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Crop Protection 22 (2003) 505–512

Crop Protection

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Seasonal patterns of adult thrips dispersal and implications for management in eastern Virginia tomato fields

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Received 30 April 2002; received in revised form 30 September 2002; accepted 30 September 2002

Abstract

Seasonal flight activity of thrips was examined in commercial tomato fields, *Lycopersicon esculentum* L., on Virginia's (USA) Eastern Shore in 2000 and 2001. In each of three regions along the Shore, populations of adult thrips infesting tomato flowers and dispersing within tomato fields were monitored weekly. *Frankliniella fusca* (Hinds) was the only thrips species captured that is currently considered as a competent vector of *Tomato spotted wilt virus* (TSWV) in most of the mid-Atlantic US region. Seasonal patterns of *F. fusca* capture were dissimilar among tomato fields across all regions; yet, more *F. fusca* were captured between mid-May and mid-June in all regions compared with those captured between transplanting and mid-May each year. Despite the relatively low observed dispersal activity of *F. fusca* before mid-May, the threat of TSWV transmission warrants protection of the crop from immigrating *F. fusca* from transplanting until the end of marketable fruit set. *Frankliniella tritici* (Lindeman) was the most frequently encountered thrips species dispersing in tomato fields and infesting tomato flowers. Seasonal patterns of *F. tritici* capture were similar among tomato fields in all regions in 2000, but were dissimilar among regions in 2001. Dispersal of *F. tritici* was most pronounced between mid-May and mid-June across all fields in each year. Because *F. tritici* was the dominant species recovered from tomato flowers, it is likely responsible for cosmetic injury to tomato fruit and should be managed to reduce fruit injury when infestations are highest, between mid May and mid June.

Keywords: Thrips; *Frankliniellla fusca*; *Frankliniella tritici*; Tomato; TSWV; Management

1. Introduction

Thrips infestations pose a significant risk to the tomato, *Lycopersicon esculentum* Mill., industry in the mid-Atlantic US (Nault and Speese, 2002). A few thrips species transmit *Tomato spotted wilt virus* (TSWV), which reduces both the number and quality of fruit produced, while others oviposit on the fruit's surface diminishing its cosmetic quality (Pohronezny et al., 1986; Linker et al., 1993). On Virginia's Eastern Shore, the incidence of TSWV and thrips-blemished fruit are more common in the spring crop than in the fall crop (Nault and Speese, 2002; Nault, unpublished).

In the southeastern US, the tobacco thrips, *Frankliniella fusca* (Hinds), and the western flower thrips, *F. occidentalis* Pergande, are considered to be the principal vectors of TSWV (Johnson et al., 1995; Eckel et al., 1996; McPherson et al., 1999; Groves et al., 2001b). In the mid-Atlantic region, however, *F. occidentalis* occurs infrequently and is likely to be an important vector only where it is locally abundant (Eckel et al., 1996). Although the onion thrips, *Thrips tabaci* Lindeman, has historically been implicated as a competent vector of TSWV, it now appears to be incapable of transmitting the prevalent isolates of TSWV collected in the southeastern US (Wijkamp et al., 1995). Loss in marketable fruit yield resulting from TSWV is greatest when plants become infected early in their development (Gitaitis et al., 1998; Moriones et al., 1998). On the Eastern Shore, yield loss during the spring crop is likely to occur

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PII: S0261-2194(02)00203-X

when TSWV infection arises between transplanting (1 April–1 May) and the last set of marketable fruit (15 June).

Oviposition by *F. occidentalis* has been shown to cause dimpling on tomato fruit, whereas eastern flower thrips, *Frankliniella tritici* (Fitch), has not previously been implicated as a cause of this injury (Salguero Navas et al., 1991b). In eastern Virginia, *F. occidentalis* has not been observed infesting tomato flowers (Nault and Speese, 2002), yet dimpling on fruit occurs frequently. Large populations of *F. tritici* in flowers have occurred concomitantly to peak thrips-injured fruit levels, suggesting that this species may be largely responsible for cosmetic injury observed on the Eastern Shore (Nault and Speese, 2002).

