The *Journal of Cotton Science 20:309–319 (2016)*
http://journal.cotton.org, © The Cotton Foundation 2016

ARTHROPOD MANAGEMENT

Efficacy of Spinetoram Against Thrips (Thysanoptera: Thripidae) in Seedling Cotton, *Gossypium hirsutum* L.

Melissa Willrich Siebert*, Steve Nolting, James E. Dripps, Larry C. Walton, Don R. Cook, Scott Stewart, Jeff Gore, Angus L. Catchot, Gus Lorenz, B. Rogers Leonard, Ames Herbert

ABSTRACT

A complex of thrips species infests seedling stage cotton, *Gossypium hirsutum* (L.), in the southern United States. Preventive control tactics are recommended to manage early season infestations, but foliar insecticides may be necessary to prevent injury for the duration of seedling development. The objective of this work was to compare efficacy of spinetoram to that of spinosad and current standard products, and to define the minimum effective spinetoram rate for satisfactory control of thrips. Foliar applied insecticides were applied with and without a surfactant against varying thrips infestation levels in field plots. Results demonstrated that infestations comprised primarily of tobacco thrip, *Frankliniella fusca* (Hinds), were more sensitive to spinetoram than spinosad at equivalent rates of active ingredient. Spinetoram applied at 13.0 to 26.0 g a.i./ha provided control comparable to commercial standards under moderate infestation levels. Consistency and numerical increases in efficacy were observed when applying spinetoram (13.0 g a.i./ha) with a surfactant. Efficacy of spinetoram at 13.0 g a.i./ha in combination with a surfactant was confirmed against onion thrips, *Thrips tabaci* (Lindeman), and in commercial scale plots. Spinetoram alone was not adequate for managing extremely high (>269 fold greater than a threshold of one thrip per plant) populations of tobacco thrips. These experiments demonstrate that spinetoram, applied at 13.0 to 26.0 g a.i./ha, has utility in the management of thrips infesting cotton seedlings.

A complex of thrip species infests seedling stage cotton, *Gossypium hirsutum* (L.), in the mid-southern and southeastern United States. These species include tobacco thrips, *Frankliniella fusca* (Hinds), flower thrips, *Frankliniella tritici* (Fitch), onion thrips, *Thrips tabaci* (Lindeman), western flower thrips, *Frankliniella occidentalis* (Pergande), and soybean thrips, *Neohydatothrips variabilis* (Beach) (Stewart et al., 2013). All species may be present on a cotton plant and proportions may vary each year, but the predominant species observed in most cotton fields is tobacco thrips (Cook et al., 2003; DuRant et al., 1994; Herbert, 2002; Stewart et al., 2013). Western flower thrips has been reported as a dominant species at some locations in Texas, Georgia, and South Carolina (Cook et al.; 2003; DuRant et al., 1994; Greenberg et al., 2009), which is important because it can be more damaging than tobacco thrips and is more difficult to control as a result of resistance to multiple insecticide classes (Faircloth et al., 2000; Gao et al., 2012; Zhao et al., 1995).

Cotton plants in the seedling stage are very sensitive to injury by thrips. Thrips feed on the surface of plant tissue and initially on cotyledon leaves, resulting in a silver or whitish appearance (Burris et al., 2000; Reed and Jackson, 2002). Feeding within the growing point causes deformation and stunting of the developing leaves and can kill apical buds if large populations are present (Leigh et al., 1996). Cotton plants are capable of surviving injury from thrips during the seedling stage and can initiate a new terminal bud if optimal growing conditions are present, but apical dominance can be lost and plant architecture altered due to excessive vegetative branching (Gaines, 1934).

M.W. Siebert, Dow AgroSciences LLC, 129 Bayou Rd, Greenville, MS 38701; S. Nolting and J.E. Dripps, Dow AgroSciences LLC, 9330 Zionsville Rd., Indianapolis, IN 46268; L.C. Walton, Dow AgroSciences LLC, 693 Walton Road SW, Tupelo, MS 38804; D.R. Cook and J. Gore, Delta Research and Extension Center, Mississippi State University, Box 197, Stoneville, MS 38776; S. Stewart, University of Tennessee, West Tennessee Research and Education Center, 605 Airways , Boulevard, Jackson, TN 38301; A.L. Catchot, Mississippi State University, Box 9775, Mississippi State, MS 39762; G. Lorenz, University of Arkansas, 2001 Highway 70 East, Lonoke, AR 72086; B.R. Leonard, Louisiana State University Agricultural Center, 104 J. Norman Efferson Hall, Baton Rouge, LA 70803-0106; and A. Herbert, Virginia Tech University, Tidewater Agricultural Research and Extension Center, 6321 Holland Road, Suffolk, VA 23437
*Corresponding author: mwillrichsiebert@dow.com

Plant height and leaf area are reduced, the initiation of reproductive stages is also delayed, and yield reductions can occur from injury sustained during the seedling stage of plant development (Burris et al., 1989; Carter et al., 1989; Cook et al., 2011; Rummel and Quisenberry, 1979,).

Preventive control tactics are commonly recommended to manage early season infestations of thrips in cotton (Cook et al., 2004; Lopez et al., 2008; Toews et al., 2010). At-planting treatment options applied as in-furrow granules or a liquid spray include aldicarb and acephate, respectively. Seed treatments using neonicotinoids (imidacloprid and thiamethoxam) have become the most common at-planting option due to ease of use and release of minimal active ingredient into the environment (Elbert et al., 2008; Smith et al., 2013; Willrich and Leonard, 2004). Although these treatments applied at planting offer systemic activity, they do not always protect cotton seedlings for the entire period during which infestations of thrips occur. Therefore, to prevent further injury, supplemental applications of foliar insecticides may be required. Additionally, efficacy of neonicotinoid seed treatments has declined against tobacco thrip in recent years in the mid-southern United States and significant cotton hectares have required applications of supplemental insecticides for control of thrips (Clarkson et al., 2014; Huseth et al., 2016; Vineyard et al., 2014,).

