Impact of Thrips (Thysanoptera: Thripidae) Management Practices on Suppression of Tomato Spotted Wilt Virus and Aphid (Homoptera: Aphididae) Control in Flue-Cured Tobacco[1]

Robert M. McPherson,[2] David C. Jones,[3] Paul F. Bertrand[4] and Alex S. Csinos[4]

The University of Georgia, College of Agriculture and Environmental Sciences, Coastal Plain Experiment Station, Department of Entomology, P. O. Box 748, Tifton, GA 31793 USA

J. Entomol. Sci. 37(2): 143-153 (April 2002)

Abstract Tomato spotted wilt tospovirus (TSWV) has become a major economic problem for tobacco growers in Georgia. Several species of thrips have been reported as vectors of TSWV. Three of these species, commonly observed on tobacco in Georgia, include *Frankliniella fusca* (Hinds), *F. occidentalis* (Pergande), and *F. bispinosa* (Morgan). This study examined the effectiveness of several thrips management practices on controlling thrips populations and suppressing the incidence of TSWV. Replicated field plots were used to evaluate aldicarb, acephate, imidacloprid, acibenzolar-S-methyl, spinosad, thiamethoxan alone and in combination, applied as pre-plant incorporated, tray drench, transplant water or foliar treatments. The insecticides imidacloprid (Admire® 2F or Provado® 1.6F) and thiamethoxan (Platinum 2® SC), applied in the transplant water or as a tray drench, were effective in reducing the early-season thrips populations and reducing the seasonal cumulative incidence of TSWV. These two products also were effective in reducing the seasonal mean population of tobacco aphids, *Myzus nicotianae*. The plant activator, acibenzolar-S-methyl (Actigard®), was effective in suppressing TSWV symptoms, but had no effect on thrips and minor impact on aphid population densities. The combination of acibenzolar-S-methyl with either imidacloprid or thiamethoxan provided better suppression of TSWV than any of the products alone. Acephate in the transplant water plus four early-season foliar sprays also was effective in reducing thrips numbers and TSWV incidence. Aldicarb and spinosad were not effective for thrips control or TSWV suppression. Acephate and aldicarb were effective in reducing aphid populations, but spinosad was not. *Frankliniella fusca* was the predominate thrips species at all test sites, ranging from 90 to 98% of the thrips complex. From 1.9 to 4.6% of the thrips collected were confirmed vectors of TSWV, based on ELISA test results. Imidacloprid, thiamethoxan, acibenzolar-S-methyl, and acephate provide thrips management options that can reduce the tobacco production losses associated with TSWV.

Key Words *Frankliniella fusca, Myzus nicotianae,* crop protection, pest management, tobacco thrips, tobacco aphid

Thrips have continued to increase in importance as economic pests of agricultural crops throughout the world due to their abundance and their ability to survive and develop on a wide range of host plants (Ananthakrishnan 1984). Thrips feeding

[1]Received 26 April 2001; accepted for publication 04 September 2001.

[2]To whom all inquiries should be addressed (email: pherson@tifton.cpes.peachnet.edu).

[3]Cooperative Extension Service, Georgia Southern University, P. O. Box 8112, Statesboro, GA 30460-8112.

[4]Department of Plant Pathology.

damages host plants directly by injuring plant tissue and indirectly by vectoring bacterial, fungal and viral plant pathogens, including tomato spotted wilt tospovirus (TSWV) [Family: Bunyaviridae] (Lewis 1973). Thrips feeding on flue-cured tobacco is considered to be of minor importance (Riley et al. 1997); however, TSWV infection can cause economic losses to tobacco (Lucas 1975, Bertrand 2001). Thrips vectors of TSWV acquire the virus when larvae feed on infected plants. The ingested virus crosses the midgut and enters the salivary glands. Transmission occurs when saliva of the infected adult thrips enters the plant tissue during feeding. An infected thrips remains a vector throughout its lifetime (Pappu et. al. 1998). TSWV has a wide host range spanning several hundred plant species including both monocots and dicots that are common in Georgia. TSWV is well established in tobacco in Georgia, causing up to 35 to 40% statewide loss in plant stands and $28.8 million in losses to the crop in 1999 (Bertrand 2000).

