Efficacy of Insecticides Against *Acrosternum hilare* and *Euschistus servus* (Hemiptera: Pentatomidae) in Virginia and North Carolina[1]

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Abstract Laboratory bioassays and field trials were conducted to evaluate the efficacy of selected organophosphate, pyrethroid, and neonicotinoid insecticides, as well as a chitin inhibitor, novaluron, against 2 common stink bug pests in Virginia, the green stink bug, *Acrosternum hilare* (Say), and the brown stink bug, *Euschistus servus* (Say). Green bean dip bioassays revealed differences in insecticide susceptibility between the 2 species. *Acrosternum hilare* adults were highly susceptible to all pyrethroids tested, the organophosphates except acephate, and the neonicotinoids except acetamiprid. *Acrosternum hilare* nymphs were also susceptible to all pyrethroids tested. In general, the neonicotinoids, dinotefuran and clothianidin, were toxic to *A. hilare,* whereas thiamethoxam and acetamiprid were toxic to *E. servus.* In field trials in soybean, the neonicotinoids, dinotefuran, imidacloprid, and thiamethoxam were efficacious at controlling stink bugs and, in general, performed comparably to the organophosphates and pyrethroids. These results indicate that neonicotinoid insecticides offer an alternative to growers for managing stink bugs that may fit with integrated pest management programs where conservation of natural enemies is a consideration.

Key Words stink bug, chemical control, selective insecticide, efficacy

Stink bugs (Heteroptera: Pentatomidae) are important economic pests of many agricultural crops and have become one of the most difficult pest groups to control in crops such as cotton, soybean, and tomato (McPherson and McPherson 2000, Greene et al. 2001, Gore et al. 2006) and many fruit crops (McPherson and McPherson 2000). Stink bugs usually attack developing fruiting forms, i.e., soybean seed, cotton bolls, and fruit of many vegetables. Direct damage to the fruit is caused by insertion of the stylets to suck plant fluids. Additionally, feeding sites provide entry points for pathogenic and decay organisms which can damage the plant (Underhill 1934, Emfinger et al. 2001).

Organophosphates (such as acephate, methamidophos, and dicrotophos) or pyrethroids (such as λ-cyhalothrin, ζ-cypermethrin, cyfluthrin, fenpropathrin, esfenvalerate,

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or permethrin) are the most commonly used insecticides to control stink bugs in most crops (Kuhar et al. 2006, Herbert 2008). However, these insecticides are broad spectrum toxicants that have environmental and human health risks and frequently destroy important natural enemies in the agro-ecosystem (Letourneau and Goldstein 2001, Tillman and Mullinix 2004). The efficacy of alternative insecticide classes for stink bug control have been evaluated in the southern United States (Willrich et al. 2004, Snodgrass et al. 2005), where the southern green stink bug, *Nezara viridula* (L.), is the most commonly encountered species (Gore et al. 2006), and where the brown stink bug, *Euschistus servus* (Say), is notoriously difficult to control (Emfinger et al. 2001, Snodgrass et al. 2005). In the MidAtlantic and northeastern United States, the green stink bug, *Acrosternum hilare* (Say) and *E. servus* comprise over 90% of the stink bug species on crops, and *N. viridula* is not found (Kamminga, unpubl. data). Moreover, insecticide efficacy data on stink bugs are lacking for this region of the U.S.

Integrated pest management programs are being used for stink bug control in agricultural systems (Cullen and Zalom 2007, Gore et al. 2006, Willrich et al. 2004). Newer insecticide classes such as the neonicotinoids and others may offer control options that are less toxic and disruptive to natural enemies, and may fit better with integrated pest management programs (Tillman and Mullinix 2004, Carvalho et al. 2006). The purpose of this research was to evaluate the efficacy of commonly used insecticides as well as the newer chemistries against stink bug pest species common to the MidAtlantic region using laboratory bioassays and field trials.