Common foliar insecticides for thrips control include acephate, dicrotophos, and dimethoate (Stewart et al., 2007). Although efficacious and economical, acephate does have the propensity to increase infestations of spider mites (Acari: Tetranychidae); cotton aphid, *Aphis gossypii* Glover; and western flower thrip (Catchot et al., 2016; Mailhot et al., 2007; O'Brien and Graves, 1992). Pyrethroid insecticides are not recommended for managing thrips because of the likelihood for secondary pest outbreaks, such as spider mites and cotton aphid (Catchot et al., 2016; Stewart et al., 2007). Use of broad spectrum insecticides, such as acephate and pyrethroid insecticides, cause disruption by suppressing the presence and numbers of predators that otherwise would suppress the development of pest infestations (Leigh et al., 1996). A few carbamate and organophosphate class insecticides are labelled, but are likely to encounter regulatory challenges that threaten their use patterns in cotton production. In August of 2010, the registrant for aldicarb, sold as Temik® brand insecticide/nematicide, agreed to cancel uses on potatoes and citrus, while uses on all other crops would be phased out in subsequent years. Aldicarb was, however, made available with a new registrant on a limited basis in Georgia for cotton and peanuts in 2016, but the molecule is currently under registration review (United States EPA, 2016). Alternative options for foliar insecticides with a large margin of safety, to include acceptable toxicological and environmental fate profiles and low application rates to minimize environmental loads, will be critical in the future for managing infestations of thrips in cotton.

Spinetoram is a semi-synthetic active ingredient representing the spinosyn chemical class of insecticides. This molecule has demonstrated higher levels of efficacy compared to that of spinosad against lepidopterous pests, thrips, and leafminers in a broad range of horticultural and agricultural crops. Spinetoram is a reduced-risk pesticide that has minimal impacts on beneficial arthropods and maintains the exceptional environmental and toxicological profile established for the spinosyn chemistry (Dripps et al., 2008, 2011; Sparks et al., 2008). The objectives of the following experiments were to 1) compare the efficacy of spinetoram to spinosad, 2) define the minimum effective rate of spinetoram required for satisfactory thrips control, and 3) characterize the influence of thrips infestation level and addition of a surfactant on resulting efficacy of spinetoram.

MATERIALS AND METHODS

Experimental Design for Small-Plot Trials. A series of experiments, each with defined objectives and unique treatments, were conducted across six states (Texas, Louisiana, Arkansas, Mississippi, Tennessee, and Virginia) and 11 locations in the southern United States during 2007 through 2010 to characterize the efficacy of spinetoram for control of thrips infesting cotton during the seedling stage. Trials were planted with cotton seed not treated with an insecticide seed treatment or without an in-furrow insecticide active against thrips. Plots were four rows on 101.6-cm centers and 6.0 to 12.2 m in length. Treatments were arranged in a randomized complete block design with four replications and applied to cotton plants at growth stages ranging from cotyledon stage to plants with two fully expanded leaves. Insecticide treatments were applied with either a tractor-mounted sprayer or a hand-held sprayer charged with CO_2 or compressed air calibrated to deliver 74.8 to 93.5 L/ha using flat fan nozzles (two per row). Treatments evaluated in the small-plot trials and specific locations across the four years of testing are discussed below.

At three to five d and six to eight d after application, five plants were randomly collected from the two center rows in each plot. Plants were processed using a whole-plant washing procedure and resulting thrips were enumerated under magnification (Burris et al. 1990). The species composition of thrips was estimated each year by identifying adult thrips to species within a single non-treated plot sample within a location. Tobacco thrips were the primary species infesting cotton in Louisiana, Arkansas, Mississippi, Tennessee, and Virginia. The range in percentage infestation by species was as follows: tobacco thrips (65.0 – 98.5%; mean 87.9%), western flower thrips (0.6-15.4%; mean 5.6%), flower thrips (0.5 – 9.8%; mean 4.6%), soybean thrips (2.0-12.5%; mean 10.5%), and onion thrips (5.0-15.0%; 10.0%). Only one trial was conducted in which tobacco thrips was not the dominant species and this was in Robstown, TX during 2008. The species composition was estimated to be 75% onion thrips, 15% flower thrips, and 15% western flower thrips.

Treatments Evaluated in Small-Plot Trials. A trial was conducted during 2007 near Greenville, MS (Washington County), with an objective of comparing efficacy of spinosad to spinetoram. The seven treatments evaluated included spinosad (Tracer® 4SC insecticide, Dow AgroSciences, LLC, Indianapolis, IN) applied at 50, 75, 100, 125, and 150 g a.i./ha; spinetoram (Radiant® 1SC insecticide, Dow AgroSciences, LLC, Indianapolis, IN) applied at 50 g a.i./ha; and a non-treated control.

In 2008, trials were conducted to evaluate the efficacy of a range of spinetoram rates against a complex of thrips comprised primarily of tobacco thrips with an objective of identifying a minimum effective rate required for control. The following five treatments were evaluated and included: spinetoram applied at 6.5, 9.75, 13, and 26 g a.i./ha, and a non-treated control. Seven trials were conducted under moderate levels of thrips infestations (mean of 2.4 to 11.6 thrips per plant in non-treated plots at the initial post treatment evaluation) and included the following locations: two trials in Holland, VA (City of Suffolk), one trial in Starkville, MS (Oktibbeha County), three trials in Stoneville, MS (Washington County), and one trial in Winnsboro, LA (Franklin Parish). Two trials were conducted under conditions of high levels of thrips infestation (mean of 53.8 to 114.5 thrips per plant in non-treated plots at the initial post treatment evaluation) and included the following locations: Greenville, MS (Washington County) and Winchester, AR (Drew County). A single trial also evaluated efficacy of spinetoram against onion thrips during 2008 in Robstown, TX (Nueces County). Five treatments including spinetoram applied at 6.5, 9.75, 13, and 26 g a.i./ha; dimethoate applied at 150.3 g a.i./ha (Dimethoate 4EC, Drexel Chemical Company, Memphis, TN); and a non-treated control.

Spinetoram, applied alone or in combination with a surfactant, was evaluated against thrips in nine trials from 2007 through 2009. Four treatments were evaluated including spinetoram applied at 13 and 26 g a.i./ha; a tank mixture of spinetoram (13 g a.i./ha) and a surfactant applied at 0.625% v/v (Dyne-amic, Helena Chemical Company, Collierville, TN; a blend of a highly refined methylated seed oil in combination with organosilicone-based nonionic surfactants); and a non-treated control. One trial was conducted in each year near Greenville, MS (Washington County), three trials were conducted during 2008 in Stoneville, MS (Washington County), and one trial was conducted during 2008 in each of the three locations: Jackson, TN (Madison County), Winchester, AR (Drew County), and Pine Bluff, AR (Jefferson County).

