Daily and temporal occurrence of *Frankliniella* spp. (Thysanoptera: Thripidae) on tomato

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Abstract

Daily occurrence and flight activity of *Frankliniella* spp. (Thysanoptera: Thripidae) in tomato fields was studied on five dates in 1990 and four dates in 1992. Higher number of *Frankliniella occidentalis* (Pergande) were observed on tomato flowers in the morning than in the afternoon on 3 of 5 and 2 of 4 sample dates in 1990 and 1992, respectively. Numbers of *Frankliniella tritici* (Fitch), *Frankliniella fusca* (Hinds) and immature thrips on flowers or foliage did not differ among sample hours. On tomato foliage, *F. fusca* and immature thrips were dominant, while few *F. occidentalis* or *F. tritici* were collected. Temperature was an important factor in the flight activity of *F. tritici*. Populations of *F. tritici* peaked earlier in the season and declined sooner than those of *F. occidentalis*. *F. occidentalis* and *F. tritici* both inhabited tomato flowers and subdivided this niche temporally, while *F. fusca* occupied a different niche, tomato foliage.

Key words: Diurnal behavior, *Frankliniella occidentalis*, *Frankliniella tritici*, *Frankliniella fusca*, tomato

INTRODUCTION

The three dominant thrips species occurring on tomatoes in North Carolina are the western flower thrips, *Frankliniella occidentalis* (Pergande), the eastern flower thrips, *Frankliniella tritici* (Fitch), and the tobacco thrips, *Frankliniella fusca* (Hinds). Adult *F. occidentalis* and *F. fusca* are pests of tomato because they are vectors of tomato spotted wilt virus (TSWV) (Sakimura, 1962, 1963). *F. occidentalis* is also a direct pest of tomato as a result of oviposition on small tomato fruit that causes cosmetic damage (Salguero Navas et al., 1991a).

Although originally limited to the western U.S., during the past 10–15 years *F. occidentalis* has become established in the southeastern U.S.; the first field collection in North Carolina was from Okra flowers in 1981. *F. occidentalis* is now present in North Carolina throughout the growing season and is capable of overwintering as an adult or larva (Cho et al., 1995a).

Daily and seasonal changes in the number and distribution of thrips on plants have previ-

ously been observed (Tappan, 1986). Lewis (1973) hypothesized that small differences in the threshold temperature for flight initiation among species result in diel periodicity of flight. Tappan (1986) reported that populations of *F. fusca* on peanut flowers increased significantly between 0800 and 1000 h. In addition, Sites et al. (1992) reported that *Thrips tabaci* Lindeman and *F. occidentalis* showed diel changes in vertical distribution on onion plants in the Texas South Plain.

Thrips densities in tomato are commonly estimated by extracting thrips from tomato flowers or aerial sticky traps (Erlich, 1991; Salguero Navas et al., 1991b). Thus, an understanding of the diurnal occurrence and flight activity of different thrips on tomato is important when sampling these insects. Although Salguero Navas et al. (1991b) reported that density estimates of *Frankliniella* spp. were not influenced by the time of day when tomatoes were sampled in Florida, little is known regarding the diurnal periodicity of *Frankliniella* spp. on tomato plants in North Carolina.

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The objectives of this study were to determine the daily occurrence on tomato and flight of *Frankliniella* spp., and to investigate temporal associations among thrips species on tomato in North Carolina.

MATERIALS AND METHODS

Studies were conducted on staked tomato plants at the Mountain Horticultural Crops Research Station, Fletcher, North Carolina, U.S.A., during 1990 and 1992. Standard cultural practices for staked tomato production in western North Carolina were followed (Konsler and Gardner, 1990), excluding insecticide use.

1990 study. Five-week-old greenhouse-grown 'Mountain Pride' tomato plants, were transplanted on 15 May in a ≈ 0.10 ha plot that consisted of 5 rows, each 30 m long and on 1.5 m centers, and plants were spaced 0.6 m apart within a row. The plot was randomly sampled on five dates: 22 June, 6 July, 16 July, 23 July, and 30 July.

To sample thrips in tomato flowers, ten flowers were randomly selected from the upper half of randomly selected plants to reduce variance due to flower position (Salguero Navas et al., 1991b). Samples were collected at 2 h intervals from 0800 to 1800 h. Each group of 10 flowers was placed in a scintillation vial (20 ml, Kimble®, Toledo, OH, U.S.A.) containing 70% ethanol. Five samples were collected at each sample period.

1992 study. Six-week-old greenhouse-grown 'NC14G' tomato plants were transplanted on 15 June in an 0.15 ha plot that consisted of 7 rows, each row 27 m long on 1.5 m centers, and plants were spaced 0.7 m apart within rows. Samples were collected only on days when the probability of rain was low.

