Development of *Frankliniella* Species (Thysanoptera:Thripidae) in Relation to Microclimatic Temperatures in Vetch[1]

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Abstract Continuous generations of *Frankliniella occidentalis* (Pergande) and *F. fusca* (Hinds) develop through the winter and spring in northern Florida on plant hosts such as hairy vetch, *Vicia villosa* Roth. Previously reported research compared development under field conditions of these thrips to predictions of temperature-dependent developmental models obtained in laboratory experiments and concluded that accumulated degree-days of ambient temperatures recorded at a nearby national weather station underestimated development of populations developing under field conditions. Thus, the objective of this study was to compare ambient temperatures to microclimate temperatures in *V. villosa* plots and its effect on thrips development. An electronic data logger was used in this experiment to continuously record over 63 d ambient, upper plant canopy, middle plant height, lower plant height, and soil temperatures in plots of *V. villosa*. The microclimatic temperatures and their degree-day accumulations, based on daily maximum and minimum records, were significantly greater ($P = 0.05$) than the ambient temperature and degree-day accumulations obtained from a nearby National Oceanic and Atmospheric Administration (NOAA) weather station. There were no significant differences in mean temperature and degree-day accumulations within the upper, middle and lower portions of *V. villosa* plants. Based on degree-day accumulations in the upper plant canopy, 3.1 generations were predicted for *F. occidentalis* and 2.4 generations for *F. fusca* during the study. However, using the NOAA degree-day accumulations, only 2.5 and 1.9 generations were predicted, respectively. During this study, an accumulated discrepancy of 3/4 of a generation was calculated for *F. occidentalis* and more than half of a generation for *F. fusca* between the NOAA weather data and the microclimate data. Thus, ambient temperatures obtained from the NOAA weather station would underestimate development, as was observed and reported previously. The results demonstrated the importance of using microclimatic measurements, rather than ambient records, for best estimating developmental potential of thrips.

Key Words Degree-days, *Frankliniella,* tobacco thrips, western flower thrips.

Thrips species are important pests of glasshouse crops, field crops, and vegetables (Allen and Broadbent 1986, Black 1987, Newsom et al. 1953, Shipp et al. 1998). Nine species of thrips transmit tomato spotted wilt tospovirus (TSWV) to numerous plant species (Sherwood et al. 2000, Ullman et al. 1997). At least three vector

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species are found on wild hosts and cultivated crops in north Florida, including the western flower thrips, *Frankliniella occidentalis* (Pergande), the tobacco thrips, *F. fusca* (Hinds), and the onion thrips, *Thrips tabaci* Lindeman. Tomato spotted wilt is a relatively new disease in Florida and its appearance has been associated with the introduction of the western flower thrips (Olson and Funderburk 1986). Both the western flower thrips and the tobacco thrips are highly efficient vectors of TSWV (Sakimura 1962, 1963). A unique feature of the vector-virus relationship is that TSWV is acquired by the thrips only during the larval stages but is primarily transmitted during the adult stage (Ullman et al. 1997).

Despite their broad host range, vector capabilities, and economic importance, little information on the life history and ecology of field populations is available for TSWV vectors. Lewis (1973) described a generalized life history of flower thrips species. Development rates, reproductive capacity, and life fertility statistics have been determined at constant and fluctuating temperatures for populations under laboratory conditions for *F. occidentalis* (Bailey 1938, Bryan and Smith 1956, Lublinkhof and Foster 1977, Robb 1989) and for *F. fusca* (Lowry et al. 1992, Puche and Funderburk 1992).

The phenology and development of thrips species follow a time scale that is temperature dependent (Lewis 1973). Additional environmental factors, such as soil moisture may also affect the rate of development and survival of thrips. Davidson and Andrewartha (1948) reported that the maximum density of *T. imaginis* Bagnall populations during spring is determined by the weather in the preceding fall, but temperature and rainfall during the early spring may modify the populations later in the year. Lewis (1973) considered temperature and rainfall the most important factors affecting the densities of thrips populations. Thus, temperature-dependent growth is an important component for explaining thrips population abundance across time. However, development times calculated at constant temperatures poorly predicted development times of insects over a broad range of fluctuating temperatures (Hagstrum and Milliken 1991).