Tomato growers in eastern Virginia direct insecticide applications at thrips infestations to reduce the risk of TSWV and to limit cosmetic fruit injury. Fields are regularly treated over the duration of the season, with the frequency of applications intensifying following the detection of large populations of dispersing thrips. The decision to spray is often based on the abundance of total thrips observed, rather than on the relative abundance of thrips species known to transmit TSWV or those responsible for blemishing fruit through oviposition. Identifying the species composition of thrips migrating into tomato fields and further determining the temporal patterns of immigration during vulnerable stages of crop development and fruit production will provide Eastern Shore tomato growers with research-based information upon which to make control decisions. The objectives of this research were to describe and compare temporal patterns of pest thrips species dispersal in tomato fields among three growing regions of Virginia's Eastern Shore, and to determine the seasonal abundance of pestiferous thrips populations present during susceptible stages of crop and fruit development.

2. Materials and methods

2.1. Description of fields

Commercial, fresh-market tomato fields were sampled for dispersing populations of adult thrips in three regions (north, central and south) along Virginia's Eastern Shore in 2000 and in 2001. In each region each year, 3 fields were sampled in the spring crop and 3 fields were sampled in the fall crop (total of 36 fields sampled). Many of the same fields were sampled both years. The spring and fall crops are transplanted in April and late June through early July, respectively. Adjacent regions were separated by at least 32 km, whereas fields within regions were separated by 1–8 km. Fields ranged in size from 20 to 40 ha and were bordered by wood lots and other tomato fields. Tomatoes were grown on beds mulched with black plastic in the spring and with white plastic in the fall. Plants were supported by a trellis and irrigated through drip tubes under the mulch. Annual rye grass, *Lolium multiforum* L., was planted between beds as a windbreak to protect tomato seedlings from wind damage. The grass was killed with a selective herbicide several weeks before harvest.

2.2. Thrips sampling and identification

Yellow sticky cards (Olson Products, Medina, OH) were used to capture dispersing adult thrips. Five cards (each $7.6\,cm \times 12.7\,cm$ and both sides exposed) were placed in all fields sampled and adjusted weekly to the height of the canopy by attaching them to the trellis supports. Cards were placed in three rows, two in each of two rows and one in another, and rows selected were $> 10\,m$ apart. Cards were collected and replaced weekly beginning before transplanting and ending at harvest in both years (spring crop: early April through late July; fall crop: early July through late September). The total number of adult thrips was counted on both sides of each sticky card and a random sample of up to 25 adults was removed from the sticky cards using HistoClear® solvent (National Diagnostics, Atlanta, GA) for species identification. A microscope slide was prepared for each trap collection using CMC-10 (Masters Chemical Co., Elk Grove, IL) as a clearing and mounting medium. Adults were then identified using a key of the Terebrantia suborder (Palmer et al., 1992) and voucher specimens are held at the Eastern Shore Agricultural Research and Extension Center near Painter, VA.

The number and species composition of adult thrips infesting tomato flowers were determined in the spring crop both years. The same fields were sampled as those described previously, with the exception that only 8 fields were sampled in 2001 ($n = 9$ in 2000 and $n = 8$ in 2001). Fields were sampled 6 and 10 times in 2000 and 2001, respectively. Twenty flowers were randomly removed from the top one-third of the canopy within each field and placed into vials containing 70% EtOH and then processed following the procedures described in Cho et al. (1995).

