Patterns of Insecticide Resistance in Onion Thrips (Thysanoptera: Thripidae) in Onion Fields in New York

A. M. SHELTON,[1] J.-Z. ZHAO, B. A. NAULT, J. PLATE, F. R. MUSSER,[2] AND E. LARENTZAKI

Department of Entomology, Cornell University, New York State Agricultural Experiment Station, 630 W. North Street, Geneva, NY 14456.

J. Econ. Entomol. 99(5): 1798–1804 (2006)

ABSTRACT To develop an insecticide resistance management program for onion thrips, *Thrips tabaci* Lindeman (Thysanoptera: Thripidae), on onions (*Allium* spp.), we surveyed populations in commercial onion fields in New York and evaluated their susceptibility to the two most widely used classes of insecticides plus two new insecticides during 2003–2005. All insecticide evaluations were conducted using the Thrips Insecticide Bioassay System (TIBS). As in our surveys conducted during 2002–2003, there were large temporal and spatial variations in susceptibility to the pyrethroid λ-cyhalothrin (Warrior) across onion-growing regions in 2003. New data indicate that the field rate of methomyl (Lannate LV) still provides control but that the genes for resistance to methomyl are present in some populations. Tests with the two new insecticides, acetamiprid (Assail 70 WP) and spinosad (SpinTor 2CS), indicated they provided >85% mortality at the field rate. To determine the spatial variation in insecticide susceptibility within a region, a series of systematic assays were conducted with λ-cyhalothrin and methomyl. In 2004 and 2005, our data indicated that the within-region spatial variation in susceptibility to λ-cyhalothrin was not large at the field rate or for the 100 ppm rate of methomyl. In 2005, a year in which *T. tabaci* densities in most fields were much higher than in 2004, growers were unable to control *T. tabaci* in particular fields and attributed this lack of control to resistance. Yet, we found similar levels of high susceptibility in all fields when using TIBS. This finding suggests that resistance had not developed and that variation in control may have been due to other factors, such as localized higher populations, poor spray coverage, too much time between spray applications, or different onion varieties.

KEY WORDS onion thrips, insecticide resistance, *Allium cepa*

Onion thrips, *Thrips tabaci* Lindeman (Thysanoptera: Thripidae), is a key insect pest of onion and other *Allium* species in many parts of the world (Lewis 1997), including New York where ≈5,300 ha is grown annually (NYASS 2004). In New York, there are five distinct regions (Fig. 1) where onions are grown, and annually 100% of the onion fields become infested with *T. tabaci.* Unlike regions in Texas and Georgia where western flower thrips, *Frankliniella occidentalis* (Pergande), and tobacco thrips, *Franklinella fusca* (Hinds), respectively, are the major thrips species attacking onion, *T. tabaci* seems to be the only thrips species that reaches damaging levels in New York. Sticky traps placed in onion fields in New York capture very low levels of the two *Franklinella* spp., but we have not found them colonizing plants in the field. We speculate that the parthogenetic mode of reproduction and the foliar-feeding (rather than pollen-feeding) habits provide *T. tabaci* with an ecological advantage over the other species. Adult and larval stages of *T. tabaci* feed on leaves and may reduce onion yield up to 50% (Fournier et al. 1995). Recently, *T. tabaci* has been reported to transmit Iris Yellow Spot virus (family *Bunyaviridae*, genus *Tospovirus*) that has emerged as a devastating and widespread disease affecting bulb onion crops in Colorado, Utah, Idaho, Washington, California, Arizona, New Mexico, and Nevada (Gent et al. 2004).

T. tabaci is especially problematic during hot, dry years because of the higher numbers of generations produced and the decreased mortality due to lack of rainfall (Lewis 1997, Shelton et al. 2003). In such years, some New York growers may apply insecticides weekly from the seedling stage in June until the onions begin to dry down in August. Such intense use of insecticides has led to resistance to the pyrethroid insecticide λ-cyhalothrin (Warrior) in several growing regions of New York (Shelton et al. 2003) and in neighboring Ontario, Canada (Allen et al. 2005). Furthermore, our research has indicated that levels of resistance in individual fields may change during the season, although it is not clear whether this change is

---

[1] Corresponding author, e-mail: ams5@cornell.edu.