The degree-day accumulation concept has been used for monitoring insect populations (Pruess 1983). Most studies involving the use of degree-day accumulations to predict developmental times in the field use data collected at constant temperatures in the laboratory or from maximum and minimum temperatures in the field (Higley et al. 1986) and do not consider hourly fluctuations of the microclimate within the canopy. Differences between host canopy and weather station temperatures can produce inaccuracies in degree-day estimates. Indeed, Toapanta et al. (1996) studying the population abundance of *Frankliniella* species during two winter/spring seasons reported that degree-day accumulations based on temperature recorded at a nearby National Oceanic and Atmospheric Administration (NOAA) weather station underestimated development and the number of generations of *F. occidentalis* in hairy vetch, *Vicia villosa* Roth, plots and *F. fusca* in wheat plots.

Phenological predictions of *Frankliniella* species development during winter and spring on wild host plants in Florida are unknown. It is important to know the number of generations that a thrips species can reach during winter and spring and the effects of temperature on their development. This information can provide valuable insights into population dynamics for the following growing season that can be used to design management programs for suppressing thrips populations, reducing incidence of tomato spotted wilt disease, and understanding insect behavior within microhabitats. Thus, the objectives of this study were to compare ambient temperatures to microclimate temperatures within the upper, middle, and lower plant canopies of *V. villosa* where thrips develope and to evaluate any differences in temperature on predictions of thrips development under field conditions.

Materials and Methods

This study was conducted at the North Florida Research and Education Center in Quincy, located 30° 32′ latitude north and 84° 35′ longitude west. Microclimate temperatures were measured in a 4-month-old plot of *V. villosa* from 25 February to 28 April 1994. The plot was oriented north to south. The soil type was a Dothan loamy sand.

Ambient, canopy, and soil temperatures were recorded continuously with a CR10 electronic datalogger (Campbell Scientific, Logan, UT) connected to an Analog Multiplexer (Model AM416 Relay Multiplexer, Campbell Scientific, Logan, UT) with a power source of two 12-v batteries. The Multiplexer increased to 32 the number of thermocouples that the CR10 datalogger could monitor. The thermocouples were scanned at 6-min intervals and averaged over 1-h periods throughout the study. Thermocouples were type T (copper and constantan) with wires 24 gauge (Omega Engineering, Inc., Stamford, CT) twisted, soldered with rosin core solder, and clipped. Thermocouples were calibrated against a certified thermometer (Fisher Scientific, Inc., Atlanta, GA) in an insulated water bath at about 24°C. All thermocouples had readings within <0.1°C of the standard.

In the vetch canopy, thermocouples were installed on a vertical wood dowel (1.5-cm diam). Thermocouples were positioned at the top of the canopy (top), at 2/3 the plant height (middle), and at 1/3 the plant height (bottom). Four dowels, containing the thermocouples, were placed in the vetch plot at 1.5 m intervals, along a parallel line 1.5-m from the edge of the plot. Thermocouples on each dowel pointed north. Canopy thermocouples at the top level were 15 cm high at the beginning of the study and were raised to 42 cm above the ground on 11 March, as the crop grew, to maintain the same relative distance of the thermocouples within the canopy. A depth of 1 cm was chosen to measure soil temperatures because prepupae and pupae of thrips develop at this depth (Lewis 1973). To simulate a national weather service station, one thermocouple was attached to a PVC pipe (2.5-cm diam) at 1.5 m above bare ground and shaded to monitor ambient temperatures next to the plot.

Daily maximum and minimum temperatures were obtained from a weather station (NOAA 08-7429-01) maintained about 250 m SE of the plot. The mean daily temperature was calculated by taking the average of the daily maximum and minimum temperature for the NOAA weather station, simulated station, and vetch canopy. In addition, the mean daily temperature was calculated from hourly records for the simulated weather station and vetch canopy.