Diurnal periodicity of occurrence and flight of thrips were monitored on tomato plants (flowers and foliage) on four dates: 20 July, 27 July, 5 August and 19 August. Tomato flowers were collected in the same manner as in 1990, except that ten samples were collected during each 2 h sampling period between 0800 and 1800 h.

Tomato foliage was sampled at 4 h intervals from 0800 to 1800 h. At each sampling period, foliage was collected from 5 randomly selected

tomato plants. All flowers were manually removed from each plant and the plant was cut into two parts; the upper and lower halves were immediately placed in separate, sealable 3.8 l plastic bags (Zip-lock®). Plants were placed in an ice chest and returned to the laboratory.

Tomato foliage was placed in a 30 mesh-sieve fixed on top of a 100 mesh-sieve. Foliage in the 30 mesh-sieve was thoroughly washed with running tap water to dislodge thrips. Thrips accumulating in the 100 mesh-sieve were backwashed with 70% ethanol into scintillation vials.

Aerial movement of thrips was monitored in 1992 using inverted yellow plastic cups (473 cm³) coated with Tanglefoot® (The Tanglefoot Company, Grand Rapid, MI, U.S.A.). Because traps were cylindrical, movement onto traps in a horizontal plane was not influenced by directional orientation of traps. Five of these traps were placed 15 cm above the plant canopy and replaced at 2 h intervals from 0800 to 1800 h. Traps collected from the plots were cut into 8 pieces and covered with clear plastic wrap for processing.

All adult thrips from each sampling method were counted and identified to species. Because no keys to species were available for immature thrips, all immatures from each sample method were combined into a single group.

Air temperature was recorded 1 m above the soil surface for each sample period, and precipitation was obtained from the Asheville Regional Airport weather station, which was located within 2 km of the research plot.

Data obtained from the hourly samples on each sampling date were analyzed using analysis of variance (ANOVA) (SAS Institute, 1985). When significant differences were indicated, means were separated using a Tukey studentized range test ($\alpha=0.05$) (SAS Institute, 1985). For tomato foliage sample, ANOVA was used to evaluate the effect on plant positions (upper and lower half) and sample hour. Interrelationships between thrips numbers and air temperatures for each sampling period were tested with Pearson's Product Moment Correlation (Sokal and Rohlf, 1981). Residual plots were inspected for instability of sample variance, and the $\log(x+1)$ transformation was applied to the

dependant variable when required (Sokal and Rohlf, 1981).

RESULTS

Temperature changes were typical for the area during both years; the lowest temperature occurred at 0800 h and the highest temperature at 1600 h. Rainfall occurred on 16 July (trace), 23 July (0.74 cm), and 30 July (0.53 cm) in 1990, but no precipitation was recorded on any of the sampling dates in 1992.

F. tritici, *F. occidentalis*, and *F. fusca* were the only adult thrips collected from tomato flowers during these studies. The number of *F. occidentalis* in tomato flowers varied with sampling periods in both years. Significantly higher numbers of *F. occidentalis* were observed in the morning (0800 or 1000 h) compared with the afternoon (1800 h) on three of five sampling dates (22 June, 16 July and 23 July) in 1990 (Table 1). This trend was observed on two sampling dates (27 July and 5 August) in 1992

Table 1. Mean number of thrips^a ($\pm$ SEM) per 10 tomato flowers, Fletcher, NC, in 1990

