MONITORING FOR PYRETHROID RESISTANCE IN BOLLWORM (*HELICOVERPA ZEA*) POPULATIONS IN TEXAS AND TAMAULIPAS, MEXICO – 2008

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Abstract

A monitoring program evaluated the susceptibility of male bollworm, *Helicoverpa zea* (Boddie), populations to the pyrethroid insecticide cypermethrin using the adult vial test. Moths were trapped near cotton fields using a synthetic pheromone trap and glass vials coated with different concentrations of cypermethrin dissolved in acetone were used to assess moth mortality. Twelve Texas counties were surveyed, along with one location in Tamaulipas, Mexico, from March to September in 2008. Data were collected from all collaborators and sent to the Insect Toxicology Laboratory (AgriLIFE Research) for estimation of lethal concentrations (LC_{50} and LC_{90}), calculation of resistance ratios, and likelihood ratio tests of equality and parallelism. Uvalde, Nueces, and Williamson Co. populations exhibited the highest LC_{50} resistant ratios: 8.4, 6.8, and 6.4, respectively. There was only one moth survivor at 60 µg/vial and two at 30 µg/vial out of over 7,500 moths tested. Generally, populations monitored across other counties maintained susceptibility, and populations' resistance levels for the state of Texas were lower in 2008 than in the previous several seasons.

Introduction

The purpose of this study was to monitor the susceptibility of *H. zea* populations to the pyrethroid insecticide cypermethrin in the main cotton production areas of Texas in 2008. The Toxicology Laboratory (Texas AgriLIFE Research) in collaboration with AgriLIFE Extension personnel has monitored bollworm populations for pyrethroid resistance in Burleson and Nueces Co. since 1998 (Martin *et al.*, 1999; 2000; Pietrantonio *et al.*, 2000; Pietrantonio and Sronce, 2001), and has more intensely monitored resistance in multiple Texas counties since 2003 (Pietrantonio *et al.*, 2004; 2005; 2006), with the addition of Rio Bravo, Tamaulipas, Mexico, in 2006 (Pietrantonio *et al.*, 2007; Junek *et al.* 2008). Pyrethroid insecticide use is widespread in cotton, grain sorghum, and corn production for control of *H. zea* and other insect pests. Continued pyrethroid susceptibility monitoring of *H. zea* populations is an important tool for resistance management not only in cotton, but in other cropping systems as well.

Materials and Methods

The Adult Vial Test (AVT) was used to monitor the susceptibility of *H. zea* populations to cypermethrin as described in detail (Pietrantonio *et al.*, 2007). Cypermethrin concentrations evaluated were: 0.15, 0.3, 0.6, 1.0, 1.5, 2.5, 3.0, 5.0, 10.0, 30.0, and 60.0 µg/vial; the location specific range depending on its resistance history. In 2008, one location in Rio Bravo, Tamaulipas, Mexico, was monitored for resistance as well as the following twelve Texas Counties in diverse production regions: Hidalgo County in the Rio Grande Valley; Nueces County in the Coastal Bend; Uvalde County in the Winter Garden; Burleson County in the Brazos Valley; Williamson and Ellis Counties in the Blackland Prairies; Tom Green, Runnels, Jones, and Scurry Counties in the Southern Rolling Plains; and Hale and Hockley Counties in the High Plains. Data were corrected for control mortality and analyzed using PoloPlus, Probit and Logit Analysis (LeOra Software; Robertson *et al.*, 2007), and dose-mortality regressions (probit lines) were plotted using SigmaPlot software. A field population collected in September 2005 from Burleson County was used as a baseline for susceptibility to cypermethrin, with corresponding LC_{50} and LC_{90} values of 0.33 µg/vial and 2.44 µg/vial, respectively. These values were used to calculate resistance ratios (RR) with 95% confidence intervals (CI) and likelihood ratio tests for equality and parallelism as calculated by the method of Robertson *et al.* (2007). The lethal concentration resistance ratios of different populations were not considered significantly different if the 95% confidence intervals included 1 (Robertson *et al.*, 2007).

Results and Discussion

Rio Bravo, Tamaulipas, Mexico

In Rio Bravo, a total of two traps spaced 15 miles apart were used to collect moths for bioassays in April and May. Approximately 2,643 acres of cotton (100% conventional), 637,175 acres of grain sorghum, and 85,600 acres of corn were planted in 2008. Bollworm population densities were greater in 2008 as compared to the previous four years; however, there were no control failures attributed to pyrethroid resistance. Grain sorghum was treated during the middle of May with generic cypermethrin at 0.0713 lb a.i./acre plus Lannate® 2.4LV (methomyl) at 0.3209 lb a.i./acre. Treatments of cypermethrin at 0.0624 lb a.i./acre plus Lorsban® 4E (chlorpyriphos) at 0.5346 lb a.i./acre and of Decis® 1.5E (deltamethrin) at 0.0642 lb a.i./acre were used in cotton for bollworm and armyworm control during mid-season. The 2008 LC_{50} resistance ratios were significantly higher than the 2005 susceptible Burleson Co. field population and were greater than 4 for both April and May sampling dates (Table 1). The May 2008 concentration-mortality probit line was parallel and not significantly different from July 2006 and May 2007 probit lines (Figure 1).

Table 1. Rio Bravo, Tamaulipas, Mexico cypermethrin bioassay for male bollworms, *Helicoverpa zea*, collected from pheromone traps, 2008. Resistance ratios (RR) with 95% confidence intervals (CI) calculated by the method of Robertson *et al.* (2007). RR marked with * indicate that LC are significantly different from the susceptible population ($p \leq 0.05$).

Date	n[a]	Slope ± SE	LC_{50}[b] (95% CI)	LC_{90}[b] (95% CI)	RR LC_{50} (95% CI)	RR LC_{90} (95% CI)	χ^2 (df)
Burleson[c]	217	1.48 ± 0.36	0.33 (0.08-0.60)	2.44 (1.52-5.77)	1	1	0.46 (3)
Apr 12	100	5.79 ± 1.67	1.43 (0.95-1.83)	2.39 (1.87-4.15)	**4.34* (1.85-10.17)**	0.98 (0.51-1.88)	3.98 (7)
May 9	100	2.65 ± 0.56	1.44 (0.95-2.00)	4.39 (3.00-9.29)	**4.37* (1.81-10.53)**	1.80 (0.84-3.84)	4.22 (7)

[a]Number of insects tested.
[b]Lethal concentration expressed in micrograms of insecticide per vial with 95% confidence intervals.
[c] Bioassay of Burleson County September 2005 susceptible field population.