Degree-day accumulations were calculated for all sources of temperature data by subtracting a lower developmental threshold from the mean temperature for every day and by using the temperature summation described by Arnold (1960),

$$\text{Degree days} = \frac{T_{max} + T_{min}}{2} - z,$$

where Tmax is the maximum daily air temperature, Tmin is the minimum daily air temperature, and z is the lower developmental threshold. The lower developmental thresholds to calculate degree day accumulations were 10.0°C and 6.5°C for *F.*

occidentalis reared on chrysanthemum and on peanuts, respectively, and 10.5°C for *F. fusca* reared on peanuts (Robb 1989, Lowry et al. 1992). No developmental maxima were used in the calculations. Degree day accumulations were calculated for both species based on temperature data from the national weather station, the simulated weather station, and the vetch microclimate.

A two-way analysis of variance without replication (Sokal and Rohlf 1981) was conducted, and daily ambient temperatures and degree day accumulations were compared between the NOAA weather station and the simulated weather station or vetch canopy using a Tukey's Test (SAS Institute 1989). The model included the thermocouple positions, the days of the study, and the error term. Mean temperatures based on hourly data from the simulated weather station were also compared to mean temperatures at the three canopy positions using Tukey's Test. A *t*-test was used to compare the two methods of mean temperature calculation.

Results and Discussion

Based on the daily maximum and minimum temperature data, the daily mean temperature of the NOAA weather station, the simulated weather station, the vetch microclimate and the soil were significantly different ($F = 19.4$; df = 5, 62; $P < 0.01$). The daily mean temperature of the NOAA weather station was significantly lower than within the vetch canopy and the simulated weather station. Within the vetch canopy, the daily mean temperature was uniform from top to bottom (Table 1, Fig. 1A). Based on hourly temperature data, the mean temperature decreased significantly in the vertical direction from the highest measurement at the simulated weather station to the lowest record at the bottom position within the vetch canopy (Table 1, Fig. 1B).

Table 1. Comparison of mean temperatures (°C) from the NOAA weather station, the simulated weather station, and the vetch microclimate (top, middle, bottom, and soil) in Gadsden Co., FL

Source	Max/Min data* ± SEM	Hourly data* ± SEM	P > t†
NOAA	17.4 ± 0.58 d**	—‡	—
Simulated	18.7 ± 0.55 bc	18.0 ± 0.18 a	n.s.¶
Top	19.3 ± 0.59 ab	17.7 ± 0.10 ab	n.s.
Middle	19.5 ± 0.61 a	17.4 ± 0.10 bc	0.05
Bottom	19.2 ± 0.61 ab	17.2 ± 0.10 c	0.05
Soil	18.0 ± 0.47 cd	17.2 ± 0.08 c	n.s.

* Max/Min data were calculated by averaging the maximum and minimum temperature for each day. Hourly data were calculated by averaging hourly readings for every day, with the exception for the national weather station.

** Means within each column with a different letter are significantly different according to the Tukey's Test ($P < 0.05$).

† *t* Test was used to compare the max/min data versus the hourly data for each position.

‡ No data are available because hourly data is not recorded by the national weather station.

¶ n.s. Not significant ($P > 0.05$).

