Comparison of Colored Sticky Traps for Monitoring Thrips Populations (Thysanoptera: Thripidae) in Staked Tomato Fields[1]

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ABSTRACT The response of flower thrips, *Frankliniella* spp., to various colors and sticky trap designs was evaluated in staked tomato fields in western North Carolina. Yellow sticky traps caught significantly more thrips compared with blue or white traps. There were no differences in the relative proportion of thrips species caught on different colored traps. The size of the flower sampling unit (i.e., 10-flowers versus all flowers per plant) did not influence the correlation between sticky trap catches and thrips abundance in flowers. Only *F. occidentalis* (Pergande) exhibited a significant correlation between percent abundance on all colors of sticky traps and percent abundance in flowers. Colored sticky traps caught high numbers of *F. tritici* (Fitch), despite the fact that few *F. tritici* were collected from flowers. In tests to evaluate different trap designs, cylindrical and cup traps caught more *F. tritici* than glass slide traps. Cylindrical sticky traps were more economical and enabled easier identification of thrips than glass slide or cup traps.

KEY WORDS *Frankliniella occidentalis, Frankliniella tritici,* color preference, tomato.

Flower thrips, *Frankliniella* spp., are worldwide pests of numerous greenhouse- and field-grown vegetable and ornamental crops (Allen and Broadbent 1986, Cho et al. 1989). The western flower thrips, *F. occidentalis* (Pergande), and the tobacco thrips, *F. fusca* (Hinds), are important pests of tomato that transmit tomato spotted wilt virus (Sakimura 1962, 1963). Also, oviposition by *F. occidentalis* inhabiting either flowers or small fruits of tomato can cause cosmetic damage that reduces the value of fruit (Salguero Navas et al. 1991b). Although originally limited to the western half of the United States, *F. occidentalis* has recently spread to the southeastern United States (Beshear 1983). *F. fusca* is a cosmopolitan species with a wide host range (Newsom et al. 1953). The flower thrips, *F. tritici* (Fitch), is an ubiquitous inhabitant of a wide

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variety of flowers in eastern North America (Watts 1936) and one of the most abundant thrips species on tomato (Salguero Navas et al. 1991a), but it is not considered a tomato pest (Salguero Navas et al. 1991b, Linker et al. 1993). However, *F. tritici* has been reported as a direct pest of cotton seedlings in South Carolina (Watts 1936) and of ornamental crops in Maryland (Henneberry et al. 1964).

Accurate population estimates of thrips species are essential for the successful application of control programs. An ideal trap for monitoring thrips populations in a pest management context should be highly attractive to thrips to ensure capture at low densities and exhibit a high correlation between trapped thrips and actual thrips populations in the field (Yudin et al. 1987). Traps based on responses of insects to color have been widely used in thrips monitoring programs (Lewis 1959, Yudin et al. 1987, Gillespie and Vernon 1990). Studies of color preferences of *Frankliniella* spp. have produced variable results. Moffitt (1964) and Yudin et al. (1987) found that white sticky traps consistently trapped more *F. occidentalis* than yellow or other colors in a pear orchard and lettuce farm, respectively. Vernon and Gillespie (1990) reported *F. occidentalis* preferred blue, violet, and yellow to green, orange, and ultraviolet (UV) reflecting white colors in a cucumber greenhouse. Walker (1974) found that for *F. tritici* and *F. fusca,* yellow and low UV-reflecting white surfaces were highly attractive. There is general agreement that low UV-reflective white, blue, blue-violet, and yellow traps are more attractive than high UV-reflective green, red, orange, black, or white (Matteson and Terry 1992).

In addition to color, the type of trap used to monitor thrips can also affect trap catch. Lewis (1959) and Matteson and Terry (1992) used cylindrical traps to monitor thrips in wheat and cotton fields, respectively, and Yudin et al. (1987) used painted cups to monitor *F. occidentalis* in lettuce fields. In contrast, Gillespie and Vernon (1990) used sticky cards to monitor *F. occidentalis* in greenhouse cucumbers. However, the efficiency and expense of these different trap types were not measured in the same crop environment.

The purpose of this study was to evaluate the efficiency of various colors and trap designs for monitoring thrips populations in tomato fields in western North Carolina, and to assess the utility of sticky trap catches in estimating thrips abundance in flowers. Although *F. tritici* is not a pest of tomato, results with this species are also reported because it is the most abundant thrips in North Carolina tomato fields and can influence the interpretation of results of *F. occidentalis* and *F. fusca* monitoring programs.