During 2007 through 2010, comparisons were made between spinetoram and standard insecticides. Eighteen trials were conducted across the following locations and years: St. Joseph, LA (Tensas Parish, 2010), Winnsboro, LA (2009, 2010), Pine Bluff, AR (2008), Winchester, AR (2008), near Greenville, MS (2007, 2008, and 2009), Stoneville, MS (2008, two trials in 2009, 2010), Starkville, MS (2008, two trials in 2009, 2010), Verona, MS (Lee County, 2008), and Jackson, TN (2008). Four treatments were evaluated and included a tank mixture of spinetoram (13 g a.i./ha) and a surfactant applied at 0.625% v/v (Dyne-amic, Helena Chemical Company, Collierville, TN); acephate applied at 224 g a.i./ha, (Orthene 90S, Valent U.S.A. Corporation, Walnut Creek, CA); dicrotophos applied at 224 g a.i./ha (Bidrin 8, Amvac, Los Angeles, CA); and a non-treated control.

Large-Plot Trials. Trials were conducted to compare a tank mixture of spinetoram (13 g a.i./ha) and a nonionic surfactant (0.625% v/v) to acephate applied at 224 g a.i./ha. Treatments were applied to cotton at approximately the two-leaf stage that had been planted with a seed treatment containing thiamethoxam (0.375 mg ai/seed). Treatments were individually applied to respective large blocks of cotton at each of three locations during 2010 [Clayton, LA (Concordia Parish); Eudora, AR (Chicot County), Milan, TN (Gibson County)]. Plots ranged from 36 to 60 rows on 96.5 to 101.6-cm centers and 122 to 305 m in length. Insecticide treatments were applied with a tractor-mounted sprayer charged with compressed air calibrated to deliver 93.5 L/ha using flat-fan nozzles (two per row). At five d after application, a sample of five plants was collected at each of five randomly selected locations within a treated plot at each location (trial) and processed as described above to assess the number of thrips immatures and adults.

Statistical Analysis. The response variable in all experiments was counts of thrips at fixed time intervals following insecticide applications. Treatments were arranged in a randomized complete block design and statistically analyzed using generalized linear mixed model analyses (Proc Glimmix, SAS Institute 2011). Goodness of fit testing indicated that the responses were overdispersed when modeled from a Gaussian or Poisson distribution; however, model fit improved when the counts were modeled from a negative binomial distribution. All models used methods that maximized the residual log pseudo-likelihood for estimations and Kenward Roger approximations for degrees of freedom estimation (SAS Institute 2011). In the large-plot trials, each location (trial) was considered a replication. The random factor for small-plot trials conducted in a single location was replication. For experiments analyzed across multiple trials, possible random factors included trial, trial by fixed effect and replication within trial; only random factors with nonzero covariance parameter estimates were included in the model. The actual model used for a particular data set is specified in the data tables.

A Tukey, or if the data were unbalanced, a Tukey-Kramer multiple comparison test was used to compare treatment means (option=Tukey, SAS Institute 2011). The one exception was the trial comparing spinosad to spinetoram where a Dunnett's test was used to compare each rate of spinosad tested to a reference spinetoram treatment applied at 50 g a.i./ha. All analyses and comparison of means were conducted at $\propto = 0.05$. Means and standard errors reported in tables are transformations of the means and standard error of the statistical output based on the ILINK option (Proc Glimmix, SAS Institute 2011).

RESULTS AND DISCUSSION

Spinosad has been widely used for the management of thrips (including western flower thrips, onion thrips, and *Scirtothrips* spp.) on fruiting and leafy vegetables, tree fruits, and ornamentals globally (Cloyd and Sadof, 2000; Dripps et al., 2011; Eger et al., 1998; Reitz and Funderburk, 2012). While management of thrips is important during early cotton development, spinosad has not been used due to the availability of more effective and economical alternative chemistries, including those applied as a foliar, an in-furrow liquid or granular material, or as a seed treatment. These experiments were conducted across the southern United States to characterize the efficacy of the more active spinosyn insecticide, spinetoram, against thrips in cotton. With greater importance placed on the incorporation of reduced-risk insecticides and fewer alternatives for managing thrips in cotton, these experiments were prompted to define the minimum effective rates of spinetoram that would be required for a cotton insect management program and to compare spinetoram to currently used foliar insecticides including acephate, dicrotophos, and dimethoate.

Comparing Activity of Spinosad and Spinetoram Against Thrips in Cotton. Mean numbers of thrips were significantly lower in plots treated with spinetoram (50 g a.i./ha) compared to the non-treated plots at both three and seven d after application. Numbers of thrips also were significantly lower in plots treated with spinetoram at both evaluation intervals compared to plots treated with spinosad (all rates, which ranged from 50 to 150 g a.i./ha) (Table 1). Spinetoram applied at 50 g a.i./ha was used as a comparison treatment because it aligns with the low boundary of the labeled rate range (52 to 88 g a.i./ha) for other labeled crops in which spinetoram is widely used commercially for control of thrips.

The results from this experiment suggests that infestations of thrips, comprised primarily of tobacco thrips, are more sensitive to spinetoram than spinosad at equivalent rates and that spinetoram may have greater utility for thrips control in cotton. Greater efficacy demonstrated here with spinetoram is consistent with comprehensive chemical structure-activity studies, which suggested that synthetic hydrogenation of a double bond in spinosyn components (J and L) would improve photostability (and, therefore, resulting residual control). The synthetic reduction of spinosyn component J was found to improve the overall level of intrinsic activity of the compound against target pests (Dripps et al., 2008). Spinetoram was the final compound that resulted from these two synthetic modifications, creating a mixture of spinosyn J and spinosyn L. These changes provided the opportunity to improve control of pests as compared to spinosad.