[2] Current address: Department of Entomology and Plant Pathology, Mississippi State University, Mississippi State, MS 39762.

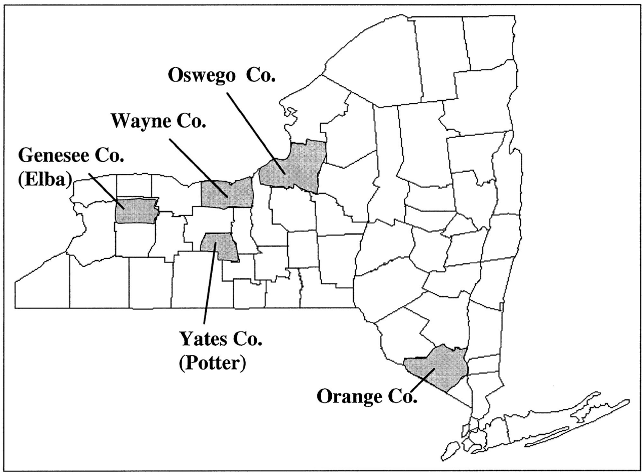

Fig. 1. Major onion-growing regions of New York. Total onion production area is 5,300 ha.

due to the evolution of resistance within the existing population as a result of individual grower practices or to the movement of populations into the field from other habitats (North and Shelton 1986), or a combination of these factors (Shelton et al. 2003). Regardless, the development of resistance to λ-cyhalothrin presents serious challenges to growers, because it is the most commonly applied insecticide against *T. tabaci,* with 85% of the onion fields in New York receiving one or more applications in 2004 (NASS 2005).

Resistance to λ-cyhalothrin in New York was documented using the Thrips Insecticide Bioassay System (TIBS), which uses an insecticide-treated 0.5 ml microcentrifuge tube (Shelton et al. 2003). As we developed more confidence in the results from our TIBS assays for λ-cyhalothrin, beginning in 2002 we provided the information directly to growers. Many growers altered their choice of insecticide based on the data we provided about λ-cyhalothrin, especially when our data indicated high levels of resistance. However, we did not have information on the susceptibility of their populations to the next most commonly used insecticide, methomyl, or to any organophosphates. Because carbamates and organophosphates are acetylcholinesterase inhibitors, from an insecticide resistance management (IRM) standpoint they can be considered a single class of insecticides based on their common target site. Besides these classes of insecticides that have national registration for use against *T. tabaci* on onions, two other classes are being developed for thrips management in onions. Spinosad (SpinTor 2 SC) is the first member of the Naturalyte class of insecticides containing secondary metabolites produced by S*accharopolyspora spinosa* Mertz & Yao, and it has a unique mode of action (Thompson et al. 2000). Spinosad has been registered on many crops for control of Lepidoptera, beetles, leafminers, and some species of thrips (since 2003, it has had a state label for *T. tabaci* on onions in Texas and in May 2006, it received a national registration). Acetamiprid (Assail 70 WP) is a second generation chloronicotinyl (neonicotinoid) insecticide, with a different mode of action from the other previously mentioned classes. It is considered to be a broad-spectrum, reduced-risk insecticide and is registered on many crops for chewing and sucking insects. Together, these two insecticides may provide new opportunities for control of *T. tabaci* on onions. However, before their widespread use, it is important to gather baseline data on their effectiveness and determine whether our existing monitoring technique (TIBS) would work with spinosad and acetamiprid.

Besides the assay method itself, it is important to know that the insects selected for the assay are representative of the field population as a whole. In *T. tabaci,* systematic sampling of commercial onion fields through time indicated that *T. tabaci* populations are initially aggregated along field borders but that they become more uniformly distributed throughout the field as the season progresses (Shelton et al. 1987). However, this pattern may not represent the distributional pattern for resistance. Because of the parthenogenetic mode of reproduction of *T. tabaci,* their ability to produce a generation in <2 wk, and reduced emigration when on a suitable host, it is likely that "hot spots" for resistance may occur and serve as foci for the spread of resistance alleles. Thus, for the early detection and management of resistance one should evaluate the variation in susceptibility not only on a temporal basis but also on a spatial basis.