Date	Time	<i>F. occidentalis</i>	<i>F. tritici</i>	<i>F. fusca</i>	Immature	Total adults
22 June	0800	2.0 $\pm$ 1.2 a ^b	21.6 $\pm$ 6.8	0.2 $\pm$ 0.2	0.0 $\pm$ 0.0	23.8 $\pm$ 6.9
	1000	1.6 $\pm$ 0.2 ab	12.4 $\pm$ 1.9	0.4 $\pm$ 0.2	0.0 $\pm$ 0.0	14.4 $\pm$ 1.9
	1200	0.2 $\pm$ 0.2 bc	11.6 $\pm$ 3.5	0.4 $\pm$ 0.2	0.0 $\pm$ 0.0	12.2 $\pm$ 3.7
	1400	0.6 $\pm$ 0.2 bc	17.2 $\pm$ 4.4	0.4 $\pm$ 0.2	0.0 $\pm$ 0.0	18.2 $\pm$ 4.6
	1600	0.6 $\pm$ 0.2 bc	28.2 $\pm$ 12.2	1.6 $\pm$ 0.2	0.0 $\pm$ 0.0	30.4 $\pm$ 12.3
	1800	0.0 $\pm$ 0.0 c	25.8 $\pm$ 9.2	0.6 $\pm$ 0.4	0.0 $\pm$ 0.0	26.4 $\pm$ 9.4
df=5,24, <i>F</i> , <i>p</i>		11.11, 0.0001	0.71, 0.632	2.52, 0.06		0.84, 0.535
6 July	0800	1.2 $\pm$ 0.4	5.0 $\pm$ 1.0	0.0 $\pm$ 0.0 b	0.6 $\pm$ 0.6	6.2 $\pm$ 1.3
	1000	1.0 $\pm$ 0.4	4.2 $\pm$ 0.4	0.0 $\pm$ 0.0 b	0.0 $\pm$ 0.0	5.2 $\pm$ 0.4
	1200	0.0 $\pm$ 0.0	4.6 $\pm$ 0.5	0.4 $\pm$ 0.2 b	0.2 $\pm$ 0.2	5.0 $\pm$ 0.6
	1400	1.0 $\pm$ 0.4	6.6 $\pm$ 2.7	0.8 $\pm$ 0.2 a	0.2 $\pm$ 0.2	8.4 $\pm$ 2.3
	1600	0.6 $\pm$ 0.4	6.0 $\pm$ 0.8	1.0 $\pm$ 0.0 a	0.0 $\pm$ 0.0	6.6 $\pm$ 0.9
	1800	0.6 $\pm$ 0.4	5.2 $\pm$ 0.8	0.4 $\pm$ 0.2 ab	0.0 $\pm$ 0.0	6.2 $\pm$ 0.8
df=5,24, <i>F</i> , <i>p</i>		1.44, 0.245	0.42, 0.83	4.00, 0.008	0.67, 0.652	0.80, 0.512
16 July	0800	5.8 $\pm$ 1.2 a	35.6 $\pm$ 1.7 a	0.0 $\pm$ 0.0	1.2 $\pm$ 0.7	41.4 $\pm$ 2.0 ab
	1000	5.8 $\pm$ 1.6 a	39.4 $\pm$ 3.7 a	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	45.2 $\pm$ 4.0 a
	1200	2.4 $\pm$ 0.9 b	29.6 $\pm$ 3.0 a	0.0 $\pm$ 0.0	0.2 $\pm$ 0.2	32.0 $\pm$ 3.4 ab
	1400	1.2 $\pm$ 0.5 b	19.2 $\pm$ 4.9 b	0.0 $\pm$ 0.0	2.0 $\pm$ 1.2	28.0 $\pm$ 4.3 c
	1600	2.6 $\pm$ 1.0 b	26.4 $\pm$ 6.5 b	0.0 $\pm$ 0.0	1.0 $\pm$ 0.3	29.0 $\pm$ 6.9 bc
	1800	1.4 $\pm$ 0.2 b	14.4 $\pm$ 2.1 b	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	15.8 $\pm$ 2.4 c
df=5,24, <i>F</i> , <i>p</i>		2.68, 0.0037	4.64, 0.004		2.06, 0.106	6.58, 0.0001
23 July	0800	3.6 $\pm$ 0.8 a	8.8 $\pm$ 2.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	12.4 $\pm$ 2.6 a
	1000	2.2 $\pm$ 1.5 b	5.2 $\pm$ 1.7	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	7.4 $\pm$ 2.9 b
	1200	4.8 $\pm$ 0.6 a	6.8 $\pm$ 1.2	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	11.6 $\pm$ 1.1 a
	1400	2.0 $\pm$ 0.5 b	4.2 $\pm$ 1.1	0.0 $\pm$ 0.0	0.4 $\pm$ 0.2	6.2 $\pm$ 1.0 ab
	1600	2.0 $\pm$ 0.8 b	4.6 $\pm$ 1.2	0.0 $\pm$ 0.0	0.2 $\pm$ 0.2	3.6 $\pm$ 0.5 b
	1800	1.8 $\pm$ 0.5 b	5.6 $\pm$ 1.2	0.0 $\pm$ 0.0	0.2 $\pm$ 0.2	7.4 $\pm$ 1.5 ab
df=5,24, <i>F</i> , <i>p</i>		13.58, 0.02	1.89, 0.134		0.76, 0.590	4.42, 0.005
30 July	0800	5.4 $\pm$ 1.3	4.0 $\pm$ 1.0	0.0 $\pm$ 0.0	1.0 $\pm$ 0.5	9.4 $\pm$ 2.0
	1000	6.8 $\pm$ 1.3	4.6 $\pm$ 0.9	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	11.4 $\pm$ 1.2
	1200	7.6 $\pm$ 2.0	4.0 $\pm$ 1.4	0.0 $\pm$ 0.0	0.4 $\pm$ 0.2	11.6 $\pm$ 3.0
	1400	6.0 $\pm$ 1.1	4.4 $\pm$ 1.6	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	10.4 $\pm$ 1.2
	1600	9.8 $\pm$ 2.4	8.6 $\pm$ 1.3	0.4 $\pm$ 0.4	0.2 $\pm$ 0.2	18.8 $\pm$ 3.5
	1800	10.4 $\pm$ 1.7	9.4 $\pm$ 1.1	0.0 $\pm$ 0.0	0.2 $\pm$ 0.2	19.8 $\pm$ 2.4
df=5,24, <i>F</i> , <i>p</i>		0.77, 0.578	2.50, 0.06	1.00, 0.439	1.94, 0.124	2.09, 0.102

^a Data transformed using $\log(x+1)$ prior to analysis, but untransformed data are presented.