Materials and Methods

Laboratory bioassays. Five bioassays were conducted with treatments representing a range of insecticide chemistries evaluated (Table 1). The first and second bioassays were conducted on *A. hilare* nymphs (fourth and fifth instars) collected from soybean fields in Painter, VA (75°49'W, 37°35'N; elevation ≈ 12 m) on 12 September 2006 and from a commercial soybean field near Cheriton, VA (75°58'W, 37°17'N; elevation ≈ 5 m) on 25 September 2006. The 2 populations represented 2 separate bioassays. Insecticide concentrations were selected to simulate recommended field rates. Bioassays were conducted using a bean-dip technique (Abudulai et al. 2003). Green beans, *Phaseolus vulgaris* (L.), were rinsed 3X in water, air dried, then dipped into insecticide/water solutions based on a 317.9 L total volume ha^{-1} field application rate for 30 sec. Pods were air dried for 1 h on a paper towel before being presented to the stink bugs. Nymphs were placed into Petri dishes (10 × 1.5 cm) with 1 pod from a respective treatment. Five nymphs in each of 4 replicates were assayed for each insecticide treatment and a control (water only). Petri dishes were maintained in a laboratory insectary at 27 ± 2°C, 40-70% RH, and a photoperiod of 12:12 (L:D). Numbers of live, dead, or "knocked down" stink bugs were determined after 72 h of exposure. Insects were considered "knocked down" if they appeared intoxicated (e.g., slow moving) but were able to right themselves when turned on their backs.

In 2007, a third bioassay was conducted using *E. servus* adults collected from a wheat field in Havelock, NC (76°54'W, 34°52'N; elevation ≈ 6 m) on 11 June. Five *E. servus* adults were placed in Petri dishes with a total of 5 replicates for each of 9 insecticide treatments and a control (water only). The fourth and fifth bioassays were completed using *A. hilare* adults collected from a commercial soybean field in Camden, NC (76°20'W, 36°32'N; elevation ≈ 3 m) on 14 August and 28 September. The

Table 1. Insecticides evaluated for stink bug efficacy in laboratory experiments conducted in Virginia from 2006-2007

Material	Product	Manufacturer	Class
acephate	Orthene 97SP	Amvac Chemical Corp.	Organophosphate
dicrotophos	Bidrin 8EC	Amvac Chemical Corp.	Organophosphate
methamidophos	Monitor 4	Bayer CropScience	Organophosphate
λ-cyhalothrin	Warrior ZT	Syngenta Crop Protection, Inc.	Pyrethroid
ζ-cypermethrin	Mustang Max	FMC Corporation	Pyrethroid
cyfluthrin	Baythroid 2	Bayer CropScience	Pyrethroid
β-cyfluthrin	Baythroid XL	Bayer CropScience	Pyrethroid
fenpropathrin	Danitol 2.4EC	Valent U.S.A. Corp	Pyrethroid
acetamiprid	Assail 30SG	United Phosphorus Inc.	Neonicotinoid
clothianidin	V-10170 50WD	Valent U.S.A. Corp	Neonicotinoid
dinotefuran	Venom 20SG	Valent U.S.A. Corp.	Neonicotinoid
imidacloprid	Trimax Pro	Bayer CropScience	Neonicotinoid
thiamethoxam	Centric 40WG	Syngenta Crop Protection, Inc.	Neonicotinoid

experimental methods, design, and analysis were the same as those used in 2006 with a total of 4 replicates per treatment.

2005 field efficacy trial. A field efficacy trial was conducted in soybean, *Glycine max,* (L.), at Painter, VA. This field contained > than 3 stink bugs per 0.91 m (1 per 1 row foot) of row threshold for stink bugs in soybeans (Herbert 2008). The experiment was arranged in a randomized complete block design with 4 replicates and included an untreated control. Individual plots were 4 rows wide (0.76 m spacing) and 12.2 m long with an untreated border row on each side. Treatments representing a range of insecticide chemistries were evaluated (Table 2) including classes that are known to be effective against stink bugs (Greene et al. 2001, Willrich et al. 2003, Tillman and Mullinix 2004). Insecticide treatments were applied on 24 August using a CO_2-pressurized backpack sprayer calibrated to deliver 133.7 L ha^{-1} at 1.22 atm using 4 8002VS spray nozzles spaced 45.7 cm apart on the spray boom. Plots were evaluated at 2, 5, and 8 d after treatment (DAT) using 2, 0.91 m rigid beat sheet (Kogan and Herzog 1980) samples per plot. The total number of *A. hilare* and *E. servus* adults and nymphs was recorded.