The objectives of this study were to use TIBS to evaluate the susceptibility to λ-cyhalothrin and methomyl of *T. tabaci* populations in commercial fields in New York, to determine the spatial pattern of susceptibility to these two insecticides within and between fields in a region, and to assess whether TIBS could be used to develop baseline data on susceptibility to two new insecticides.

Materials and Methods

Insecticides and Bioassay for Identifying Thrips Susceptibility. All assays were performed using TIBS, a method developed by Rueda and Shelton (2003) but modified slightly by Shelton et al. (2003) when documenting resistance to λ-cyhalothrin in New York. Insecticides included two labeled products, Warrior (λ-cyhalothrin, Syngenta Crop Protection, Inc., Greensboro, NC) and Lannate LV (methomyl, DuPont, Wilmington, DE), and two products that are anticipated to become useful in the future, Assail 70 WP (acetamiprid, Cerexagri-Nisso, LLC, King of Prussia, PA) and SpinTor 2CS (spinosad, Dow AgroSciences, Indianapolis, IN). Vials were treated with a solution containing one of these insecticides diluted with water and to which was added Bond spreader/sticker (Loveland Industry, Loveland, CO) at 2%. This spreader sticker also was added to the water control. For all trials, *T. tabaci*-infested onion plants were collected randomly from commercial fields and returned to our laboratory where second instars of similar size were removed from the plants and used in the bioassays. Control mortality in our tests was $<5\%$.

2003 Tests with Methomyl and λ-Cyhalothrin. During the 2003 growing season, populations of *T. tabaci* were collected at two periods (mid-season and late season) from eight commercial onion fields encompassing the major onion-growing areas of New York. In a ninth field, a single collection was made at mid-season. We collected at least 10 plants per site at >10 randomly selected sites per field. When plants were returned to the laboratory, we collected ≤ 10 *T. tabaci* from any one plant for the assays. For each collection, we tested the populations against λ-cyhalothrin at the recommended field dose of 100 ppm. This decision was based on our previous studies, which indicated poor control of thrips when LC_{50} values were >100 ppm (Shelton et al. 2003). For methomyl, we used the recommended field rate (3600 ppm) and a rate of 100 ppm, because preliminary tests on several populations indicated nearly 100% mortality with the field rate. We felt the 100 ppm rate would differentiate populations and provide an indication of the presence of resistance alleles. We used five replicates of each dose with 20 thrips per replicate, and percentage of mortality was corrected using Abbott's formula (Abbott 1925).

2005 Tests with Methomyl, λ-Cyhalothrin, and Spinosad. A single collection was made during mid-season in eight commercial onion fields by using procedures outlined above for 2003. Assays for methomyl and λ-cyhalothrin also were performed as in 2003, except we used a single dose of 100 ppm for each. The decision to use a single dose for methomyl was based on our desire to assess whether there were differences between populations at a dose insects would be exposed to on different parts of the plant (although a single dose may leave the nozzle, there will be a mosaic of doses on the plant due to spray patterns and residue declines). Based on the TIBS data for methomyl from 2003, only one population displayed $<90\%$ mortality at 3,600 ppm (compared with 14 populations at 100 ppm), so we concluded using 100 ppm was a reasonable choice to differentiate populations. For spinosad and acetamiprid, we used the field rates of 308 and 296 ppm, respectively to obtain baseline data on susceptibility.

Additional Tests with Spinosad and Acetamiprid. In 2003 and 2004, five populations of *T. tabaci* were collected from two onion-growing regions and subjected to a complete dose–mortality assay for spinosad. We selected six to seven doses that we assumed, based on preliminary studies, would encompass a mortality range of ≈10–90%, plus an untreated control. We used five replicates of each dose with 20 thrips per replicate (vial). A dose of 308 ppm was always included because this amount is equivalent to a recommended field rate.