^b Means within a column and date followed by the same letter are not significantly different ($\alpha=0.05$) by Tukey studentized range honestly significant difference (HSD) test.

(Table 2). Changes in mean density of *F. tritici* in flowers at different sampling hours varied among sampling dates, but sampling hour had no effect on the number of *F. tritici* at flowers in either year. On 16 July 1990, variation in the number of *F. tritici* in each sampling time was apparent, but this coincided with the presence of rain. *F. fusca* and immature thrips populations were present in low numbers in flowers and did not show any diurnal pattern of abundance.

On tomato foliage, *F. fusca*, a foliage feeder (Palmer et al., 1989), and immature thrips were predominant (20 July: $F=28.42$, $df=4,70$, $p<0.05$; 27 July: $F=24.73$, $df=4,70$, $p<0.05$; 5 August: $F=37.52$, $df=4,70$, $p<0.05$; 19 August: $F=36.29$, $df=4,70$, $p<0.05$), while

few *F. tritici* and *F. occidentalis* were observed (Table 3). Thrips numbers (adults and immatures) did not differ significantly ($p>0.05$) among plant positions (upper and lower plant strata) on any of the sample hours and dates, hence, whole plant populations are shown in Table 3. In addition, there were no significant differences among sample hours for either adults or immature thrips (Table 3). As the season progressed, the number of adult *F. fusca* decreased, but the number of immatures tended to remain stable.

F. tritici was the dominant species of thrips caught on sticky traps during July and early August in 1992, while *F. occidentalis* populations increased in number during August (Table 4). When *F. tritici* populations were at their

Table 2. Mean number of thrips^a ($\pm$ SEM) per 10 tomato flowers, Fletcher, NC, in 1992