Materials and Methods

Experiments were conducted in commercial tomato fields from 1990 to 1992 in western North Carolina (Henderson and Haywood counties). For the color preference test, four tomato fields (Hayood, Dana, Mills S, and Mills J) were surveyed in 1990 and two (Haywood and Fruitland) in 1991. The nearest distance between surveyed fields was ≈ 15 km for both years. Two separate tomato fields (Fruitland and Mills J), 35 km apart, were used for the trap design test in 1992. Tomato fields selected for this study were located in different cropping environments. The Haywood field was surrounded by forest and annual weeds, and the Mills J and S fields were surrounded by alfalfa,

corn, soybean, and fallow fields. The Dana and Fruitland fields were surrounded by apple orchards. The fields varied in size from approximately 6 to 8 ha, with approximately 2600 tomato plants per ha. Crops were grown according to recommended commercial practices (Konsler and Gardner 1990), including the use of insecticides.

Color Preference Test. Traps consisted of a 5.0 × 7.5 cm piece of index card covered with two glass microscope slides (2.5 × 7.5 cm, Carolina Biological Supply Co., Burlington, NC) on each side. Traps were clamped together by a 5.1-cm binder clip, and the outer surfaces of glass slides were coated with a think layer of sticky material (Tanglefoot®, The Tangle Foot Co., Grand Rapids, MI).

Colors tested were blue (Pacific blue Sp-7 paint, Pro Hardware, Stanford, CT), yellow (John Deere yellow No. 2306 paint, Kurffes Coating Inc., Louisville, KY), and white (index card paper). Before trap construction, index cards were thoroughly coated on both sides with blue or yellow paint and allowed to dry.

The reflectance of each color was determined using a Li-Cor-1800 Portable Spectrophotometer® with a Li-1800-12 integrating sphere (Li-Cor, Inc/Li-Cor, Ltd., Lincoln, NE). The reflectance (R) of each sample was measured at 2-nm intervals from 330 to 800 nm . Reflectance (R) was calculated as:

$$R = \frac{(I_s - I_D)R_R}{(I_r - I_D)}$$

where I_s is the measured sphere output when the sample is illuminated, I_R is the measured sphere output when the reference material, barium sulfate, is illuminated, R_R is the reflectance of the reference material and I_D is the illuminance due to 'stray' radiation (Li-Cor 1981). To determine whether the glass slide covering the painted index cards affected reflectance curves of the paint, spectral reflectance of blue, yellow, and white surfaces with and without glass slides were measured by the same method. All reflectance measurements were conducted without applying sticky material to avoid damage to the spectrophotometer.

In tomato fields, the three different-colored traps were hung in a random array on a wood bar with eye hooks spaced 35 cm apart. The bar was attached to a wooden pole and its height adjusted weekly to ≈ 15 cm above the plant canopy. Because white traps were found to be least attractive to thrips in 1990, white traps were replaced in the experiment by traps consisting of side by side blue and yellow cards (2.5 × 7.0 cm) (hereafter called "double-colored trap"), and blue, yellow, and double-colored traps were tested in 1991. Double-colored traps were tested to determine if they enhanced trap catch compared to solid yellow or blue. Depending on field size, three to five trap arrays of each colored trap were placed in each field. One trap array was placed in the middle of the field, and the remaining trap arrays were placed equidistant from the central array (>10 m from the edge of field). Compass orientation of traps was not considered, but all traps within a field were oriented in the same direction. Each trap was replaced weekly and all thrips were counted and identified to species with the aid of a microscope.

To compare the number of thrips caught on traps with thrips populations in tomato flowers, flower samples also were collected weekly from the same fields. Each field was partitioned into 16 to 30 sections, depending on field size, and 10 randomly selected tomato flowers were collected from the upper half of plants in each section. Flowers were placed in a 20-ml scintillation vial, (Kimble®, Toledo, OH) containing 70% ethanol. The mean number of flowers per plant on each sample date was estimated by counting the number of flowers on 25 randomly-selected tomato plants over the entire field. The average number of thrips per plant on each sample date was estimated by multiplying the mean number of thrips per flower by the average number of flowers per plant. Trap catches were correlated with thrips abundance based on numbers per 10 flowers, and with the estimated number of thrips per plant.

