Zeal | 151 | 0.00 b | 0.00 b | 0.01 b | 0.03 b |

**Table 5. Continued**

| Mite Category | Treatment | Rate (g a.i/ha) | Number per Leaf on Indicated Days after Treatment (DAT)* | | | |
|---|---|---|---|---|---|---|
| | | | 7 DAT | 14 DAT | 24 DAT | 29 DAT |
| | Envidor 2 SC | 245 | 0.00 b | 0.00 b | 0.00 b | 0.01 b |
| | Envidor 2 SC | 316 | 0.00 b | 0.00 b | 0.00 b | 0.00 b |

* Treatments were applied on Sept. 5, 2006.

** Means in the same sample date and same mite category and followed by the same letter are not significantly different (ANOVA, df $_{8,31}$, F-Test, $P < 0.05$).

† Desperado has two active ingredients (sulfur and pyridaben) and was applied 9.35 L per ha this is equal to 6,210 g sulfur/ha and 506 g pyridaben/ha.

of bifenazate (Table 1). When sampled at 1 wk after the application, the 140 g a.i./ha treatment did not cause a significant reduction in pecan leaf scorch mite adults and nymphs and significantly reduced pecan leaf scorch mite eggs by ~58%, whereas, treatments with dicofol and the higher rates of bifenazate were highly effective and caused similar reductions in pecan leaf scorch mite abundance. The abundance of pecan leaf scorch mite adults and nymphs and pecan leaf scorch mite eggs at 2 wks after application were significantly lower in all treatments than in the nontreated control.

In 2004, the efficacy of bifenazate at 280 and 420 g a.i./ha was similar to the standard dicofol at 2242 g a.i./ha 1 wk after the first application. Pecan leaf scorch mite abundance was strongly regulated by natural control by winds and driving rains. Rains from Hurricane Frances inundated the plots on 6 September, and mites were not found in the control or treated plots after the storm. The second application of the treatments, on 9 October, resulted in reductions in pecan leaf scorch mite below the nontreated control in all 3 miticide treatments (Table 2).

Bifenazate and dicofol efficacies against pecan leaf scorch mite adults and nymphs, pecan leaf scorch mite eggs, and phytoseiids was variable in the 2005 trial at Tift Co (Table 3). Dicofol controlled pecan leaf scorch mites and nymphs for the entire 6 wks. Dicofol controlled pecan leaf scorch mite eggs for 1 wk and not afterward. The abundance of phytoseiid mites was significantly lower in the dicofol treatment than in the nontreated trees for 6 wks after the treatment date. The lower concentration (420 g a.i./ha) of bifenazate controlled pecan leaf scorch mite adults and nymphs for 1 wk and there was no perceived effect of this treatment until 5 and 6 wks after treatment when pecan leaf scorch mite adult and nymph abundance was again reduced. Similarly, the 420 g a.i/ha bifenazate treatment reduced pecan leaf scorch mite egg abundance 1, 4, 5 and 6 wks after treatment and not at 2 and 3 wks after treatment. The higher concentration (560 g a.i./ha) of bifenazate controlled pecan leaf scorch mite adults and nymphs for 1 through 5 weeks after treatment. Pecan leaf scorch mite egg abundance was reduced by the higher concentration of bifenazate 1, 4 and 5 wks after treatment. There were no significant differences in phytoseiid mite abundance between the nontreated and the two bifenazate treatments for 1 through 6 wks after treatment.