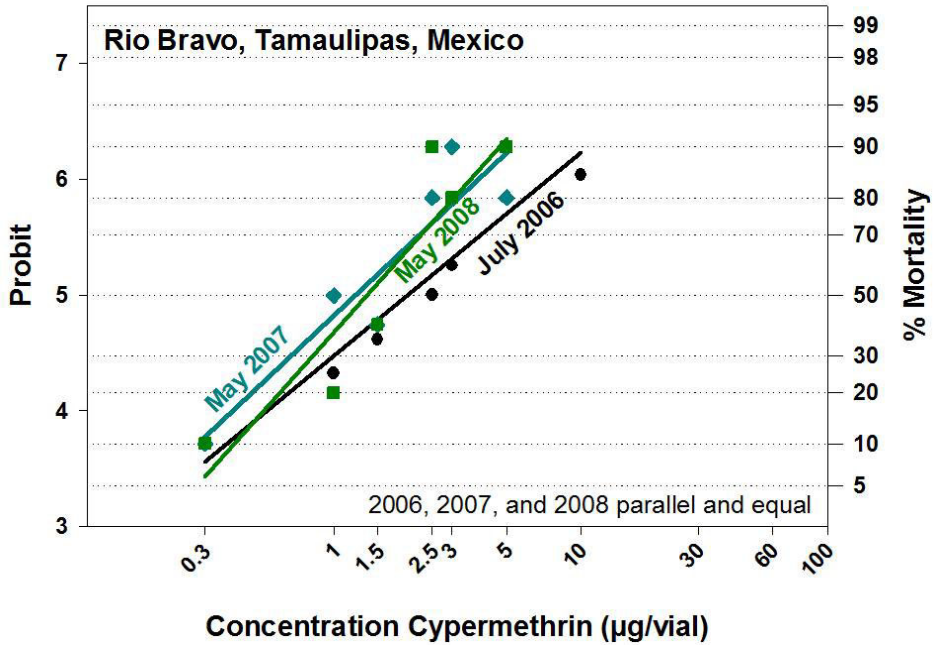

Figure 1. Concentration-mortality lines for the most resistant bollworm moth populations collected from 2006, 2007, and 2008 in Rio Bravo, Tamaulipas, Mexico, and exposed 24 h to cypermethrin in the vial assay. Probit lines are parallel and not significantly different ($p \leq 0.05$).

Hidalgo County

In Hidalgo County, three traps spaced 100 yards apart were used to collect moths for bioassays in May and June. There were 16,000 acres planted in cotton, 163,500 acres of grain sorghum, and 24,000 acres of corn. The LC_{50} resistance ratio for May was significantly higher than the 2005 susceptible Burleson Co. field population (Table 2), and the concentration-mortality probit line was parallel but significantly less resistant than the May 2007 probit line (Figure 2).

Table 2. Hidalgo Co. cypermethrin bioassay for male bollworms, *Helicoverpa zea*, collected from pheromone traps, 2008. Resistance ratios (RR) with 95% confidence intervals (CI) calculated by the method of Robertson *et al.* (2007). RR marked with * indicate that LC are significantly different from susceptible population ($p \leq 0.05$).

Date	n[a]	Slope ± SE	LC_{50}[b] (95% CI)	LC_{90}[b] (95% CI)	RR LC_{50} (95% CI)	RR LC_{90} (95% CI)	χ^2 (df)
Burleson[c]	217	1.48 ± 0.36	0.33	2.44	1	1	0.46 (3)

			(0.08-0.60)	(1.52-5.77)			
May 9-30	100	9.74 ± 3.35	1.22	1.66	**3.70***	0.68	0.02 (7)
			(0.99-1.48)	(1.40-3.19)	**(1.62-8.44)**	(0.36-1.27)	
June 2-27	120	3.18 ± 0.66	0.68	1.71	2.05	0.70	4.25 (7)
			(0.41-0.93)	(1.24-2.87)	(0.84-4.99)	(0.35-1.40)	

[a]Number of insects tested.
[b]Lethal concentration expressed in micrograms of insecticide per vial with 95% confidence intervals.
[c] Bioassay of Burleson County September 2005 susceptible field population.

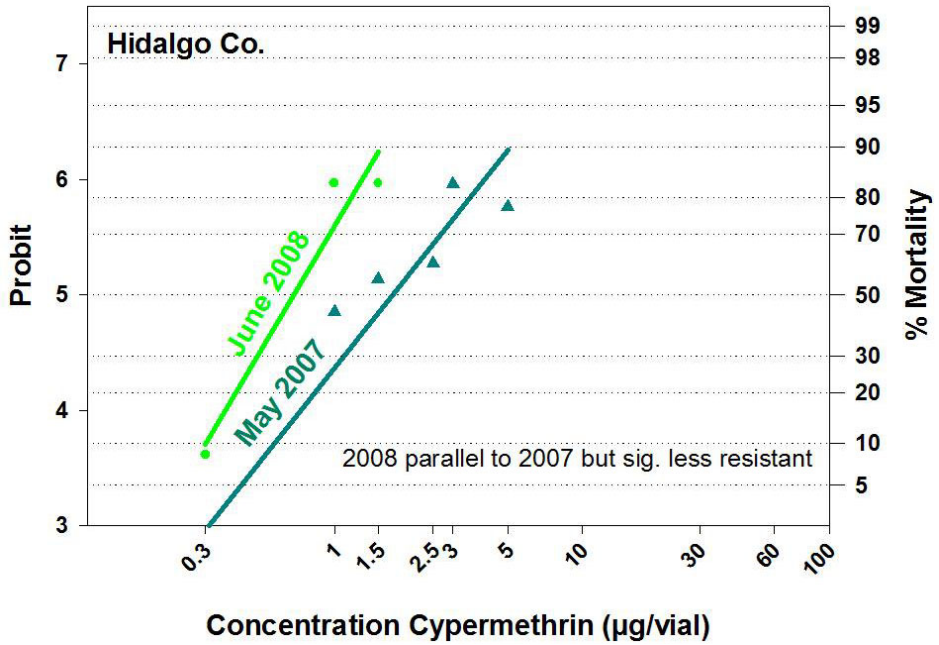

Figure 2. Concentration-mortality lines for the most resistant bollworm moth populations collected from 2007 and 2008 in Hidalgo Co. and exposed 24 h to cypermethrin in the vial assay. Both lines are parallel and the 2008 population is significantly less resistant than the 2007 probit line ($p \leq 0.05$).