2.3. Data analyses

Data were analyzed independently for each cropping season and year (spring crop: early April through late July and fall crop: early July through late September). Similarly, data for *F. fusca* and *F. tritici* were analyzed separately because they were identified as the most significant pest species. For each data set, the mean cumulative proportion of either *F. fusca* or *F. tritici* thrips adults captured through time was determined. For example, to calculate the mean cumulative proportion of *F. fusca* adults captured on any date, the mean cumulative number of *F. fusca* adults captured by a particular date was used as the numerator and the total number of *F. fusca* adults captured over the entire season was used as the denominator. Seasonal patterns of these mean cumulative proportions were first arcsine transformed and then compared among regions using a repeated-measures analysis of variance (ANOVA) at a probability level of $P<0.05$ (PROC GLM: REPEATED with polynomial contrasts) (SAS Institute, 1990). This procedure is designed to produce a general covariance structure to account for possible serial correlations among samples collected on successive dates (Meredith and Stehman, 1991). The mean proportion of the season total number of adult *F. fusca* and *F. tritici* captured during vulnerable stages of the crop (transplanting: 1 April through 1 May; fruit formation: 15 May through 15 June) were estimated by regressing logit-transformed proportions captured over time in only the spring-cropping season (PROC REG of SAS at $P<0.05$).

For each thrips species, the number of adults collected per 20 flowers in each field was averaged across all sampling dates. Because we were not interested in comparing the abundance of species across regions, the mean number of adults per 20 flowers per field over the season was analyzed by ANOVA (PROC GLM) and means for each species were compared using LSMEANS at $P<0.05$ (SAS Institute, 1990).

F. fusca was the only TSWV vector encountered and *F. tritici* was the most abundant species infesting tomato flowers. Therefore, the results and discussion will focus on describing temporal dispersal patterns of these two species in tomato fields. Because damage associated with TSWV incidence and thrips-blemished fruit are significantly greater in the spring- than in the fall-cropping season (Groves et al., 2002b; Nault and Speese, 2002), the results and discussion will only focus on dispersal patterns of *F. fusca* and *F. tritici* during the spring seasons.

3. Results

3.1. Thrips identification

Five species of adult thrips including *F. fusca*, *F. tritici*, *T. tabaci*, cereal thrips, *Limothrips cerealium* (Haliday) and soybean thrips, *Neohydatothrips variabilis* (Beach), were captured on sticky cards in our tomato fields in 2000 and 2001. In the spring crop of 2000 and 2001, the most common species trapped was *F. tritici* (total numbers were 13,815 and 13,575, respectively), followed by *N. variabilis* (3638 and 1783, respectively), *T. tabaci* (78 and 3622, respectively), *F. fusca* (1515 and 1440, respectively) and *L. cerealium* (260 and 396, respectively). In the fall crop of 2000 and 2001, *F. tritici* (total numbers were 1846 and 5425, respectively) and *N. variabilis* (1630 and 5502, respectively) were the most common species captured, followed by *F. fusca* (633 and 2002, respectively), *T. tabaci* (0 and 2159, respectively) and *L. cerealium* (0 and 54, respectively). Of these species, only *F. fusca* is considered a competent vector of TSWV in the mid-Atlantic region. In the spring crop, *F. fusca* adults began immigrating into tomato fields in early April. Dispersal into fields was greatest between mid May and early July with noticeable increases during the third week of May and again during the third week of June in both years (Fig. 1A and C). In the fall crop, *F. fusca* dispersal was greatest in July 2000 and July and August 2001 and then declined in September (Fig. 2A and C).