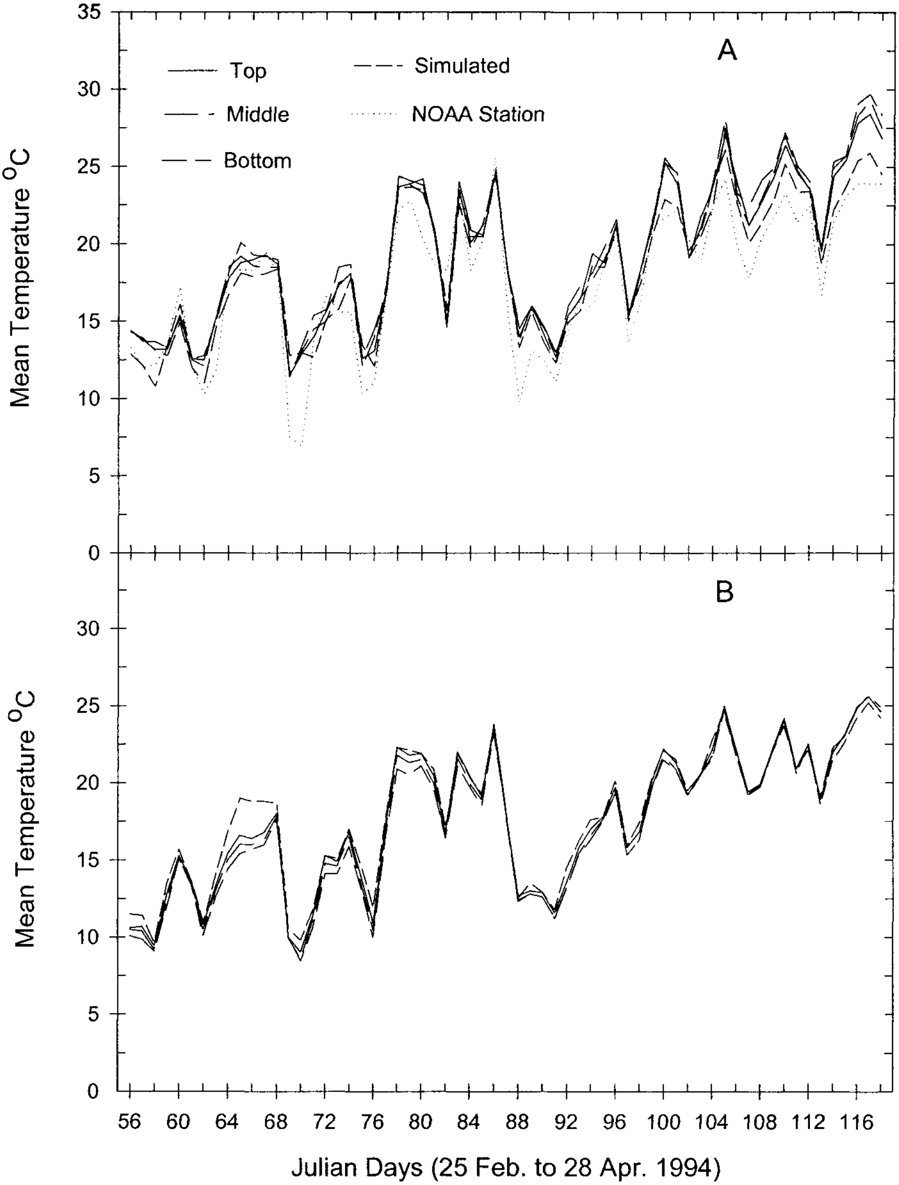

Fig. 1. Mean temperature based on daily maximum and minimum temperature (A) and on hourly records (B) for thermocouples recording ambient temperature and temperature in the top, middle, and bottom of the plant canopy of *V. villosa,* Gadsden Co. FL. (Hourly records for NOAA station not available).

The daily mean temperature computed using hourly records at the middle and bottom positions within the vetch canopy were significantly lower than the daily mean temperature computed using maximum and minimum data (Table 1). No significant differences between the two methods of mean temperature computation were detected at the simulated weather station, at the top of the vetch canopy, and in the soil (Table 1).

The differences in daily mean temperatures between ambient weather recordings and vetch microclimate are important because small changes in environmental factors can influence development of insects (Rosenberg et al. 1983), as well as the design of alternative methods for insect management (Hatfield 1982).

Using daily maximum and minimum data, the daily mean temperature calculated from the NOAA weather station was lower than the daily mean temperature at the bottom, middle, and top positions within the vetch canopy (Table 1). Differences as large as 8.5 degrees on individual days were obtained indicating underestimation of temperature data by the NOAA weather station (Fig. 1A). The statistical differences found in daily mean temperatures from all the sites are important because insect development is strongly related to changes in temperature similar to those found between the vetch microclimate and the NOAA weather station (Sharpe and DeMichele 1977). Messenger (1959) concluded that the use of standard meteorological records is somewhat unrealistic when attempting to relate climate to insect behavior and survival, because different climatic factors vary in intensity within limited distances in the natural environment.