Date	Time	<i>F. occidentalis</i>	<i>F. tritici</i>	<i>F. fusca</i>	Immature	Total adults
20 June	0800	0.8 $\pm$ 0.3	0.5 $\pm$ 6.8	0.3 $\pm$ 0.2	0.2 $\pm$ 0.1	1.6 $\pm$ 0.4
	1000	0.5 $\pm$ 0.2	1.0 $\pm$ 0.4	0.1 $\pm$ 0.1	0.0 $\pm$ 0.0	1.6 $\pm$ 0.5
	1200	0.2 $\pm$ 0.1	1.1 $\pm$ 0.3	0.4 $\pm$ 0.2	0.0 $\pm$ 0.0	1.7 $\pm$ 0.4
	1400	0.5 $\pm$ 0.2	0.9 $\pm$ 0.3	0.3 $\pm$ 0.2	0.0 $\pm$ 0.0	1.7 $\pm$ 0.3
	1600	0.7 $\pm$ 0.3	1.3 $\pm$ 0.4	0.6 $\pm$ 0.3	0.0 $\pm$ 0.0	2.6 $\pm$ 0.5
	1800	0.4 $\pm$ 0.2	0.6 $\pm$ 0.3	0.4 $\pm$ 0.2	0.0 $\pm$ 0.0	1.4 $\pm$ 0.4
	df=5,24, <i>F</i> , <i>p</i>	0.70, 0.624	0.75, 0.593	0.68, 0.633	2.25, 0.07	0.51, 0.764
27 July	0800	3.3 $\pm$ 0.6 a ^b	4.8 $\pm$ 2.1	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	8.4 $\pm$ 2.1
	1000	0.5 $\pm$ 0.2 b	2.7 $\pm$ 0.5	0.1 $\pm$ 0.1	0.2 $\pm$ 0.2	3.3 $\pm$ 0.6
	1200	0.2 $\pm$ 0.2 b	6.2 $\pm$ 1.6	0.0 $\pm$ 0.0	0.1 $\pm$ 0.1	6.4 $\pm$ 1.6
	1400	0.1 $\pm$ 0.1 b	5.7 $\pm$ 1.0	0.2 $\pm$ 0.1	0.1 $\pm$ 0.1	6.1 $\pm$ 1.1
	1600	0.4 $\pm$ 0.4 b	6.8 $\pm$ 1.7	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	7.2 $\pm$ 1.7
	1800	0.3 $\pm$ 0.2 b	7.1 $\pm$ 1.7	0.1 $\pm$ 0.1	0.0 $\pm$ 0.0	6.2 $\pm$ 0.8
	df=5,24, <i>F</i> , <i>p</i>	18.97, 0.0001	0.84, 0.527	1.06, 0.393	0.50, 0.773	0.80, 0.512
5 August	0800	2.3 $\pm$ 0.6 a	1.6 $\pm$ 0.7	0.2 $\pm$ 0.2	0.2 $\pm$ 0.2	4.1 $\pm$ 1.1
	1000	0.5 $\pm$ 0.3 b	4.9 $\pm$ 1.4	0.0 $\pm$ 0.0	0.5 $\pm$ 0.4	5.4 $\pm$ 1.2
	1200	1.1 $\pm$ 0.4 b	1.9 $\pm$ 0.5	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	3.0 $\pm$ 0.7
	1400	1.5 $\pm$ 0.4 ab	5.2 $\pm$ 1.8	0.0 $\pm$ 0.0	0.3 $\pm$ 0.2	6.7 $\pm$ 1.8
	1600	1.9 $\pm$ 0.5 ab	5.0 $\pm$ 1.4	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	6.9 $\pm$ 1.5
	1800	1.3 $\pm$ 0.2 b	3.6 $\pm$ 1.6	0.1 $\pm$ 0.1	0.1 $\pm$ 0.1	6.2 $\pm$ 1.6
	df=5,24, <i>F</i> , <i>p</i>	3.98, 0.047	1.74, 0.141	1.69, 0.153	2.06, 0.106	6.58, 0.0001
17 August	0800	4.3 $\pm$ 0.9	1.2 $\pm$ 0.5	0.0 $\pm$ 0.0	1.8 $\pm$ 0.7	5.5 $\pm$ 0.9
	1000	3.5 $\pm$ 0.8	0.2 $\pm$ 0.2	0.0 $\pm$ 0.0	3.4 $\pm$ 0.7	4.2 $\pm$ 1.2
	1200	3.2 $\pm$ 0.4	0.6 $\pm$ 0.2	0.1 $\pm$ 0.1	1.3 $\pm$ 0.4	3.9 $\pm$ 0.5
	1400	2.6 $\pm$ 0.5	0.4 $\pm$ 0.2	0.0 $\pm$ 0.0	2.1 $\pm$ 0.7	3.0 $\pm$ 0.4
	1600	4.0 $\pm$ 1.0	0.5 $\pm$ 0.3	0.0 $\pm$ 0.0	2.4 $\pm$ 0.5	4.5 $\pm$ 0.9
	1800	3.3 $\pm$ 0.7	0.1 $\pm$ 0.1	0.0 $\pm$ 0.0	1.9 $\pm$ 0.7	3.4 $\pm$ 0.7
	df=5,24, <i>F</i> , <i>p</i>	0.41, 0.837	1.74, 0.142	1.00, 0.427	1.22, 0.313	0.67, 0.643

^aData transformed using $\log(x+1)$ prior to analysis, but untransformed data are presented.

^bMeans within a column and date followed by the same letter are not significantly different ($\alpha=0.05$) by Tukey studentized range honestly significant difference (HSD) test.

Table 3. Mean number of thrips ($\pm$ SEM) collected from tomato foliage, Fletcher, NC, 1992