Forty-three thrips species have been reported to occur on flue-cured tobacco foliage and flowers in Georgia (McPherson et al. 1992). Three of these species are vectors of TSWV, and include the tobacco thrips, *Frankliniella fusca* (Hinds) (Sakimura 1963), the western flower thrips, *F. occidentalis* (Pergande) (Sakimura 1962) and *F. bispinosa* (Morgan) (Webb et al. 1997). Effective control of these thrips species and the virus they vector requires an understanding of the effects of various pest management practices on thrips population densities and TSWV incidence. Information on the impact of thrips management practices on flue-cured tobacco and the resultant TSWV infection is limited (Csinos et al. 2001, McPherson et al. 1999, Pappu et al. 2000). Consequently, this study was conducted to determine the effects of tray drench, transplant water, and foliar applications of selected insecticides and plant activators on thrips control and the impact on TSWV incidence in tobacco.

Materials and Methods

In 1997-1998, a series of trials were conducted in Jeff Davis, Tift and Ware counties in Georgia. Sites were located on cooperator farms or at the Coastal Plain Experiment Station and ranged in size from 1.0 to 5.0 ha. Cultivar 'K326' flue-cured tobacco was transplanted at all test sites between 26 March and 6 April. Production practices were followed according to Georgia Cooperative Extension Service recommendations (Moore 1999) and included a pre-plant incorporated tank mix of pesticides for weed control, blue mold control, nematode suppression, and soil insect control. Fertilizer (6-6-18) was applied at around 1100 kg per ha, in a split application (applied a few days after transplanting and about one month after transplanting).

All plots at each test site were arranged in a randomized complete block design with four replications per treatment. Each plot in cooperator trials consisted of four rows, 91 to 122 cm wide, 68 m long and four rows, 91 to 111 cm wide, by 15 m on experiment station test sites. Plant house tray drench treatments were applied 1 to 8 days prior to transplanting using a CO_2-powered backpack sprayer delivering 210 ml of spray solution per 200-cell tray. Transplant water treatments were applied in 938 L of water per ha through the mechanical transplanter at the time of transplanting and foliar treatments were applied with a CO_2-powered backpack sprayer delivering 179 to 253 L per ha depending on test site. Foliar side dress applications were made 48 days after transplant at the 1997 Ware Co. test site. Aldicarb® 15G (Aventis, Research Triangle Park, NC) was applied in a 35-cm band with a dual-wheel push granular applicator and immediately incorporated into the upper 15 cm of soil at bed formation at the 1998 Tift Co. test site.

Plots at the experiment station were sampled for thrips each week beginning 1 wk after transplanting and continuing until the plants were topped and a sucker control agent applied. All tobacco foliage on plants 2, 4, 6, and 8 on row 2 of each plot were examined for live thrips. The number of tobacco aphids, *Myzus nicotianae* Blackman, was also recorded from these same 4-plant observations to assess the impact of thrips management practices on this serious non-target pest species. On alternate sampling dates, thrips also were collected randomly from plants after counts were made. These thrips were placed in phosphate-buffered saline containing 2% polyvinyl pyrrolidone and 0.02% sodium azide, returned to the laboratory, identified, then assayed using an enzyme-linked immunosorbent assay (ELISA) to determine the presence of a nonstructural TSWV protein (Bandla et al. 1994). Presence of the NSs protein indicates that the virus is being replicated in the thrips and thus the thrips is a potential vector. A single thrips sample (one date in early May) was obtained from the Ware Co. site (500 thrips) and the Jeff Davis Co. site (108 thrips) in 1998 to examine with ELISA. Individual thrips were processed in a micro titer plate. A positive ELISA response indicated that the thrips was capable of transmitting TSWV. To be a positive response, the ELISA reflectance reading had to be 2X higher than the negative thrips value obtained on the same date (from two thrips known to be free from TSWV exposure) plus the substrate had to turn yellow. A weakly positive ELISA response was noted if the thrips sample had either a positive ELISA value or positive color change, but not both.