Table 1. Efficacy of a single foliar application of spinosad or spinetoram against thrips on seedling cotton grown in the absence of an insecticide seed treatment or an in-furrow insecticide[z,y]

Treatment (rate)	Mean ± SEM number of thrips larvae per 5 plants	
	3 d after application	7 d after application
Non-treated	157.0 ± 16.3* (P < 0.0001)	132.4 ± 26.1* (P < 0.0001)
Spinosad (50 g a.i./ha)	104.3 ± 11.2* (P < 0.0001)	80.3 ± 16.1* (P = 0.0002)
Spinosad (75 g a.i./ha)	85.5 ± 9.4* (P < 0.0001)	78.2 ± 15.7* (P = 0.0003)
Spinosad (100 g a.i./ha)	61.8b ± 7.1* (P < 0.0001)	55.0 ± 11.2* (P = 0.0091)
Spinosad (125 g a.i./ha)	41.5 ± 5.1* (P = 0.0089)	75.2 ± 15.1* (P = 0.0004)
Spinosad (150 g a.i./ha)	54.5 ± 6.4* (P = 0.0002)	59.3 ± 12.0* (P = 0.0043)
Spinetoram (50 g a.i./ha)	24.3 ± 3.4	27.2 ± 5.8

Means within columns followed by an asterisk are significantly different from spinetoram applied at 50 g a.i./ha based on Dunnett's test (*P* < 0.05).

[z] Tobacco thrips were the primary species infesting seedling cotton.

[y] Single trial conducted in Greenville, MS during 2007. Model effects at each evaluation date: fixed = treatment, random = replication.

Determination of Minimum Effective Spinetoram Rate for Control of Thrips in Cotton. Under conditions of moderate thrips infestations (comprised primarily of tobacco thrips), spinetoram applied at 13.0 and 26.0 g a.i./ha significantly reduced numbers of thrips compared to the non-treated control at three to five d after application (Table 2). There were no significant differences in numbers of thrips between spinetoram applied at lower rates (6.5 and 9.75 g a.i./ha) and the non-treated control. At six to eight d after application, there were no differences in mean numbers of thrips among the spinetoram treatments. However, numbers of thrips were significantly lower for plots treated with 26.0 g a.i./ha of spinetoram compared to the non-treated plots. Under conditions of high levels of thrips infestations (comprised primarily of tobacco thrip), there were no significant differences among treatments for mean numbers of thrips at three to five and at six to eight d after application.

Results from these experiments suggest that spinetoram applied at 13.0 to 26.0 g a.i./ha provides significant reductions of moderate thrips infestations on seedling cotton. Most cotton producing states recommended a treatment threshold of one thrip per plant, while other states have treatment thresholds for thrips ranging from two to five thrips per plant (Cook et al., 2011). Thrip densities in the experiments with moderate levels of infestation ranged from 11.8 to 58.1 times greater than the treatment threshold based on one thrip per plant and, with plants not receiving an at-planting insecticide, provided a robust testing scenario for evaluating spinetoram effectiveness on cotton seedlings. With high thrip densities (>269 fold greater than a threshold of one thrip per plant), a single application of spinetoram applied at rates ≤26.0 g a.i./ha was not adequate for thrips management. While it was not tested in these experiments, either higher rates (>26.0 g a.i./ha) or sequential applications may be required to manage high infestations occurring in commercial cotton fields.

Spinetoram applied at rates ≤50 g a.i./ha for thrips should be more effective in cotton compared with other labeled crops because of smaller plant size at the time of application, which should result in optimal coverage. The possible use of a lower rate of spinetoram for thrips in cotton would not necessarily increase the risk of resistance in other spinosyn-sensitive pests that infest cotton, such as Lepidoptera, because of the temporal separation between those pests in cotton. Thrip species that infest cotton also infest specialty crops that are commonly treated with spinosyn insecticides for thrips management, but at a labeled rate greater than required for seedling cotton. The risk of resistance in this case would also not be increased because specialty crops are not commonly grown in close proximity to cotton production areas. In both of these cases (Lepidoptera and thrips on specialty crops), the insect pests of concern are unlikely to be exposed to low rates of spinetoram.

Influence of a Surfactant Co-applied with Spinetoram. At three to five d after application, all of the insecticide treatments significantly reduced thrips densities (infestation comprised primarily of tobacco thrips) relative to the non-treated control (Table 3). There were no significant differences in mean number of thrips between spinetoram applied at 13.0 g a.i./ha, alone or in a combination with a surfactant, and spinetoram applied at 26.0 g a.i./ha. At six to seven d after application, there were no significant differences in mean numbers of thrips among the insecticide treatments. Spinetoram applied at 13.0 g a.i./ha with a surfactant significantly reduced thrips densities compared to the non-treated control. The results suggest that the addition of a surfactant to spinetoram may result in more consistent efficacy over time and at a lower rate than without the surfactant.

Table 2. Efficacy of a single foliar application of spinetoram against thrips on seedling cotton, grown in the absence of an insecticide seed treatment or an in-furrow insecticide[z]

Treatment	Mean ± SEM number of thrips larvae per 5 plants			
	Moderate Infestations (Mean ± SEM)[y]		High Infestations (Mean ± SEM)[x]	
	3 to 5 d[w]	6 to 8 d	3 to 5 d	6 to 8 d
Non-treated	18.7 ± 8.0a	35.8 ± 10.5a	398.8 ± 234.4	230.8 ± 112.8
6.5 g a.i./ha	12.2 ± 5.2ab	29.4 ± 8.7ab	147.6 ± 89.0	92.8 ± 45.4
9.75 g a.i./ha	9.6 ± 4.2ab	25.8 ± 7.6ab	157.7 ± 94.9	95.4 ± 46.5
13.0 g a.i./ha	7.2 ± 3.1b	29.5 ± 8.7ab	87.8 ± 52.9	54.8 ± 26.9
26.0 g a.i./ha	5.5 ± 2.4b	20.3 ± 6.2b	85.1 ± 51.3	33.6 ± 16.6
	$F = 5.39$, df = 4, 21.3 $P = 0.0037$	$F = 4.58$, df = 4, 85.9 $P = 0.0021$	$F = 1.52$, df = 4, 4.0 $P = 0.3475$	$F = 5.47$, df = 4, 3.9 $P = 0.0672$

Means within columns followed by the same letter are not significantly different ($P > 0.05$, Tukey).

[z] Tobacco thrips were the primary species infesting seedling cotton.