2006 field efficacy trials. In August 2006, 2 field efficacy trials were conducted in commercial soybean fields located in Camden, NC. Both fields also were found to have > than 3 stink bugs per 0.91 m row (1 per 1 row foot), the threshold for stink bugs in soybeans (Herbert 2008). Plots were 5 rows wide (0.61 m spacing) and 12.2 m long with 2 untreated border rows on each side. The experimental design, treatment application methods, and sampling method were the same as those used in 2005. Insecticide treatments were applied on 7 August (Trial 1) and on 8 August

Table 2. Insecticides evaluated for stink bug efficacy in field experiments conducted in Virginia from 2006-2007

Material	Product	Manufacturer	Class
acephate	Orthene 97SP	Amvac Chemical Corp.	Organophosphate
dicrotophos	Bidrin 8EC	Amvac Chemical Corp.	Organophosphate
chlorpyrifos/ γ-cyhalothrin	Cobalt	Dow AgroSciences	Organophosphate + Pyrethroid
λ-cyhalothrin	Karate 1EC + Karate Z	Syngenta Crop Protection, Inc.	Pyrethroid
cyfluthrin	Baythroid 2	Bayer CropScience	Pyrethroid
λ-cyhalothrin + thiamethoxam	Endigo ZC	Syngenta Crop Protection, Inc.	Pyrethroid + Neonicotinoid
acetamiprid	Assail 30SG	United Phosphorus Inc.	Neonicotinoid
clothianidin	V-10170 50WD	Valent U.S.A. Corp	Neonicotinoid
dinotefuran	Venom 20SG	Valent U.S.A. Corp.	Neonicotinoid
imidacloprid	Trimax Pro	Bayer CropScience	Neonicotinoid
thiamethoxam	Centric 40WG	Syngenta Crop Protection, Inc.	Neonicotinoid
novaluron	Diamond 0.83EC	Chemtura Corp.	Chitin inhibitor
oxamyl	Vydate C-LV	E.I. Dupont de Nemours and Co.	Carbamate
GF-1796	—	Dow AgroSciences	Experimental
V-10191	—	Valent U.S.A. Corp.	Organophosphate

(Trial 2). Stink bug populations were assessed at 2, 4, and 7 DAT (Trial 1) and 3, 6, and 10 DAT (Trial 2).

Statistical analysis. All data were analyzed using an analysis of variance procedure (PROC GLM, SAS Institute 2001). For all field trials, total number of stink bug adults and nymphs (all species combined) were compared among treatments using LSD procedures to separate means at the $P \leq 0.05$ level of significance. For laboratory bioassays, proportion mortality data were arc-sine square root transformed prior to analysis to stabilize variance.

Results

Laboratory bioassays. In 2006, the 2 bean-dip bioassays produced consistent results (Fig. 1). Treatment with the pyrethroids λ-cyhalothrin, ζ-cypermethrin, cyfluthrin, and fenpropathrin resulted in the highest mortality at 72 h post exposure. Dinotefuran performed equally well as the pyrethroids in bioassay 2, but was significantly less effective in bioassay 1. In contrast, clothianidin resulted in statistically similar mortality as the pyrethroids in bioassay 1, but was significantly lower in bioassay 2.