In 2003 and 2005, seven populations of *T. tabaci* were collected from four onion-growing regions and subjected to a single dose (field rate of 296 ppm) of acetamiprid (sufficient numbers of larvae were not available for a complete dose–mortality assay). Procedures were identical to those used for the single doses noted above.

Patterns of Spatial Distribution. In 2004 and 2005, we examined the spatial variation in susceptibility to λ-cyhalothrin and methomyl using a single rate of 100 ppm for each insecticide. In 2004, we examined three large commercial onion regions (Potter, Elba, and Orange), each region encompassing dozens of onion fields and covering ≈120 ha. In each region, we selected fields managed by a single grower by using the same insecticides and timing. In each region, from 23 to 53 equally spaced (33-m) sites were selected and, ≈15 plants per site (3-m radius) were removed, bagged, and then returned to the laboratory where assays were performed as described above. Assays were first performed with λ-cyhalothrin, and, if there were sufficient numbers of thrips, then methomyl.

In 2005, we examined two regions, one ≈100 ha (Potter) and the other ≈850 ha (Elba). The Potter region consisted of a single block of onions, and we selected 25 equally spaced sites that encompassed the block. At each site, we selected three subsites within a 3-m radius, thus providing 25 sites and 75 subsites. In the Elba region, there were ≈25 fields within the 850 ha, and we selected eight fields. In each field, we selected three sites (two toward the ends and one near the center), and then we selected three subsites within a 3-m radius of the site, thus providing 24 sites and 72 subsites. In both regions at each subsite about five plants were removed, bagged, and then returned to the laboratory where TIBS assays were performed as described above. In the Potter and Elba regions, each grower managed all the areas from which we sampled and did so using the same insecticide and frequency of application. However, the growers indicated that they had variable success in some fields or parts of field. For example, the Elba grower claimed that he had differential success in 2005 with poor control in four of the fields, moderate control in two fields, and good control in two fields. He attributed these differences to insecticide resistance.

Table 1. Mortality of onion thrips to two insecticides in different regions of New York, 2003

Region	% mortality (SEM)					
	Warrior (λ-cyhalothrin)		Lannate LV (methomyl)			
	100 ppm (field rate)		100 ppm		3,600 ppm (field rate)	
	Mid-season	Late season	Mid-season	Late season	Mid-season	Late season
Elba1	28.1 (9.4)cd		95.8 (2.7)a		99.0 (1.1)a	
Elba2	70.8 (4.3)ab	48.9 (6.8)ab*	91.8 (3.5)a	81.9 (7.5)ab	96.9 (2.0)a	97.9 (1.3)ab
Orange1	27.8 (7.6)cd	67.0 (7.0)ab*	24.5 (5.7)b	29.8 (5.7)cd	99.0 (1.0)a	100.0 (0)a
Orange2	27.1 (7.2)cd	10.2 (5.3)cd	26.6 (9.0)b	49.0 (8.9)bc	100.0 (0)a	81.9 (4.9)c*
Orange3	80.9 (6.9)ab	6.1 (3.8)d*	5.2 (2.6)b	9.5 (2.0)d	94.8 (3.3)a	95.8 (1.3)ab
Oswego1	6.3 (3.9)d	35.1 (12)bc*	27.6 (8.3)b	87.6 (6.7)a*	98.0 (1.2)a	100.0 (0)a
Oswego2	90.6 (3.0)a	81.3 (2.7)a	72.4 (8.6)a	92.4 (3.3)a	98.0 (2.0)a	100.0 (0)a
Potter1	52.6 (12.0)bc	59.8 (2.5)ab	87.4 (6.1)a	46.9 (9.1)c*	97.9 (1.3)a	91.7 (2.7)bc
Potter2	48.5 (5.9)bc	78.4 (3.0)a*	87.4 (5.4)a	92.8 (3.9)a	98.9 (1.1)a	100.0 (0)a

Mean ± SEM within a column followed by same letters are not significantly different ($P > 0.05$; HSD).

* Significant difference between mid- and late season for an insecticide–concentration–field combination ($P < 0.05$; HSD).

