Estimation of the immigration time of *Scirtothrips dorsalis* Hood (Thysanoptera: Thripidae) adults in citrus orchards as a function of the total effective temperature

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Abstract

Scirtothrips dorsalis adults generally immigrate into citrus orchards immediately after emerging from other suitable host plants surrounding the orchards; however, a method to predict adult immigration time has not yet been established. In this study, I examined the relationship between immigration time and total effective temperature for *S. dorsalis* using trap data collected every few days. The investigation was performed in eight citrus orchards in Shizuoka Prefecture from early May to mid-September in 1999, 2000, and 2001. The total effective temperature was calculated using data from meteorological stations located near the orchards. In each orchard, a positive linear relationship was observed between total effective temperature (y) and the generation number (x) at each immigration peak. The slope and y -intercept of the regression lines did not differ significantly among five orchards in the central district of Shizuoka Prefecture; after pooling the entire data, the linear relationship could be expressed as $y=70.67+314.92x$ ($n=84$, $r^2=0.989$, $p<0.001$). In two of the three orchards in the western district of Shizuoka Prefecture, the regression lines did not differ significantly in their slope (using the same equation form).

Key words: *Scirtothrips dorsalis*; citrus; total effective temperature; immigration; insect trap

INTRODUCTION

Scirtothrips dorsalis Hood, commonly known as the yellow tea thrips, produces seven or eight generations every year in Shizuoka Prefecture, Japan (Sakakibara and Nishigaki, 1988; Tatara, 1994). The species is one of the most serious economic pests of citrus plants because large numbers of adults immigrate into citrus orchards from host plants surrounding the orchards (Tatara, 1994; Masui, 2007a) and damage the fruit surface during a long period, typically from June to October (Nishino and Kodomari, 1988; Tatara and Furuhashi, 1992). To control *S. dorsalis* infestations, insecticides are sprayed periodically (four to five times from June to September) during the period when the adults generally immigrate into the orchards. Yellow sticky traps are used to monitor the abundance of adult thrips in the orchards to provide guidance on the optimal timing of the sprays

(Ohkubo, 1989; Muraoka, 1990; Masui et al., 1995; Tatara, 1995). However, because it is often difficult to predict the time of adult immigration using these traps, control of the thrips is frequently unsuccessful.

Scirtothrips dorsalis overwinters in the adult stage (Okada and Kudo, 1982; Shibao et al., 1991), and overwintering adults start to lay eggs simultaneously in late March or early April (Masui, 2007b). This suggests that the developmental stage of the individuals has little variation in the spring and that the total effective temperature could potentially be used to forecast the time of adult emergence in each generation. Previous research has shown that the first three peaks of adult occurrence, including that of the overwintering generation from March to June, can be estimated by calculating the total effective temperature from January 1 in citrus orchards (Tatara, 1994) and vineyards (Shibao, 1996). However the subsequent four

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or five peaks, which reflect the generations from July to October, have been left unexamined. Thus, in this study, I examined the possibility of predicting the immigration time of adult *S. dorsalis* into citrus orchards both before and after June by calculating the total effective temperature.

MATERIALS AND METHODS

Study site. The investigation was carried out in five citrus orchards (Fuji, Shimizu, Shizuoka, Fujieda, and Haibara) in the central district of Shizuoka Prefecture and three citrus orchards (Iwata, Hosoe, and Mikkabi) in the western district (Fig. 1). Pesticides were applied following the conventional approach in each orchard.

Peak days of adult immigration. A yellow sticky trap designed by Muraoka (1990) was used to monitor adult abundance in each orchard from 1999 to 2001. A flat yellow (6.5Y 8.5/15.0 according to the Munsell Color System) polyvinyl chloride plate (20×20 cm) covered on both sides by transparent sticky sheets (20×15 cm) was placed vertically at a height of 1.5 m in each orchard. The number of adults captured by the trap was counted every few days from early March to mid-September. The traps were changed before 0900 h or after 1600 h, during the period when few adults fly (Okada et al., 1981; Tataru, 1995). The mean number of adults captured per day in each trap was calculated by dividing the total catch by the number of days during which the trap was exposed. A 5-d moving average of trap data was calculated to identify the peak days of trap catch.

Fig. 1. Map of Shizuoka Prefecture showing the location of experiment orchards (a–h) and the meteorological stations (●). a, Fuji; b, Shimizu; c, Shizuoka; d, Fujieda; e, Haibara; f, Iwata; g, Hosoe; and h, Mikkabi.

Calculation of total effective temperature.

Based on the report of Tataru (1994), the developmental zero temperature and the maximum temperature threshold for the development of *S. dorsalis* were fixed at 9.7 and 33.0°C, respectively. The effective temperature for 1 d was calculated using the following equation:

$$H(T_i) = \left(\sum T_i \right) / 24 \quad (1)$$

where T_i represents the effective temperature for every hour during the monitoring period; $T_i = 0$ ($t \leq 9.7$), $T_i = t - 9.7$ ($9.7 \leq t < 33.0$), or $T_i = 23.3$ ($t \geq 33.0$); and t represents the temperature recorded at intervals of 1 h. The total effective temperature (H) was calculated by summation of the $H(T_i)$ values obtained from January 1. The total effective temperatures in the five orchards in the central district and the three orchards in the western district were calculated using data provided by Automated Meteorological Data Acquisition System (AMeDAS) stations in Shimizu (35°03.2'N, 138°31.3'E) and Hamamatsu (34°42.5'N, 137°43.1'E), respectively (Fig. 1).