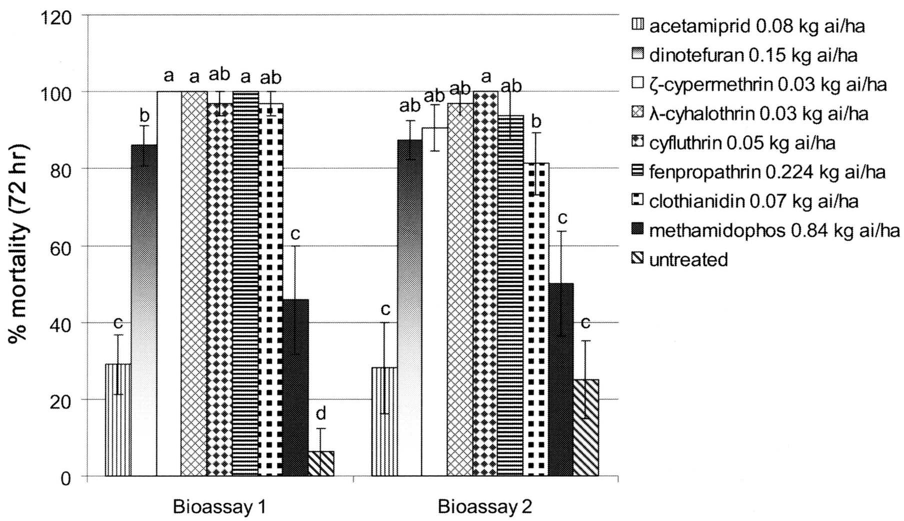

Fig. 1. (2006) Mean ± SE (n = 20) percent mortality of 2 bioassays (assay 1 and assay 2) of *A. hilare nymphs* collected from Cheriton, VA after 72 h exposure to treated green beans. Bars with a letter in common are not significantly different (P < 0.05)

Acetamiprid and methamidophos resulted in significantly lower mortality than all other treatments except the untreated control in both bioassays.

In 2007, the bioassay on *E. servus* adults resulted in similar results to the 2006 bioassays with *A. hilare* nymphs (Fig. 2). At 72 h post exposure, acephate, cyfluthrin, dicrotophos, clothianidin, thiamethoxam and acetamiprid resulted in the highest mortality and were not significantly different. Dinotefuran and imidacloprid were not as toxic as acephate but were statistically equal to thiamethoxam and acetamiprid. Also, λ-cyhalothrin did not perform as well as cyfluthrin.

The fourth and fifth bioassays on *A. hilare* adults resulted in high mortality for all treatments except acetamiprid and acephate (Fig. 3). Acetamiprid and acephate resulted in 85% mortality; both were numerically lower than the other insecticides tested.

2005 field efficacy trial. Two stink bug species were present in this trial, 70% *A. hilare* (86% nymphs, 14% adults) and 30% *E. servus* (56% nymphs, 44% adults). Treatments resulted in significant differences in total stink bug numbers for all days sampled after treatment. At 2 DAT, all treatments had significantly lower numbers than the untreated control (F = 8.67; df = 13, 39; P < 0.0001) (Table 3). At 5 DAT, numbers of stink bugs in the imidacloprid, cyfluthrin, and acetamiprid treatments were not significantly different than in the control (F = 2.77; df = 13, 39; P = 0.007). At 8 DAT, numbers of stink bugs in the dinotefuran treatment at 0.10 kg ai ha^{-1} was also not significantly different than the untreated control.

When averaged over the 3 post treatment dates, there was a significant difference in total number of stink bugs among treatments (F = 9.91; df = 13, 39; P < 0.0001) (Table 3). The application of acephate, dicrotophos, dinotefuran, cyfluthrin, and oxamyl at

