MONITORING FOR PYRETHROID RESISTANCE IN BOLLWORM (HELICOVERPA ZEA) POPULATIONS IN TEXAS AND TAMAULIPAS, MEXICO - 2007

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Abstract

The susceptibility of the cotton bollworm, *Helicoverpa zea* (Boddie), to the pyrethroid insecticide cypermethrin was monitored in the main production regions of Texas though a statewide monitoring program conducted from April to September, 2007. Twelve Texas counties were surveyed, along with one location in Tamaulipas, Mexico. Moths were trapped near cotton fields using a synthetic pheromone. Glass vials coated with different concentrations of cypermethrin dissolved in acetone were used to assess moth mortality. LC_{50}, LC_{90}, and resistance ratios were calculated for each location. As in previous years, populations exhibiting the highest LC_{50} resistant ratios were from Nueces, Burleson, Williamson and Uvalde Counties. For the first time in Uvalde Co., individual moths survived high concentrations up to 60

µg/vial, and towards the end of the growing season, the LC_{50} resistance ratio of about 11 indicated a highly resistant population, the most resistant of 2007. Populations monitored in other Texas counties and Mexico generally maintained susceptibility.

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 2007. The Toxicology Laboratory, Texas AgriLife Research, 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). 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. In 2007, Rio Bravo, Tamaulipas, Mexico, was included in the monitoring program, 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, and Jones Counties in the Southern Rolling Plains; and Hockley, Swisher, and Parmer Counties in the High Plains. Data were analyzed using Polo PC, Probit and Logit Analysis program (Russell *et al.*, 1977), and dose-mortality regressions were plotted using SigmaPlot software. Data were corrected for mortality. 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, and confidence intervals for these ratios were calculated as described by Robertson and Preisler (1992). The lethal concentration resistant ratios of different populations were not considered significantly different if the 95% confidence intervals included 1 (Robertson and Preisler, 1992).

Results and Discussion

Rio Bravo, Tamaulipas, Mexico

In Rio Bravo, a total of three traps spaced over 23.1 miles were used to collect moths for bioassays in April and May. Approximately 4,400 acres of cotton (100% conventional), 1,482,500 acres of grain sorghum, and 247,000 acres of corn were planted in 2007. Bollworm population densities were lower in 2007 as compared to the previous four years, with insufficient numbers of moths collected after May to conduct further bioassays. Crops other than cotton were treated around 15 May with generic cypermethrin at 0.032 lb a.i./acre and Karate-Z® 1.0EC (lambda-cyhalothrin) at 0.027-0.32 lb a.i./acre. One generation of bollworm in mid-season required treatment, and about 70% of the cotton acreage was treated with one of these pyrethroids or Lorsban® (chlorpyrifos). Susceptibility to pyrethroids was maintained in 2007 in Rio Bravo, Mexico, with only the bioassay in May indicating a significantly higher LC_{50} (resistance ratio 3.7) (Table 1). The May 2007 bioassay probit line was parallel and not significantly different from that of July 2006 (Fig. 1).

Table 1. Rio Bravo, Tamaulipas, Mexico cypermethrin bioassay for male bollworms, *Helicoverpa zea*, collected from pheromone traps, 2007. Resistance ratio (RR) with 95% confidence intervals (CI) calculated by the method of Robertson and Preisler (1992). 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% CL)	LC_{90}[b] (95% CL)	RR LC_{50} (95% CI)	RR LC_{90} (95% CI)	χ^2 (df)
Burleson[c]	400	1.47 ± 0.35	0.33 (0.08-0.59)	2.44 (1.51-5.76)	1	1	0.45 (3)
4/20/2007	100	1.06 ± 0.43	0.96** (0.18-2.25)	15.30** (4.93-2356.55)	2.90 (0.76-11.03)	6.25 (0.68-56.92)	1.16 (4)
5/11/2007	100	1.98 ± 0.51	1.23 (0.66-1.87)	5.48 (3.20-22.17)	**3.74*** (1.48-9.43)	2.24 (0.86-5.81)	3.20 (4)

[a]Number of insects tested.
[b]Lethal concentration expressed in micrograms of insecticide per vial with 95% confidence limits.
[c] Bioassay of Burleson County September 2005 susceptible field population.
**indicates LC with 90% confidence limits.

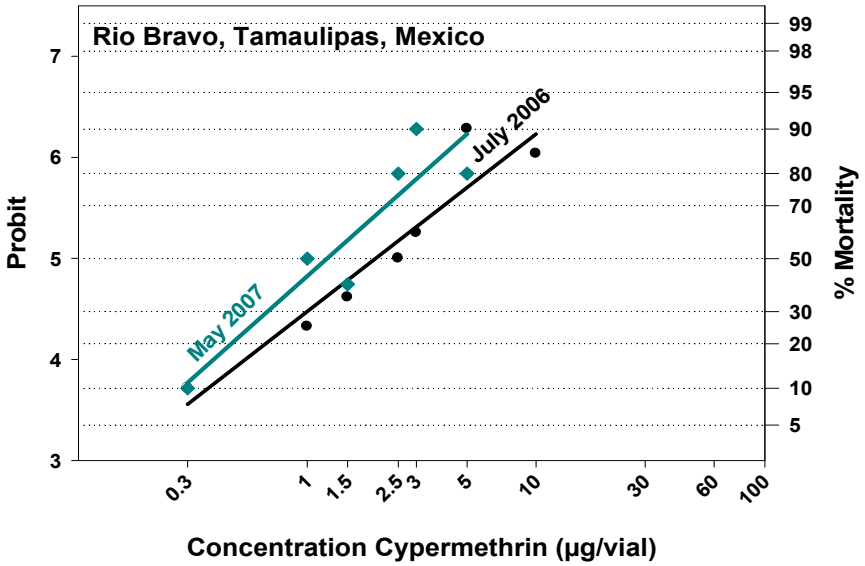

Figure 1. Concentration-mortality lines for bollworm moths collected in 2006 and 2007 in Rio Bravo, Tamaulipas, Mexico and exposed 24 h to cypermethrin in the vial assay. Lines are parallel and not significantly different ($p < 0.05$).

Hidalgo County

In Hidalgo County, three traps spaced 100 yards apart were used to collect moths for bioassays in May. There were 17,200 acres planted in cotton (38% *Bt*, of which 21% was Bollgard® I and 79% was Bollgard II®), 156,257 acres of grain sorghum, and 17,025 acres of corn. Karate-Z® 1.0EC (lambda-cyhalothrin) was applied at 0.025 lb a.i./acre on 4 June, and Baythroid® XL (beta-cyfluthrin) was applied at 0.02 lb a.i./acre on 23 and 29 June, and 14 July, to control bollworm, boll weevil, beet armyworm, and fall armyworm infestations in cotton. The bioassay conducted in May indicated a resistant population in Hidalgo Co. (Table 2).