All plants in each field plot were examined weekly for visual symptoms of spotted wilt. Symptomatic plants were flagged and dated, and the cumulative percentage of infected plants was calculated. Symptoms of TSWV in tobacco vary, depending primarily on the age of the plant when infected, but symptomatic plants are easily diagnosed. Infected leaves become yellow then reddish brown, the buds are distorted and dead tissue is noticeable along the leaf veins (Reich 1995). To confirm diagnosis of TSWV, representative symptomatic plants were tested by ELISA using a commercially available kit (Agdia Inc., Elkart, IN).

All plants on row 2 of each plot at the experiment station sites were harvested a total of four times from mid-June until mid-July, cured and weighed according to Georgia Cooperative Extension Service guidelines (Moore 1999). Insect count data, % TSWV symptomatic plant data, and yield data were analyzed using an analysis of variance and means were separated using either Waller-Duncan K-ratio t test or the LSD ($P = 0.05$) (SAS Institute 1990).

Results and Discussion

The imidacloprid (Bayer, Kansas City, MO) treatments applied in 1997 significantly reduced the incidence of TSWV symptomatic plants compared to the untreated control, 22.8, 16.8 and 42.9% for transplant water, tray drench, and control, respectively, in Ware Co. ($F = 19.93$; df = 5, 15; $P < 0.01$) (Table 1). A single foliar application of imidacloprid at side dress on 13 May (42.8%), two foliar sprays of imidacloprid in mid-May (42.2%), and acephate in the transplant water (41.4%) did not reduce TSWV incidence. The foliar applications in May would correspond with when most applications are made in Georgia for insect pest control. The lack of effectiveness of imidacloprid in reducing TSWV when applied as a single foliar spray at side-dress or as two

Table 1. Evaluation of imidacloprid and acephate for seasonal mean ± SEM suppression of tomato spotted wilt virus in flue-cured tobacco, Ware Co., GA, 1997

Treatment and formulation*	Rate (formulation)	TSWV total % infected plants
Imidacloprid 2 F (TPW)	29.5 ml/1000 plants	22.8 ± 4.1 b
Imidacloprid 2 F (TD)	29.5 ml/1000 plants	16.8 ± 2.8 b
Acephate 75 S (TPW)	1.1 kg/ha	41.4 ± 5.8 a
Untreated	—	42.9 ± 6.3 a
Imidacloprid 2 F (side dress spray)	1165 ml/ha	42.8 ± 6.0 a
Imidacloprid 1.6 F (foliar sprays)	291 ml/ha	42.2 ± 5.1 a

* Transplanted 26 March. TPW = transplant water treatment, TD = tray drench treatment applied 20 March, a single side dress foliar application applied on 13 May, and the foliar sprays applied on 13 and 20 May. Column means followed by the same letter are not significantly different (Waller-Duncan K-ratio *t*-test, $P = 0.05$).

mid-season foliar sprays demonstrates the need for this material to be applied as either a tray drench or a transplant water treatment to suppress TSWV. Four foliar applications of acephate (Valent USA Corp., Walnut Creek, CA) or spinosad (Dow AgroSciences, Indianapolis, IN), from early April until mid-May, significantly reduced the seasonal mean populations of thrips in Tift Co. ($F = 11.25$; df = 5, 15; $P < 0.01$) (Table 2). Tobacco aphid population densities also were reduced in the acephate plots, except in the acephate TPW + spinosad treatment which had higher aphid populations than in the spinosad foliar alone or the untreated plots ($F = 3.88$; df = 5,15; $P < 0.01$) (Table 2). Acephate transplant water, foliar, transplant water + foliar and acephate transplant water + spinosad foliar treatments, did have lower mean TSWV symptomatic plants than in the spinosad treatment ($F = 2.97$; df = 5,15; $P < 0.05$), but these lower TSWV percentages were not different than in the untreated plots (Table 2). All sampling for thrips, aphids, and TSWV symptomatic plants was discontinued at this Tift Co. test site after the 26 May sample, due to a hail storm on 1 June. At the other 1997 Tift Co. test site, three early-season foliar sprays of spinosad, imidacloprid, acephate, or methomyl (DuPont, Wilmington, DE) did not effectively reduce the seasonal mean thrips population, the cumulative percentage of TSWV symptomatic plants, nor did they increase cured yields (Table 3). The imidacloprid, acephate and methomyl treatments did significantly reduce aphid densities ($F = 8.76$; df = 7,21; $P < 0.01$). Over 95% of the 780 thrips collected from the Tift Co. tobacco test sites were identified as the tobacco thrips, *F. fusca,* and 2.0% were positive vectors of TSWV and another 1.5% were weakly positive vectors.