The experiment at the commercial pecan orchard in Ware Co. indicated that bifenazate plus the release of phytoseiid mites is a more effective method for pecan

**Table 6. Enterprise pecan budget, cost and return analysis, using three economic scenarios**

| Measure & Product Type* | Scenario | | | | | |
|---|---|---|---|---|---|---|
| | Experimental | | 10% reduction price & yield | | 23% increase yield | |
| | nontreated | treated | nontreated | treated | nontreated | treated |
| **Production** | | | | | | |
| Yield (kg nuts/ha) | 1638 | 2437 | 1638 | 2193 | 1638 | 2016 |
| Price ($US/kg) | 2.40 | 2.40 | 2.16 | 2.16 | 2.40 | 2.40 |
| **Budget** | | | | | | |
| Gross Revenue ($) | 3938 | 5857 | 3541 | 4738 | 3938 | 4844 |
| Insect control cost ($) | 215 | 215 | 215 | 215 | 215 | 215 |
| Mite control cost ($) | 0 | 62 | 0 | 62 | 0 | 62 |
| Total variable costs ($) | 1723 | 1785 | 1723 | 1785 | 1723 | 1785 |
| Total fixed costs ($) | 1852 | 1852 | 1852 | 1852 | 1852 | 1852 |
| Total harvest and marketing costs ($) | 355 | 355 | 355 | 355 | 355 | 355 |
| Net income ($) | –207 | 1588 | –604 | 469 | –207 | 564 |
| Costs production per kg ($) | 2.53 | 1.75 | 2.53 | 1.95 | 2.53 | 2.12 |
| **Ratio Analysis** | | | | | | |
| Net income ratio (%) | –5.3 | 27.6 | –17.1 | 9.9 | –5.3 | 12.1 |
| Variable cost revenue ratio (%) | 52.8 | 36.3 | 48.7 | 45.2 | 43.8 | 44.2 |
| Miticide cost revenue ratio (%) | 0 | 1.1 | 0 | 1.3 | 0 | 0.3 |

* Calculations are: Gross revenue = Yield * Price; Net income = Gross revenue – [Insect control costs + Mite control costs + Total variable costs + Total fixed costs + Harvesting and marketing costs]; Net income ratio = 100 * Net income ÷ Gross revenue; Variable cost revenue = 100 * [Total variable costs + Harvesting and marketing costs] ÷ Gross revenue; Insecticide cost revenue ratio = 100 * Miticide cost ÷ Gross revenue.

leaf scorch mite control than the application of bifenazate alone (Table 4). One week after the application pecan leaf scorch mite abundance was not significantly different between the 2 treatments, however, phytoseiid abundance was significantly lower in the bifenazate alone treatment than in the bifenazate plus western predatory treatment. The effects, 2 wks after treatment, were similar to the effects 3 wks after treatment. Pecan leaf scorch mite adults and nymph counts and pecan leaf scorch mite egg counts were significantly lower in the bifenazate plus western predatory mite treatment than in the bifenazate alone treatment. Phytoseiid mite abundance was significantly lower in the bifenazate treatment than in the bifenazate plus western predatory mite treatment. Four weeks after treatment, pecan leaf scorch mite adults and nymphs were significantly higher in the bifenazate plus western predatory mite treatment than in the bifenazate treatment, and pecan leaf scorch mite egg counts were similar in the 2 treatments. In the late fall of the year and 16 wks after the treatment, the pecan leaf scorch mite had left the pecan leaves for overwintering sites on the stems and only the phytoseiids were still active on the leaves. Phytoseiid abundance was higher (12-14 mites/20 leaves) than during the summer (0.34-3.5 mites/20 leaves) in both treatments and not significantly different between the 2 treatments. Similar abundance of phytoseiid mites was encountered during sampling at 1 y after treatment. Samples were collected in 2005 (52 wk post-treatment) before the grower began his mite control program. Pecan leaf scorch mite abundance also was higher in the 52 wk counts than in the posttreatment counts of the previous season.