Nueces County

Monitoring was conducted from March to September of 2008 in Nueces Co. and moths for bioassays were collected from two traps spaced 300 yards apart. There were an estimated 83,464 acres of cotton planted in the area (~73% *Bt*, 80% of which was Bollgard® II or Widestrike™), 198,000 acres of grain sorghum, and 5,000 acres of corn. There were no reported bollworm control problems and population densities were lower than in previous years. High labeled rates of Mustang Max® 0.8E (zeta-cypermethrin), Baythroid® XL (beta-cyfluthrin), and Asana® XL 0.66E (esfenvalerate) were used to control bollworm in grain sorghum in May and June. Many growers used Lannate® 2.4LV (methomyl) for control of fall armyworms in their grain sorghum as well. LC_{50} resistance ratios for bollworm populations in Nueces Co. remained high (3-6) throughout the season (Table 3), but were lower than seen in previous years (Pietrantonio *et al.* 2007; Junek *et al*., 2008). The concentration-mortality probit line from June 2008 was not parallel to and was significantly less resistant than probit lines from all previous years (Figure 3).

Table 3. Nueces Co. cypermethrin bioassay for male bollworms, *Helicoverpa zea*, collected from pheromone traps, 2008. Resistance ratios (RR) with 95% confidence intervals (CI) calculated by the method of Robertson *et al.* (2007). RR marked with * indicate that LC are significantly different from susceptible population ($p \leq 0.05$).

Date	n[a]	Slope ± SE	LC_{50}[b] (95% CI)	LC_{90}[b] (95% CI)	RR LC_{50} (95% CI)	RR LC_{90} (95% CI)	χ^2 (df)
Burleson[c]	217	1.48 ± 0.36	0.33	2.44	1	1	0.46 (3)
			(0.08-0.60)	(1.52-5.77)			
Mar 21-	400	2.17 ± 0.40	1.53	5.95	**4.63***	**2.44***	6.44 (7)
Apr 5			(0.96-2.00)	(4.55-9.48)	**(1.92-11.14)**	**(1.25-4.74)**	
Apr 14-18	310	2.41 ± 0.30	1.46	4.98	**4.42***	**2.04***	2.70 (7)

			(1.17-1.78)	(3.85-7.25)	**(1.92-10.22)**	**(1.06-3.91)**	
May 4	200	3.26 ± 0.53	2.22	5.47	**6.70***	**2.24***	1.68 (7)
			(1.81-2.69)	(4.19-8.65)	**(2.91-15.42)**	**(1.15-4.36)**	
May 15-17	190	1.99 ± 0.51	1.33	5.87	**4.04***	**2.40***	2.49 (7)
			(0.50-2.07)	(3.87-13.78)	**(1.49-10.94)**	**(1.10-5.23)**	
June 4-9	200	3.01 ± 0.47	2.24	5.81	**6.77***	**2.38***	17.46 (7)
			(1.40-3.48)	(3.67-21.58)	**(2.94-15.61)**	**(1.22-4.64)**	
Aug 4-11	210	2.78 ± 0.42	1.11	3.20	**3.35***	1.31	12.86 (7)
			(0.62-1.60)	(2.16-7.16)	**(1.43-7.84)**	(0.68-2.51)	
Sept 3-9	140	2.85 ± 0.56	1.35	3.80	**4.08***	1.56	13.75 (7)
			(0.58-2.12)	(2.36-18.62)	**(1.73-9.64)**	(0.77-3.13)	

[a]Number of insects tested.
[b]Lethal concentration expressed in micrograms of insecticide per vial with 95% confidence intervals.
[c]Bioassay of Burleson County September 2005 susceptible field population.

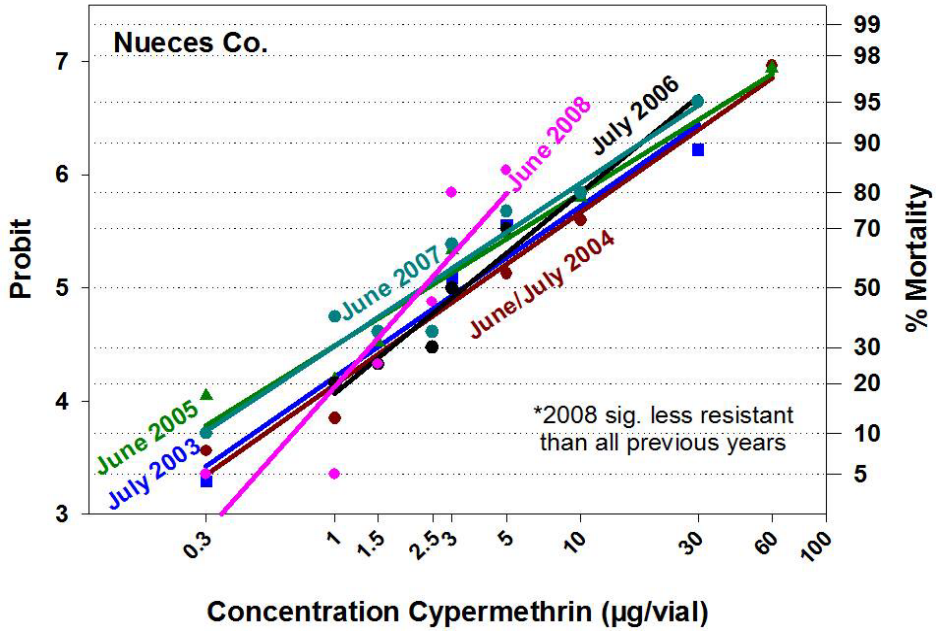

Figure 3. Concentration-mortality lines for the most resistant bollworm moth populations collected from 2003 to 2008 in Nueces Co. and exposed 24 h to cypermethrin in the vial assay. The 2008 line is not parallel to, and is significantly less resistant than, probit lines for all other years ($p \leq 0.05$).

Uvalde County

In Uvalde Co. monitoring was conducted from June to August. Moths were collected from six traps spaced from 200 yards to 0.5 miles apart. There were 6,400 acres planted in cotton (90% *Bt*, of which 60% was Bollgard® II), 21,900 acres of grain sorghum, and 17,700 acres of corn. Bollworm pressure was typical in corn and green beans, light in grain sorghum, and was much lighter in cotton than seen in previous seasons. The LC_{50} resistance ratio for June was significantly higher than the 2005 susceptible Burleson Co. field population and was the highest ratio seen for all counties in 2008 (Table 4). The concentration-mortality probit line was parallel and not significantly different from the July 2005 and 2007 probit lines (Figure 4).

Table 4. Uvalde Co. cypermethrin bioassay for male bollworms, *Helicoverpa zea*, collected from pheromone traps, 2008. Resistance ratios (RR) with 95% confidence intervals (CI) calculated by the method of Robertson *et al.* (2007). RR marked with * indicate that LC are significantly different from susceptible population ($p \leq 0.05$).