The results of this study agreed with those of Graser et al. (1987) who found significant differences between microclimate temperature and air temperature using various row spacings in sorghum. Bale (1991), working on cold tolerance of insects and the microclimate, reported significant differences between ambient temperature and temperatures within the grass canopy during winter periods and concluded that it was twice as likely to freeze at the soil surface than in the air within the canopy. Other studies have also demonstrated the effect of microclimate on the daily abundance of flying Diptera (Peng et al. 1992) and on insect activity and dispersal of plant pathogens (Castro et al. 1991).

Temperature patterns within vetch canopy. Based on temperature records averaged hourly, significant differences were detected between the mean temperature at the simulated weather station and in the vetch canopy ($F = 9.5$; df = 4, 248; $P < 0.01$). The mean temperature using hourly data within the vetch canopy was 17.7°C at the top of the canopy and decreased to 17.4°C at the middle and 17.2°C at the bottom (Table 1). The mean soil temperature at 1 cm below the ground was 17.2°C. The vetch provided a 95% ground cover, and there was less daily temperature fluctuation in the soil compared with canopy and ambient temperatures based on SEM values (Table 1).

Patterns of hourly temperatures within the vetch canopy were compared for days representing a wide range of conditions during the study. A typical sunny day, 6 March 1994, was chosen to show temperature changes during a 24-h period (Fig. 2). On this day, between 0000 and 0500 hours, temperatures at all locations were relatively uniform. Between 0600 and 0700 hours, the canopy reached its minimum mean temperature. Graser et al. (1987) reported that this phenomena is a typical nighttime inversion when both the soil and the air above the canopy were sources of heat. The lowest mean temperature for this day was between the middle and top canopy, which suggested radiational cooling to the night sky. Sunrise was around 0730 hours (Fig.