3.2. Capture from flowers

Mean seasonal abundance of the five most commonly encountered thrips species sampled from tomato flowers in the spring crop differed significantly among each other in 2000 ($F = 11.90$; df$=4$, 40; $P<0.0001$) and 2001 ($F = 14.96$; df$=4$, 35; $P<0.0001$). *F. tritici* was the most prevalent species infesting flowers in both years (96% and 91% of the total sampled in 2000 and 2001, respectively), while only a few *N. variabilis* and *L. cerealium* adults were encountered. In 2000, *F. tritici*, *F. fusca* and *T. tabaci* were found at densities of 7.39 ± 2.11, 0.33 ± 0.13 and 0.02 ± 0.02 adults per 20 tomato flowers per field, respectively. In 2001, these species were observed at densities of 10.46 ± 2.63, 0.25 ± 0.08 and 0.81 ± 0.23 adults per 20 flowers per field, respectively. These results are similar to those by Nault and Speese (2002) who reported that *F. tritici* was the most abundant thrips species in tomato flowers on Virginia's Eastern Shore from 1998 through 2000 and that high infestations occurred concomitantly to peak thrips-injured fruit levels. Comparatively high abundance of *F. tritici* relative to the other species infesting tomato flowers and the absence of *F. occidentalis* from our samples provide compelling indirect evidence that *F. tritici* is responsible for the thrips-blemished fruit often observed in the spring tomato crop in Virginia. In the spring, *F. tritici* adult immigration rates into tomato fields were low throughout April, but numbers of adults began to increase in mid-May with the greatest activity occurring during the third and first week of June in 2000 and 2001, respectively (Fig. 1B and D). Dispersal rates of *F. tritici* in the fall tomato crop were low throughout the season in both years (Fig. 2B and D).

3.3. Seasonal patterns of F. fusca dispersal

The mean cumulative proportions of *F. fusca* adults captured through time differed significantly among regions in 2000 (region $\times$ date: $F = 2.58$; df$=28$, 56;

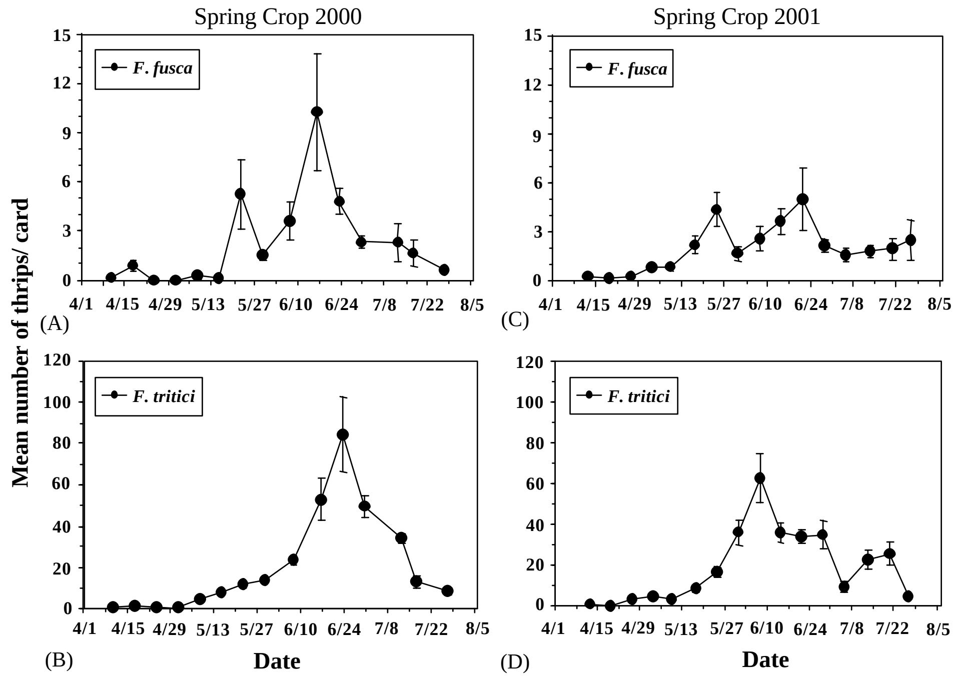

Fig. 1. Mean (± SEM) number of *Frankliniella fusca* and *F. tritici* adults captured per sticky card in the spring crop of commercially grown tomato fields on Virginia's Eastern Shore in (A and B) 2000 and (C and D) 2001 ($n = 9$).