Date	n[a]	Slope ± SE	LC_{50}[b] (95% CI)	LC_{90}[b] (95% CI)	RR LC_{50} (95% CI)	RR LC_{90} (95% CI)	χ^2 (df)
Burleson[c]	217	1.48 ± 0.36	0.33	2.44	1	1	0.46 (3)

			(0.08-0.60)	(1.52-5.77)			
June 13	400	2.20 ± 0.41	2.76	10.59	**8.36***	**4.33***	6.98 (7)
			(1.78-3.64)	(7.70-18.80)	**(3.48-20.07)**	**(2.14-8.76)**	
Aug 8-10	400	1.47 ± 0.21	0.76	5.65	2.30	**2.31***	8.22 (7)
			(0.34-1.24)	(3.55-11.84)	(0.91-5.84)	**(1.13-4.73)**	

[a]Number of insects tested.
[b]Lethal concentration expressed in micrograms of insecticide per vial with 95% confidence intervals.
[c]Bioassay of Burleson County September 2005 susceptible field population.

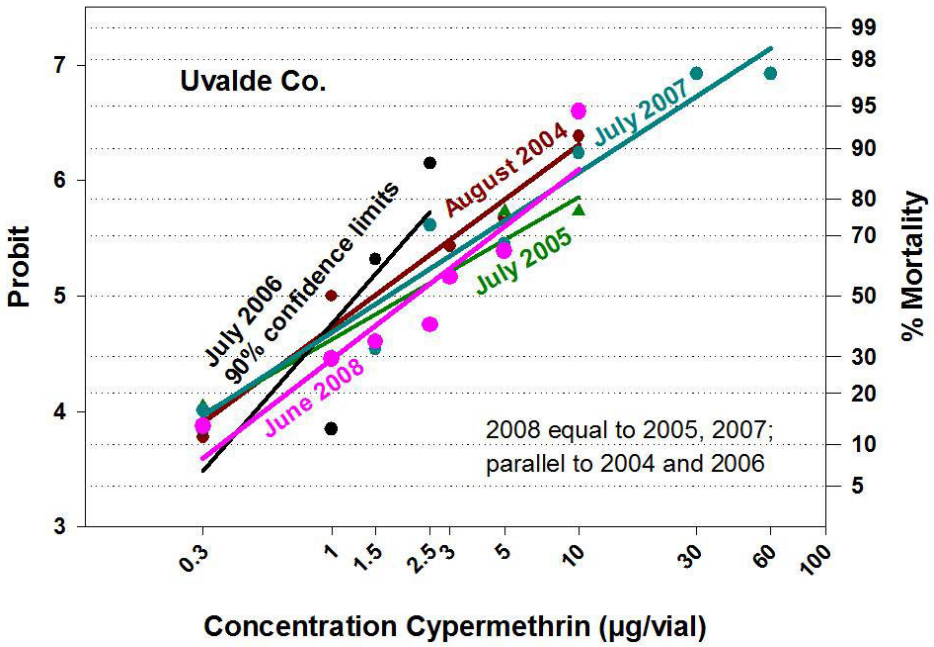

Figure 4. Concentration-mortality lines for the most resistant bollworm moth populations collected from 2004 to 2008 in Uvalde Co. and exposed 24 h to cypermethrin in the vial assay. The 2008 line is parallel with all lines and not significantly different from probit lines from 2005 and 2007 ($p \leq 0.05$).

Burleson County

Monitoring in Burleson Co. was conducted from May to September in 2008. Six traps spaced across four miles were used for moth collections. There were 9,400 acres of cotton (95% *Bt*, of which 40% was Bollgard® II), 5,500 acres of grain sorghum, and 13,600 acres of corn. *Helicoverpa zea* densities were similar to the previous four years. Fall armyworms and rice stinkbugs were treated in grain sorghum in June with Mustang Max® 0.8E (zeta-cypermethrin) at 0.025 lb a.i./acre. Applications of Sniper® 2E (bifenthrin) at 0.0781 lb a.i./acre were made in cotton in July for control of bollworms and stink bugs. The only sampling date with an LC_{50} resistance ratio significantly different than the 2005 susceptible Burleson Co. field population was July 5 (Table 5), but resistance levels were generally low for Burleson Co. in 2008. The 2008 concentration-mortality probit line was significantly less resistant than probit lines seen in all previous years (Figure 5).

Table 5. Burleson Co. cypermethrin bioassay for male bollworms, *Helicoverpa zea*, collected from pheromone traps, 2008. Resistance ratios (RR) with 95% confidence intervals (CI) calculated by the method of Robertson *et al.* (2007). RR marked with * indicate that LC are significantly different from susceptible population ($p \leq 0.05$).

Date	n[a]	Slope ± SE	LC_{50}[b] (95% CI)	LC_{90}[b] (95% CI)	RR LC_{50} (95% CI)	RR LC_{90} (95% CI)	χ^2 (df)
Burleson[c]	217	1.48 ± 0.36	0.33	2.44	1	1	0.46 (3)
			(0.08-0.60)	(1.52-5.77)			
May 1-4	383	2.03 ± 0.29	0.41	1.74	1.23	0.71	5.74 (7)
			(0.26-0.56)	(1.33-2.48)	(0.51-3.01)	(0.37-1.37)	
May 30-31	400	1.97 ± 0.30	0.39	1.72	1.17	0.71	4.14 (7)

			(0.21-0.56)	(1.28-2.52)	(0.46-2.96)	(0.36-1.37)	
July 5	386	3.95 ± 0.93	1.09	2.30	**3.29***	0.94	4.35 (4)
			(0.36-1.43)	(1.81-4.73)	**(1.40-7.75)**	(0.51-1.73)	
Aug 28-29	290	2.88 ± 0.58	0.72	2.00	2.17	0.82	2.16 (7)
			(0.40-0.99)	(1.54-2.86)	(0.88-5.39)	(0.43-1.56)	
Sept 24	400	2.30 ± 0.36	0.41	1.48	1.24	0.61	4.42 (7)
			(0.24-0.58)	(1.11-2.11)	(0.50-3.08)	(0.32-1.16)	

[a]Number of insects tested.
[b]Lethal concentration expressed in micrograms of insecticide per vial with 95% confidence intervals.
[c]Bioassay of Burleson County September 2005 susceptible field population.