The imidacloprid treatments were all effective in reducing the final incidence of TSWV symptomatic plants at the Ware Co. test in 1998 ($F = 6.56$; df = 8,24; $P < 0.01$) (Table 4). The acephate transplant water + spinosad foliar sprays and the spinosad foliar spray alone treatments were not effective, and actually had higher incidences of TSWV than in the untreated plots. Nearly 90% of the 500 thrips collected from the Ware Co. test were identified as *F. fusca,* and 2.8% of these were confirmed as

Table 2. Effects of selected transplant water (TPW) and foliar (F) insecticide treatments on the seasonal mean ± SEM populations of thrips and aphids and incidence of tomato spotted wilt virus (TSWV) in flue-cured tobacco, Tift Co., GA, 1997

Treatment and kg AI/ha*	Mean thrips (9 dates)**	Mean aphids (9 dates)**	Mean % TSWV**
Acephate 75S 1.1 TPW	31.3 ± 14.7	31.9 ± 22.5	11.7 ± 4.1
Acephate 75S 1.1 TPW + Acephate 75S 0.84 F	3.1 ± 2.1	0.4 ± 0.3	10.4 ± 3.4
Acephate 75S 1.1 TPW + Spinosad 4SC 0.05 F	10.7 ± 6.6	427.8 ± 218.9	9.8 ± 2.1
Acephate 75S 0.084 F	3.7 ± 1.1	0.1 ± 0.1	12.9 ± 2.8
Spinosad 4SC 0.05 F	10.8 ± 6.9	217.3 ± 180.1	21.1 ± 4.4
Untreated	28.4 ± 12.3	200.0 ± 148.8	17.6 ± 3.1
LSD (P = 0.05)	8.8	205.5	8.1

* Transplanted on 27 March. Foliar applications applied on 8 April, 22 April, 1 May, and 13 May.
** Thrips, aphid, and TSWV monitoring was discontinued after the 26 May sample due to a hail storm on 1 June. Thrips and aphid counts are the mean number per four plants.

positive or weakly positive vectors of TSWV. Similar significant results were noted at the Jeff Davis Co. test site in 1998 (F = 3.48; df = 8,24; P < 0.01) (Table 5). The acephate transplant water + four early-season foliar sprays was effective in reducing TSWV as were all the imidacloprid treatments alone or in combinations with spinosad or acephate. Ninety-eight percent of the 108 thrips identified from the Jeff Davis Co. test were *F. fusca,* and 1.9% of these thrips were confirmed TSWV positive or weakly positive vectors. The aldicarb and imidacloprid only treatments were not effective in reducing TSWV at the Tift Co. site in 1998, but the other insecticide and insecticide/plant growth regulator treatments were effective (F = 6.88; df = 8,24; P < 0.01) (Table 6). It is unclear why the imidacloprid tray drench and tray drench + foliar sprays did not reduce TSWV infection at this site. The tray drench was applied 1 d prior to transplanting, so perhaps the imidacloprid did not have sufficient time to translocate throughout the plant and provide initial TSWV protection at transplanting. All treatments that included imidacloprid, either alone or in combination with other products, had significantly lower seasonal mean thrips populations than in the untreated plots (F = 2.44; df = 8.24; P < 0.05). All the treated plots had lower tobacco aphid population densities than in the untreated plots (F = 43.21; df = 8,24; P < 0.01) (Table 6). Cured yields were not different between the treatments at this test site. Over 96% of the 1000 thrips identified at the Tift Co. site were *F. fusca,* and 4.6% of these thrips were confirmed as vectors of TSWV.