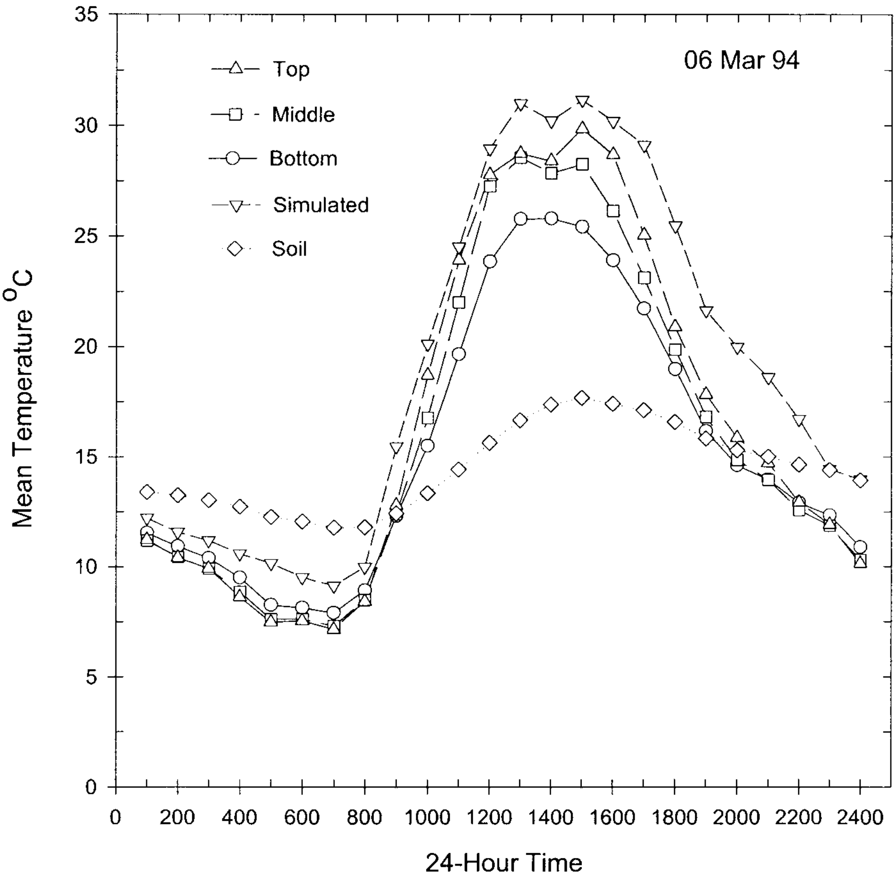

Fig. 2. Mean temperature based on hourly records on 06 March 1994 of ambient temperatures and temperatures under the canopy of *V. villosa* (top, middle, and bottom of the plant canopy, and soil), Gadsden Co., FL.

2). Warming at this time of the year is slow, and by 0930 hours the top of the canopy was uniformly warmer than the middle and the bottom levels of the canopy by more than 1°C. Temperature increased quickly after 1000 hours, and the entire canopy warmed to its maximal mean temperature between 1400 and 1500 hours near the top of the canopy. By 1800 hours, the mean temperatures at the three positions within the canopy were again uniform until the end of the day. Ambient temperature at the simulated weather station was consistently higher than the microclimate temperature throughout the whole day. The amplitude of hourly soil temperature at 1 cm below ground was between 12°C and 17°C, which represents an isothermal condition. Rosenberg and Brown (1974) reported the same patterns of soil temperature when investigating heat conduction and thermal properties of soils.

The influence of row spacing and direction on microclimate has been evaluated by Hatfield (1982), who concluded that the pattern in canopy temperature was similar at the 18 and 36 cm height. Although these differences appear to be minor, they are sufficient to influence insect behavior and dispersal, the epidemiology of plant diseases, and the rate of weed control (Castro et al. 1991).

The hourly temperature profiles in this study (Fig. 2) agreed well with the profiles for within-canopy and air temperature presented by Oi et al. (1989) studying the developmental time of the Pacific spider mite, *Tetranychus pacificus* McGregor, and with the profiles obtained from a bean and corn polyculture (Castro 1987).

Predictions of *Frankliniella* species development. Degree-day accumulations based on temperature data from the NOAA weather station were significantly lower than accumulations based on temperature data from the simulated weather station and the vetch canopy, when using developmental thresholds of 10°C ($F = 19.0$; df = 5, 62; $P < 0.01$) and 6.5°C ($F = 18.9$; df = 5, 62; $P < 0.01$) for *F. occidentalis,* and 10.5°C ($F = 19.4$; df = 5, 62; $P < 0.01$) for *F. fusca* (Table 2). There were no significant differences in degree day accumulations among positions within the vetch canopy for both *Frankliniella* species (Table 2). Predictions of development of these thrips species were characteristic of poikilothermic organisms: development time decreased linearly as temperature increased (Sharpe and DeMichele 1977).

Degree day accumulations for *F. occidentalis* were similar for all locations between day 56 and day 78 (Fig. 3). At the beginning of day 80, due to increased temperatures, degree day accumulations in the vetch canopy were higher than the NOAA weather station. A similar pattern on degree day accumulations was noted for *F. fusca* (Fig. 3).

The average number of degree days required for development from egg to adult for *F. occidentalis* at a threshold of 10°C was 173 (Robb 1989). For *F. fusca,* the degree days at a threshold of 10.5°C was 234 (Lowry et al. 1992). Assuming that the

Table 2. Degree day (DD) accumulations and corrected theoretical number of generations predicted for *F. occidentalis* and *F. fusca* based on temperature data from the NOAA weather station, the simulated weather station and the vetch canopy, Gadsden Co., FL

	*F. occidentalis**				*F. fusca**	
	DD	Generations**	DD	Generations**	DD	Generations†
Source	z = 10°C		z = 6.5°C		z = 10.5°C	
NOAA	469.9 d	2.7	684.3 d	2.7	439.9 d	1.9
Simulated	547.5 bc	3.2	768.0 bc	3.0	516.0 bc	2.2
Top	586.7 ab	3.4	807.2 ab	3.2	555.2 ab	2.4
Middle	600.0 a	3.5	820.5 a	3.2	568.5 a	2.4
Bottom	578.5 ab	3.3	799.0 ab	3.1	547.0 ab	2.3
Soil	501.8 cd	2.9	722.3 cd	2.8	470.3 cd	2.0

* Numbers in each column with a different letter are significantly different according to the Tukey's Test ($P < 0.05$).