Trap Design Test. In a separate experiment, three different types of yellow-colored traps were evaluated: glass slide, cylindrical, and cup. The glass slide trap was the same as that used in the color preference test (double-sided surface area was 65 cm^2). The cylindrical trap consisted of a section of yellow-painted plastic polyvinyl chloride (PVC) pipe, 2.50-cm diam × 7.35 cm long (surface area, 57.7 cm^2). The painted pipe was wrapped with a clear plastic sleeve coated with Tanglefoot® (Olson Products-Sable Fly Trap, after Matteson and Terry [1992]). The cup trap consisted of a white paper cup (surface area, 69.7 cm^2) painted yellow and mounted upside down on a tomato stake and secured with a 5.1-cm binder clip at the bottom of the cup. An even thickness of sticky material was applied to these traps. Five individual traps of each type were randomly placed in each of two fields. All traps were located > 10 m from the edge of fields, and distance between traps was spaced > 1 m. All three trap types were maintained approximately 15 cm above the plant canopy throughout the season. Traps were replaced weekly and returned to the laboratory to count and identify thrips. The cylindrical and cup traps were covered with clear plastic wrap to facilitate processing. The processing time and construction costs for each trap type were recorded throughout the season. To compare the cup, cylindrical, and glass slide traps, catches were expressed on a per unit basis (no. of thrips per 57.7 cm2).

Because each trap design was painted the same yellow color (John Deere yellow No. 2306 paint), the UV reflectance patterns of different trap designs were not compared. Also, the spectrophotometer used in this study did not allow us to measure UV reflectance of each trap design, given their differences in shape.

Statistical Analysis. Multivariate analysis of variance (MANOVA) was used to test the interaction effect of color x field in the color preference test. One-way analysis of variance with color as the treatment effect in each field was then used to test for effect of color on trap catch; means were separated by the least-significant difference (LSD test ($P \leq 0.05$) (SAS Institute 1985). To determine if color affected the proportion of each thrips species captured, the relative proportions of various thrips species on each colored trap were calculated over the entire season and MANOVA was used to test whether the proportional catches of thrips species varied among blue, yellow, white (1990) or double-colored (1991) traps. Correlation analysis (PROC CORR, SAS Institute 1985) was used to assess the relationship between number of adult thrips

collected on colored sticky traps and thrips collected from flowers by sample dates. A *t*-test was used to test for homogeneity of correlation coefficients for correlations between trap catches and the 10-flower and whole-plant sample units (Sokal and Rohlf 1981). Finally, linear regression (PROC GL , SAS Institute 1985) was used to determine the relationship between both the number and proportion of *F. occidentalis* and *F. tritici* on different colored traps and in tomato flowers. Residual plots were inspected for instability of sample variance, and log (x + 1) transformation was applied to the dependent variable when required (Sokal and Rohlf 1981), but untransformed means are presented.

Results and Discussion

Thrips Species on Traps and in Flowers. Adult thrips accounted for 99.9% of total thrips collected on sticky traps. The proportion of different species on traps varied among test fields, but *F. tritici, F. occidentalis,* and *F. fusca* were the dominant species, accounting for 90.6% and 91.5% of all thrips caught in 1990 and 1991, respectively (Table 1). Other thrips collected on sticky traps were *Neohydatothrips variabilis* (Beach), *Anaphothrips obscurus* (Muller), *Thrips trehernei* (Priesner), and *Tubulifera* sp.

Adult thrips accounted for 96% of all thrips collected from tomato flowers. *F. tritici* was the dominant thrips species in four of six fields, while *F. occidentalis* was the dominant thrips species in the other two fields (Table 2). Average number of flowers per plant was not significantly different among surveyed fields for both years ($F = 12.6$; df = 5, 885; $P = 0.0001$).

UV Reflectance Patterns. The relative reflectance pattern across the wavelengths measured were similar with and without glass slides, and the maximum difference was less than 10% among tested colors (Fig. 1). The percent reflectance of blue, yellow, and white with glass was similar to that measured by others (Parrella and Jones 1985, Zehnder and Trumble 1985, Matteson and Terry 1992, Stark and Vargas 1992). Vernon and Gillespie (1990) reported that greenhouse glass transmitted from 90 to 97% of incident wavelengths between 350 and 700 nm, and Matteson and Terry (1992) reported that clear plastic with sticky material (Tanglefoot company, Grand Rapids, MI) did not alter spectral reflectance.