The 2006 efficacy trial determined that pecan leaf scorch mites and pecan leaf scorch mite eggs were significantly reduced in abundance by all the miticide treatments 7, 14 and 24 d after treatment (DAT) (Table 5). There were a few mites found alive in treated pecan trees, but the differences between miticide treatments were not significant. Mite and egg abundances in miticide-treated trees only differed significantly from the abundances in trees in the nontreated control. Pecan leaf scorch mite and egg abundances at 29 DAT were naturally reduced in the nontreated control trees, and the abundances of mites and eggs in the Acramite 50WS, Acramite 4SC and Dicofol 4E treated trees were not significantly different from the abundances of mites and eggs in the nontreated control. Trees treated with Microthiol Disperss, Zeal and Envidor 2 SC (both concentrations) had significantly lower abundances of mites and eggs than the nontreated control at 29 DAT. Phytoseiids abundances were similar in the Acramite 50WS treated and the nontreated control trees. Phytoseiid abundances were significantly lower in the Dicofol, Microthiol Disperss, Zeal, and Envidor (both concentrations) treated trees than in the nontreated control or Acramite 50WS treated trees at 7, 14 and 24 DAT. Phytoseiid abundance was similar in the Acramite 4SC treated trees and nontreated control trees at 14 DAT and was significantly lower in the Acramite 4SC treated trees than in the nontreated control trees at 7 and 24 DAT.

## Discussion

Earlier research indicates that bifenazate is selectively more toxic to two-spotted spider mite than predatory phytoseiid mites (James 2002, Kim and Seo 2001, Kim and Soo 2002). Field trials of bifenazate in combination with predatory mite releases were also among the effective treatments for two-spotted spider mite in strawberry (Rhodes et al. 2006). Our results indicate that in field trials, bifenazate is an effective chemical control for pecan leaf scorch mite that conserves phytoseiid mites in pecan orchards. Acramite 50WS, and to a lesser extent, Acramite 4SC conserved phytoseiid mites, whereas, the other miticides had lower abundance of phytoseiid mites. The combination of bifenazate and release of western predatory mite was found to be an effective integrated pest management of pecan leaf scorch mite. Mite control by any of the miticide treatments did not increase pecan yields in the single season efficacy trials reported herein. However, mite injury may require more than one season to cause yield losses.

The cost of control with bifenazate may be justified when based on literature values of the potential yield reductions associated with a lack of mite control in pecan. The current cost of control with bifenazate at 420 g a.i./ha is ~$62/ha. Chemical control cost of all other arthropod pests of pecan per season is ~$215/ha. Chemical control of pecan leaf scorch mite is perceived as a high cost control measure by pecan growers based on a recent pecan enterprise budget (Fonsah et al. 2002). An economic analysis using the pecan enterprise budget with 5 yrs average price per pound and 2 yrs experimental yield data show that a cost of $62/ha is an economically efficient alternative to no mite control for Georgia pecan growers as the yield and eventually gross revenue for the mite control system is superior (Table 6). The impact of mite control on pecan nut production has only been reported in one large scale field experiment conducted over 3 seasons, and the yield decrease without mite control was ~23% (Dutcher et al. 1984). A sensitivity analysis using 10% reduction in actual experimental yield per ha and 10% reduction in actual 5 yrs average price per pound for pecans was used. The results revealed that the net income and net income ratio are both higher with mite control at a cost of $62/ha than without mite control. A sensitivity analysis using actual 5 yrs average price per kg and a 23% increase in production in trees treated with mite control also favored the application of miticide as the net income and the net income ratio were higher with the miticide application. Obviously, the economic analysis is favorable if yield, in fact, is increased by the miticide. With increased yield, production/kg and the miticide cost revenue ratios are higher with the miticide treatment resulting in higher profitability and a more favorable investment portfolio (Table 6). However, a detrimental impact of pecan leaf scorch mite feeding on pecan yield has only been measured in extremely high populations of pecan leaf scorch mites for 3 seasons (Dutcher et al. 1984). Further research is needed over several seasons with larger plot sizes to adequately assess the economic connection between mite control and pecan production and to measure the actual benefits of continuous treatment of the same trees over 3 or more seasons with bifenazate and the integration of bifenazate and western predatory mite. Similar experiments are also needed with other new miticides and other predatory mites so that alternative controls can be provided for commercial pecan growers.