Date	Time	No. thrips $\pm$ SEM per tomato plant ^a				
		<i>F. occidentalis</i>	<i>F. tritici</i>	<i>F. fusca</i>	Immature	Total adults
20 July	1000	0.1 $\pm$ 0.1 c ^b	0.1 $\pm$ 0.1 c	2.5 $\pm$ 0.6 a	1.5 $\pm$ 0.5 b	2.9 $\pm$ 0.4
	1400	0.0 $\pm$ 0.0 c	0.4 $\pm$ 0.2 c	2.4 $\pm$ 0.6 a	2.1 $\pm$ 0.8 a	2.8 $\pm$ 0.6
	1800	0.2 $\pm$ 0.1 b	1.3 $\pm$ 1.1 b	2.2 $\pm$ 0.5 a	1.2 $\pm$ 0.3 b	3.7 $\pm$ 0.9
27 July	0800	0.2 $\pm$ 0.1 b	0.1 $\pm$ 2.1 c	1.4 $\pm$ 0.8 ab	2.3 $\pm$ 0.9 a	1.7 $\pm$ 2.1
	1400	0.2 $\pm$ 0.1 c	0.5 $\pm$ 0.2 c	2.2 $\pm$ 0.3 b	5.5 $\pm$ 1.0 a	3.0 $\pm$ 0.3
	1800	0.3 $\pm$ 0.2 c	0.5 $\pm$ 0.2 c	2.4 $\pm$ 0.5 b	4.0 $\pm$ 1.3 a	3.5 $\pm$ 0.6
5 August	0800	0.5 $\pm$ 0.2 b	0.4 $\pm$ 0.2 b	0.0 $\pm$ 0.0 b	3.3 $\pm$ 0.8 a	0.9 $\pm$ 0.3
	1400	0.1 $\pm$ 0.1 b	0.0 $\pm$ 0.0 b	0.5 $\pm$ 0.3 b	1.8 $\pm$ 0.4 a	0.6 $\pm$ 0.3
	1800	0.2 $\pm$ 0.1 b	0.2 $\pm$ 0.2 b	1.0 $\pm$ 0.3 b	3.1 $\pm$ 0.8 a	1.4 $\pm$ 0.4
19 August	0800	0.3 $\pm$ 0.2 b	0.1 $\pm$ 0.1 b	0.1 $\pm$ 0.1 b	3.9 $\pm$ 0.7 a	0.5 $\pm$ 0.3
	1400	0.0 $\pm$ 0.0 b	0.0 $\pm$ 0.0 b	0.0 $\pm$ 0.0 b	5.1 $\pm$ 1.2 a	0.0 $\pm$ 0.0
	1800	0.1 $\pm$ 0.1 b	0.0 $\pm$ 0.0 b	0.0 $\pm$ 0.0 b	2.0 $\pm$ 0.7 a	0.1 $\pm$ 0.1
ANOVA	df	<i>F</i> value (<i>p</i> value)				
Time (<i>T</i>)	2	2.39 (0.10)	0.73 (0.48)	1.03 (0.35)	1.44 (0.24)	0.63 (0.54)
Position (<i>P</i> _o)	1	0.69 (0.41)	1.28 (0.26)	1.79 (0.18)	3.35 (0.07)	2.18 (0.14)
<i>T</i> $\times$ <i>P</i> _o	2	0.47 (0.76)	1.55 (0.22)	0.43 (0.65)	0.25 (0.78)	0.56 (0.57)

^aMean total number for each sampling time inclusive of both plant positions (upper half and low half).

^bMeans within a row and date followed by the same letter are not significantly different ($\alpha=0.05$) by Tukey studentized range honestly significant difference (HSD) test.

highest (20 and 27 July, and 5 August), aerial sticky trap catches were higher between 1200–1800 h compared with 0800–1200 h. Peak flight activity of this species was observed between 1400–1600 h on 2 of the 4 sampling dates. Although *F. occidentalis* numbers were considerably lower than *F. tritici*, *F. occidentalis* flight did not appear to be depressed during the morning (1000–1200 h), as was *F. tritici*. *F. fusca* populations were low on all sample dates and there was no evidence of flight periodicity. No immatures were observed on aerial traps.

No significant correlations were detected between air temperature and number of thrips in flowers or on foliage, with the exception of *F. occidentalis* in flowers on 22 June 1990 ($F=8.5$, $df=24$, $p<0.001$, $r=0.63$). A significant positive correlation between air temperature and aerial trap catch of *F. tritici* occurred on 3 of 4 sample dates ($df=24$, $p<0.05$; $F=11.7$, $r=0.69$ on 20 July, $F=7.5$, $r=0.58$ on 27 July, and $F=20.7$, $r=0.79$ on 5 August). There was no significant correlation between air temperature and aerial trap catch of *F. occidentalis* or *F. fusca* on any sample date.

Densities of the three adult *Frankliniella* species and immature thrips on the various sample dates differed from one another in both years (Figs. 1 and 2). In 1990, the density of *F. tritici* in flowers was highest on 22 June and 16 July and was relatively low on 7, 22 and 30 July. *F. occidentalis* populations increased steadily as the season progressed, peaking on the last sampling date (30 July). In 1992, the highest number of *F. tritici* in flowers and on aerial traps occurred on 27 July. Temporal trends of *F. occidentalis* in flowers were similar in 1990 and 1992. The number of immatures from flowers gradually increased as the season progressed, similar to that of adult *F. occidentalis* in flowers. *F. fusca* populations on foliage and in flowers were highest on the earliest sampling date and declined as the season progressed, but the number of *F. fusca* captured on traps peaked on July 27.

DISCUSSION

Generally, higher numbers of *F. occidentalis* were observed on flowers in the morning compared with the afternoon. Lewis (1973) suggested that some thrips species are habitually more

Table 4. Mean number of thrips ($\pm$ SEM) per aerial sticky trap, Fletcher, NC, in 1992