Table 2. Hidalgo Co. cypermethrin bioassay for male bollworms, *Helicoverpa zea*, collected from pheromone traps, 2007. Resistance ratio (RR) with 95% confidence intervals (CI) calculated by the method of Robertson and Preisler (1992). 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% CL)	LC_{90}[b] (95% CL)	RR LC_{50} (95% CI)	RR LC_{90} (95% CI)	χ^2 (df)
Burleson[c]	400	1.47 ± 0.35	0.33 (0.08-0.59)	2.44 (1.51-5.76)	1	1	0.45 (3)
5/15-17/2007	181	1.88 ± 0.43	1.39 (0.78-2.03)	6.70 (4.09-20.73)	**4.22*** (1.69-10.51)	**2.74*** (1.13-6.66)	3.03 (4)

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

Nueces County

Monitoring for bollworm susceptibility to cypermethrin was conducted from April to August of 2007 in Nueces Co. Moths for bioassays were collected from two traps spaced one mile apart. There were an estimated 261,000 acres of cotton planted in the area (~60% Bollgard II®), 285,000 acres of grain sorghum, and 30,000 acres of corn. There were no reported bollworm control problems or field failures in the area, although producers did express concern for stink bug problems in cotton and sorghum. Bollworm population densities were generally lower in cotton, grain sorghum, and corn in 2007 as compared with the previous four years. Approximately 40% of the grain sorghum acreage was treated in May and June for bollworm and/or rice stink bug. About one-half of this received a pyrethroid treatment of Mustang Max® 0.8E (zeta-cypermethrin) at 0.0225 lb a.i./acre. The remainder was treated with Lannate® 2.4LV (methomyl) at 0.15 lb a.i./acre + Dimate® 4E (dimethoate) at 0.25 lb a.i./acre, Lannate® 2.4LV alone at 0.3 lb a.i./acre, or Dimate® 4E alone at 0.375 lb a.i./acre. About 30% of the cotton acreage was treated for bollworm in June and July. Pyrethroids applied were: Mustang Max® 0.8E at 0.0225 lb a.i./acre, Decis® 1.5E (deltamethrin) at 0.03 lb a.i./acre, and Karate-Z® 2.08CS (lambda-cyhalothrin) at 0.04 lb a.i./acre. High rates of pyrethroids were used to achieve good to excellent control. Bollworm oviposition did not persist for long periods and larval numbers were not excessively high. Where less than desirable control was achieved, it was likely related to dense canopy, rainfall removal of insecticide, or delay in treatment due to rainfall. LC_{50} resistance ratios for bollworm populations in Nueces Co. remained high (5-7) throughout the season (Table 3). The bioassay probit line from June 2007 was parallel to those of mid-season 2003 to 2006, and was not significantly different to those of 2003, 2005, and 2006 (Fig. 2).

Table 3. Nueces Co. cypermethrin bioassay for male bollworms, *Helicoverpa zea*, collected from pheromone traps, 2007. Resistance ratio (RR) with 95% confidence intervals (CI) calculated by the method of Robertson and Preisler (1992). 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% CL)	LC_{90}[b] (95% CL)	RR LC_{50} (95% CI)	RR LC_{90} (95% CI)	χ^2 (df)
Burleson[c]	400	1.47 ± 0.35	0.33 (0.08-0.59)	2.44 (1.51-5.76)	1	1	0.45 (3)
4/02-05/2007	300	2.41 ± 0.48	2.25 (1.61-2.98)	7.65 (5.20-16.69)	**6.83*** (2.89-16.14	**3.13*** (1.45-6.77)	2.17 (3)
4/24-27/2007	270	2.49 ± 0.50	1.68 (1.10-2.16)	5.49 (4.10-9.58)	**5.08*** (2.13-12.09)	**2.25*** (1.13-4.47)	3.04 (5)
6/04-06/2007	200	1.42 ± 0.23	2.27 (1.54-3.24)	18.13 (10.3-49.87)	**6.87*** (2.83-16.67)	**7.42*** (2.92-18.79)	4.43 (6)
7/11-17/2007	190	1.96 ± 0.46	2.49 (1.54-3.57)	11.20 (6.73-38.27)	**7.53*** (3.09-18.39)	**4.58*** (1.83-11.46)	1.48 (4)
8/15-17/2005	110	2.13 ± 0.63	2.25 (1.38-3.62)	9.00 (4.96-68.21)	**6.83*** (2.77-16.83)	**3.68*** (1.25-10.79)	2.66 (3)

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

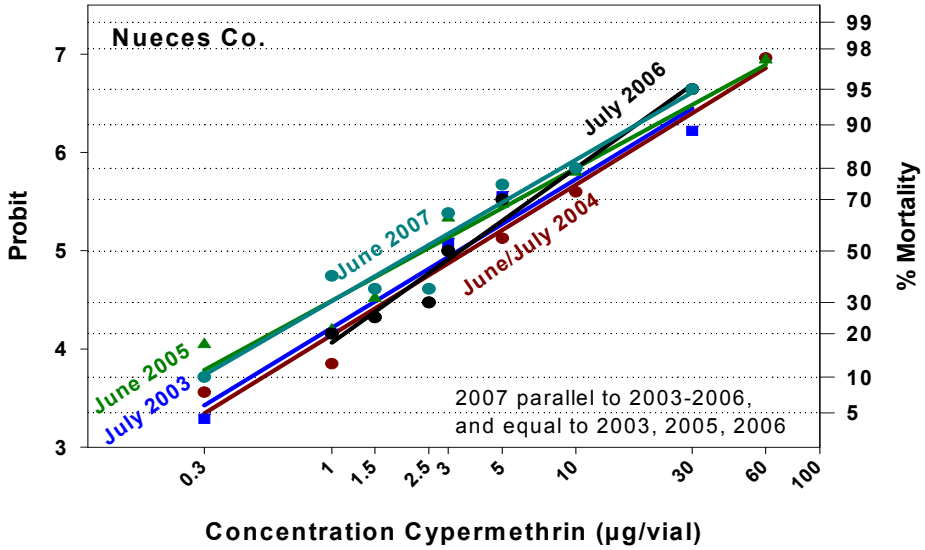

Figure 2. Concentration-mortality lines for bollworm moths collected in 2003 to 2007 in Nueces Co. and exposed 24 h to cypermethrin in the vial assay. All lines are parallel and the 2007 line is not significantly different from 2003, 2005, or 2006 ($p < 0.05$).