[y] Seven trials in moderate infestations (Starkville and Stoneville, MS, Winnsboro LA, and Holland, VA). Model effects at three to five d: fixed = treatment, random = trial, trial x treatment. Model effects at six to eight d: fixed = treatment, random = trial.

[x] Two trials in high infestations (Winchester, AR and Greenville, MS.) during 2008. Model effects at three to five d: fixed = treatment, random = trial, trial x treatment. Model effects at six to eight d: fixed = treatment, random = trial, trial x treatment, replication (trial)

[w] days after application.

Table 3. Influence of a surfactant, co-applied with spinetoram, for control of a complex of thrips in seedling cotton[z,y]

Treatment	Mean ±SEM number of thrips larvae per 5 plants	
	3 to 5 d[x]	6 to 7 d
Non-treated	43.5 ± 21.0a	108.3 ± 73.1a
Spinetoram (13.0 g a.i./ha)	14.10 ± 6.8b	63.0 ± 42.5ab
Spinetoram (13.0 g a.i./ha) + surfactant (0.625% v/v)	10.37 ± 5.0b	43.9 ± 29.6b
Spinetoram (26.0 g a.i./ha)	10.53 ± 5.1b	50.9 ± 34.4ab
	$F = 19.49$, df = 3, 24.7, $P = 0.0001$	$F = 3.80$, df = 3, 9.2, $P = 0.0497$

Means within columns followed by the same letter are not significantly different ($P > 0.05$, Tukey).

[z] Tobacco thrips were the primary species infesting seedling cotton.

[y] Nine trials conducted across Pine Bluff and Winchester, AR; Greenville and Stoneville, MS; and Jackson, TN during 2007 - 2009. Model effects at three to five d: fixed = treatment, random = trial, trial x treatment. Model effects at six to seven d: fixed = treatment, random = trial, trial x treatment, replication (trial).

[x] d after application.

Similar to the present experiments, Bueno et al. (2007) demonstrated that spinosad mixed with a surfactant significantly reduced infestations of *Liriomyza huidobrensis* (Blanchard) up to 50% when compared to spinosad at the same rate without the surfactant (polyether-polymethylsiloxane-copolymer). Palumbo (2002) demonstrated that the addition of a penetrating surfactant (crop oil concentrate) to spinosad resulted in greater mortality of leafminers, *Liriomyza* spp.; however, efficacy against Lepidoptera larvae and western flower thrips was not improved. Liu et al. (1999) demonstrated in a leaf residue bioassay with cabbage looper, *Trichoplusia ni* (Hübner) on cabbage (*Brassicae* spp.), that spinosad in combination with a surfactant (Dyne-amic) had greater residual activity compared to spinosad alone.

Spinosyns exhibit translaminar movement in leaves. Eger and Lindenberg (1998) suggested that the addition of penetrating surfactants might increase translaminar movement and result in higher insecticidal activity. Spinosyns have both contact and ingestion activity; therefore, insects must contact the treated leaf surface or ingest the treated tissue. Surfactants likely aid in leaf surface coverage and also penetration into the leaf or other cryptic feeding sites, thus optimizing exposure of both thrips adults and larvae.

Efficacy of a Minimum Effective Spinetoram Rate Against Infestations Comprised Primarily of Tobacco Thrips and Efficacy Against Onion Thrips. At three to five and six to seven d after application, numbers of tobacco thrips were not significantly different between spinetoram applied at 13.0 g a.i./ha with a surfactant and plots treated with acephate or dicrotophos (Table 4). For onion thrips at three d after application, only spinetroam applied at 13.0 and 26.0 g a.i./ha reduced densities relative to the non-treated control, whereas spinetoram applied at lower rates (6.5 and 9.75 g a.i./ha) and dimethoate were not different from the non-treated control (Table 5). At seven d after application, there were no differences in mean numbers of onion thrips among treatments (Table 5). Although the infestation level of onion thrips exceeded an action threshold, densities were lower as compared to other trials in which tobacco thrips were the predominant species.

Large Scale Trials. There were no significant differences in densities of adult thrips between plots treated with spinetoram applied with a surfactant (mean ± SEM: 3.0 ± 1.1) and plots treated with acephate (mean ± SEM: 1.7 ± 0.7) [F = 1.07, df = 1, 1.7, P = 0.4267; fixed effect = treatment, random effect = trial, trial x treatment]. Similarly, there were no significant differences in densities of immature thrips between plots treated with spinetoram applied with a surfactant (mean ± SEM: 2.9 ± 1.5) and plots treated with acephate (mean ± SEM: 6.2 ± 3.0) [F = 5.06, df = 1, 1.6, P = 0.1860; fixed effect = treatment, random effect = trial, trial x treatment]. These larger scale trials conducted on commercial fields provided confirmation for the small plot field-testing, in that 13.0 g a.i./ha of spinetoram (with a surfactant) provided control similar control to a recommended standard, and demonstrated the efficacy of spinetoram in a production system in which a seed treatment was used at-planting. At the Louisiana location, spider mites, *Tetranychus* spp., were observed to infest the plot treated with acephate beginning at 14 d after application and plant heights were visually reduced compared to the adjacent plot treated with spinetoram as result of injury sustained from the spider mite infestation.

Table 4. Influence of a surfactant, co-applied with spinetoram, for control of a complex of thrips in seedling cotton[z,y]

Treatment	Mean ±SEM number of thrips larvae per 5 plants[x]	
	3 to 5 d[3]	6 to 7 d
Non-treated	52.4 ± 13.1a	53.3 ± 14.4a
Spinetoram (13.0 g a.i./ha) + surfactant (0.625% v/v)	13.7 ± 3.4b	14.6 ± 4.0b
Acephate (224 g a.i./ha)	11.0 ± 2.8b	14.1 ± 3.9b
Dicrotophos (224 g a.i./ha)	12.1 ± 3.2b	14.9 ± 4.1b
	F = 31.97, df = 3, 43.4, P = 0.0001	F = 38.59, df = 3, 36.6, P = 0.0001

Means within columns followed by the same letter are not significantly different (P > 0.05, Tukey).

[z] Tobacco thrips were the primary species infesting seedling cotton.