Statistical Analysis. Percentage of mortality in all tests was corrected using Abbott's formula (Abbott 1925). The POLO program was used for probit analysis of dose–response data (Russell et al. 1977, LeOra Software 1997). SAS programs were used for analysis of variance (ANOVA) (SAS Institute 2003) to determine susceptibility differences among regions and between seasons. Mortality data were transformed using arcsine (x) before each ANOVA was performed. Treatment means were compared and separated by Tukey's studentized range (honestly significant difference [HSD]) test.

Correlation analysis was used to determine whether a positive relationship existed between percentage of mortality of onion thrips exposed to λ-cyhalothrin and methomyl. Analyses were conducted separately for the 2003 mid-season and late season data sets by using the procedure PROC GLM in SAS at $P < 0.05$ (SAS Institute 2003). Evidence of a significant positive relationship would indicate the possibility of cross-resistance in New York onion thrips populations between these products.

The variation in thrips susceptibility to λ-cyhalothrin and to methomyl between sites and between subsites was examined by calculating the intracluster correlation coefficient, ρ. This statistic provides a measure of relatedness of clustered data by comparing the variance between sites with the variance within sites. The equation below was used to calculate ρ:

$$\rho = s_b^2 / (s_b^2 + s_w^2)$$

where s_b^2 is the variance between clusters and s_w^2 is the variation within clusters. The values for ρ range from 0 to 1. If the value for ρ is near 1, there is little variation within clusters. In contrast, if the value for ρ is near 0, the variation between clusters is small.

Results

2003 Tests with Methomyl and λ-Cyhalothrin. During mid-season across all fields, the mortality to λ-cyhalothrin ranged from 6.3 to 90.6% (Table 1). Within a region, there was considerable variation in mortality in the Oswego region (6.3–90.6%), but little difference in the Potter region (48.5–52.6%). Between sampling times for λ-cyhalothrin, some populations decreased in susceptibility (e.g., Orange3 went down from 80.9 to 6.1%), increased in susceptibility (e.g., Orange1 went up from 27.8 to 67%), or remained similar. *T. tabaci* populations displayed similar variation in percentage of mortality to methomyl at 100 ppm over both time periods (5.2–95.8%), with some populations changing between sample periods. In contrast, less variation was seen for methomyl at the field rate of 3,600 ppm (71.9–100%) for either sample time. These results indicate that methomyl can still provide control but that genes for resistance to methomyl and λ-cyhalothrin are present in some populations of *T. tabaci.*

There was no relationship between percentage of mortality of *T. tabaci* populations exposed to λ-cyhalothrin and methomyl during either mid-season ($F = 0.29$; df = 1, 7; $P = 0.60$) or late season ($F = 2.52$; df = 1, 6; $P = 0.16$), indicating that cross-resistance between these products did not occur.

2005 Tests with Methomyl, λ-Cyhalothrin, and Spinosad. For λ-cyhalothrin at 100 ppm, percentage of mortality across all fields ranged from 43.6 to 90.4%, whereas for methomyl at 100 ppm the range was from 61.6 to 97.9% (Table 2). At the field rate of spinosad

Table 2. Mortality of onion thrips to three insecticides in different regions of New York, 2005

Region	% mortality (SEM)		
	λ -Cyhalothrin (100 ppm, field rate)	Methomyl (100 ppm)	Spintor 2CS (spinosad) (308 ppm, field rate)
Elba1	87.6 (5.9)ab	80.9 (12)a	100.0 (3.0)a
Elba2	47.2 (6.1)b	71.6 (16)a	100.0 (3.0)a
Orange1	43.6 (7.7)b	83.0 (7.4)a	100.0 (3.0)a
Orange2	78.9 (11)ab	95.8 (4.2)a	100.0 (3.0)a
Potter1	89.6 (6.6)a	97.9 (2.1)a	85.4 (7.8)b
Potter2	83.0 (13)ab	94.1 (3.9)a	100.0 (3.0)a
Wayne1	90.7 (5.1)a	92.3 (5.7)a	94.1 (4.0)ab
Wayne1[a]	60.0 (12)ab	62.6 (10)a	

Mean ± SEM within a column followed by same letters are not significantly different ($P > 0.05$; HSD).