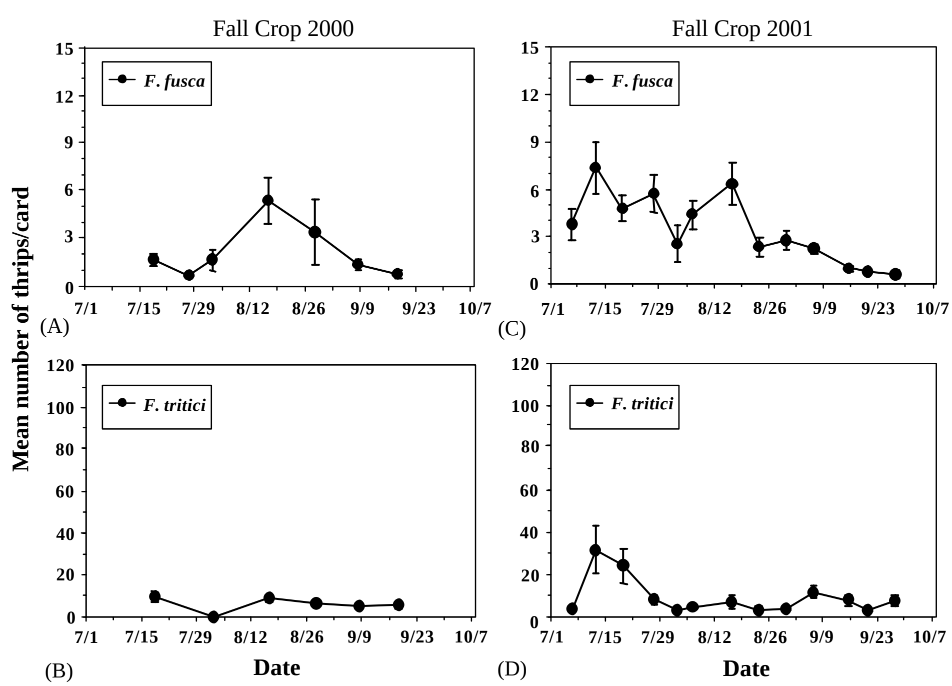

Fig. 2. Mean (± SEM) number of *Frankliniella fusca* and *F. tritici* adults captured per sticky card in the fall crop of commercially grown tomato fields on Virginia's Eastern Shore in (A and B) 2000 and (C and D) 2001 ($n = 9$).

$P = 0.0013$) and 2001 (region × date: $F = 3.73$; df = 30, 60; $P < 0.0001$) (Fig. 3). In 2000, first flights (8–15 April) of *F. fusca* detected within tomato occurred earlier in fields in the southern region of the Eastern Shore than in those in the central or northern regions. However, the rate of increase in mean cumulative proportion of thrips per trap in the southern region did not appear to differ from comparable rates in the central and northern

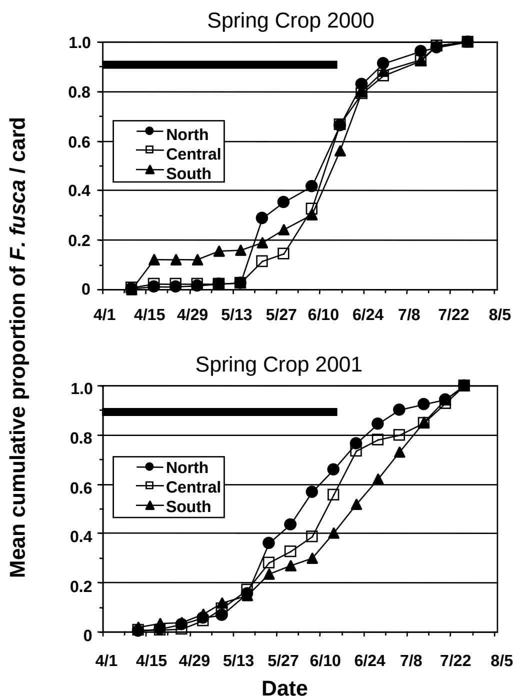

Fig. 3. Mean cumulative proportion of *Frankliniella fusca* adults captured in tomato fields within each of the three regions on the Eastern Shore during the spring-cropping season in 2000 and in 2001. Proportions represent the cumulative number of *F. fusca* adults divided by the season total number of *F. fusca* adults. The solid black bar represents the period in which infection by TSWV is likely to result in yield loss.