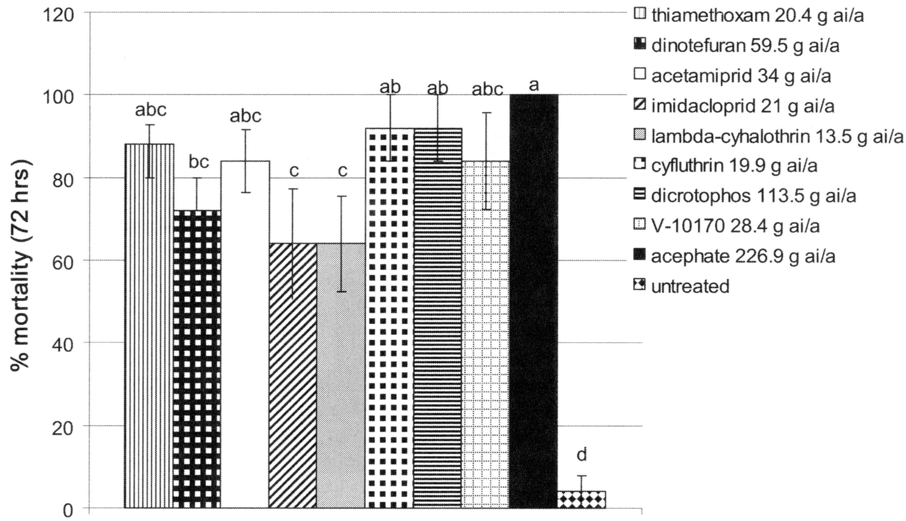

Fig. 2. **(2007) Mean ± SE (n = 25) percent mortality of *E. servus* adults collected from Havelock, NC after 72 h of exposure to treated green beans. Bars with a letter in common are not significantly different (P < 0.05)**

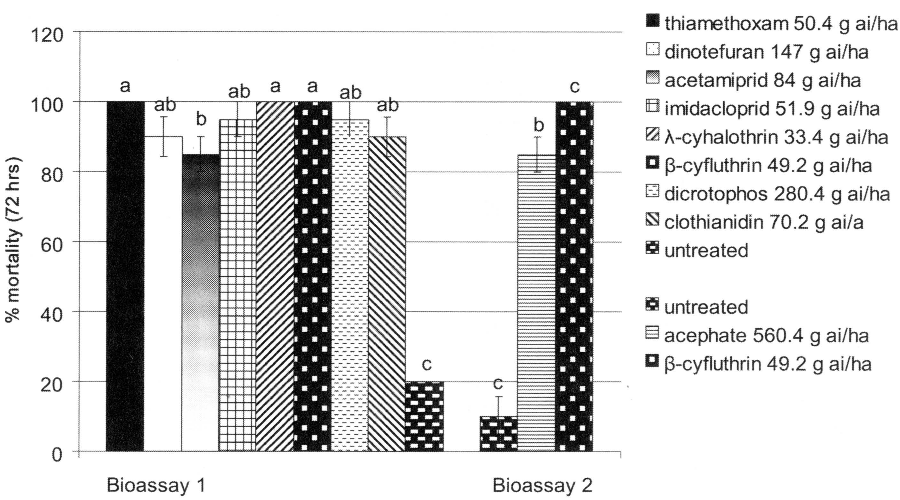

Fig. 3. **(2007) Mean ± SE (n = 20) percent mortality of 2 bioassays (assay 1 and assay 2) of *A. hilare* adults collected from Camden, NC after 72 h of exposure to treated green beans. Bars with a letter in common are not significantly different (P < 0.05)**

high rates had significantly fewer stink bugs than novaluron, a chitin inhibitor, at 0.07 kg ai ha^{-1} and acetamiprid at 0.05 kg ai ha^{-1} (Table 3). The tank mix of novaluron and acephate did not perform significantly better than acephate alone, though it did perform significantly better than novaluron at the higher rate.

2006 field efficacy trials. For both trials, the 2 most common species present were 90% *A. hilare* (28% nymphs and 72% adults) and 10% *E. servus* (75% nymphs and 25% adults). In Trial 1, all treatments except novaluron resulted in significantly lower stink bug numbers than the untreated control on all sample dates. Unlike results from 2005, dinotefuran and imidacloprid significantly decreased stink bug numbers at each DAT (Table 4). The numbered compounds GF-1796 and V-10191, and the chlorpyrifos and γ-cyhalothrin resulted in fewer stink bugs compared with the carbamate (oxamyl) at 0.28 kg ai ha^{-1}. Across all sample dates, all treatments performed significantly better than the untreated control. Dinotefuran at 0.04 kg ai ha^{-1} was found to be as efficacious as all pyrethroids and organophosphates evaluated and performed significantly better than the other neonicotinoids evaluated (Table 4). The least efficacious insecticides were imidacloprid and thiamethoxam at the 0.07 kg ai ha^{-1} and 0.06 kg ai ha^{-1}, respectively, followed by novaluron at 0.07 kg ai ha^{-1}.