[a] Second collection in the same field of Wayne1.

Table 3. LC_{50} values for SpinTor 2CS (spinosad) against onion thrips in different regions of New York, 2003–2004

Yr	Region	n	Slope (SE)	LC_{50} (95% CI) (ppm)	χ^2 (df)
2003	Elba1	600	0.939 (0.078)	2.12 (1.37–3.16)	5.0 (4)
	Elba2	600	1.268 (0.129)	2.89 (1.32–5.39)	11.8 (4)
	Potter	500	0.960 (0.087)	2.01 (0.593–4.84)	5.1 (3)
2004	Elba	217	1.075 (0.143)	0.61 (0.21–1.29)	6.3 (5)
	Potter	215	1.197 (0.161)	0.89 (0.50–1.42)	0.78 (5)

(308 ppm), all but one population had mortality >90%, and the lowest mortality was 85.4%.

Additional Tests with Spinosad and Acetamiprid. For the five populations of *T. tabaci* subjected to a complete dose–mortality assay for spinosad, the LC_{50} values ranged from 0.61 to 2.89 ppm, which was less than a five-fold difference between populations (Table 3). These LC_{50} values were 107–505 times lower than the field rate, suggesting that good control would be achieved in the field. The seven populations of *T. tabaci* tested against acetamiprid at the recommended field rate displayed similar and high mortality, ranging from 93.9 to 100% (Table 4).

Patterns of Spatial Distribution. In 2004 the spatial variation in susceptibility to λ-cyhalothrin was not large at the 100 ppm field rate (range, within and between regions: 86.0–100%), or for the 100 ppm rate of methomyl (range, within and between regions: 87.8–100%), (Table 5). Generally, fewer assays were performed with methomyl because of insufficient numbers of thrips. In 2004, only two of the sites had *T. tabaci* populations whose mortality was <90% for λ-cyhalothrin and only one of the sites had mortality <90% for methomyl. From a control standpoint, these data indicate little variability within or between these regions.

For the 2005 data (Table 5), we averaged the percentage of mortality of the three subsites to obtain a mortality value for each site. For λ-cyhalothrin and methomyl, the variation in mortality of the 24–25 sites was <10% for Potter or Elba. Based on spatial analysis of thrips mortality to λ-cyhalothrin and methomyl, within-site variation was greater than between-site variation at both the Potter and Elba locations, indicating that there were no major hot spots in insecticide resistance within a certain portion of each location. For Potter, the ρ value for λ-cyhalothrin and methomyl was 0.24 and 0.33, respectively. For Elba, ρ for λ-cyhalothrin and methomyl was 0.25 and 0.20, respectively. From a control standpoint, these data indicate little variation within a region or within a field with all but one subsample displaying >80% mortality. Thus, either insecticide should have been effective in each field we examined under normal circumstances.

Discussion

New York onion growers have had, until the recent registration of spinosad, only two unique types of conventional insecticides to use against *T. tabaci:* pyrethroids (e.g., λ-cyhalothrin) and organophosphate/carbamate insecticides (e.g., methomyl). Large variation in susceptibility to λ-cyhalothrin at the field rate occurs in populations of *T. tabaci* collected from onion fields in New York, and changes in susceptibility occur within and between seasons. Within a single season, we can hypothesize that increases in susceptibility can occur if large numbers of *T. tabaci* move into onions from surrounding field crops (e.g., wheat, *Triticum aestivum* L.) where they have not been treated with insecticides. Such migrations have been documented from wheat, oats, *Avena sativa* L., and alfalfa, *Medicogo sativa* L., into cabbage, *Brassica oleracea* L. var. *capitata*, in upstate New York (North and Shelton 1986, Shelton and North 1986). It is more surprising to us, and more problematic to growers, to see populations become more tolerant in a single season. Some of the populations we sampled had dramatic increases in tolerance to λ-cyhalothrin over ≈40 d, a period in which nearly three generations of *T. tabaci* might be produced and during which growers may have applied as many as eight sprays on a 5-d schedule (e.g., Table 1 where Orange3 decreased from 80.9 to 6.1% mortality). Far less variation in mortality was seen at the field rate of methomyl, with only one value below 90% (Table 1). However, as seen in Table 1, the variation at 100 ppm between populations collected at mid-season from individual fields in 2003 was as high as >90% (Elba1 to Orange 3), and this finding could be a premonition of future problems in some fields. Acetamiprid and spinosad may become useful insecticides for onion thrips management because of their different modes of action, and this study presents baseline data on susceptibility to each insecticide. Although TIBS measures contact rather than ingestion toxicity, it worked surprisingly well for acetamiprid and spinosad.