Uvalde County

In Uvalde Co. monitoring was conducted from June to September 2007. Moths were collected from six traps spaced from 200 yards to 0.5 miles between traps. There were 18,000 acres planted in cotton (85% *Bt*, of which 80% was Bollgard II®), 47,000 acres of grain sorghum, and 50,000 acres of corn. This area reported the highest *H. zea* population densities and pyrethroid usage of the last four years, but no field failures were reported. Several factors may have contributed to the control problems, including low volume aerial application with poor coverage and frequent rains that interfered with application. Control of *H. zea* was maintained by using the highest label rates, changing the pyrethroid used, or in some cases changing to an organophosphate. It is also speculated that the high percentage of *Bt* cotton helped prevent problems in cotton. Heavy *H. zea* early-season pressure in green beans required multiple pyrethroid applications for control. There were additional problems on cucumbers, and *H. zea* was a new pest in artichoke crops (~120 acres), but pyrethroids were used in both crops for control. In June and July about 95% of the grain sorghum acreage was treated for stink bugs with Karate-Z® 2.08CS (lambda-cyhalothrin) at 0.03 to 0.035 lb a.i./acre or Mustang Max® 0.8E (zeta-cypermethrin) at 0.0225 lb a.i./acre. About 50% of grain sorghum acreage was treated for sorghum midge in June with Asana® XL 0.66E (esfenvalerate) at 0.015 lb a.i./acre or Mustang Max® 0.8E at 0.0225 lb a.i./acre. There were additional treatments for headworm (*H. zea*) in June and July with Karate-Z® 2.08CS at 0.03-0.035 lb a.i./acre or Mustang Max® 0.8E at 0.0225 lb a.i./acre. Populations of corn earworm (*H. zea*) were high in sweet corn and treated alternately with Lannate® 2.4LV and pyrethroids. In field corn, *H. zea* pressure was intense and was treated in June with Mustang Max® 0.8E at 0.0225 lb a.i./acre. In non *Bt*, conventional cotton, growers had to treat multiple (4 to 5) times to keep bollworm numbers down, as there were protracted egg-laying periods and larval hatch. There were no problems with bollworms in *Bt* cotton. The highest resistance ratio in 2007 was recorded from Uvalde Co. populations in September (Table 4). Bioassay probit lines from mid-season in 2004, 2005, and 2007 were parallel and not significantly different (Fig. 3).

Table 4. Uvalde Co. cypermethrin bioassay for male bollworms, *Helicoverpa zea*, collected from pheromone traps, 2007. Resistance ratio (RR) with 95% confidence intervals (CI) calculated by the method of Robertson and Preisler (1992). 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% CL)	LC_{90}[b] (95% CL)	RR LC_{50} (95% CI)	RR LC_{90} (95% CI)	χ^2 (df)
Burleson[c]	400	1.47 ± 0.35	0.33 (0.08-0.59)	2.44 (1.51-5.76)	1	1	0.45 (3)
6/14-15/2007	400	1.19 ± 0.23	1.04 (0.38-1.83)	12.41 (7.21-32.15)	**3.17*** (1.08-9.30)	**5.07*** (2.09-12.32)	4.62 (6)
7/12-14/2007	400	1.48 ± 0.21	1.95 (1.11-2.89)	14.35 (9.6-25.76)	**5.92*** (2.33-15.03)	**5.87*** (2.79-12.35)	4.94 (5)
9/13-14/2007	300	4.22 ± 1.18	3.58 (2.35-4.49)	7.21 (5.58-14.00)	**10.85*** (4.63-25.44)	**2.95*** (1.50-5.78)	4.09 (5)

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

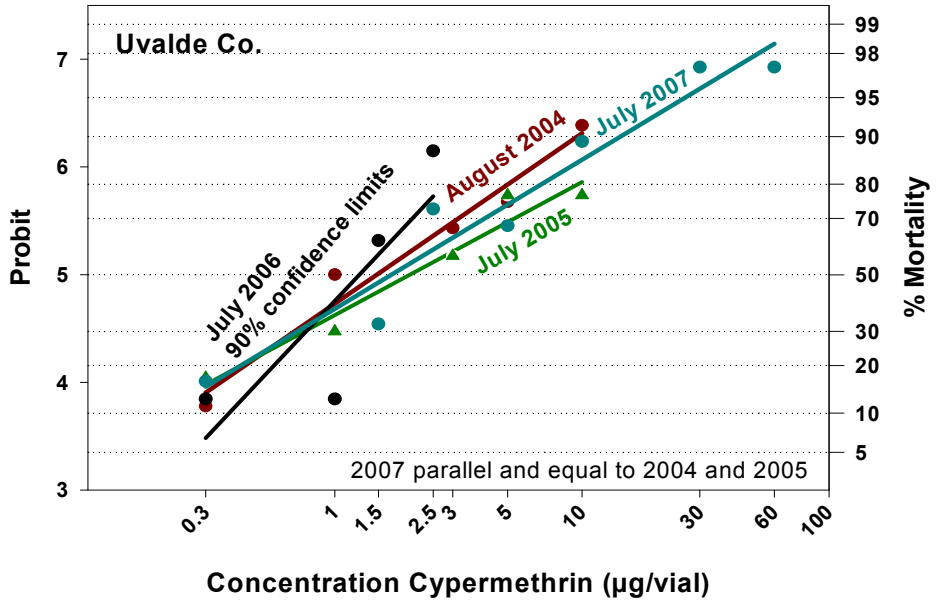

Figure 3. Concentration-mortality lines for bollworm moths collected in mid-season from 2004 to 2007 in Uvalde Co. and exposed 24 h to cypermethrin in the vial assay. The 2007 line is parallel and not significantly different from those of 2004 and 2005 ($p < 0.05$).

Burleson County

Monitoring in Burleson Co. was conducted from April to September, 2007. Seven traps spaced over four miles were used for moth collections. There were 12,962 acres of cotton (95% Bollgard® I), 5,477 acres of grain sorghum, and 12,962 acres of corn. *Helicoverpa zea* densities were similar to the previous four years and high during early July due to migrations from corn. A few control problems occurred, but these were likely due to poor coverage because of larvae in bloom tags. Headworm (*H. zea*) was treated in grain sorghum on 3 July with Mustang Max® 0.8E (zeta-cypermethrin) at 0.0225 lb a.i./acre. Applications in cotton were Mustang Max® 0.8E at 0.0225 lb a.i./acre on 10 July, and Sniper® (bifenthrin) at 0.078 lb

a.i./acre on 23 July. Bioassays showed a high resistance ratio in April and again in July (Table 5). Bioassay probit lines from the years 2000 to 2005 indicated progressive susceptibility to cypermethrin (Fig. 4). Since 2005, the level of resistance has continued to increase at mid season, but has not reached levels seen from 2000 to 2003. The July 2007 bioassay probit line is parallel and not significantly different from those in July 2004 and 2006 (Fig. 4).