Although *F. fusca* was the predominate species in the thrips complex at all test sites (ranging from 90 to 98%), other species were commonly observed at low numbers on tobacco foliage. These included *F. occidentalis, F. bispinosa, Limothrips cerealium* (Haliday), and *Chirothrips* spp. Both *F. occidentalis* and *F. bispinosa* are

Table 3. Effects of selected early-season foliar insecticide treatments on the seasonal mean ± SEM populations of thrips and aphids, incidence of tomato spotted wilt virus, and cured yield of flue-cured tobacco, Tift Co., GA, 1997

Treatment and kg AI/ha*	Mean thrips (7 dates)	Mean aphids (7 dates)	Mean % TSWV	Cured yield kg/ha
Spinosad 4SC 0.025	32.9 ± 10.3	782.8 ± 223.1	29.2 ± 7.7	3021 ± 321
Spinosad 4SC 0.05	29.5 ± 12.1	672.7 ± 200.5	23.8 ± 5.8	3207 ± 266
Spinosad 4SC 0.075	28.5 ± 8.9	971.0 ± 410.7	23.3 ± 8.1	3202 ± 308
Spinosad 4SC 0.1	30.8 ± 15.5	1644.2 ± 571.3	19.0 ± 5.9	3595 ± 417
Imidacloprid 1.6F 0.056	32.8 ± 16.1	13.7 ± 10.5	19.2 ± 5.5	2998 ± 290
Acephate 75S 0.84	22.8 ± 14.1	18.3 ± 13.1	17.9 ± 6.8	3241 ± 315
Methomyl 2.4LV 0.5	25.3 ± 8.3	71.8 ± 32.3	16.6 ± 12.0	2946 ± 288
Untreated	35.2 ± 15.9	375.4 ± 161.5	29.8 ± 14.1	2942 ± 490
LSD ($P = 0.05$)	NS	310.3	NS	NS

* Transplanted on 1 April. Foliar applications applied on 8 April, 21 April, and 15 May. Thrips and aphid counts are the mean number per four plants.

reported vectors of TSWV and are potentially transmitting some of the TSWV infection in tobacco, even though their population densities are low.

Previous reports have demonstrated the effectiveness of acibenzolar-S-methyl (Syngenta, Greensboro, NC) in reducing TSWV in tobacco (Csinos et al. 2001, Pappu et al. 2000). However, foliar applications starting 4 wks after transplanting did not provide protection against TSWV. Csinos et al. (2001) stated that acibenzolar-S-methyl needs to be applied to tobacco transplants 7 to 9 d prior to transplanting to have sufficient time for this product to activate the host plant defense mechanism to provide protection from TSWV. Pappu et al. (2000) revealed that although acibenzolar-S-methyl applied prior to tobacco transplanting does reduce the amount of TSWV symptomatic plants, the percent ELISA positive plants is not different between the untreated and acibenzolar-S-methyl treated plants, indicating that the plant activator is suppressing the virus symptoms. Both Csinos et al. (2001) and Pappu et al. (2000) reported on the added effectiveness of using the plant activator plus the insecticide imidacloprid to suppress TSWV symptomatic tobacco plants. The results reported herein support the findings of these previous studies, plus this current research demonstrates that thiamethoxan (Syngenta, Greensboro, NC) as a tray drench treatment and acephate as a transplant water treatment plus early-season foliar sprays are also effective in suppressing TSWV. In addition, the current study documents the impacts of acibenzolar-S-methyl, imidacloprid, thiamethoxan, acephate, and other thrips management practices on tobacco aphid population densities.

In conclusion, the insecticide imidacloprid, applied in the transplant water or as a greenhouse tray drench, has demonstrated an effectiveness in reducing the incidence of TSWV in flue-cured tobacco in Georgia. This treatment can reduce the seasonal mean populations of tobacco thrips, the most common vector. Acephate

Table 4. Evaluation of imidacloprid, spinosad, and acephate for suppression of tomato spotted wilt virus in flue-cured tobacco, Ware Co., GA, 1998