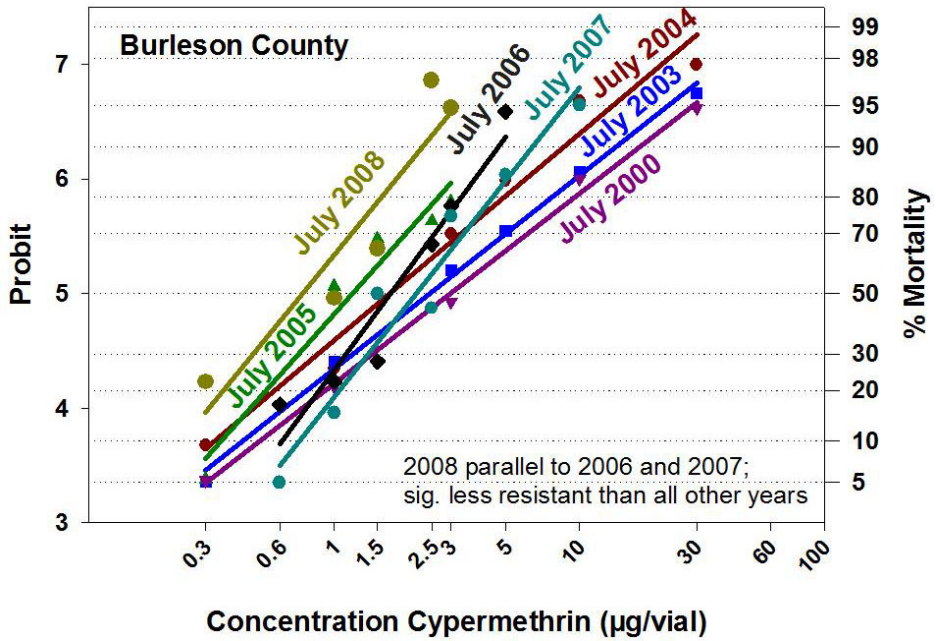

Figure 5. Concentration-mortality lines for the most resistant bollworm moth populations collected from 2000 and 2003 to 2008 in Burleson Co. and exposed 24 h to cypermethrin in the vial assay. The 2008 line is not parallel with, and is significantly less resistant than, probit lines from all previous years ($p \leq 0.05$).

Williamson County

Monitoring in Williamson Co. was conducted from May to July, and three traps spaced 0.25 miles apart were used for moth collections. There were 13,049 acres planted in cotton (90% *Bt*, of which 64% was Bollgard® II), 10,546 acres of grain sorghum, and 53,524 acres of corn. Bollworm population densities were relatively low as compared to the past four years. LC_{50} resistance ratios were significantly higher than the 2005 susceptible Burleson Co. field population for all sampling dates, and the highest resistance ratio was 6.4 on July 10 (Table 6). The concentration-mortality probit line from July 2008 line is parallel with 2003, 2005, and 2007, and is not significantly different from the 2007 probit line (Figure 6).

Table 6. Williamson Co. cypermethrin bioassay for male bollworms, *Helicoverpa zea*, collected from pheromone traps, 2008. Resistance ratios (RR) with 95% confidence intervals (CI) calculated by the method of Robertson *et al.* (2007). RR marked with * indicate that LC are significantly different from susceptible population ($p \leq 0.05$).

Date	n[a]	Slope ± SE	LC_{50}[b] (95% CI)	LC_{90}[b] (95% CI)	RR LC_{50} (95% CI)	RR LC_{90} (95% CI)	χ^2 (df)
Burleson[c]	217	1.48 ± 0.36	0.33	2.44	1	1	0.46 (3)
			(0.08-0.60)	(1.52-5.77)			
June 18-19	100	1.56 ± 0.35	1.13	7.49	**3.41***	**3.07***	5.66 (7)
			(0.54-1.81)	(4.16-26.52)	**(1.29-9.04)**	**(1.16-8.13)**	
July 10	100	1.30 ± 0.27	2.12	20.40	**6.40***	**8.35***	11.54 (7)
			(0.58-5.19)	(7.40-788.98)	**(2.40-17.04)**	**(2.68-26.03)**	

[a]Number of insects tested.
[b]Lethal concentration expressed in micrograms of insecticide per vial with 95% confidence intervals.
[c] Bioassay of Burleson County September 2005 susceptible field population.

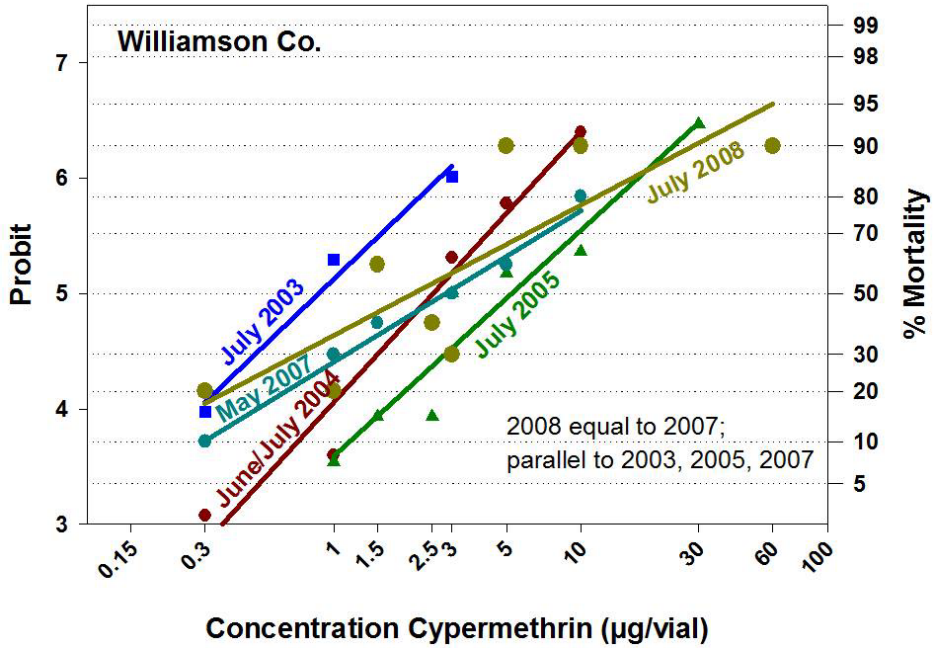

Figure 6. Concentration-mortality lines for the most resistant bollworm moth populations collected in 2003 to 2005, 2007, and 2008 in Williamson Co. and exposed 24 h to cypermethrin in the vial assay. The 2008 line is parallel with 2003, 2005, and 2007, and is not significantly different from the 2007 probit line ($p \leq 0.05$).