Table 5. Burleson Co. cypermethrin bioassay for male bollworms, *Helicoverpa zea*, collected from pheromone traps, 2007. Resistance ratio (RR) with 95% confidence intervals (CI) calculated by the method of Robertson and Preisler (1992). 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% CL)	LC_{90}[b] (95% CL)	RR LC_{50} (95% CI)	RR LC_{90} (95% CI)	χ^2 (df)
Burleson[c]	400	1.47 ± 0.35	0.33 (0.08-0.59)	2.44 (1.51-5.76)	1	1	0.45 (3)
4/27/2007	200	2.44 ± 0.77	2.02 (0.91-2.85)	6.76 (4.38-31.03)	**6.13*** (2.46-15.23)	**2.77*** (1.16-6.58)	1.50 (5)
5/11/2007	199	1.80 ± 0.37	0.70 (0.47-1.01)	3.59 (2.27-8.93)	2.12 (0.85-5.29)	1.47 (0.64-3.38)	3.87 (4)
6/15/2007	200	1.90 ± 0.42	1.52 (1.00-2.24)	7.20 (4.16-25.45)	**4.61*** (1.89-11.23)	**2.94*** (1.13-7.64)	1.14 (4)
6/28/2007	200	3.17 ± 0.88	1.65 (0.84-2.19)	4.18 (3.12-8.42)	**4.98*** (2.04-12.18)	1.71 (0.85-3.41)	0.46 (3)
7/13/2007	200	2.68 ± 0.40	2.07 (1.66-2.58)	6.24 (4.59-10.42)	**6.28*** (2.72-14.53)	**2.56*** (1.28-5.11)	4.68 (5)
7/26/2007	161	1.69 ± 0.37	1.36 (0.68-2.15)	7.74 (4.44-24.62)	**4.11*** (1.57-10.73)	**3.17*** (1.24-8.06)	1.21 (5)
8/09-10/2007	152	2.49 ± 0.74	1.45 (0.60-2.11)	4.72 (3.13-14.83)	**4.38*** (1.71-11.21)	1.93 (0.86-4.33)	0.60 (5)
8/23-24/2007	190	1.36 ± 0.33	0.72 (0.30-1.18)	6.24 (3.27-30.08)	2.18 (0.80-5.94)	2.55 (0.87-7.43)	2.87 (4)
9/06/2007	200	2.42 ± 0.35	1.19 (0.92-1.50)	4.02 (2.91-6.81)	**3.60*** (1.55-8.38)	1.64 (0.81-3.32)	4.01 (5)
9/19-20/2007	244	2.17 ± 0.57	1.14 (0.53-1.65)	4.43 (2.89-12.77)	**3.45*** (1.35-8.77)	1.81 (0.79-4.12)	2.25 (3)

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

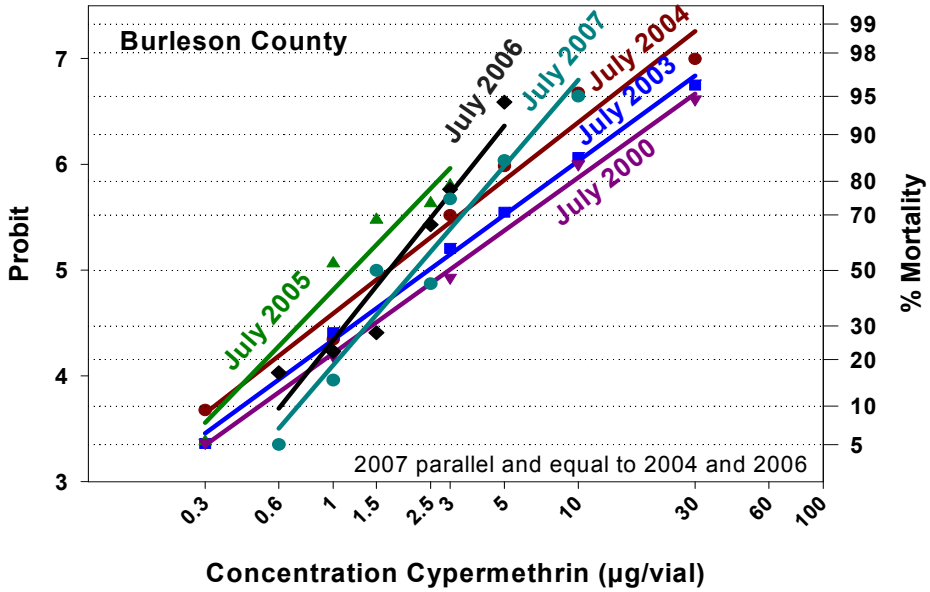

Figure 4. Concentration-mortality lines for bollworm moths collected in 2000 and 2003 to 2007 in Burleson Co. and exposed 24 h to cypermethrin in the vial assay. The 2007 line is parallel to and not significantly different from those of 2004 and 2006 ($p < 0.05$).

Williamson County

Monitoring in Williamson Co. consisted of one bioassay conducted in May, and two traps spaced 0.5 miles apart were used for moth collections. There were 25,000 acres planted in cotton (60% *Bt*, of which 30% was Bollgard II®), 30,000 acres of grain sorghum, and 100,000 acres of corn. Bollworm population densities were relatively low as compared to the past four years, and only limited treatments were made in the northern part of the county. Bollworm control was achieved in cotton with Larvin® 3.2F (thiodicarb) at 0.6 to 0.8 lb a.i./acre. Grain sorghum was treated from 10 to 25 June with the pyrethroids Baythroid® XL (beta-cyfluthrin), Asana® XL 0.66E (esfenvalerate), and Karate-Z® 2.08CS (lambda-cyhalothrin) at the label rate for grain sorghum. Only one bioassay was conducted in early season in Williamson Co. which indicated a high resistance ratio of 8 (Table 6). Wind trajectories conducted for the week prior to the date of bioassays indicated possible migration from the south (not shown). The bioassay probit line from May 2007 was parallel to those from July 2003 and July 2005, and not significantly different from those of June/July 2004 and July 2005 (Fig. 5).