[y] Eighteen trials conducted across St. Joseph and Winnsboro, LA; Pine Bluff and Winchester, AR; Greenville, Starkville, Stoneville, and Verona, MS; and Jackson, TN during 2007 – 2010. Model effects at each evaluation date: fixed = treatment, random = trial, trial x treatment, replication (trial).

[x] d after application.

Table 5. Efficacy of a single foliar application of spinetoram against onion thrips on seedling cotton, grown in the absence of an insecticide seed treatment or an in-furrow insecticide[z]

Treatment (rate)	Mean (±SEM) number of thrips larvae per 5 plants	
	3 d after application	7 d after application
Non-treated	19.2 ± 5.2a	4.3 ± 1.5
Spinetoram (6.5 g a.i./ha)	9.4 ± 2.8ab	3.0 ± 1.2
Spinetoram (9.75 g a.i./ha)	7.7 ± 2.3ab	2.0± 0.9
Spinetoram (13.0 g a.i./ha)	5.6 ± 1.8b	1.5 ± 0.7
Spinetoram (26.0 g a.i./ha)	4.8 ± 1.6b	2.5 ± 1.0
Dimethoate (150.3 g a.i./ha)	7.8 ± 2.4ab	2.5 ± 1.0
	F = 8.34, df = 5, 8.3, P = 0.0103	F = 0.72, df = 5, 14.9, P = 0.6207

Means within columns followed by the same letter are not significantly different (P > 0.05, Tukey).

[z] Single trial conducted in Robstown, TX during 2008. Model effects at each evaluation date: fixed = treatment, random = replication.

Although only a single location (trial) of the large-plot experiments observed spider mite infestations (mite flaring), it provides evidence that spinetoram, as a more selective insecticide, may have less of an impact on predators of spider mites that occur on cotton compared to some other standards. Natural enemies of spider mites on cotton include *Geocoris* spp. and *Orius* spp. (Cook et al., 2011; Wilson et al., 1991). *Orius insidiosus* (Say) is an important predator in cotton, and survival on spinosad-treated cotton in laboratory studies was similar to that on non-treated cotton in lab studies (Pietrantonio and Benedict, 1999). The selectivity of spinetoram and compatibility with key natural enemies, including *Orius* spp., has been confirmed in specialty crops (Srivastava et al., 2008). It should be noted that mite flaring was not observed within any of the small-plot trials and is likely due to the short duration of those experiments (≤ eight d), thus not allowing for secondary pest infestations to develop. Future experiments should be initiated to confirm the consistency at which spinetoram applications can prevent secondary spider mite infestations in cotton.

Results from four years of field testing have demonstrated that foliar applications of spinetoram at rates as low as 13.0 g a.i./ha can be used to effectively manage thrips infesting cotton seedlings. The experiments presented herein are the first to document the effectiveness of spinetoram against infestations comprised primarily of tobacco thrips and onion thrips, of which the former is the most widely distributed species across mid-southern and southeastern cotton production regions. Other thrips species were present in low proportions within the infestations tested and provide support for the efficacy of spinetoram against a population of thrips. Western flower thrips also infest and injure cotton and are problematic to control due to insecticide resistance, but infestations during this four-year series of experiments did not result in a location having a complex predominantly comprised of western flowers thrips. Chapman et al. (2012) demonstrated that spinetoram provided greater efficacy than other insecticides when the thrips complex on cotton was comprised of 30-40% western flowers thrips, which was more than previous years at that particular test site (and greater than the proportion estimated in the experiments presented here). In specialty crops, where western flower thrips are the predominant species, spinosyn insecticides have been cited as the most efficacious insecticides (Reitz and Funderburk, 2012).

Spinetoram will not provide control of thrips infestations that greatly exceed treatment thresholds on seedling cotton. Foliar applications of spinetoram will likely be most effective when used to supplement control of infestations that develop on cotton that received a preventive at-planting insecticide (in-furrow applied insecticide or seed applied insecticide). Infestations of thrips on cotton that received a preventive at-planting insecticide would not be expected to have high infestations. The results of these experiments also suggest that including a surfactant with spinetoram will optimize control.

A Federal Insecticide Fungicide and Rodenticide Act (FIFRA) Section 2(ee) recommendation supporting lower use rates (13.1 – 26.2 g a.i./ha) of spinetoram has been developed to support early season suppression of thrips on cotton for the states of

Alabama, Arkansas, Georgia, Louisiana, Mississippi, Missouri, North Carolina, South Carolina, Tennessee, and Virginia, and counties in Texas that produce cotton in the absence of vegetable crops (Crop Data Management Systems, 2016). The supplemental label is required because the lowest rate labeled on the FIFRA Section 3 federal registration for spinetoram on cotton is 24.5 g a.i./ha. The attributes and efficacy provided by spinetoram will have an excellent fit in foliar management programs for thrips on cotton seedlings and provides the opportunity to use an underexploited mode of action in cotton (Insecticide Resistance Action Committee Group 5).

ACKNOWLEDGEMENT

The authors gratefully acknowledge the efforts of our many colleagues at Dow AgroSciences, Louisiana State University AgCenter, Mississippi State University, University of Arkansas, University of Tennessee, Virginia Tech and private researchers who contributed to this project. ®™ Trademark of The Dow Chemical Company ("Dow") or an affiliated company of Dow.

REFERENCES

Bueno, A.F., A.C. Santos, G.R. Tofoli, L.A. Pavan, and R.C.O.F. Bueno. 2007. Reduction of spinosad rate for controlling *Liriomyza huidobensis* (Diptera: Agromyzidae) in dry beans (*Phaseolus vulgaris* L.) and its impact on *Frankliniella schultzei* (Thysanoptera: Thripidae) and *Diabrotica speciosa* (Coleoptera: Chrysomelidae). BioAssay 2:3 [Online]. Available at https://www.bioassay.org.br/bioassay/article/download/51/83 (verified 30 Jun. 2016).

Burris, E., K.J. Ratchford, A.M. Pavloff, D.J. Boquet, B.R. Williams, and R.L. Rogers. 1989. Thrips on seedling cotton: related problems and control. La. Agric. Expt. Stn. Bulletin No. 811. 19 pp.

Burris, E., A.M. Pavloff, B.R. Leonard, J.B. Graves, and G. Church. 1990. Evaluation of two procedures for monitoring populations of early season insect pests (Thysanoptera: Thripidae and Homoptera: Aphididae) in cotton under selected management strategies. J. Econ. Entomol. 83: 1064-1068.