Ellis County

Two traps approximately 0.75 miles apart were used in Ellis Co. to collect moths. Approximately 35,000 acres of cotton (98% *Bt*, of which 54% was Bollgard® II), 17,000 acres of grain sorghum, and 45,000 acres of corn were planted. Population densities of bollworm were lower than the previous four years and field infestations were light. Grain sorghum was sprayed in early July with Baythroid® 2E (cyfluthrin) at 0.0234 lb a.i./acre for stinkbugs. Statistically significant data were not obtained due to a high level of control mortality. There was a single survivor collected at 30 µg/vial (Figure 9), but overall resistance levels were relatively low.

Tom Green and Runnels Counties

In Tom Green and Runnels Counties, two traps (one in each county, spaced four miles apart) were used to collect moths for bioassays in July and August. There were 200,000 acres of cotton (85% *Bt*, of which 90% was Bollgard® II or Widestrike™), 50,000 acres of grain sorghum, and 3,500 acres of corn planted. Population densities of bollworms were higher in corn and grain sorghum than in the previous four years, however, levels were average in cotton. Grain sorghum fields were treated during July and August with Mustang Max® 0.8E (zeta-cypermethrin) at 0.0352 lb a.i./acre for bollworms and fall armyworms, and with Baythroid® 2E (cyfluthrin) at 0.0188 lb a.i./acre for fall armyworms. None of the samples produced resistance ratios that were significantly different from the 2005 susceptible Burleson Co. field population (Table 7).

Table 7. Tom Green and Runnels Co. cypermethrin bioassay for male bollworms, *Helicoverpa zea*, collected from pheromone traps, 2008. Resistance ratios (RR) with 95% confidence intervals (CI) calculated by the method of Robertson *et al.* (2007). RR marked with * indicate that LC are significantly different from susceptible population ($p \leq 0.05$).

Date	n[a]	Slope ± SE	LC_{50}[b] (95% CI)	LC_{90}[b] (95% CI)	RR LC_{50} (95% CI)	RR LC_{90} (95% CI)	χ^2 (df)
Burleson[c]	217	1.48 ± 0.36	0.33 (0.08-0.60)	2.44 (1.52-5.77)	1	1	0.46 (3)

July 10	90	1.66 ± 0.40	0.37 (0.11-0.68)	2.17 (1.19-6.25)	1.11 (0.36-3.38)	0.89 (0.35-2.23)	4.97 (6)
July 17-23	150	1.53 ± 0.30	0.60 (0.24-1.03)	4.10 (2.42-9.56)	1.81 (0.64-5.17)	1.68 (0.72-3.94)	1.11 (7)
Aug 8	100	1.80 ± 0.37	0.41 (0.20-0.66)	2.14 (1.28-5.29)	1.25 (0.47-3.32)	0.88 (0.37-2.07)	5.06 (7)
Aug 27	100	1.56 ± 0.35	0.33 (0.12-0.56)	2.16 (1.23-6.14)	0.98 (0.34-2.82)	0.88 (0.36-2.19)	4.13 (7)

[a]Number of insects tested.
[b]Lethal concentration expressed in micrograms of insecticide per vial with 95% confidence intervals.
[c]Bioassay of Burleson County September 2005 susceptible field population.

Jones and Scurry Counties

In Jones and Scurry Counties, moth collections were made from one trap in each county. There were 128,000 acres of cotton (85-90% *Bt*, of which 99% was Bollgard® II), 12,100 acres of grain sorghum and no acreage of corn planted. Bollworm populations were relatively low due to severe drought conditions. Grain sorghum fields were treated with Tombstone® 2EC (cyfluthrin) at 0.0438 lb a.i./acre for headworms (*H. zea*) and fall armyworms. The only population with an LC_{50} resistance ratio significantly different than the 2005 susceptible Burleson Co. field population was from September, however due to variation in that experiment, LC_{50} and LC_{90} values could not be estimated and the LC_{50} RR confidence interval is quite wide (Table 8). In general, Jones and Scurry Counties maintained susceptibility to pyrethroids.

Table 8. Jones and Scurry Counties cypermethrin bioassay for male bollworms, *Helicoverpa zea*, collected from pheromone traps, 2008. Resistance ratios (RR) with 95% confidence intervals (CI) calculated by the method of Robertson *et al.* (2007). RR marked with * indicate that LC are significantly different from susceptible population ($p \leq 0.05$).

Date	n[a]	Slope ± SE	LC_{50}[b] (95% CI)	LC_{90}[b] (95% CI)	RR LC_{50} (95% CI)	RR LC_{90} (95% CI)	χ^2 (df)
Burleson[c]	217	1.48 ± 0.36	0.33 (0.08-0.60)	2.44 (1.52-5.77)	1	1	0.46 (3)
July 8-9	80	1.45 ± 0.31	0.59 (0.25-1.08)	4.51 (2.27-16.70)	1.78 (0.63-5.06)	1.85 (0.65-5.28)	2.35 (5)
Aug 11-17	170	1.99 ± 0.31	0.54 (0.24-0.96)	2.40 (1.33-7.53)	1.65 (0.67-4.07)	0.98 (0.46-2.08)	11.42 (7)

[a]Number of insects tested.
[b]Lethal concentration expressed in micrograms of insecticide per vial with 95% confidence intervals.
[c]Bioassay of Burleson County September 2005 susceptible field population.

Hale County

Two traps spaced ten miles apart were used to trap moths in Hale Co. in July and August. There were 257,000 acres of cotton (50% *Bt*, of which 49% were Bollgard® II), 90,000 acres of grain sorghum, and 60,000 acres of corn. *Helicoverpa zea* population densities were higher this year than seen in the previous four seasons. Bollworms in cotton and headworms (*H. zea*) in grain sorghum were treated in August with Ammo® 2.5EC (cypermethrin) at 0.08 lb a.i./acre, Karate-Z® 1EC (lambda-cyhalothrin) at 0.025 lb a.i./acre, Baythroid® 2E (cyfluthrin) at 0.044 lb a.i./acre, or Mustang Max® 0.8E (zeta-cypermethrin) at 0.0188 lb a.i./acre. None of the samples produced resistance ratios that were significantly different from the 2005 susceptible Burleson Co. field population (Table 9).

Table 9. Hale Co. cypermethrin bioassay for male bollworms, *Helicoverpa zea*, collected from pheromone traps, 2008. Resistance ratios (RR) with 95% confidence intervals (CI) calculated by the method of Robertson *et al.* (2007). RR marked with * indicate that LC are significantly different from susceptible population ($p \leq 0.05$).