** The corrected number of generations was based on 173 (z = 10°C) and 254 (z = 6.5°C) degree days required for egg to adult development (Robb 1989, Lowry et al. 1992).

† The corrected number of generations were based on 234 degree days required for egg to adult development (Lowry et al. 1992).

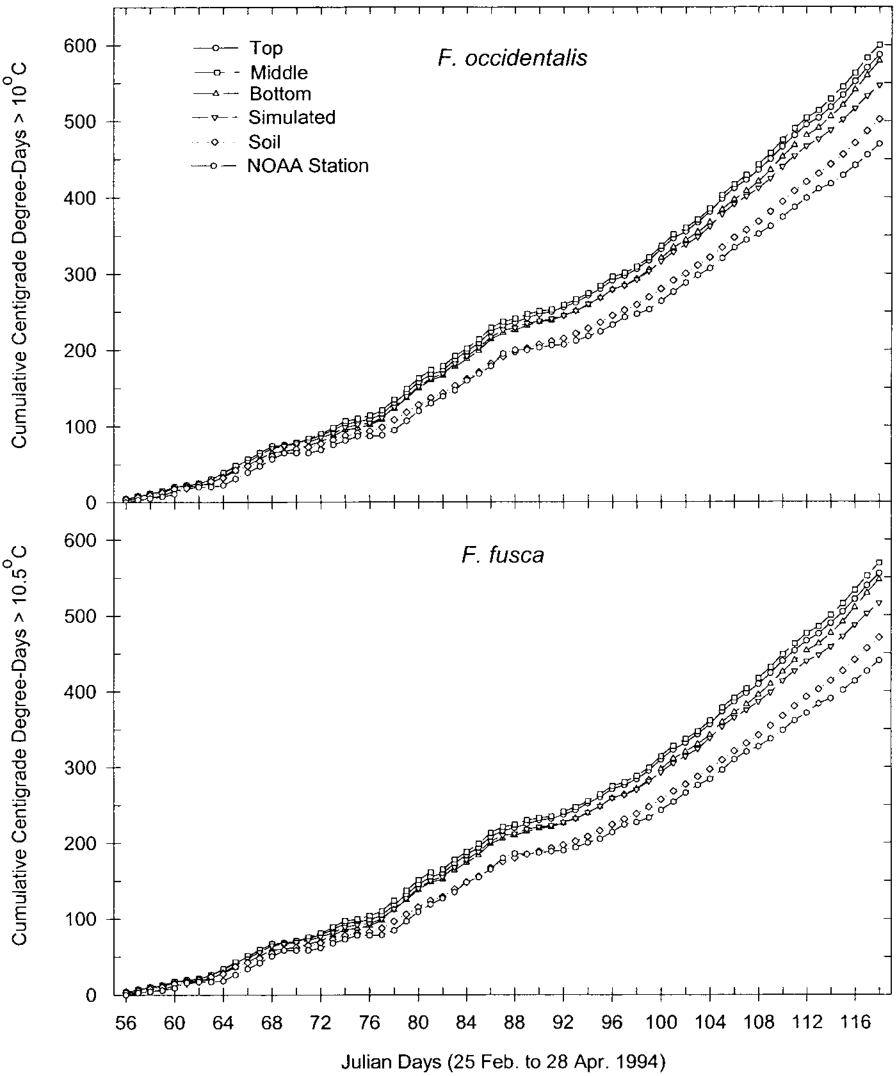

Fig. 3. Degree day accumulations for *F. occidentalis* and *F. fusca* from maximum and minimum temperatures from the NOAA weather station, the simulated weather station, and the vetch microclimate (top, middle, and bottom, and soil), Gadsden Co., FL.

preoviposition period in the laboratory for *F. occidentalis* is 2 d at a mean temperature of 20°C (Robb 1989) and 1 d for *F. fusca* (Lowry et al. 1992), additional degree days are required for development of a complete generation of either *Frankliniella* species.