Table 6. Williamson Co. cypermethrin bioassay for male bollworms, *Helicoverpa zea*, collected from pheromone traps, 2007. Resistance ratio (RR) with 95% confidence intervals (CI) calculated by the method of Robertson and Preisler (1992). 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% CL)	LC_{90}[b] (95% CL)	RR LC_{50} (95% CI)	RR LC_{90} (95% CI)	χ^2 (df)
Burleson[c]	400	1.47 ± 0.35	0.33 (0.08-0.59)	2.44 (1.51-5.76)	1	1	0.45 (3)
5/22/2007	100	1.30 ± 0.39	2.85 (1.56-6.48)	27.60 (9.93-1067.82)	**8.62*** (3.18-23.34)	**11.29*** (2.07-61.34)	0.41 (5)

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

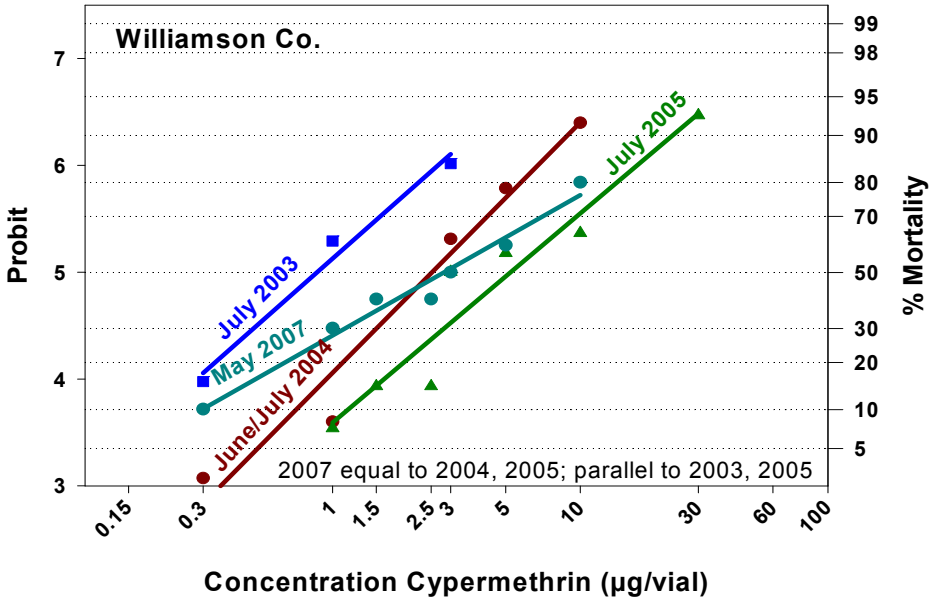

Figure 5. Concentration-mortality lines for bollworm moths collected in 2003 to 2005, and 2007 in Williamson Co. and exposed 24 h to cypermethrin in the vial assay. Lines 2003, 2005, and 2007 are parallel, and the 2007 line is not significantly different from 2004 or 2005 ($p < 0.05$).

Ellis County

In Ellis Co. one trap was used to collect moths. Approximately 38,000 acres of cotton (99% *Bt*, of which 8% was Bollgard II®), 42,000 acres of grain sorghum, and 50,000 acres of corn were planted. Population densities of bollworm were much higher in 2007 as compared to the previous four years. Grain sorghum was sprayed from 2 to 6 July with Warrior® (lambda-cyhalothrin) at 0.015 lb a.i./acre and Baythroid® 2 (cyfluthrin) at 0.016 lb a.i./acre for sorghum midge, and from 9 to 18 July with Warrior® at 0.02 lb a.i./acre and Baythroid® 2 at 0.02 lb a.i./acre for headworm (*H. zea*) and stinkbug. High population densities of bollworms were present in mid-July in *Bt* cotton, under bloom tags and in blooms. Rainfall during this time caused bloom tags to remain on bolls, which offered a favorable oviposition site. Control was achieved from 7 to 20 July with applications of high rates of Baythroid® 2 at 0.10 lb/acre, Karate-Z® 2.08CS (lambda-cyhalothrin) at 0.04 lb/acre, or Mustang Max® 0.8E (zeta-cypermethrin) at 0.025 lb/acre. Ellis County populations remained susceptible to pyrethroids (Table 7). The bioassay probit line from June 2007 was parallel to, but significantly different from bioassays conducted in July 2004 and 2005 (Fig. 6).

Table 7. Ellis Co. cypermethrin bioassay for male bollworms, *Helicoverpa zea*, collected from pheromone traps, 2007. Resistance ratio (RR) with 95% confidence intervals (CI) calculated by the method of Robertson and Preisler (1992).

Date	n[a]	Slope ± SE	LC_{50}[b] (95% CL)	LC_{90}[b] (95% CL)	RR LC_{50} (95% CI)	RR LC_{90} (95% CI)	χ^2 (df)
Burleson[c]	400	1.47 ± 0.35	0.33 (0.08-0.59)	2.44 (1.51-5.76)	1	1	0.45 (3)
5/28 to 6/14/2007	205	1.04 ± 0.27	0.44 (0.07-0.99)	7.36 (3.11-53.56)	1.33 (0.35-4.98)	3.01 (0.83-10.81)	3.96 (4)

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

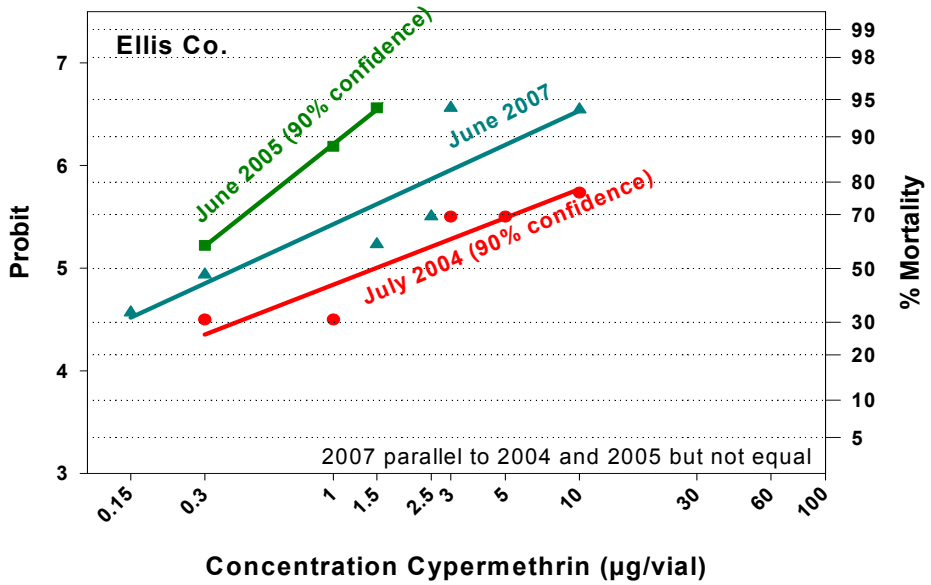

Figure 6. Concentration-mortality lines for bollworm moths collected in 2004, 2005, and 2007 in Ellis Co. and exposed 24 h to cypermethrin in the vial assay. All lines are parallel and are significantly different ($p < 0.05$).