regions through the remainder of the early spring (between 15 April and 13 May) (Fig. 3). In 2001, initial dispersal of *F. fusca* adults was similar among all regions until 19 May, but the rate of increase in mean cumulative proportions captured between 19 May and 7 June was greatest in the northern region (Fig. 3).

Although few (<1%) adult *F. fusca* were collected during the typical transplanting interval (1 April–1 May) in all regions over both years (Table 1), some adult flights were detected during this interval. Symptoms of TSWV typically become apparent in mid to late May, suggesting that transmission of this virus most likely occurs between 1 April and 1 May. Forty-eight percent to 85% of the mean season total numbers of adults were captured during the initiation of marketable fruit formation (mid-May through mid-June).

3.4. Seasonal patterns of F. tritici dispersal

Mean cumulative proportion of *F. tritici* adults captured through time was similar among regions in 2000 (region × date: $F = 1.11$; df = 28, 56; $P = 0.3584$), but not in 2001 (region × date: $F = 2.06$; df = 30, 60; $P = 0.0085$) (Fig. 4). In 2001, initial seasonal patterns of *F. tritici* dispersal appeared to be similar among regions for most of the spring-crop until late June (Fig. 4). Between late June and mid-July, the frequency of adults captured in the central and southern regions declined compared with those in the northern region.

Table 1
Linear regression estimates of the mean cumulative proportion of either *Frankliniella fusca* or *F. tritici* adults captured on sticky cards in the spring-crop in commercial tomato fields in 2000 and 2001

Season	Region	N[a]	Equation[b]	n	R^2	Predicted percentage of season total number of thrips captured by: 1 April (JD 91)	1 May (JD 121)	15 May (JD 135)	15 June (JD 166)
Frankliniella fusca									
Spring 2000	North	525	$y = 0.097x - 15.455$	3	0.97	<1	<1	<1	81
	Central	720	$y = 0.093x - 15.217$	3	0.95	<1	<1	<1	63
	South	270	$y = 0.063x - 9.909$	3	0.88	<1	<1	4	85
Spring 2001	North	495	$y = 0.084x - 13.502$	3	0.97	<1	<1	1	74
	Central	675	$y = 0.077x - 12.827$	3	0.97	<1	<1	<1	48
	South	270	$y = 0.061x - 10.172$	3	0.97	<1	<1	1	48
Frankliniella tritici									
Spring 2000	All	13,815	$y = 0.095x - 15.827$	9	0.98	<1	<1	<1	47
Spring 2001	North	4,605	$y = 0.123x - 19.975$	3	0.98	<1	<1	<1	74
	Central	4,380	$y = 0.094x - 15.578$	3	0.95	<1	<1	<1	52
	South	4,590	$y = 0.101x - 16.747$	3	0.93	<1	<1	<1	52

[a] N represents the cumulative number of thrips captured over the season.
[b] y is the predicted mean cumulative proportion of adults captured per card and x is Julian Date (JD).
Crops were transplanted between 1 April and 1 May, marketable fruit initiation occurred between 1 May and 1 June and final marketable fruit set occurred by 15 June.