Burris, E., C. Allen, R. Bagwell, D. Cook, B. Freeman, G. Herzog, G. Lentz, R. Leonard, and J. Reed. 2000. Thrips (Thysanoptera: Thripidae), a multi-state survey: summary of observations for Arkansas, Alabama, Georgia, Louisiana, Mississippi, and Tennessee. La. Agric. Exp. Stn. Research Information Sheet 103. 4 pp.

Catchot, A.L. C. Allen, J. Bibb, D. Cook, D. Dodds, J. Gore, T. Irby, E. Larson, B. Layton, J. MacGown, S. Meyers, and F. Musser. 2016. Cotton insect management, pp. 2-21. *In* Insect control guide for agronomic crops 2016. Mississippi State University Extension Service Pub. No. 2471. [Online] Available at https://extension.msstate.edu/sites/default/files/publications/publications/p2471_0.pdf. (verified 30 Jun. 2016)

Carter, F.L. N.P. Tugwell, J.R. Phillips, and M.J. Cochran. 1989. Thrips control strategy: effect on crop growth, yield, maturity and quality, pp. 295-297. *In* Proc. Beltwide Cotton Conferences, National Cotton Council, Memphis, TN.

Chapman, J.S., K.D. Emfinger, T.S. Williams, and B.R. Leonard. 2012. Efficacy of selected insecticides against thrips in cotton, 2011. Arthropod Management Tests, Vol. 37. doi: 10.4182/amt.2012.F33

Clarkson, D.L., G.M. Lorenz, N.M. Taillon, A.W. Plummer, B.C. Thrash, L.R. Orellana, M.E. Everett. 2014. The interaction of pre-emerge herbicides and insecticide seed treatments and its effects on early season cotton, pp. 778-781. *In* Proc. Beltwide Cotton Conferences, National Cotton Council, Memphis, TN.

Cloyd, R.E. and C.D. Sadof. 2000. Effects of spinosad and acephate on western flower thrips inside and outside a greenhouse. Hort. Tech. 10: 359-362.

Cook, D.R., C.T. Allen, E. Burris, B.L. Freeman, G.A. Herzog, G.L. Lentz, B.R. Leonard, and J.T. Reed. 2003. A survey of thrips (*Thysanoptera*) species infesting cotton seedlings in Alabama, Arkansas, Georgia, Louisiana, Mississippi, and Tennessee. J. Entomol. Sci. 38: 669-681.

Cook, D.R., B.R. Leonard, M.M. Willrich, J. Gore, and R.H. Gable. 2004. Residual toxicity of seed treatments and soil applied insecticides to tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), in cotton. J. Agric. Entomol. 20: 187-192.

Cook, D., A. Herbert, D.S. Akin, and J. Reed. 2011. Biology, crop injury, and management of thrips (Thysanoptera: Thripidae) infesting cotton seedlings in the United States. J. Integrated Pest. Management. 2(2); DOI: http://dx.doi.org/10.1603/IPM10024.

Crop Data Management Systems. 2016. Radiant® SC insecticide: 2(ee) recommendation, R-358-016 for early season suppression of thrips in cotton (various states). [Online] Available at http://www.cdms.net/ldat/ld8DN007.pdf. (verified 30 Jun 2016).

Dripps, J., B. Olson, T. Sparks, and G. Crouse. 2008. Spinetoram: how artificial intelligence combined natural fermentation with synthetic chemistry to produce a new spinosyn insecticide. Plant Health Progress [Online] Available at https://www.plantmanagementnetwork.org/pub/php/perspective/2008/spinetoram/ (verified 30 Jun 2016)

Dripps, J.E., R.E. Boucher, A. Chloridis, C.B. Cleveland, C.V. Deamicis, L.E. Gomez, D.L. Paroonagian, L.A. Pavan, T.C. Sparks, and G.B. Watson. 2011. Chapter 5, The Spinosyn Insecticides, pp. 163-212. In Green Trends in Insect Control, O. Lopez and J. G. Fernández-Bolaños [eds.], Royal Society of Chemistry, Cambridge, UK.

DuRant, J.A., M.E. Roof, and C.L. Cole. 1994. Early season incidence of thrips (*Thysanoptera*) on wheat, cotton, and three wild host plant species in South Carolina. J. Agric. Entomol. 11: 61-71.

Eger, J.E. and L.B. Lindenberg. 1998. Utility of spinosad for insect control in Florida vegetables. Proc. Fla. State Hort. Soc. 111:55-57.

Eger, J.E., J. Stavisky, and J.E. Funderburk. 1998. Compartive toxicity of spinosad to *Frankliniella* spp (*Thysanoptera: Thripidae*), with notes on a bioassay technique. Florida Entomologist 81: 547- 551.

Elbert, A., M. Haas, B. Springer, W. Thielert, and R. Nauen. 2008. Applied aspects of neonicotinoid uses in crop protection. Pest Management Sci 64: 1099.

Faircloth, J., J.R. Bradley, Jr., and J. Van Duyn. 2000. Reproductive success and damage potential of tobacco thrips and western flower thrips on cotton seedlings, pp. 1108-1111. In Proc. Beltwide Cotton Conferences, National Cotton Council, Memphis, TN.

Gaines, J.C. 1934. A preliminary study of thrips on seedling cotton with special reference to the population, migration, and injury. J. Econ. Entomol. 27: 740-743.

Gao, Y., Z. Lei, and S.R. Reitz. 2012. Western flower thrips resistance to insecticides: detection, mechanisms and management strategies. Pest Management Sci. 68: 1111-1121.

Greenberg, S.M., T-X Liu, and J.J. Adamczyk. 2009. Thrips (*Thysanoptera: Thripidae*) on cotton in the Lower Rio Grande Valley of Texas: species composition, season abundance, damage, and control. Southwestern Entomologist 34: 417-430.

Herbert, D.A., Jr. 2002. Yield protection strategies for thrips in Virginia cotton. CD-ROM H046.pdf. In Proc. Beltwide Cotton Conferences, National Cotton Council, Memphis TN.