Color Preference Test. Colors used in this study significantly affected catches of thrips (Table 1). The interaction term of color x field was highly significant for both years ($F = 13.96$; df = 9, 17; $P = 0.0001$). Therefore, the data were analyzed for effects of colors on thrips catch in each field. In all fields in 1990, significantly more total thrips were caught on blue and yellow traps than on white traps. There were significantly more total thrips caught on yellow than blue traps at two (Mills S and Mills J) of four fields in 1990, but no significant differences were found in the number of thrips caught on yellow and blue traps at the other two fields in 1990. *F. tritici* was caught in significantly higher numbers on blue and yellow traps than on white in 1990, but there were no differences among colors in 1991 when white traps were replaced with doubled-colored traps, indicating that double-colored did not enhance the response of thrips to traps. With the exception of the Mills S and Dana fields, in

Table 1. Season average number of thrips collected on blue, yellow, white, and double-colored (D-C) sticky traps in tomato fields in western North Carolina.

Year	Field	Color	Mean number of thrips ± SEM per sticky trap per week				
			F. occidentalis	*F. tritici*	*F. fusca*	Others	Total
1990	Haywood	Blue	0.17 ± 0.06 a	14.41 ± 3.19 a	0.25 ± 0.06 a	0.26 ± 0.09 a	17.08 ± 3.26 a
		Yellow	0.13 ± 0.05 a	25.52 ± 5.53 a	0.36 ± 0.07 a	0.26 ± 0.07 a	26.28 ± 5.64 a
		White	0.08 ± 0.03 a	4.34 ± 0.88 b	0.27 ± 0.08 a	0.25 ± 0.08 a	4.96 ± 0.96 b
	Mills S	Blue	0.89 ± 0.24 a	5.80 ± 0.70 b	0.16 ± 0.04 a	0.25 ± 0.05 b	7.10 ± 0.76 b
		Yellow	0.86 ± 0.21 a	9.25 ± 1.05 a	0.21 ± 0.05 a	0.44 ± 0.07 a	10.75 ± 1.06 a
		White	0.08 ± 0.03 b	1.70 ± 0.22 c	0.25 ± 0.06 a	0.21 ± 0.05 b	2.23 ± 0.26 c
	Dana	Blue	7.45 ± 1.60 a	7.67 ± 1.03 a	0.10 ± 0.03 a	0.56 ± 0.17 a	15.79 ± 2.16 a
		Yellow	6.70 ± 1.10 a	7.57 ± 1.02 a	0.14 ± 0.03 a	0.77 ± 0.20 a	15.17 ± 1.92 a
		White	1.35 ± 0.23 b	2.24 ± 0.32 b	0.11 ± 0.04 a	0.31 ± 0.06 a	4.01 ± 0.49 b
	Mills J	Blue	0.20 ± 0.07 a	9.92 ± 1.31 b	0.28 ± 0.08 a	0.77 ± 0.19 a	11.17 ± 1.33 b
		Yellow	0.19 ± 0.05 a	20.20 ± 3.01 a	0.55 ± 0.15 a	0.91 ± 0.18 a	21.84 ± 3.18 a
		White	0.09 ± 0.05 a	4.13 ± 0.17 c	0.59 ± 0.16 a	0.78 ± 0.20 a	5.59 ± 1.06 c
1991	Haywood	Blue	0.00 ± 0.00	4.94 ± 0.63 a	0.04 ± 0.03 a	0.14 ± 0.04 a	5.11 ± 0.62 a
		Yellow	0.00 ± 0.00	5.95 ± 1.13 a	0.06 ± 0.03 a	0.15 ± 0.05 a	6.16 ± 1.13 a
		D-C	0.00 ± 0.00	5.06 ± 0.96 a	0.08 ± 0.03 a	0.13 ± 0.05 a	5.26 ± 0.97 a
	Fruitland	Blue	6.47 ± 1.79 a	4.53 ± 0.89 a	0.00 ± 0.00 a	0.09 ± 0.07 a	11.09 ± 2.17 a
		Yellow	6.69 ± 2.35 a	3.97 ± 0.96 a	0.06 ± 0.04 a	0.44 ± 0.18 a	11.16 ± 3.19 a
		D-C	6.38 ± 2.08 a	4.16 ± 0.69 a	0.09 ± 0.68 a	0.47 ± 0.25 a	11.09 ± 2.62 a

Means within the same column and field followed by the same letter are not significantly different ($P < 0.05$), LSD. Data were transformed using log (x + 1) prior to analysis, but untransformed data are presented.