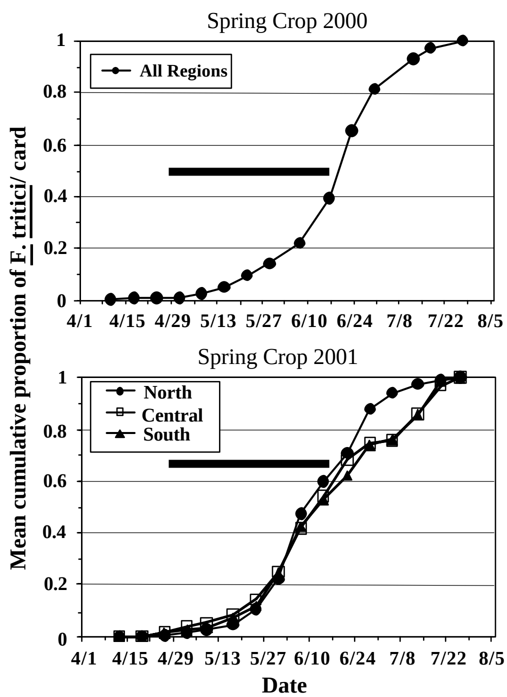

Fig. 4. Mean cumulative proportion of *Frankliniella tritici* adults captured in tomato fields within each of the three regions on the Eastern Shore during the spring-cropping season in 2000 and in 2001. Proportions represent the cumulative number of *F. tritici* adults divided by the season total number of *F. tritici* adults. The solid black bar represents the period in which oviposition by thrips would cause dimpling on fruit.

Very few *F. tritici* adults were actively dispersing in tomato fields following transplanting and through initial flower development (before mid-May) (Table 1). Shortly after initial flower and fruit development, however, 52–74% of the season total numbers of *F. tritici* were present from mid-May through mid-June (Table 1).

4. Discussion

F. fusca is considered to be the only competent vector of the common TSWV isolates present in the mid-Atlantic US and was the only competent TSWV vector species encountered in this study. This species is also considered the principal vector of TSWV in tomato, pepper, peanut and tobacco in other regions of the southeastern US where populations of *F. occidentalis* are encountered infrequently (Barbour and Brandenburg, 1994; Eckel et al., 1996; Groves et al., 2001b). On Virginia's Eastern Shore, the incidence of TSWV in tomato fields is more prevalent in the spring crop than in the fall crop and negatively affects yield when infections take place between transplanting (1 April–1 May) and the development of the last set of marketable fruit (15 June). In contrast, the fall crop is transplanted from late June through July at which time TSWV infections occur infrequently. This lack of apparent TSWV infection in fall-grown tomato may be the result of comparatively fewer TSWV inoculum sources harboring vector species (Groves et al., 2001a, b) and significantly reduced flight activity of *F. fusca* during the summer (Groves et al., 2002b). Moreover, there may be a reduced probability that dispersing thrips will transmit TSWV between crops that are intensively managed with insecticides (Puche et al., 1995; Gitaitis et al., 1998). Hence, it is more important to identify the critical periods of *F. fusca* adult dispersal and TSWV movement during the spring crop than in the fall crop for designing and implementing appropriate TSWV management strategies.

In both years of this study, *F. fusca* adults were active in tomato fields throughout the entire spring-cropping season with relatively low rates of dispersal until mid-May across all regions. Based on these observations, efforts to control *F. fusca* populations to reduce incidence of TSWV would not initially appear warranted until after mid May, when adults became more active in tomato fields. In North Carolina, Groves et al. (2002b) similarly reported reduced dispersal activity of *F. fusca* early in the spring (March and April); however, despite the comparatively low activity of *F. fusca* during this period, significant occurrence of TSWV was detected in sentinel TSWV-susceptible plants, *Petunia hybrida* var. 'Celebrity Blue'. In early spring, *F. fusca* appear to emigrate from overwintering sites, which include perennial and winter annual plants that harbor TSWV, onto nearby susceptible crops (Groves et al., 2001b). Therefore, although few *F. fusca* adults appear to colonize tomato fields early in the spring, the proportion carrying TSWV may be relatively high. For this reason, protection of the crop from *F. fusca* to reduce risk of TSWV is still recommended from transplanting until the end of marketable fruit set.