Date	n[a]	Slope ± SE	LC_{50}[b] (95% CI)	LC_{90}[b] (95% CI)	RR LC_{50} (95% CI)	RR LC_{90} (95% CI)	χ^2 (df)
Burleson[c]	217	1.48 ± 0.36	0.33 (0.08-0.60)	2.44 (1.52-5.77)	1	1	0.46 (3)
July 11	89	2.97 ± 1.05	0.23	0.63	0.71	**0.26***	2.46 (6)

			(0.06-0.40)	(0.37-3.21)	(0.26-1.95)	**(0.11-0.63)**	
July 31	100	0.96 ± 0.31	0.42	8.96	1.26	3.67	5.31 (7)
			(0.02-1.16)	(3.30-159.01)	(0.25-6.37)	(0.84-15.95)	
Aug 08	100	1.34 ± 0.41	0.31	2.85	0.95	1.17	2.40 (7)
			(0.02-0.79)	(1.21-14.33)	(0.21-4.30)	(0.38-3.56)	
Aug 22	200	1.07 ± 0.25	0.28	4.32	0.84	1.77	7.05 (7)
			(0.02-0.73)	(1.83-23.66)	(0.21-3.32)	(0.64-4.91)	
Aug 27	100	2.00 ± 0.48	0.41	1.78	1.24	0.73	2.84 (7)
			(0.15-0.72)	(1.03-4.42)	(0.43-3.58)	(0.31-1.72)	

[a]Number of insects tested.
[b]Lethal concentration expressed in micrograms of insecticide per vial with 95% confidence intervals.
[c]Bioassay of Burleson County September 2005 susceptible field population.

Hockley County

In Hockley Co., moth collections were made from two traps spaced 100 yards apart. Approximately 180,000 acres of cotton (48% *Bt*, of which 99% was Bollgard® II), 70,000 acres of grain sorghum but no acreage of corn was planted in 2008. Bollworm population densities were moderate and primarily noted in grain sorghum. In August, treatments were made in grain sorghum for headworms (*H. zea*), and in cotton for *Lygus* sp. with Ammo® 2.5 EC (cypermethrin) at 0.064 lb a.i./acre. The only date with an LC_{50} resistance ratio significantly different than the 2005 susceptible Burleson Co. field population was on Aug 11 (Table 10). The concentration-mortality probit line indicated this population was significantly more resistant than population probit lines seen in all previous years, however, levels of resistance were still relatively low (Figure 7).

Table 10. Hockley Co. cypermethrin bioassay for male bollworms, *Helicoverpa zea*, collected from pheromone traps, 2008. Resistance ratios (RR) with 95% confidence intervals (CI) calculated by the method of Robertson *et al.* (2007). RR marked with * indicate that LC are significantly different from susceptible population ($p \leq 0.05$).

Date	n[a]	Slope ± SE	LC_{50}[b] (95% CI)	LC_{90}[b] (95% CI)	RR LC_{50} (95% CI)	RR LC_{90} (95% CI)	χ^2 (df)
Burleson[c]	217	1.48 ± 0.36	0.33	2.44	1	1	0.46 (3)
			(0.08-0.60)	(1.52-5.77)			
July 21-23	110	3.86 ± 1.02	0.40	0.86	1.21	**0.35***	2.64 (7)
			(0.21-0.64)	(0.55-2.01)	(0.47-3.11)	**(0.16-0.78)**	
Aug 11	120	2.09 ± 0.54	0.97	4.00	**2.94***	1.64	3.53 (7)
			(0.35-1.57)	(2.53-9.75)	**(1.06-8.15)**	(0.73-3.65)	
Aug 24-Oct 1	80	2.36 ± 0.79	0.27	0.93	0.80	**0.38***	1.62 (7)
			(0.04-0.52)	(0.47-3.80)	(0.25-2.63)	**(0.15-0.98)**	

[a]Number of insects tested.
[b]Lethal concentration expressed in micrograms of insecticide per vial with 95% confidence intervals.
[c]Bioassay of Burleson County September 2005 susceptible field population.

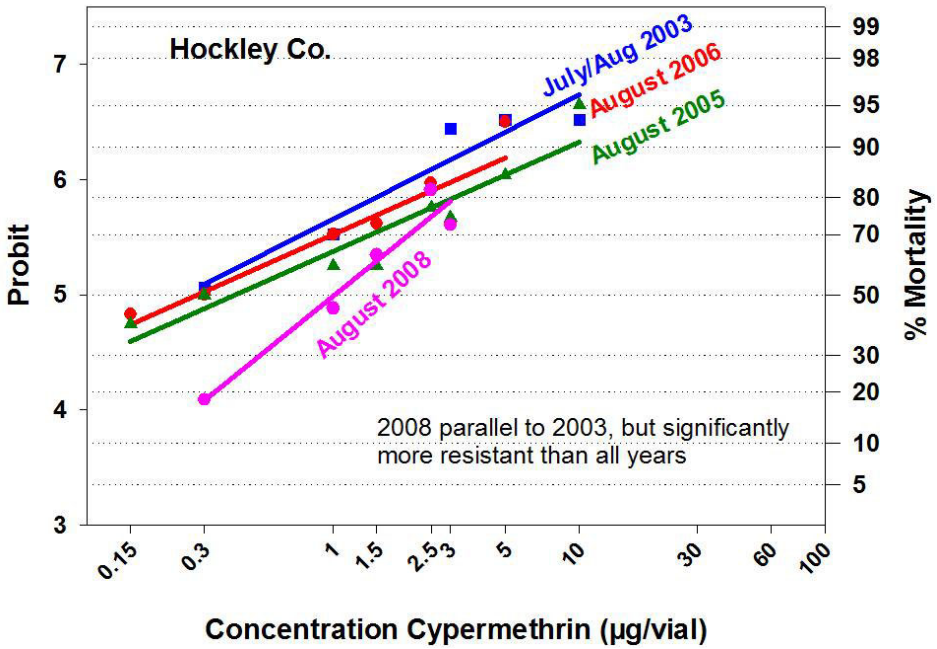

Figure 7. Concentration-mortality lines for the most resistant bollworm moth populations collected in 2003, 2005, 2006, and 2008 in Hockley Co. and exposed 24 h to cypermethrin in the vial assay. The 2008 line is parallel with 2003, but is significantly more resistant than population probit lines from all previous years ($p \leq 0.05$).