Table 2. Season average number of thrips collected from tomato flowers in western North Carolina.

Year	Field	No. flowers*	Mean number of thrips ± SEM per 10 flowers				
			F. occidentalis	*F. tritici*	*F. fusca*	Others**	Total
1990	Haywood	7.33	0.04 ± 0.02	6.15 ± 0.84	0.11 ± 0.03	0.04 ± 0.02	6 .34 ± 0.84
	Mills S	7.40	0.80 ± 0.17	4.86 ± 0.78	0.34 ± 0.08	0.04 ± 0.02	6.04 ± 0.79
	Dana	6.93	2.83 ± 0.39	2.08 ± 0.14	0.04 ± 0.02	0.25 ± 0.09	5.20 ± 0.65
	Mills J	7.33	0.07 ± 0.03	1.20 ± 0.22	0.47 ± 0.15	0.00 ± 0.00	1.74 ± 0.31
1991	Haywood	7.15	0.00 ± 0.00	0.63 ± 0.01	0.09 ± 0.01	0.02 ± 0.01	0.66 ± 0.09
	Fruitland	8.02	12.84 ± 1.14	0.73 ± 0.12	0.00 ± 0.00	0.66 ± 0.11	14.23 ± 1.19

* Mean number of flowers per plant during sample dates.
** Others included thrips larvae.

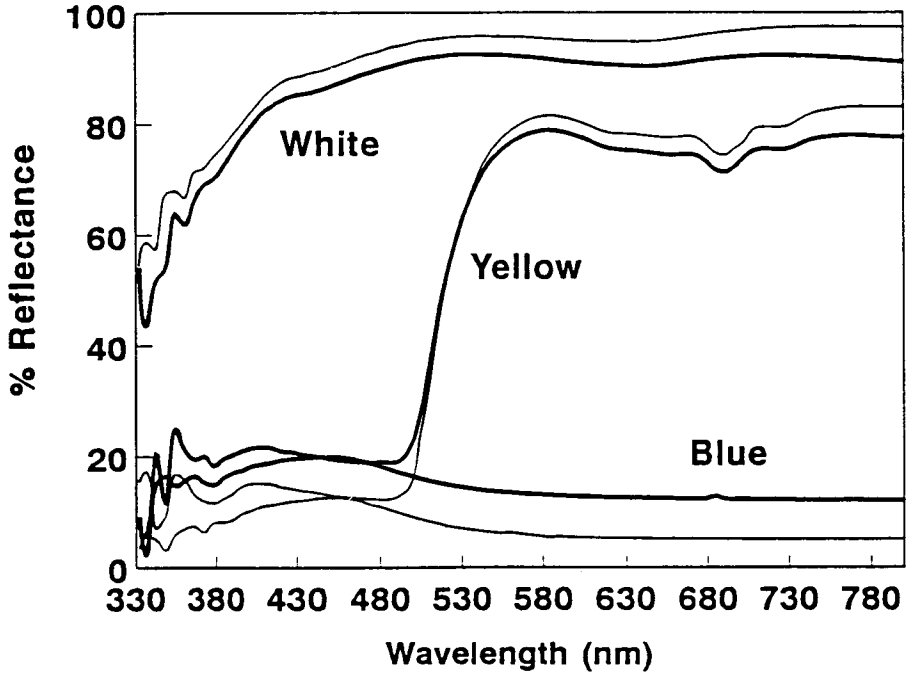

Fig. 1. Spectral reflectance curves of blue, yellow, and white with (thick line) and without (thin line) glass slide.

which a relatively high number of *F. occidentalis* were caught in 1990, catches of *F. occidentalis* and *F. fusca* showed no differences among the trap colors in 1990 or 1991. This was probably due to the low capture numbers of both species. Our results under conditions of relatively high densities of *F. occidentalis* are consistent with those of Robb (1989), who found that yellow and blue traps attracted more *F. occidentalis* than green or white in a chrysanthemum greenhouse. In contrast, Moffit (1964) and Yudin et al. (1987) found that white traps consistently caught more *F. occidentalis* than yellow traps in pear orchards and lettuce fields, respectively. Walker (1974) reported that *F. tritici* preferred yellow and low UV remitting white in rye field.