Tom Green and Runnels Counties

In Tom Green and Runnels Counties a total of five traps spaced several miles apart were used to collect moths for bioassays in the two counties. There were 206,000 acres of cotton (70% *Bt*, of which 40% was Bollgard II® or Widestrike®), 85,000 acres of grain sorghum, and 3,500 acres of corn planted. Population densities of bollworms were higher in 2007 than in the previous four years, however, no control problems or field failures were reported in the area. Over 600 moths were tested, but statistical analyses showed these moths were not significantly different from the susceptible population. No moths survived above the 3 µg/vial dosage. Control was achieved with mid- to full-rates of insecticides. Grain sorghum fields were treated during the first two weeks of July with Baythroid® 2 (cyfluthrin) at 0.01625 lb a.i./acre and Mustang Max® 0.8E (zeta-cypermethrin) at 0.01875 lb a.i./acre. A few cotton fields were treated in the second week of August with Denim® 0.16EC (emamectin benzoate) at 0.01 lb a.i./acre, Mustang Max® 0.8E at 0.01875 lb a.i./acre, or Steward® 1.25SC (indoxacarb) at an unknown rate. Insufficient numbers of moths were collected to conduct successful bioassays, but of the moths that were tested, none survived beyond the 1.5 µg/vial dosage (Fig. 9).

Jones County

In Jones Co., moth collections were made using one trap. There were 70,000 acres of cotton (70-75% *Bt*, of which 95% was Bollgard II®), and 15,000 acres of grain sorghum planted (no corn). Bollworm population densities were comparable to those in 2004 and 2005 when population numbers and damage were significant. In these three years, growing conditions were good due to above average rainfall. In 2007, there were chronic infestations of bollworm all season long in cotton and grain sorghum. Some fields planted with non-*Bt* cotton varieties had control problems apparently due to poor application timing and coverage, and two or three applications were made. Further, mixed populations of bollworm and fall armyworm made control difficult, however, bollworm larvae less than 0.25 in length were typically controlled. Cotton fleahopper and cotton aphid populations were in high densities in 2007, and it is believed that applications to control these pests reduced natural enemies, thereby contributing to heavier caterpillar infestations. Because of the mixed populations, fields were treated with the highest recommended rates of pyrethroids. Grain sorghum field treatments included Tombstone® (cyfluthrin) at 0.044 lb a.i./acre and Karate-Z® 2.08CS (lambda-cyhalothrin) at 0.04 lb a.i./acre. Cotton field treatments included: Tombstone® at 0.032 to 0.04225 lb a.i./acre, Mustang Max® 0.8E (zeta-cypermethrin) at 0.0225 lb a.i./acre, and Karate-Z® 2.08 CS at 0.04 lb a.i./acre. A few fields received an application of Karate-Z® 1.0EC at 0.04 lb a.i./acre mixed with Curacron® 8E (profenofos) at 0.75 lb a.i./acre. Some fields were treated with Steward® 1.25SC (indoxacarb) at 0.11 lb a.i./acre, or Intrepid® 2F (methoxyfenozide) at 0.095

lb a.i./acre. Jones County populations remained susceptible to pyrethroids, although in September the resistance ratio reached 4 (Table 8). Comparisons of 2007 bioassay probit lines to September 2005 adjacent Fisher and Mitchell Counties indicate that all are parallel and not significantly different (Fig. 7).

Table 8. Jones Co. cypermethrin bioassay for male bollworms, *Helicoverpa zea*, collected from pheromone traps, 2007. Resistance ratio (RR) with 95% confidence intervals (CI) calculated by the method of Robertson and Preisler (1992). 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% CL)	LC_{90}[b] (95% CL)	RR LC_{50} (95% CI)	RR LC_{90} (95% CI)	χ^2 (df)
Burleson[c]	400	1.47 ± 0.35	0.33 (0.08-0.59)	2.44 (1.51-5.76)	1	1	0.45 (3)
7/26/2007	100	1.41 ± 0.48	0.76 (0.15-1.61)	6.16 (2.57-188.09)	2.30 (0.72-7.36)	2.52 (0.60-10.51)	0.22 (4)
9/20/2007	100	1.18 ± 0.43	1.42** (0.46-3.78)	17.33** (5.65-761.33)	**4.31*** (1.17-15.81)	7.09 (0.88-57.06)	1.73 (3)

[a]Number of insects tested.
[b]Lethal concentration expressed in micrograms of insecticide per vial with 95% confidence limits.
[c]Bioassay of Burleson County September 2005 susceptible field population.
**indicates LC with 90% confidence limits.

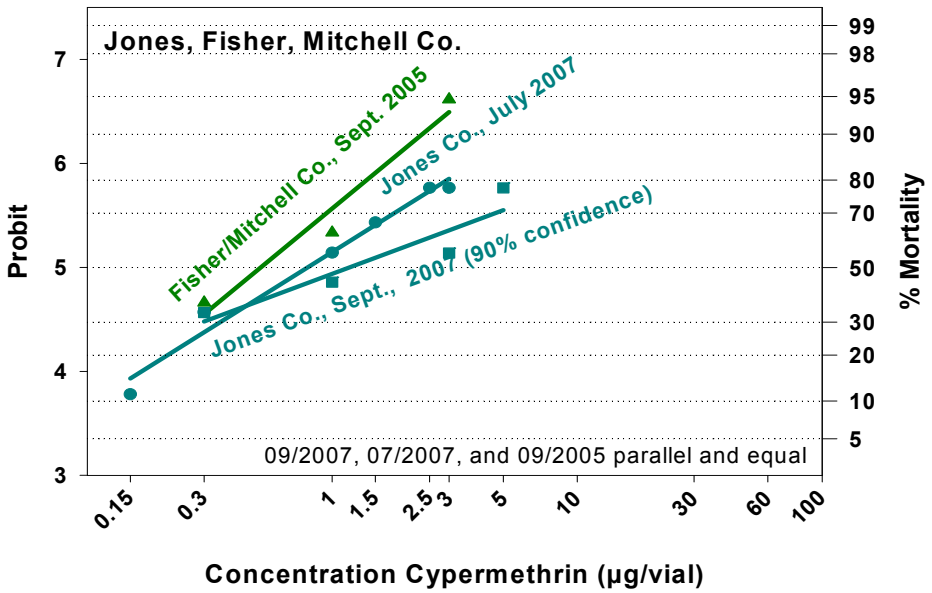

Figure 7. Concentration-mortality lines for bollworm moths collected in 2005 and 2007 in Jones, Fisher, and Mitchell Co. and exposed 24 h to cypermethrin in the vial assay. All lines are parallel and not significantly different ($p < 0.05$).