Date	Time ^a	<i>F. occidentalis</i>	<i>F. tritici</i>	<i>F. fusca</i>	Others ^c	Total adults
20 June	1000	0.0 $\pm$ 0.0 b ^b	0.3 $\pm$ 0.3 c	0.3 $\pm$ 0.3	0.3 $\pm$ 0.3	1.3 $\pm$ 0.9 b
	1200	1.0 $\pm$ 0.6 ab	7.0 $\pm$ 0.6 b	1.0 $\pm$ 0.6	1.3 $\pm$ 0.9	10.3 $\pm$ 0.9 a
	1400	0.0 $\pm$ 0.0 b	17.3 $\pm$ 0.9 a	1.3 $\pm$ 0.6	2.0 $\pm$ 1.3	20.3 $\pm$ 4.5 a
	1600	0.3 $\pm$ 0.3 ab	6.7 $\pm$ 0.7 b	2.7 $\pm$ 0.3	0.6 $\pm$ 0.3	10.6 $\pm$ 1.2 a
	1800	2.0 $\pm$ 0.6 a	11.3 $\pm$ 1.3 ab	0.3 $\pm$ 0.3	1.3 $\pm$ 0.9	15.0 $\pm$ 3.0 a
	df=5.24, <i>F</i> , <i>p</i>	5.21, 0.061	66.70, 0.001	2.91, 0.08	0.54, 0.70	19.98, 0.001
27 July	1000	1.3 $\pm$ 0.9	1.0 $\pm$ 1.0 c	4.3 $\pm$ 2.0 ab	0.7 $\pm$ 0.3 c	7.3 $\pm$ 1.5 c
	1200	0.0 $\pm$ 0.0	9.3 $\pm$ 2.3 b	8.3 $\pm$ 1.2 a	3.0 $\pm$ 0.6 ab	20.7 $\pm$ 1.9 b
	1400	0.0 $\pm$ 0.0	11.3 $\pm$ 3.2 b	0.3 $\pm$ 0.3 b	5.7 $\pm$ 1.5 a	17.3 $\pm$ 3.8 bc
	1600	0.0 $\pm$ 0.0	128.7 $\pm$ 26.4 a	0.7 $\pm$ 0.7 b	6.7 $\pm$ 1.3 a	136.3 $\pm$ 26.6 a
	1800	0.3 $\pm$ 0.3	65.0 $\pm$ 11.2 a	1.1 $\pm$ 0.6 b	1.3 $\pm$ 0.7 bc	67.7 $\pm$ 12.2 a
	df=5.24, <i>F</i> , <i>p</i>	2.13, 0.152	35.58, 0.0001	7.19, 0.005	7.43, 0.005	39.52, 0.0001
5 August	1000	4.0 $\pm$ 1.2 b	1.0 $\pm$ 0.2 b	0.0 $\pm$ 0.0	3.0 $\pm$ 0.6	8.0 $\pm$ 2.3 b
	1200	16.0 $\pm$ 3.1 a	8.7 $\pm$ 1.8 a	0.3 $\pm$ 0.3	8.0 $\pm$ 2.7	33.0 $\pm$ 3.0 a
	1400	13.0 $\pm$ 3.2 a	23.6 $\pm$ 3.2 a	0.3 $\pm$ 0.3	3.3 $\pm$ 0.9	40.3 $\pm$ 3.2 a
	1600	11.3 $\pm$ 2.2 a	30.3 $\pm$ 5.3 a	0.0 $\pm$ 0.0	5.3 $\pm$ 0.3	46.7 $\pm$ 6.2 a
	1800	13.3 $\pm$ 4.1 a	17.7 $\pm$ 6.3 a	1.0 $\pm$ 0.6	3.7 $\pm$ 2.2	35.7 $\pm$ 4.8 a
	df=5.24, <i>F</i> , <i>p</i>	4.64, 0.022	22.96, 0.0001	1.43, 0.2951	2.06, 0.106	19.17, 0.0001
19 August	1000	2.0 $\pm$ 0.3 b	0.3 $\pm$ 0.3 b	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0 b	0.3 $\pm$ 0.3 b
	1200	4.0 $\pm$ 1.5 a	2.7 $\pm$ 0.3 a	0.0 $\pm$ 0.0	0.7 $\pm$ 0.7 ab	7.3 $\pm$ 2.8 a
	1400	4.0 $\pm$ 2.0 a	1.3 $\pm$ 1.3 a	0.0 $\pm$ 0.0	1.3 $\pm$ 0.3 a	6.7 $\pm$ 3.7 a
	1600	8.7 $\pm$ 0.7 a	1.0 $\pm$ 0.6 a	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0 b	9.7 $\pm$ 1.2 a
	1800	3.7 $\pm$ 1.5 a	1.7 $\pm$ 1.2 a	0.0 $\pm$ 0.0	1.7 $\pm$ 0.7 a	7.0 $\pm$ 0.6 a
	df=5.24, <i>F</i> , <i>p</i>	9.30, 0.002	1.36, 0.426		4.72, 0.021	9.72, 0.0018

^aHour 1000 corresponds with the time interval 0800–1000 h and hour 1800 corresponds with 1600–1800 h.

^bMeans within a column and date followed by the same letter are not significantly different ($\alpha=0.05$) by Tukey studentized range honestly significant difference (HSD) test.