In Trial 2, all insecticide treatments had significantly lower stink bug numbers at 3 and 6 DAT than the untreated control, except novaluron at 0.07 kg ai ha^{-1} (Table 5). These results were similar to the field efficacy trials in 2005 and 2006 (Trial 1). Only 3

Table 3. Mean number of stink bugs (70% *Acrosternum hilare* and 30% *Euschistus servus* adults and nymphs) in soybean after insecticide applications in Painter, VA, 2005*

		Mean number per 0.91 row meter beat sheet			
Material	kg ai ha^{-1}	2 DAT	5 DAT	8 DAT	Avg DAT
acephate	1.09	0.25 e	0.25 d	1.00 cd	0.50 e
dicrotophos	0.28	0.25 e	0.38 cd	1.00 cd	0.54 e
cyfluthrin	0.05	0.25 e	1.25 bcd	0.25 d	0.59 e
acetamiprid	0.05	1.25 cd	1.50 abc	1.50 bcd	1.42 bc
dinotefuran	0.10	0.25 e	0.88 cd	2.50 ab	1.21 cde
dinotefuran	0.15	0.25 e	1.13 cd	0.25 d	0.54 e
imidacloprid	0.06	0.50 de	1.5 abc	0.50 cd	0.84 cde
thiamethoxam	0.06	0.63 de	1.13 cd	1.25 bcd	1.00 cde
oxamyl	0.28	0.38 de	0.63 cd	0.88 cd	0.63 e
novaluron + acephate	0.04 + 0.54	0.75 cde	0.25 d	1.00 cd	0.65 de
novaluron	0.07	1.63 bc	0.75 cd	1.75 bc	1.38 cd
untreated	—	3.75 a	2.38 ab	3.75 a	3.29 a
LSD		1	1.23	0.14	0.72

*A total of 14 treatments were evaluated, but due to confidentiality agreements only 12 are reported.

Table 4. (Trial 1) Mean number of stink bugs (90% *Acrosternum hilare* and 10% *Euschistus servus* adults and nymphs) in soybean after insecticide applications in Camden, NC, 2006

		Mean number per 0.91 row meter beat sheet			
Material	kg ai ha^{-1}	2 DAT	4 DAT	7 DAT	Avg DAT
acephate	0.28	2.38 b-d	0.63 e	1.38 f-h	1.46 fg
dicrotophos	0.28	0.38 f	0.75 de	2.00 e-h	1.04 g
chlorpyrifos + γ-cyhalothrin	0.28 + 0.01	2.50 b-d	3.25 cd	2.00 e-h	2.58 d-f
bifenthrin	0.05	1.38 d-f	1.75 c-e	1.50 f-h	1.54 e-g
β-cyfluthrin	0.02	1.13 d-f	2.13 c-e	1.38 f-h	1.54 e-g
λ-cyhalothrin	0.03	0.25 f	0.75 de	0.63 gh	0.54 g
λ-cyhalothrin	0.05	1.00 d-f	1.25 de	0.25 h	0.83 g
dinotefuran	0.04	0.63 ef	2.25 c-e	2.25 e-g	1.71 e-g
imidacloprid	0.07	1.75 b-f	3.88 c	4.38 bc	3.33 cd
thiamethoxam	0.06	3.13 bc	4.13 c	4.13 b-d	3.79 c
oxamyl	0.28	1.50 c-f	3.00 c-e	3.63 c-e	2.71 c-e
novaluron	0.07	3.38 b	6.88 b	5.75 ab	5.33 b
GF-1796	0.50	1.63 c-f	2.63 c-e	3.13 c-f	2.46 d-f
V-10191	0.56	2.25 b-e	2.75 c-e	2.50 d-f	2.50 d-f
untreated	—	5.50 a	9.50 a	7.00 a	7.33 a
LSD		1.66	2.52	1.82	1.2

treatments were found to be effective at 10 DAT, the λ-cyhalothrin and thiamethoxam tank mix at 0.03 and 0.04 kg ai ha^{-1}, λ-cyhalothrin at 0.05 kg ai ha^{-1}, and the novaluron and dicrotophos tank mix at 0.03 and 0.28 kg ai ha^{-1}. Across all sample dates, all insecticides evaluated had significantly lower stink bug numbers when compared with the untreated control (Table 5). Dicrotophos at 0.28 kg ai ha^{-1} did not show a significant treatment effect when applied with novaluron at the 0.03, 0.04, or 0.07 kg ai ha^{-1}. However, the novaluron and dicrotophos tank mix treatments had significantly lower stink bug numbers than novaluron at 0.07 kg ai ha^{-1}.