Treatment and formulation*	Rate (formulation)	Cumulative % TSWV symptomatic plants (±SEM)				
		5/1	5/14	5/28	6/11	6/26
Untreated	—	0.2 ± 0.1	4.8 ± 1.1	11.2 ± 2.1	15.1 ± 2.4	16.3 ± 1.4 c
Imidacloprid 2F (TPW)	29.5 ml/1000 plants	0.2 ± 0.1	3.0 ± 1.3	7.5 ± 0.8	11.0 ± 1.0	11.9 ± 1.1 d
Imidacloprid 2F (TPW)	53 ml/1000 plants	0.4 ± 0.2	2.3 ± 0.5	5.7 ± 0.7	9.3 ± 1.9	10.0 ± 1.5 de
Imidacloprid 2F (TD)	29.5 ml/1000 plants	0.1 ± 0.1	1.1 ± 0.6	3.7 ± 0.4	6.6 ± 1.7	7.6 ± 2.2 ef
Imidacloprid 2F (TD) +	29.5 ml/1000 plants	0.1 ± 0.1	0.7 ± 0.5	2.7 ± 0.4	5.2 ± 0.6	5.6 ± 1.8 f
Imidacloprid 2F (TPW)	23.6 ml/1000 plants					
Imidacloprid 2F (TPW) +	29.5 ml/1000 plants	0.3 ± 0.2	3.3 ± 1.2	9.3 ± 1.0	14.0 ± 7.0	15.4 ± 2.3 c
Spinosad 4SC (Foliar)	145 ml/ha					
Imidacloprid 2F (TD) +	29.5 ml/1000 plants	0.1 ± 0.1	1.0 ± 0.2	4.5 ± 0.3	7.6 ± 1.0	8.6 ± 1.9 e
Spinosad 4SC (Foliar)	145 ml/ha					
Spinosad 4SC (Foliar)	145 ml/ha	0.1 ± 0.1	4.0 ± 1.3	11.8 ± 1.0	18.6 ± 1.5	20.3 ± 1.8 b
Acephate 75S (TPW) +	1.1 kg/ha	0.1 ± 0.1	5.0 ± 1.5	14.1 ± 1.5	21.8 ± 1.9	23.5 ± 3.2 a
Spinosad 4SC (Foliar)	145 ml/ha					

* Transplanted on 6 April. TPW represents transplant water treatment, TD represents tray drench treatment applied on 2 April, and foliar sprays were applied on 10 April, 20 April, 27 April, and 4 May. Column means with the same letter are not significantly different (Waller-Duncan K-ratio *t* test, $P = 0.05$).

Table 5. Evaluation of imidacloprid, spinosad, and acephate for suppression of tomato spotted wilt virus in flue-cured tobacco, Jeff Davis Co., GA, 1998

Treatment and formulation*	Rate (formulation)	Cumulative % TSWV symptomatic plants (± SEM)				
		4/27	5/11	5/25	6/8	6/22
Untreated	—	0.4 ± 0.3	3.0 ± 1.3	11.0 ± 2.3	15.4 ± 2.3	16.8 ± 2.8 a
Imidacloprid 2F (TPW)	29.5 ml/1000 plants	0.3 ± 0.1	1.7 ± 1.2	6.5 ± 1.0	9.6 ± 1.7	10.6 ± 1.8 b
Imidacloprid 2F (TPW)	53 ml/1000 plants	0.2 ± 0.1	1.1 ± 0.2	4.5 ± 0.6	6.6 ± 0.8	7.6 ± 1.0 d
Imidacloprid 2F (TD)	29.5 ml/1000 plants	0.0 ± 0.0	1.0 ± 0.4	4.5 ± 0.5	7.1 ± 1.3	8.2 ± 1.1 cd
Imidacloprid 2F (TD)	53 ml/1000 plants	0.0 ± 0.0	0.3 ± 0.1	2.9 ± 0.4	4.5 ± 0.9	5.2 ± 0.9 e
Imidacloprid 2F (TPW) +	29.5 ml/1000 plants	0.2 ± 0.1	1.4 ± 0.2	5.8 ± 0.6	8.4 ± 1.8	9.7 ± 1.0 bc
Spinosad 4SC (Foliar)	145 ml/ha					
Imidacloprid 2F (TD) +	29.5 ml/1000 plants	0.1 ± 0.0	0.6 ± 0.1	4.0 ± 0.3	6.8 ± 0.5	8.0 ± 0.7 cd
Spinosad 4SC (Foliar)	145 ml/ha					
Imidacloprid 2F (TPW) +	29.5 ml/1000 plants	0.2 ± 0.1	1.6 ± 0.3	6.2 ± 1.4	9.4 ± 1.9	10.6 ± 1.5 b
Acephate 75S (TPW)	1.1 kg/ha					
Acephate 75S (TPW) +	1.1 kg/ha					
Acephate 75S (Foliar)	1.1 kg/ha	0.2 ± 0.1	1.2 ± 0.2	5.9 ± 1.1	9.7 ± 1.5	11.4 ± 2.3 b