^cOther thrips included *Thrips tabaci* Lindeman, *Microcephalothrips abdominalis* (Crawford), *Anaphothrips obscurus* (Muller), *Neohydatothrips variabilis* (Beach), *Odontothrips* sp. and Tubulifera.

Fig. 1. Population of *Frankliniella occidentalis*, *F. tritici*, *F. fusca*, and immature thrips in tomato flowers, Fletcher, NC, 1990. Values are mean ($\pm$ SEM) numbers of thrips per sample.

noticeable earlier in the day than others. Erlich (1991) reported that dispersal of *F. occidentalis* on greenhouse tomato was higher early in the morning (0900 h) and near dusk (1700 h) than at all other times. In addition, swarming behavior of *F. occidentalis* in the morning was observed on cotton and alfalfa in Arizona (Terry and Gardner, 1989). However, Salguero Navas et al. (1991b) reported that density estimates of *F. occidentalis* in tomato flowers were not influenced by sampling time in Florida, but they did not attempt to estimate thrips density changes in the afternoon.

Few *F. fusca* adults were recovered from flowers or aerial traps compared to *F. occidentalis* and *F. tritici*, but this species was the dominant thrips on foliage. In contrast, Salguero Navas et al. (1991b) reported that *F. fusca* preferred tomato flowers and rarely inhabited

Fig. 2. Population of *Frankliniella occidentalis*, *F. tritici*, *F. fusca*, and immature thrips on tomato flowers, foliage and sticky traps above tomatoes, Fletcher, NC, 1992. Values are mean ($\pm$ SEM) numbers of thrips per sample.

other plant structures. Tappan (1986) reported that the largest density of *F. fusca* occurred in peanut flowers between 1100 and 1200 h, but there was no evidence in our data to indicate that *F. fusca* showed diurnal periodicity.

F. tritici was the only thrips species in our study that exhibited an association with flight activity and air temperature. Lewis (1973) reported that the most important micro-weather factors affecting the flight of thrips were temperature and light. The movement of thrips is known to increase as a function of increasing temperature (Davidson and Andrewartha, 1948; Harding, 1961). Watts (1936) reported that *F. tritici* adults are sluggish and seldom fly at temperatures below 15°C. In Florida, aerial trap catches of *Frankliniella* spp. were related to daily mean temperature in tomato fields, but thrips were not identified to species (Erlich, 1991). Because colored sticky traps were used to measure flight activity, light intensity and wind speeds may also have been important factors affecting thrips flight (Cho et al., 1995b). However, Erlich (1991) reported that *Frankliniella* spp. trap catches were not relat-

ed to wind speed or precipitation in tomato fields in Florida.

Temporal patterns of abundance of *F. tritici* and *F. occidentalis* were considerably different in this study. *F. tritici* populations peaked earlier and declined sooner than *F. occidentalis* populations. However, Salguero Navas et al. (1991b) reported that high densities of *F. tritici*, *F. occidentalis*, and *F. fusca* occurred at similar times in tomato fields in Florida. Differences in the temporal occurrence of *F. tritici* and *F. occidentalis* in this study are not likely to be the result of interspecific interaction, because the time of occurrence of these species is similar in other areas of North Carolina where only one of the species is found (Eckel et al., 1996).

The association of immature thrips with adult *Frankliniella* spp. on tomato plants is not clear because immature stages of Terebrantia spp. could not be identified to the species level. To clarify the association, immature thrips must be identified by rearing them to the adult stage. Many authors provide the rearing methods for various thrips species in the laboratory or greenhouse (see Loomans and Murai, 1997).

However, in general, these rearing methods are inappropriate for identifying immature thrips from thrips populations where many thrips species coexist because each rearing method is developed for a specific thrips species. Therefore, greater emphasis should be placed on identifying immature thrips from the hosts to more clearly understand the relationship between certain species of thrips and host plants.

Thrips populations in tomato fields are usually estimated from tomato flowers or aerial sticky traps because these methods are less expensive and more manageable than whole plant inspection (Cho, 1993). However, *F. occidentalis* and *F. fusca* occupied different niches on tomato plants. *F. occidentalis* preferred to inhabit tomato flowers and *F. fusca* mainly inhabited on foliage or other plant structures. Also, *F. occidentalis* and *F. tritici* exhibited different flight patterns in tomato fields. Because *F. tritici* is a more active flier than *F. occidentalis*, the round shape sticky traps catch more *F. tritici* than the flat sticky traps during windy conditions (Cho et al., 1995b). Thus, it is possible to underestimate or overestimate different thrips species densities if only one sampling method is used to estimate thrips populations. To avoid this problem, different sampling methods may be necessary for different thrips species. Because *F. occidentalis* populations were generally higher in the morning compared with the afternoon, the time of day in which sampling is conducted should be consistent from one sample period to another to detect true changes in population fluctuations.

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