Huseth, A.S., T.M. Chappell, K. Langdon, S.C. Morsello, S. Martin, J.K. Greene, A. Herbert, A.L. Jacobson, F.P. F. Reay-Jones, T. Reed, D.D. Reisig, P.M. Roberts, R. Smith, and G.G. Kennedy. 2016. *Frankliniella fusca* resistance to neonicotinoid insecticides: an emerging challenge for cotton pest management in the Eastern United States. Pest Manag. Sci. (In press).

Leigh, T.F., S.H. Roach, and T.F. Watson. 1996. Biology and ecology of important insect and mite pests of cotton, pp. 17-162. *In* E.G. King, J.R. Phillips, and R.J. Coleman [eds.], Cotton insects and mites: characterization and management. The Cotton Foundation Publisher, Memphis, TN.

Liu, Tong-Xian, Sparks, A.N., Hendrix, W.H., and B. Yue. 1999. Effects of SpinTor (spinosad) on cabbage looper (*Lepidoptera: Noctuidae*): Toxicity and persistence of leaf residue on cabbage under field and laboratory conditions. J. Econ. Entomol. 92(6): 1266-1273.

Lopez, J.D., Jr., B.K. Fritz, M.A. Latheef, Y. Lan, D.E. Martin, and W.C. Hoffman. 2008. Evaluation of toxicity of selected insecticides against thrips on cotton in laboratory bioassays. J. Cotton. Sci. 12: 188-194.

Mailhot, D., J. Marois, and D. Wright. 2007. Species of thrips associated with cotton flowers. J. Cotton Sci. 11: 186-198.

O'Brien, P.J. and J.B. Graves. 1992. Insecticide resistance and reproductive biology of *Aphis gossypii* Glover. Southwestern Entomologist 17: 115-122.

Palumbo, J.C. 2002. The effects of adjuvants on the insecticidal activity of Success (spinosad) on lettuce and melons. 2002 Vegetable Report, University of Arizona College of Agriculture and Life Sciences. [Online] Available at http://extension.arizona.edu/sites/extension.arizona.edu/files/pubs/az1292_2h.pdf (verified 30 Jun. 2016).

Pietrantonio, P.V. and Benedict, J.H. 1999. Effect of new cotton insecticide chemistries, tebufenozide, spinosad and chlorfenapyr, on *Orius insidious* and two *Cotesia* species. Southwestern Entomologist 24(1): 21 -29.

Reed, J.T. and C.S. Jackson. 2002. Thrips on Mississippi seedling cotton: pest overview and 15-year summary of pesticide evaluation. Miss. Agric. Forestry Exp. Stat. Bull. No. 1124. 30 pp.

Reitz, S. R. & J. Funderburk. 2012. Management strategies for western flower thrips and the role of insecticides, pp 355 – 384. *In* F. Perveen (ed.) Insecticides - Pests Engineering. InTech, Rijeka, Croatia.

Rummel, D.R. and J.E. Quisenberry. 1979. Influence of thrips injury on leaf development and yield of various cotton genotypes. J. Econ. Entomol. 72: 706-709.

SAS Institute Inc. 2011. SAS/STAT User's Guide, version 9.3. SAS Institute Inc., Cary, NC.

Smith, J.F., A.L. Catchot, F.R. Musser and J. Gore. 2013. Effects of aldicarb and neonicotinoid seed treatments on twospotted spider mites in cotton. J. Econ. Entomol. 106 (2): 807-815.

Sparks, T.C., G.D. Crouse, J.E. Dripps, P. Anzeveno, J. Martynow, C.V. DeAmicis, and J. Gifford. 2008. Neural network-based QSAR and insecticide discovery: spinetoram. J. Comput Aided Mol Des 22: 393-401.

Srivastava, M., L. Bosco, J. Funderburk, S. Olson, S. and A. Weiss. 2008. Spinetoram is compatible with the key natural enemy of *Frankliniella* species thrips in pepper. Plant Health Progress [Online]. Available at http://www.plantmanagementnetwork.org/pub/php/research/2008/pepper/ (verified 30 Jun. 2016).

Stewart, S.D., G.M. Lorenz, K.L. Willis, B.A. Hanks, S.J. Steckel, C.K. Colwell. 2007. Thrips control in seedling cotton, pp. 1654-1658. *In* Proc. Beltwide Cotton Conferences, National Cotton Council, Memphis, TN.

Stewart, S. D., D. S. Akin, J. Reed, J. Bacheler, A. Catchot, D. Cook, J. Gore, J. Greene, A. Herbert, R. E. Jackson, D. L. Kerns, B. R. Leonard, G. M. Lorenz, S. Micinski, D. Reisig, P. Roberts, G. Studebaker, K. Tindall and M. Toews. 2013. Survey of thrips species infesting cotton across the southern US Cotton Belt. J. Cotton Sci. 17: 263-269. https://www.cotton.org/journal/2013-17/4/263.cfm

Toews, M.D., R.S. Tubbs, D.Q. Wann, and D. Sullivan. 2010. Thrips (*Thysanoptera: Thripidae*) mitigation in seedling cotton using strip tillage and winter cover crops. Pest Manag. Sci. 66: 1089-1095.

United States EPA. 2016. Draft human health and ecological risk assessments: aldicarb, bensulide, coumaphos, ethalfluralin, and pirimiphos-methyl registration review. [Online] Available at https://www.regulations.gov/document?D=EPA-HQ-OPP-2012-0161-0020 (verified 30 Jun. 2016)/

Vineyard, C., S. Stewart, L. Steckel, and H. Kelly. 2014. The effects of pre-emergence herbicides on neonicotinoid seed treatments in seedling cotton, p. 777. *In* Proc. Beltwide Cotton Conferences, National Cotton Council, Memphis, TN.

Willrich, M.M. and B.R. Leonard. 2004. Seed Treatments: An Alternative Pesticide Delivery System for Managing Early Season Stink Bugs in Field Corn. La. Agric. 47.

Wilson, L.T., P.J. Trichilo, and D. Gonzales. 1991. Natural enemies of spider mites (*Acari: Tetranychidae*) on cotton: density regulation or casual association? Environ. Entomol. 20: 849-856.

Zhao, G., W. Liu, J.M. Brown, and C.O. Knowles. 1995. Insecticide resistance in field and laboratory strains of western flower thrips (*Thysanoptera: Thripidae*). J. Econ. Entomol. 88: 1164-1170