Hockley County

Hockley Co. experienced very low population densities of bollworms in 2007. Moth collections were made from two traps spaced 400 yards apart. Approximately 230,000 acres of cotton (45% *Bt*, of which 95% was Bollgard II®), 26,000 acres of grain sorghum, and 400 acres of corn were planted in 2007, however, no pyrethroid applications were made in this area. It is speculated that number of acres planted in *Bt* crops

may have contributed to the low numbers of bollworms. Insufficient numbers of moths were collected in Hockley Co. to conduct successful bioassays, but of the moths that were tested, none survived beyond the 1.5 µg/vial dosage (Fig. 9).

Swisher County

Moth collections in Swisher Co. were made from two traps spaced two miles apart. In the Hale/Swisher County region there were 475,000 acres of cotton (10% Bollgard® I and 15% Bollgard II®), 110,000 acres of grain sorghum, and 90,000 acres of corn. Population densities of bollworm appeared to be slightly higher than the previous four years, but there were no reported control problems. Pyrethroids were used on grain sorghum from 24 July to 10 September for control of sorghum midge, southwestern corn borer, and corn earworm (*H. zea*). From 24 July to 10 August, 5% of grain sorghum fields were treated for southwestern corn borer with Warrior® (lambda-cyhalothrin) at 0.03 lb a.i./acre. From 10 August to 10 September, 20% of grain sorghum fields were treated with Karate® 1E (lambda-cyhalothrin) at 0.016 lb a.i./acre for sorghum midge. Thirty-five percent of sorghum fields were treated for bollworms from 20 August to 10 September with Karate® 1E at 0.03 lb a.i./acre. Control of bollworm in cotton was achieved with a pyrethroid, and about 40% of the cotton acreage was treated from 5 August to 12 September with Ammo® 2.5EC (cypermethrin) at 0.08 lb a.i./acre. Insufficient numbers of moths were collected in Swisher Co. to conduct successful bioassays, but of the moths that were tested, none survived beyond the 1.0 µg/vial dosage (Fig. 9).

Parmer County

In Parmer Co., moth collections were made using four to six traps spaced 300 feet apart. A total of 65,000 acres of cotton (25% *Bt*, of which 35% was Bollgard II®), 44,000 acres of grain sorghum, and 100,000 acres of corn were planted in 2007. Population densities of bollworms were lower in comparison with the previous four years and moderate levels were reported in cotton and other crops, however no control problems were reported. Pyrethroid treatments included: Ammo® 2.5EC (cypermethrin) applied from 20 June 15 July to 40% of cotton acreage for *Lygus*; Capture® 2EC (bifenthrin) applied to corn for southwest corn borer from 25 July to 10 August; Mustang Max® 0.8E (zeta-cypermethrin) applied for podworms (*H. zea*) on green beans weekly from 15 July to September; Mustang Max® 0.8E applied for podworms on black-eyed peas from 10 to 30 August. Insecticides of other chemical classes were applied for bollworm in cotton from 10 to 25 August. Bioassays conducted in June and July in Parmer Co. indicated that bollworm populations remained susceptible to pyrethroids with non-significant resistant ratios (Table 9). Bioassay probit lines from June 2003, Sept. 2006, and July 2007 were parallel and not significantly different (Fig. 8).

Table 9. Parmer Co. cypermethrin bioassay for male bollworms, *Helicoverpa zea*, collected from pheromone traps 2007. Resistance ratio (RR) with 95% confidence intervals (CI) calculated by the method of Robertson and Preisler (1992).

Date	n[a]	Slope ± SE	LC_{50}[b] (95% CL)	LC_{90}[b] (95% CL)	RR LC_{50} (95% CI)	RR LC_{90} (95% CI)	χ^2 (df)
Burleson[c]	400	1.47 ± 0.35	0.33 (0.08-0.59)	2.44 (1.51-5.76)	1	1	0.45 (3)
6/21/2007	100	1.31 ± 0.38	0.99 (0.32-2.00)	9.36 (3.89-133.21)	2.99 (0.99-8.98)	3.83 (0.94-15.53)	4.02 (5)
7/06/2007	100	1.69 ± 0.38	0.73 (0.39-1.22)	4.18 (2.22-16.92)	2.22 (0.85-5.81)	1.71 (0.61-4.80)	2.40 (4)

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

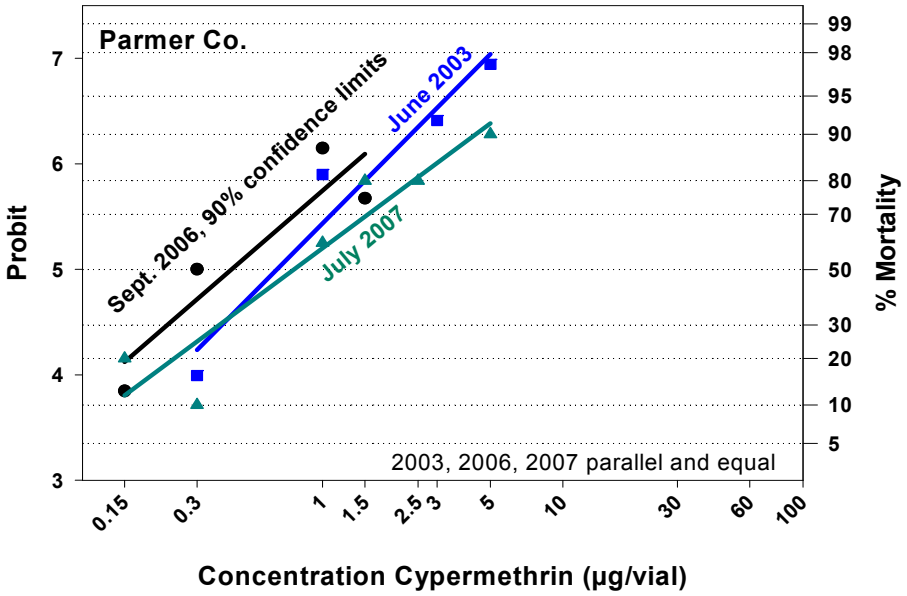

Figure 8. Concentration-mortality lines for bollworm moths collected in 2003, 2006, and 2007 in Parmer Co. and exposed 24 h to cypermethrin in the vial assay. All lines are parallel and not significantly different ($p < 0.05$).