* Transplanted 30 March, TPW represents transplant water treatment, TD represents tray drench treatment applied on 18 March, and foliar sprays were applied on 3 April, 13 April, 20 April, and 27 April. Column means with the same letter are not significantly different (Waller-Duncan K-ratio *t* test, $P = 0.05$).

Table 6. Effects of selected transplant and foliar insecticide treatments on the mean ± SEM percent tomato spotted wilt virus infection (TSWV), seasonal populations of thrips and aphids, and cured yields on flue-cured tobacco, Tift Co., GA 1998

Treatment and rate (formulation)*	Cumulative % TSWV	Mean/4 plants Thrips	Mean/4 plants Aphids	Yield kg/ha
Aldicarb 15G PPI 15.7 kg/ha	39.3 ± 5.6a	31.5 ± 7.0abc	35.8 ± 21.1c	2604 ± 315a
Imidacloprid 2F TD 29.5 ml/1000 plants	39.6 ± 5.3a	22.7 ± 6.0bc	7.1 ± 5.0c	3123 ± 465a
Aldicarb ppi + Imidacloprid TD 15.7 kg + 29.5 ml	17.0 ± 4.8cd	18.4 ± 7.2c	1.4 ± 1.2c	2458 ± 195a
Actigard TD + F 25 gm AI/7000 plants	9.6 ± 2.5d	29.5 ± 8.8abc	747.7 ± 271.6b	2400 ± 277a
Imidacloprid TD + F 41.3 ml/1000 plants	26.2 ± 4.6bc	26.9 ± 5.3bc	2.6 ± 1.5c	2857 ± 310a
Imidacloprid/Actigard TD + F 41.3 ml + 25 gm	7.1 ± 4.7d	17.9 ± 6.9c	10.6 ± 9.9c	2398 ± 299a
Thiamethoxan TD + F 28 gm AI/7000 plants	21.7 ± 2.8c	28.9 ± 5.5bc	1.9 ± 1.8c	3155 ± 503a
Thiamethoxan/Actigard TD + F 28 gm + 25 gm	9.0 ± 2.9d	33.4 ± 7.3ab	1.1 ± 1.0c	2497 ± 225a
Untreated	34.4 ± 3.4ab	43.7 ± 9.1a	1706.6 ± 645.3a	2142 ± 440a

* Transplanted 30 March. PPI represents pre-plant incorporated, TD represents tray drench treatment applied 29 March, F represents foliar sprays that were applied 6 April, 13 April, and 20 April. Column means with the same letter are not significantly different (Waller-Duncan K-ratio *t* test, $P = 0.05$).

transplant water plus repeated early-season foliar sprays can also be used to reduce TSWV infection. Thiamethoxan tray drench is also effective, when applied alone, in reducing the incidence of TSWV. The plant activator, acibenzolar-S-methyl (Actigard®) also has been demonstrated to reduce the incidence of TSWV symptomatic plants throughout the season. However, plant injury and stunting can occur if rates of this product are too high, generally above 2 gm AI/7000 plants tray drench or 14 gm AI/7000 plants as a foliar spray (Csinos 2001). The combination of acibenzolar-S-methyl with either imidacloprid or thiamethoxan provides the best suppression of TSWV. All three products have been labeled recently for use on tobacco, although acibenzolar-S-methyl is approved for blue mold control and not TSWV suppression. These materials provide producers with pest management options that can reduce the production losses associated with TSWV infection.

Acknowledgments

The authors express their gratitude to K. Lewis, D. Taylor and W. Tillery for their technical assistance, D. Ullman at the University of California at Davis for supplying the TSWV negative and positive thrips species used in the ELISA tests, and Phillip Morris Tobacco Company, the Georgia Agricultural Commodity Commission for Tobacco, and the University of Georgia Agricultural Experiment Stations for financial support of this project.