Data from Tables 1 and 2 and our previous report (Shelton et al. 2003) suggest that variation in susceptibility may result in control failures and that there is a critical need to sample individual fields by using TIBS at least once per year, and ideally more often. The number of sites per field to sample will depend on the variation in susceptibility. In 2004, *T. tabaci* populations were lower than normal because of wet, cool conditions and growers sprayed less frequently, which may explain the smaller variation within and between regions (Table 5). In 2005, it was hot and dry in the Potter and Elba regions, and populations were especially high. Both growers indicated there were areas in

Table 4. Mortality of onion thrips with Assail 70WP (acetamiprid) in different regions of New York, 2003 and 2005

Yr	Region	% mortality at label rate (296 ppm)
2003	Orange1	93.9
2005	Elba1	96.9
	Elba2	93.3
	Orange1	100.0
	Orange2	100.0
	Potter1	96.0
	Wayne1	94.2

Table 5. Spatial variation (within and between regions) of mortality of *T. tabaci* to Warrior (λ -cyhalothrin) at 100 ppm and Lannate LV (methomyl) at 100 ppm in New York onion-growing regions in 2004 and 2005

Region	Yr	Total no. samples and subsamples[a]	No. samples and subsamples[a] observed within each range of % mortality					Mean % mortality
			75–79.9	80–84.9	85–89.9	90–94.9	95–100	
Warrior (λ -cyhalothrin)								
Elba	2004	23	0	0	1	1	21	96.6
Potter	2004	53	0	0	1	5	47	98.0
Orange Co.	2004	25	0	0	0	5	20	96.4
Total	2004	101	0	0	2	11	88	97.3
Elba	2005	24 (72)	0 (0)	0 (1)	0 (4)	3 (3)	21 (64)	98.1
Potter	2005	25 (74)[b]	0 (1)	0 (0)	0 (0)	1 (4)	24 (69)	98.7
Total	2005	49 (146)	0 (1)	0 (1)	0 (4)	4 (7)	45 (133)	98.4
Lannate LV (methomyl)								
Elba	2004	18	0	0	0	2	16	97.0
Potter	2004	55	0	0	1	1	53	98.7
Orange Co.	2004	7	0	0	0	2	5	95.9
Total	2004	80	0	0	1	5	74	98.1
Elba	2005	24 (72)	0 (0)	0 (0)	0 (0)	0 (0)	24 (72)	99.7
Potter	2005	25 (74)[b]	0 (0)	0 (1)	1 (1)	0 (4)	24 (68)	98.9

[a] Subsamples are listed in parentheses.

[b] One-subsample was lost before the assay could be performed.

their regions where they had either poor or good control with λ-cyhalothrin and methomyl, and they suggested poor control was due to resistance. Based on our assays (Table 5), the susceptibility to each insecticide was high and fairly uniform. For λ-cyhalothrin, percentage of mortality in the 25 sites in Potter ranged from 90.4 to 100 and for the 24 sites in Elba the range was 92.2 to 100. Even the lowest mortality in a subsample was 77%. Based on our previous studies in which we compared TIBS assays to spray performance (Shelton et al. 2003), we would have expected high mortality and control of the populations by using these insecticides. We suggest that the growers' perception of resistance was incorrect and that variation in control may have been due to other factors such as localized higher populations, poor spray coverage, too much time between spray applications, different onion varieties, or some other factor. Additional research is needed to identify which factor(s) or combinations of factors are responsible for control failures when thrips populations are shown to be susceptible to the insecticides that are being used. Because of some biological characteristics of thrips (e.g., short generation time, high reproductive capacity, wide host range, oviposition within plant tissue, and proclivity for larvae and adults to seek sheltered areas on plants), they have become increasingly problematic in crop production.