UV reflection can affect the response of thrips to colors. Matteson and Terry (1992) reported that highly reflective UV white (78% reflectance at 365 nm) captured fewer thrips compared with low UV reflective white (14% reflectance at 365 nm), but colors with less than 35% UV reflectance at 365 nm had no negative effect on the numbers of thrips captured. The white-colored traps used in this study had a UV reflectance of 66% at 365 nm, whereas the blue and yellow traps with glass slides had less than 35% UV reflectance at 365 nm (Fig. 1). Thus, the high UV reflectance of our white traps probably accounts for their reduced attractiveness. In addition, differences in hue, saturation, or intensity of colors may affect the response of thrips to different colors. Vernon and

Gillespie (1990) and Walker (1974) examined the effects of color saturation and intensity on the visual behavior of *F. occidentalis* and *F. tritici*, respectively, and suggested that these factors may be of considerable importance in color perception by anthophilus thrips. Brødsgaard (1989) evaluated several shades of blues and found that some blue shades were more attractive to *F. occidentalis* than yellow or white. The use of different saturation or intensity of blue, yellow, and white in the color preference studies may explain the differences in reports of relative attractiveness of blue, yellow, and white traps to thrips.

Trap color did not affect the relative proportion of thrips species caught in 1990 within fields (Haywood, $F = 1.03$; df = 6, 12; $P = 0.44$; Mills S, $F = 1.11$; df = 6, 12; $P = 0.42$; Dana, $F = 2.28$; df = 6, 12; $P = 0.12$; Mill J, $F = 2.72$; df = 6, 12; $P = 0.09$). Similarly, the relative proportion of the three species caught on the double-colored traps was the same as that on the blue and yellow traps in 1991 (Haywood, $F = 0.44$; df = 6, 12; $P = 0.76$; Fruitland, $F = 2.34$; df = 6, 12; $P = 0.09$). Generally, *F. tritici* was the dominant species, but the percentage of each species varied among test fields. For example, in the Haywood field, *F. tritici* accounted for approximately 88% of all thrips in 1990, but only approximately 63% at the Dana field. Similarly, no *F. occidentalis* were caught at the Haywood field in 1990, but approximately 27% of the thrips caught at the Dana field were *F. occidentalis*. The remaining fields had relatively low numbers of *F. occidentalis* (< 14%). Similar dramatic differences in species composition were observed between the Haywood and Fruitland fields in 1991. The apparent localized infestation of *F. occidentalis* may have been the result of surrounding cropping systems at these sites. Few *F. fusca*, a foliage feeder, were caught on sticky traps during this study.

The high proportion of flower feeding thrips caught on colored traps may have been due to the placement of traps just above the plant canopy. The majority of tomato flowers occurred on the top of plants. Gillespie and Vernon (1990) hypothesized that movement of *F. occidentalis* within a crop field occurs just above the canopy. Salguero Navas et al. (1991a) reported that significantly higher numbers of *F. occidentalis* and *F. tritici* were collected from tomato flowers located in the upper than in the lower half of plants, but that flower location did not influence density estimates of *F. fusca*.

Relationship between Trap Catches and Flower Samples. Correlations between thrips collected from tomato flowers and colored sticky traps are presented in Table 3. Generally, thrips catches on yellow and white traps had higher correlation coefficients with thrips in the 10-flower sample unit compared with blue-colored traps. In addition, correlations of trap catches and the two different flower sampling units (10-flowers and all flowers per plant) were not significantly different, indicating that the size of the flower sample unit (10-flowers versus all flowers per plant) did not affect the correlation between sticky trap catches and thrips abundance in flowers. Salguero Navas et al. (1991 a) also reported that seasonal abundance patterns of thrips per tomato flower were significantly correlated with seasonal patterns of abundance per tomato plant in Florida, indicating that estimates from individual flowers provided an accurate estimate of whole plant populations. Although not significantly different, tomato fields where *F. tritici* was dominant (Haywood, Mills S, and Mills J)

Table 3. Correlations between number of adult thrips collected from tomato flowers and thrips captured on colored sticky traps in commercial tomato fields in western North Carolina.