Discussion

In general, results of field and laboratory trials were consistent in demonstrating the efficacy of selected pyrethroids, organophosphates, and neonicotinoids on the stink bugs, *A. hilare* and *E. servus*. Of the neonicotinoids evaluated, dinotefuran generally resulted in the highest mortality and acetamiprid the lowest. Results of the bioassays were consistent with Willrich et al. (2003) showing that the organophosphate acephate was numerically more toxic to *E. servus* adults than dicrotophos.

Table 5. (Trial 2) Mean number of stink bugs (90% *Acrosternum hilare* and 10% *Euschistus servus* adults and nymphs) in soybean after insecticide applications in Camden, NC, 2006

		Mean number per 0.91 row meter			
Material	kg ai ha^{-1}	3 DAT	6 DAT	10 DAT	AvgDAT
dicrotophos	0.28	1.25 c	0.75 d	1.50 ab	1.17 cd
λ-cyhalothrin	0.05	0.75 c	0.38 d	0.63 b	1.13 cd
λ-cyhalothrin	0.08	0.50 c	0.88 d	2.00 ab	0.58 d
thiamethoxam	0.06	3.13 b	3.38 b	3.00 a	3.17 b
λ-cyhalothrin + thiamethoxam	0.03 + 0.04	1.00 c	1.00 d	1.00 b	1.00 cd
novaluron	0.07	7.38 a	2.63 bc	1.88 ab	3.96 b
novaluron + dicrotophos	0.03 + 0.28	0.75 c	1.50 cd	0.88 b	1.04 cd
novaluron + dicrotophos	0.04 + 0.28	1.63 bc	1.00 d	2.75 a	1.79 c
novaluron + dicrotophos	0.07 + 0.28	1.25 c	0.38 d	2.63 a	1.42 cd
untreated	—	7.25 a	7.00 a	2.63 a	5.63 a
LSD		1.53	1.6	1.61	1

Acrosternum hilare nymphs were found to be more susceptible to the pyrethroids λ-cyhalothrin and cyfluthrin than *E. servus* adults. *Acrosternum hilare* nymphs were susceptible to all pyrethroids tested. *Acrosternum hilare* adults were highly susceptible to all pyrethroids tested, all organophosphates tested except acephate, and all neonicotinoids tested except acetamiprid. There may be differences between susceptibility of the life stages (Willrich et al. 2003) resulting in differences between the mortality of *A. hilare* nymphs and adults. In general, dinotefuran and clothianidin were toxic to *A. hilare* adults and nymphs, whereas thiamethoxam and acetamiprid were toxic to adult *E. servus*.

Data from field trials in soybean showed that all insecticides tested can provide control for up to 10 d. However, none of the treatments exhibited total control in the field due to possible reinvasion, natural fluctuations, or egg hatch which was not directly measured. The organophosphates and pyrethroids tended to be more effective than the neonicotinoid, acetamiprid, and the chitin inhibitor, novaluron. The field efficacy trials supported the assessment by Cullen and Zalom (2007) who showed that a pyrethroid and neonicotinoid mix is not more effective than a pyrethroid alone against *Euschistus conspersus* (Uhler). The chitin inhibitor, novaluron, did not prove to be as effective as most other treatments, unless tank-mixed with either acephate or dicrotophos. Three neonicotinoids evaluated in 2005, dinotefuran, imidacloprid, and thiamethoxam, and dinotefuran alone in 2006, were as efficacious as the organophosphates and pyrethroids. These results indicate that neonicotinoids offer an alternative for managing stink bugs that may fit with integrated pest management programs where conservation of natural enemies is a consideration.

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