Using a developmental threshold of 10°C for *F. occidentalis,* 600 degree days were accumulated at the middle of the vetch canopy over a 63-d-period (Table 2).

This is equivalent to 3.5 generations, which is higher than the 2.5 generations obtained using data from the NOAA weather station. In the case of *F. fusca,* 569 degree days were accumulated at the middle of the canopy at a threshold of 10.5°C. This is equivalent to 2.4 generations, which is also higher than the 1.9 generations calculated using data from the national weather station. These results coincided well with the predicted number of generations previously calculated based on field sampling data for the same thrips species (Toapanta et al. 1996).

The difference in degree day accumulations between the NOAA weather station and at the middle of the vetch canopy was 130.1 for *F. occidentalis* and 128.6 for *F. fusca.* These differences represent a 21% and 23% underestimation of development time for *F. occidentalis* and *F. fusca,* respectively. Moreover, the 130.1 degree day difference represents 3/4 of one generation for the western flower thrips and for *F. fusca,* the 128.6 degree days difference represents more than half of a generation. Therefore, this study provides evidence that prediction of development in the field of *Frankliniella* species is underestimated when ambient temperature data from the NOAA weather station are used.

The following comparison illustrates the fitness of the prediction of thrips development based on microclimate temperatures. *Frankliniella occidentalis* was predicted to complete 3.5 generations during 63 d (Table 2) at a mean temperature of about 20°C (Table 1). Thus, every generation would require about 20.3 d. This prediction agrees well with Bryan and Smith (1956) who reported an average developmental time of 21.8 d from egg through late pupa at 20°C with Lublinkoff and Foster (1977) who calculated an average developmental time of 22.4 d, from egg to egg, at 20.0°C, and with Lowry et al. (1992) who reported an average developmental time of 18.7 d from egg to adult at 20.0°C. However, this result differs from Robb (1989) who calculated an average developmental time of 26 d at the same temperature. *Frankliniella fusca* was predicted to complete 2.4 generations during 63 d (Table 2) at a mean temperature of about 20.0°C (Table 1), thus every generation requires about 26 d. This prediction is only 2 d longer than the 24 d reported by Lowry et al. (1992). Prediction of *F. occidentalis* and *F. fusca* development calculated using degree-day accumulations in the vetch canopy agreed with peaks of abundance reported in Toapanta et al. (1996).

The quality of food and the conditions in the laboratory in which populations of thrips developed in previous studies could have caused variations in development times and predictions of development. Lowry et al. (1992) attributed differences in development of *F. occidentalis* and *F. fusca* in their study compared to previous studies to host plants and temperature regimes. Porter et al. (1991) reported that "effective temperature sum" or degree days for the European corn borer, *Ostrinia nubilalis* (Hübner), vary with environmental conditions and as a result of genetic adaptations of individual populations, and Funderburk et al. (1984) found an overestimation of seedcorn maggot, *Delia platura* (Meigen), development by using air temperatures, which reflects differences between air temperature and temperature in the actual microclimate where *D. platura* occurs.

Our results here emphasize the importance of microclimate temperatures in prediction of insect development in the field. However, more work is required to identify the effects of weather and microclimate on thrips development during the whole year, and to determine the climatic variables that will affect overwintering thrips in Florida, particularly because thrips are vectors of the TSWV and may function as virus reservoirs during winter months. An improved understanding of the phenology of *F.*

occidentalis and *F. fusca* and their relationships with their hosts and climate will contribute greatly to the identification of factors important in the regulation and stability of populations and the development of ecologically-based pest management programs to suppress vector populations and incidence of TSWV.

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