Conclusion

Analysis of the 2008 monitoring season revealed an overall reduction in bollworm resistance to pyrethroid insecticides. Population densities of *H. zea* were generally lower throughout most growing areas compared with previous years, likely due to drought and a reduction in overall acreage. As observed in previous years, populations exhibiting the highest LC_{50} resistance ratios were from Uvalde, Nueces, and Williamson Counties, with ratios of 8.4, 6.8, and 6.4, respectively. These were the only three counties that had LC_{50} resistance ratios of greater than 5 (Figure 8); however, they are still lower than has typically been observed in these counties in previous seasons (Pietrantonio *et al.*, 2007; Junek *et al.*, 2008). Only one moth survived 60 µg/vial (Williamson Co.), and two survived 30 µg/vial (one each from Uvalde and Ellis Counties), out of over 7,500 moths tested, indicating a very low percentage of moths surviving the most extreme rates of cypermethrin (Figure 9). Populations from Burleson, Hidalgo, and Hockley Counties, and Tamaulipas, Mexico, were significantly more resistant than the 2005 susceptible Burleson Co. field population based on likelihood ratio tests for equality, but the extent of resistance was still relatively low based upon resistance ratios. Reduction in pyrethroid resistance was likely due to multiple factors, including: 1) Lower insect pressure, 2) Use of insecticides with a different mode of action from pyrethroids, such as organophosphates and carbamates, 3) Use of high rates of pyrethroids that effectively eliminate heterozygous individuals whose survival may accelerate the evolution of resistance, and 4) An increase in the percentage of cotton acres planted to *Bt*-expressing cultivars.

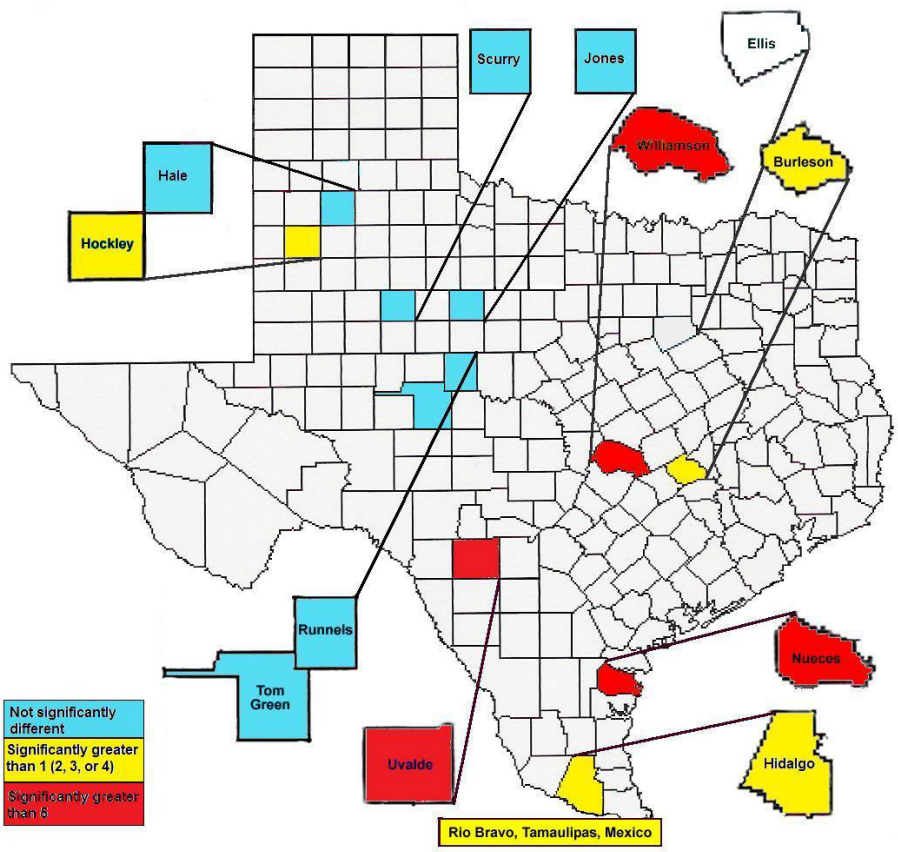

Figure 8. Highest LC_{50} resistance ratios in counties in 2008, compared with a 2005 susceptible Burleson Co. field population. Values in blue represent a resistance ratio not significantly different from 1 (no resistance in the population). Values in yellow represent a resistance ratio significantly different than 1, but less than 5 (e.g., 2, 3, 4) (resistance is present but likely does not result in field control failures). Values in red represent a resistance ratio greater than 5, indicating a highly resistant population.

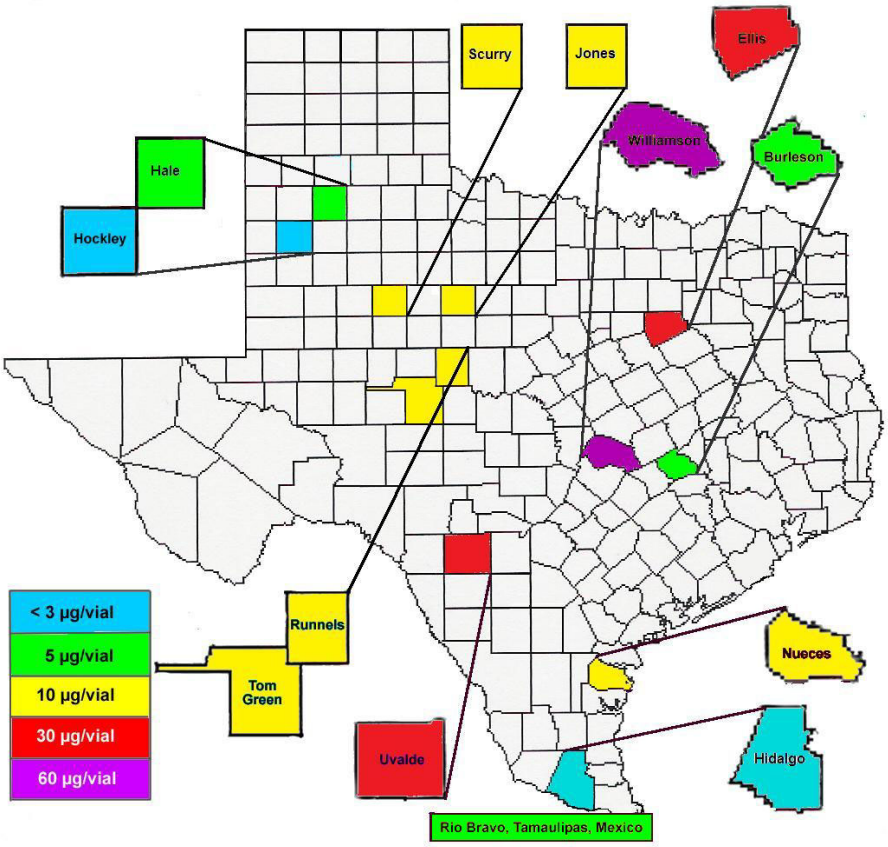

Figure 9. Highest concentration of cypermethrin in µg/vial at which individual moth survivorship was observed in 2008.

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