Year	Field	Color	*n*	Correlation coefficient (r)		*t*-test*
				Ten Flowers	All flowers/plant	
1990	Haywood	blue	10	0.722	0.823	NS
		yellow	10	0.697	0.891	NS
		white	10	0.326	0.256	NS
	Mills S	blue	9	0.080	0.256	***
		yellow	9	0.633	0.745	NS
		white	9	0.924	0.960	NS
	Dana	blue	11	0.158	0.401	NS
		yellow	11	0.454	0.241	NS
		white	11	0.452	0.291	NS
	Mills J	blue	9	0.061	0.172	NS
		yellow	9	0.781	0.872	NS
		white	9	0.890	0.968	NS
1991	Fruitland	blue	9	0.845	0.570	NS
		D-C**	9	0.908	0.422	NS
		white	9	0.864	0.455	NS
	Haywood	blue	8	0.440	0.556	NS
		yellow	8	0.765	0.815	NS
		white	8	0.610	0.768	NS

* *t* test for homogeneity of correlation coefficients between 10-flower and whole plant samples with sticky trap catches.
** Double color trap.
*** Denotes statistically significant at $P < 0.001$.

generally had higher correlation coefficients between thrips catches on sticky traps and all flowers per plant compared to 10-flower samples. In contrast, the opposite was true in Dana and Fruitland, where *F. occidentalis* was the dominant thrips species. Our results show that trap catches of thrips are not independent of populations in flowers and can be influenced by thrips species composition in tomato flowers.

To more clearly explain the utility of sticky traps in estimating the abundance of *F. occidentalis* and *F. tritici* in tomato flowers, several linear regression analyses were performed (Table 4). Data on *F. occidentalis* and *F. tritici* captures on traps and in flowers were regressed only when *F. occidentalis* occurred in tomato flowers, regardless of the presence of *F. tritici*. Regression of *F. occidentalis* on traps and in flowers was not possible when *F. tritici* was the

Table 4. Linear regression equations between thrips species on colored sticky traps (y) and thrips in tomato flowers (x).

Color	*F. occidentalis* equation	$P > F$	r^2	*F. tritici* equation	$P > F$	r^2
	Percent thrips on traps versus percent thrips in flowers					
Blue	y = 0.287 + 0.412 (± 0.049)*x	0.001	0.77	y = 59.294 + 0.202 (± 0.118) x	0.36	0.25
Yellow	y = 0.337 + 0.414 (± 0.057) x	0.001	0.76	y = 61.698 + 0.202 (± 0.065) x	0.001	0.58
White	y = 1.990 + 0.203 (± 0.070) x	0.001	0.47	y = 73.091 + 0.046 (± 0.123) x	0.86	0.06
	Number of thrips on traps versus number in 10 tomato flowers					
Blue	y = 1.690 + 0.023 (± 0.550) x	0.052	0.13	y = 8.401 + 0.227 (± 0.508) x	0.66	0.13
Yellow	y = 1.825 + 11.276 (± 0.687) x	0.074	0.11	y = 9.833 + 0.129 (± 1.053) x	0.04	0.04
White	y = 1.127 + 2.817 (± 1.348) x	0.052	0.20	y = 5.109 + 0.155 (± 0.691) x	0.83	0.00
	Number of thrips on traps versus number in all flowers/plant					
Blue	y = 3.012 = 0.002 (± 0.068) x	0.970	0.01	y = 9.302 - 0.043 (± 0.066) x	0.52	0.02
Yellow	y = 2.943 - 0.011 (± 0.080) x	0.890	0.00	y = 11.840 - 0.072 (± 0.147) x	0.35	0.01
White	y = 0.375 - 0.761 (± 0.794) x	0.351	0.06	y = 4.797 - 0.038 (± 0.777) x	0.62	0.17

* Standard error of slope estimate.

dominant thrips (> 99%) in flowers, because no *F. occidentalis* were found on traps. When adult thrips numbers or percent thrips composition on sticky traps were correlated with adult thrips numbers in 10-flower, all flowers per plant, or percent composition of thrips in flowers only percent composition of *F. occidentalis* on traps and percent composition in flowers exhibited significant relationships ($P < 0.05$). A significant relationship between percent composition of *F. tritici* on traps and in flowers was obtained only for yellow-colored traps. No significant relationship was detected between thrips numbers on traps and in flowers (10-flowers or all flowers per plant). Blue and yellow traps had similar regression statistics for *F. occidentalis* and indicate that when *F. occidentalis* accounted for 50% of thrips in flowers, this species accounted for 21% of thrips on blue or yellow sticky traps. These results suggest that the proportion of *F. occidentalis* on blue and yellow colored traps may be used to estimate the proportion of *F. occidentalis* in flowers, but not the number of thrips in flowers.