References Cited

Ananthakrishnan, T. N. 1984. Bioecology of thrips. Indira Publ. Oak Park, MI. 233 p.

Bandla, M. D., D. M. Westcot, K. D. Chenault, D. E. Ullman, T. L. German and J. L. Sherwood. 1994. Use of monoclonal antibody to the nonstructural protein encoded by the small RNA of tomato spotted wilt tospovirus to identify viruliferous thrips. Phytopath. 84: 1427-1431.

Bertrand, P. 2000. 1999 Tobacco disease losses. 1999 Georgia Tobacco Research-Extension Report. University of Georgia Coop. Res.-Ext. Publ. 1-2000: 2.

2001. 2000 Tobacco disease losses. 2000 Georgia Tobacco Research-Extension Report. University of Georgia Coop. Res.-Ext. Publ. 1-2001: 2.

Csinos, A. S. 2001. Actigard phytotoxicity evaluation on tobacco. 2000 Georgia Tobacco Research-Extension Report. University of Georgia Coop. Res.-Ext. Publ. 1-2001: 154-155.

Csinos, A. S., H. R. Pappu, R. M. McPherson and M. G. Stephenson. 2001. Management of tomato spotted wilt virus in flue-cured tobacco with acibenzolar-S-methyl and imidacloprid. Plant Disease 85: 292-296.

Lewis, T. 1973. Thrips, their biology, ecology and economic importance. Academic Press, London 323 pp.

Lucas, G. B. 1975. Diseases of tobacco, 3rd edition, Biological Consulting Assoc., Raleigh, NC. 621 pp.

McPherson, R. M., R. J. Beshear and A. K. Culbreath. 1992. Seasonal abundance of thrips (Thysanoptera: Suborders Terebrantia and Tubulifera) in Georgia flue-cured tobacco and impact of management practices on the incidence of tomato spotted wilt virus. J. Entomol. Sci. 27: 257-268.

McPherson, R. M., H. R. Pappu and D. C. Jones. 1999. Occurrence of five thrips species on flue-cured tobacco and impact on spotted wilt disease incidence in Georgia. Plant Disease 83: 765-767.

Moore, J. M. (ed.) 1999. 2000 Georgia Tobacco Grower's Guide. Univ. Georgia. Coop. Ext. Serv. Publ. CSS-99-14. 52 pp.

Pappu, H. R., A. S. Csinos, R. M. McPherson, D. C. Jones and M. G. Stephenson. 2000.

Effect of acibenzolar-S-methyl and imidacloprid on suppression of tomato spotted wilt *Tospovirus* in flue-cured tobacco. Crop Protection 19: 349-354.

Pappu, H. R., J. W. Todd, A. K. Culbreath, M. D. Bandla and J. L. Sherwood. 1998. First report on the multiplication of tomato spotted wilt tospovirus in the tobacco thrips, *Frankliniella fusca.* Plant Dis. 82: 1282.

Reich, R. C. 1995. Flue-cured tobacco field manual. R. J. Reynolds Tob. Co. Pub. Winston-Salem, NC. 85 p.

Riley, D. G., G. K. Douce and R. M. McPherson. 1997. Summary of losses from insect damage and costs of control in Georgia, 1996. Georgia Agric. Expt. Stn. Spec. Publ. 91. 58 pp.

SAS Institute. 1990. SAS/STAT Users Guide, Version 6, 4th edition. SAS Institute, Cary, NC.

Sakimura, K. 1962. *Frankliniella occidentalis* (Thysanoptera: Thripidae), a vector of the tomato spotted wilt virus, with special reference to the color forms. Ann. Entomol. Soc. Am. 55: 387-389.

1963. *Frankliniella fusca,* an additional vector for the tomato spotted wilt virus with notes on *Thrips tabaci,* another vector. Phytopathol. 53: 412-415.

Webb, S. E., M. L. Kok-Yokomi and J. H. Tsai. 1997. Evaluation of *Frankliniella bispinosa* as a potential vector of tomato spotted wilt virus. Phytopathol. (Supplement) 87: S102.