Our present lack of understanding of the ecology of *T. tabaci* in onion fields (e.g., overwintering sites and movement patterns into, out of, and within onion fields) continues to hamper our overall ability to manage this pest. However, management should not rely solely on the use of insecticides, because resistance is occurring to the currently registered insecticides and will probably occur with any new products if they are not used in an overall IRM strategy. How best to develop a more sustainable strategy needs further experimentation, but TIBS may play a key role in monitoring susceptibility, and any new insecticides should be introduced within the context of an overall IRM strategy that considers the ecology of onion thrips and other noninsecticidal tactics.

Acknowledgments

We thank Holly Townley for technical assistance and our cooperating growers and extension specialists (C. MacNeil, M. Ullrich, C. Hoepting, and J. Vanderheide). This research was supported in part by the New York State Onion Growers Research and Development Program and the Pest Management Alternatives Program.

References Cited

Abbott, W. S. 1925. A method of computing the effectiveness of an insecticide. J. Econ. Entomol. 18: 265–267.

Allen, J.K.M., C. D. Scott-Dupree, J. H. Tolman, and C. R. Harris. 2005. Resistance of *Thrips tabaci* to pyrethroid and organophosphorus insecticides in Ontario, Canada. Pest Manage. Sci. 61: 809–815.

Fournier, F., G. Boivin, and R. K. Stewart. 1995. Effects of *Thrips tabaci* (Thysanoptera: Thripidae) on yellow onion yields and economic thresholds for its management. J. Econ. Entomol. 88: 1401–1407.

Gent, D. H., H. R. Schwartz, and R. Khosla. 2004. Distribution and incidence of IYSV in Colorado and its relation to onion plant population and yield. Plant Dis. 88: 446–452.

LeOra Software. 1997. POLO-PC: probit and logit analysis. LeOra Software, Berkeley, CA.

Lewis, T. 1997. Thrips as crop pests. CAB International, Oxon, United Kingdom.

[NASS] National Agricultural Statistics Service. 2005. Agricultural chemical usage, 2004 vegetables summary. (http://usda.mannlib.cornell.edu/reports/nassr/other/pcu-bb/agcv0705.txt).

[NYASS] New York Agricultural Statistics Service. 2004. Vegetables: annual summary. (http://www.nass.usda.gov/ny/01jan/veg0103.htm).

North, R. C., and A. M. Shelton. 1986. Colonization and intraplant distribution of *Thrips tabaci* on cabbage. J. Econ. Entomol. 79: 219–223.

Rueda, A., and A. M. Shelton. 2003. Development and evaluation of a thrips insecticide bioassay system for monitoring resistance in *Thrips tabaci.* Pest Manage. Sci. 59: 553–558.

Russell, R. M., J. L. Robertson, and N. E. Savin. 1977. POLO: a new computer program for probit analysis. Bull. Entomol. Soc. Am. 23: 209–213.

SAS Institute 2003. SAS/STAT user's guide, version 9.1. SAS Institute, Cary, NC.

Shelton, A. M., and R. C. North. 1986. Species composition and phenology of Thysanoptera within field crops adjacent to cabbage fields. Environ. Entomol. 15: 513–519.

Shelton, A. M., J. P. Nyrop, R. C. North, C. Petzoldt, and R. Foster. 1987. Development and use of a dynamic sequential sampling program for onion thrips, *Thrips tabaci*, on onions. J. Econ. Entomol. 80: 1051–1056.

Shelton, A. M., B. A. Nault, J. Plate, and J. Z. Zhao. 2003. Regional and temporal variation in susceptibility to lambda-cyhalothrin in onion thrips in onion fields in New York. J. Econ. Entomol. 96: 1843–1848.

Thompson, G. D., R. Dutton, and T. C. Sparks. 2000. Spinosad - a case study: an example from a natural products discovery programme. Pest Manage. Sci. 56: 696–702.

Received 27 February 2006; accepted 5 July 2006.