Trap Design Test. The differential thrips composition in the Mills J and Fruitland fields enabled us to compare the relative effectiveness of different trap designs for the different thrips species. The dominant thrips on sticky traps at Mills J was *F. tritici,* while in the Fruitland field *F. occidentalis* was predominant. Although the number of *F. occidentalis* and *F. tritici* differed between fields, the mean catch of *F. occidentalis* did not differ among trap types within a field (Table 5). However, the mean number of *F. tritici* caught varied considerably with trap type in both fields; the cup and cylindrical traps caught more *F. tritici* per unit area than flat glass side traps.

This differential efficiency of traps in capturing *F. occidentalis* and *F. tritici* may be related to differences in the dispersal characteristics of the two species. *F. tritici* is a relatively strong flier (Irwin 1991) and is known to migrate from southern to northern U. S. early in the spring (Lewis 1973). Sticky traps rely heavily on the movement of thrips in the air. Thrips are generally weak fliers, and airborne thrips will almost always be blown by the wind (Lewis 1973). Cylindrical traps are more efficient than flat traps for collecting plant pathogens (Knutson 1972) and aphids (Heathcote 1957), because the airflow around cylindric traps is less turbulent, and therefore catch insects and pathogens blown from all directions. In addition, Taylor (1962) showed that wind speeds could affect the efficiency of cylindrical traps for different insects, i.e., cylindrical traps caught more small insects and plant pathogens as wind speeds increased. Therefore, if *F. tritici* is more active than *F. occidentalis,* the cup and cylindrical traps would be expected to catch more *F. tritici* than the flat glass trap during windy conditions.

The cost of maintaining four traps for 12 weeks at each field was $3.27, $3.90, and $52.99 for cylindrical, cup, and glass traps, respectively, excluding labor and sticky material costs. Unlike glass slides and cups, the colored plastic pipe used for cylindrical traps could be reused year after year, further reducing costs. Processing times for each trap were dependent on the number and diversity of thrips. Generally, the cylindrical and glass slide traps required less processing time than cup traps. The average processing time was 14.1, 24.8 and 10.3 min per trap for the cylindrical, cup and glass slide trap, respectively. Also, identification of thrips was easier on the cylindrical trap because the use of

Table 5. Comparison of thrips catches per 57.7 cm2 among cup, cylindrical, and glass slide traps during 1992 in tomato fields in western North Carolina.

Field	Trap	Mean number of thrips ± SEM			
		F. tritici	*F. occidentalis*	*F. fusca*	Total
Mills J	cup	70.98 ± 13.94 a	3.57 ± 1.20 a	0.31 ± 0.14 a	76.06 ± 14.63 a
	cylindrical	52.38 ± 10.10 a	1.36 ± 0.28 a	0.28 ± 0.11 a	55.43 ± 10.21 a
	glass	25.72 ± 6.17 b	1.89 ± 0.52 a	0.21 ± 0.11 a	28.51 ± 6.65 b
Fruitland	cup	19.57 ± 13.60 a	102.70 ± 23.47 a	0.29 ± 0.18 a	124.65 ± 21.84 a
	cylindrical	17.76 ± 4.38 a	71.67 ± 11.84 a	0.23 ± 0.12 a	92.85 ± 13.52 a
	glass	9.10 ± 1.93 b	74.00 ± 10.34 a	0.13 ± 0.07 a	84.62 ± 12.91 a

Means within the same column followed by the same letter are not significantly different ($P < 0.05$), LSD.

clear plastic allowed for the observation of both the dorsal and ventral sides of thrips.

In summary, yellow-colored sticky traps caught significantly more thrips than blue or white traps. The cylindrical trap design was most economical and allowed for easier identification of thrips than did the other trap designs. The yellow cylindrical trap was differentially attractive to *F. tritici* and *F. occidentalis* in a mixed population, and it can be used to estimate the relative proportion of *F. occidentalis* versus other thrips species occurring in tomato flowers. Based on the results presented here, yellow cylindrical traps are recommended for monitoring thrips in tomato fields in western North Carolina.

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