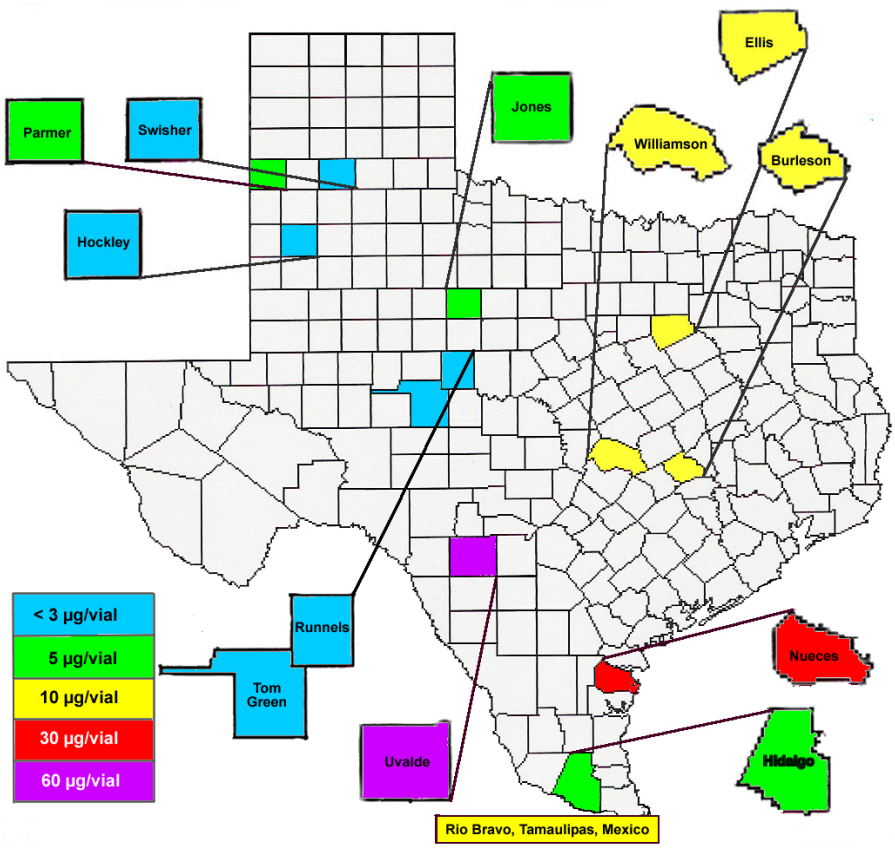

Figure 9. Highest concentration of cypermethrin in µg/vial at which moth survivorship was observed, 2007.

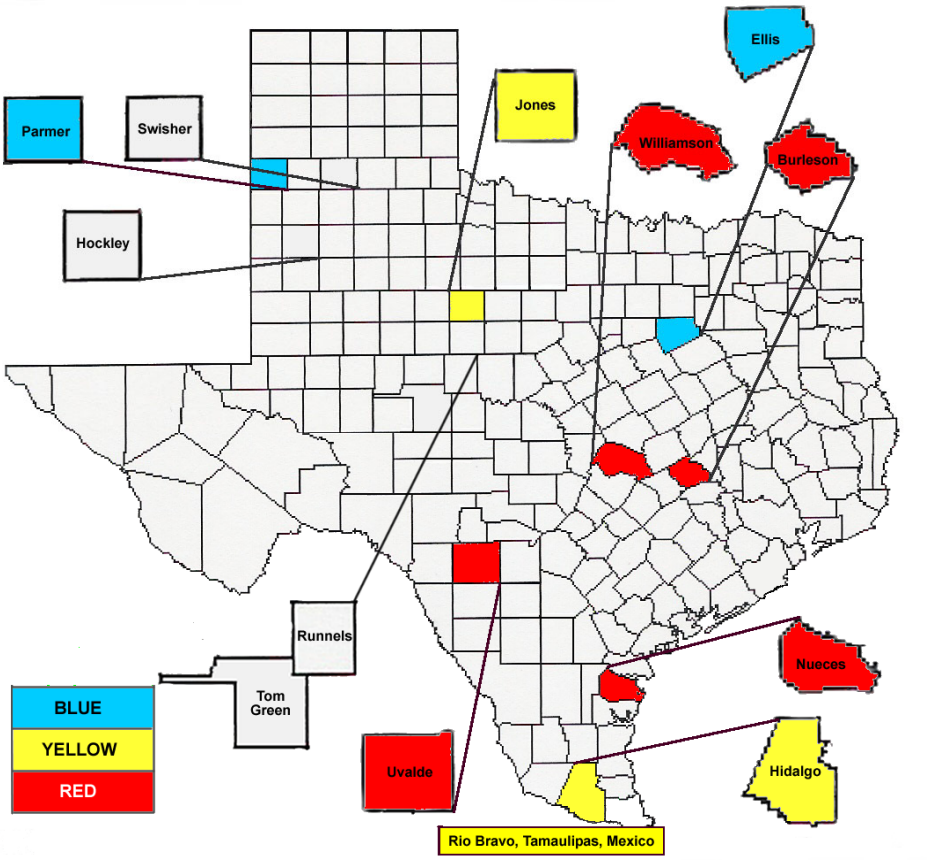

Figure 10. Highest LC_{50} resistance ratios of individual counties in 2007, compared with a susceptible Burleson Co. population from September 2005. Values in blue represent a resistance ratio not significantly different from 1. Values in yellow represent a resistance ratio significantly different than 1, but less than 5X (e.g., 2X, 3X, 4X). Values in red represent a resistance ratio greater than 5X.

Conclusion

Analysis of the 2007 monitoring season revealed heavy pyrethroid use across the state of Texas for control of *H. zea* in cotton and other cropping systems, as well as for other insect pests. Although population densities of *H. zea* were generally higher in most areas than in the previous four years, control was achieved with high rates of pyrethroids and/or other chemistries with different modes of action. As in previous years, populations exhibiting the highest LC_{50} resistant ratios were from Nueces, Burleson, Williamson and Uvalde Co. For the first time in Uvalde Co., individual moths survived high concentrations of 30 and 60 µg/vial, and toward the end of the growing season, the LC_{50} resistance ratio of approximately 11 indicated a highly resistant population, the most resistant of 2007. In addition, high survivorship (10 µg/vial) was observed in Ellis County and in Tamaulipas, Mexico, so these areas should continue to be closely monitored to see how resistance evolves in the coming seasons. Populations monitored in other Texas counties and Mexico generally maintained susceptibility.

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