A multi-faceted approach is encouraged to manage thrips as the primary means for reducing the incidence of TSWV in vegetable crops (Cho et al., 1989; Riley and Pappu, 2000). In a continuous and diverse vegetable production system in Hawaii, TSWV incidence was reduced in susceptible vegetable crops by planting fields away from crop fields known to harbor TSWV-infected plants and by planting fields after nearby fields harboring potentially viruliferous thrips had been harvested and plowed (Cho et al., 1989). In a seasonal vegetable production system in southern Georgia, Riley and Pappu (2000) demonstrated a significant reduction in TSWV in tomato using the TSWV-resistant variety 'Stevens', by planting early in the season or by using a silver-colored reflective plastic mulch; however, the benefits of each technique in reducing levels of TSWV were not necessarily additive, nor did they result in acceptable levels of marketable yield. In contrast, intensive usage of insecticides reduced TSWV and in all cases increased marketable yield. In these experiments, a systemic insecticide (e.g., imidacloprid) was used at transplanting followed by foliar insecticide applications (e.g., lambda-cyhalothrin, methamidaphos and spinosad) made one to two times per week for most of the season. The success of this strategy may primarily reflect the use of imidacloprid, which repels thrips and has been shown to reduce transmission of TSWV by *F. fusca* in tomato, pepper and tobacco (Pappu et al., 2000; Groves et al., 2001a). This compound contains antifeedent properties that likely cause the repellency (Abraham and Epperlein, 1999; Woodford and Mann, 1992). Currently in eastern Virginia, tomato growers follow the insecticide usage regimen described by Riley and Pappu (2000) to manage thrips and TSWV. Because protection of the crop from *F. fusca* may be necessary only from transplanting until mid-June, the continued use of foliar insecticide applications targeting thrips after mid-June is perhaps unwarranted.

F. tritici was the most commonly encountered species captured dispersing in tomato fields and infesting tomato flowers. Similarly, *F. tritici* has been reported to be very common in tomato flowers in Florida (Salguero Navas et al., 1991a), Georgia (Riley and Pappu, 2000) and North Carolina (Eckel et al., 1996; Cho et al., 1995). Infestation levels of *F. tritici* in tomato flowers are typically greatest early in the spring (May) than later in the season (Salguero Navas et al., 1991a; Nault and Speese, 2002). Because *F. tritici* appears to be responsible for causing cosmetic injury to tomato fruit primarily during the spring-cropping season in Virginia, control of *F. tritici* may reduce losses in fruit quality.

Because dispersal patterns of *F. tritici* were similar among tomato fields across all regions of the Eastern Shore, control decisions for this pest can be made uniformly. Given that dispersal activity of *F. tritici* was extremely low in tomato before mid-May, this pest should be managed most intensively between mid-May and mid-June, when flowers begin to develop until the end of marketable fruit set. Although *F. tritici* has not been previously considered a pest of tomato in other tomato growing regions, reducing cosmetic fruit injury by *F. occidentalis* using foliar insecticide sprays has been recommended when densities of thrips exceed 1–5 per flower (Pohronezny et al., 1986; Linker et al., 1993). Perhaps, this approach will work well for managing *F. tritici*. The use of cultural management tactics, such as those used to reduce *F. occidentalis* infestations in Georgia tomato fields described by Riley and Pappu (2000), may also control *F. tritici*.

Acknowledgements

Assistance with data collection by A. Drewer, E. Hurst, C. Moore, and J. Speese was greatly appreciated. We thank L. Gayle of Taylor and Fulton, Inc. and J. Louks and B. Hall of Kuzzens Inc. for allowing us to sample thrips on their farms. We also especially appreciate Dr. C. Brownie (Department of Statistics, North Carolina State University) for assisting us with statistical analyses. The Virginia Agricultural Council partially supported this research.

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