## Acknowledgments

Thanks to the Georgia Agricultural Commodity Commission for Pecans for funding the project, Mr. Harold Voigt for the use of the commercial acreage in Ware Co., GA and assistance in application of the treatments, and Chemtura Corp. for the donation of Acramite® formulations in sufficient amounts for the large-scale field trials.

## References Cited

**Beers, E. and R. Talley. 2005.** Efficacy of insecticides for tetranychid mites. Reports Ann. Western Orchard Pest and Disease Management Conf. 79.

**Boethel, D. J. 1978.** Mites associated with Louisiana pecans. J. Georgia Entomol. Soc. 13: 98-100.

**Dekeyser, M. A., P. T. McDonald and G. W. Angle. 2003.** The discovery of bifenazate, a novel carbazate acaricide. CHIMIA Intern. J. Chem. 57: 702-704.

**Dutcher, J. D. 2007.** Impact of predatory mites releases on the abundance of pecan leaf scorch mite. J. Entomol. Sci. 42: 517-524.

**Dutcher, J. D., R. E. Worley, J. W. Daniell, R. B. Moss and K. F. Harrison. 1984.** Impact of six insecticide-based arthropod pest management strategies on pecan yield, quality, and return bloom under four irrigation/soil-fertility regimes. Environ. Entomol. 13: 1644-1653.

**Flechtmann, C. H. W. and R. Davis. 1971.** Some acarina from Georgia pecans with notes on their biology. J. Georgia Entomol. Soc. 6: 33-44.

**Fonsah, G. E., K. Harrison and B. Mitchell. 2002.** Pecan enterprise cost analysis 2002; 22 pp AGECON-02-077 Coop. Ext. Serv., Coll. Agric. Environ. Sci., Univ. Georgia.

**Goff, W. D., J. R. McVay and W. S. Gazaway. 1996.** Pecan production in the Southeast: a guide for growers. 1996. Alabama Coop. Ext. System, Circular ANR 459. 222 p.

**Guillebeau, P. 2006.** Georgia Pest Management Handbook. Univ. Georgia Coop. Ext. Serv. Special Publ. No. 28.

**Hood, G. 2006.** Poptools. vers. 2.71. CSIRO, Canberra, Australia.

**Hogmire, H. and A. Biggs. 2006.** Pesticide update. The orchard monitor. Coop. Ext. Serv., Kearneysville Tree Fruit Research and Education Center, West Virginia Univ.

**James, D. G. 2002.** Selectivity of the miticide, bifenazate, and the aphidicide, pymetrozine, to spider mite predators in Washington hops. J. Acarol. 28: 175-179.

**Kim, S. S. and S. G. Seo. 2001.** Relative toxicity of some acaricides to the predatory mite, *Amblyseius womersleyi* and the two spotted spider mite, *Tetranychus urticae* (Acari: Phytoseiidae, Tetranychidae). Appl. Entomol. Zool. (Jpn.) 36(4): 509-514.

**Kim, S. S. and S. S. Soo. 2002.** Comparative toxicity of some acaricides to the predatory mite, *Phytoseiulus persimilis* and the twospotted spider mite, *Tetranychus urticae.* BioControl 47(5): 563-573.

**Krantz, G. W. 1978.** A Manual of Acarology. Oregon State Univ. Press, Corvallis, OR.

**McDonald, P. T. and R. C. Moore. 2002.** Safety of the acaricide bifenazate (Acramite) to beneficial mites in Connecticut apple orchard. Abst. no. 0132. Prog. Ann. Mtg. Entomol. Soc. Amer., Ft Lauderdale, FL.

**Rhodes, E. M., O. E. Liburd, C. Kelts, S. I. Rondon and R. R. Francis. 2006.** Comparison of single and combination treatments of *Phytoseiulus persimilis, Neoseiulus californicus*, and acramite (bifenazate) for control of twospotted spider mites in strawberries. Exp. Appl. Acarol. 39(3-4): 213-225.

**Steele, R. G. and J. H. Torrie. 1980.** Principles and Procedures of Statistics, Ed. 2. McGraw-Hill, New York.