Data analysis. Simple regression analysis was used to determine the relationship between the total effective temperature (y) and the generation number (x). The generation number was estimated from the days of peak trap catches. The differences in slopes and y -intercepts of the regressions among the orchards were examined by means of analysis of covariance (ANCOVA).

RESULTS

Peak days of adult immigration

The seasonal changes in the number of *S. dorsalis* captured in the citrus orchards are presented, along with the total effective temperature, in Fig. 2. Although the patterns of trap catches differed among the orchards and years, the peak days of the trap catches were consistent. The numbers of adults captured in the 1st and 2nd generations peaked when the total effective temperatures reached approximately 400 and 700 degree-days, respectively; this result was consistent with that reported by Tataru (1994). Additionally, in each orchard, peak days were detected at intervals of approximately 300 degree-days after the 2nd generation. In total, six peaks (i.e., six generations) were

Fig. 2. Seasonal changes in the number of *S. dorsalis* adults captured in the sticky trap in the citrus orchards in relation to the total effective temperature accumulated from January 1. Arrows indicate the peak days of trap catch.

detected by the time the total effective temperature reached 2,200 degree-days, except in some cases wherein the peaks were obscured because of low abundance (e.g., in most orchards in 2001). Although the sex ratio of the captured adults fluctuated during the research period, no difference in the peak days was observed between male and female thrips. The exact dates of the peak days of adult immigration into each citrus orchard in each generation are presented in Table 1.

Total effective temperature on peak days of adult immigration

A positive linear relationship was observed between the total effective temperature (y) and the generation number (x) for each immigration peak in each orchard (Fig. 3: $n=13$ to 17, $r^2=0.987$ to 0.994, $p<0.001$). The regression lines did not differ significantly among the five orchards (Fuji, Shimizu, Shizuoka, Fujieda, and Haibara) in the central district in terms of their slope (ANCOVA, $F=2.346$, $p=0.062$) and y -intercept (ANCOVA, $F=1.581$, $p=0.188$). This result indicates that the

Table 1. The peak days in trap catches of *S. dorsalis* adults in citrus orchards and the total effective temperature

Site	Year	Date						Total effective temperature (DD)					
		1st	2nd	3rd	4th	5th	6th	1st	2nd	3rd	4th	5th	6th
a) Fuji	1999	5/17	6/12	6/29	7/27	8/17	9/4	399	683	894	1,325	1,696	2,013
	2000	5/16	6/8	7/4	7/25	8/8	9/3	374	630	960	1,305	1,544	2,003
	2001	5/15	6/14	6/30	—	8/19	9/8	376	710	933	—	1,799	2,117
b) Shimizu	1999	5/22	6/20	7/12	7/25	8/7	9/4	449	784	1,072	1,290	1,522	2,013
	2000	N.D.	6/14	7/10	7/28	8/14	8/30	N.D.	690	1,050	1,348	1,650	1,932
	2001	N.D.	6/15	7/3	7/23	8/11	9/2	N.D.	720	983	1,337	1,656	2,030
c) Shizuoka	1999	5/25	6/11	7/3	7/31	8/13	8/29	481	670	948	1,396	1,628	1,908
	2000	5/16	6/11	—	7/28	8/8	8/31	374	662	—	1,348	1,544	1,948
	2001	5/14	6/13	7/2	7/22	8/13	8/24	364	700	968	1,318	1,692	1,882
d) Fujieda	1999	5/22	6/7	7/1	7/26	8/12	9/2	449	621	921	1,308	1,610	1,982
	2000	5/16	6/14	7/5	7/25	8/17	8/30	374	690	974	1,305	1,698	1,932
	2001	5/14	6/15	7/4	—	8/11	8/24	364	720	1,000	—	1,656	1,882
e) Haibara	1999	5/23	6/13	7/3	7/27	8/15	9/4	459	696	948	1,325	1,661	2,013
	2000	5/23	6/16	7/8	8/4	8/16	9/2	439	714	1,018	1,471	1,682	1,985
	2001	N.D.	6/22	7/6	7/21	8/13	8/24	N.D.	808	1,036	1,299	1,692	1,882
f) Iwata	1999	5/13	6/9	7/2	7/25	8/9	8/29	362	648	941	1,297	1,570	1,925
	2000	5/17	6/9	7/3	7/20	8/11	9/2	363	628	939	1,222	1,606	2,002
	2001	5/12	6/17	6/29	7/22	—	8/22	341	748	926	1,332	—	1,880
g) Hosoe	1999	5/18	6/20	7/7	—	8/14	—	410	790	1,007	—	1,657	—
	2000	5/19	6/16	6/30	—	8/11	—	382	700	888	—	1,606	—
	2001	N.D.	6/18	7/3	7/19	8/3	8/19	N.D.	762	993	1,277	1,551	1,831
h) Mikkabi	1999	5/18	6/15	7/9	7/27	8/18	9/10	396	713	1,031	1,331	1,727	2,130
	2000	5/20	6/13	7/9	7/25	8/18	—	379	659	1,032	1,314	1,728	—
	2001	5/23	6/16	7/1	7/19	8/15	—	456	706	936	1,248	1,734	—

N.D.: not determined, —: obscure because of low occurrence.

adult immigration time in these orchards can be uniformly estimated using data from the Shimizu AMeDAS station. A positive linear relationship was also observed ($n=84$, $r^2=0.989$, $p<0.001$) when data from all five orchards were pooled, and the regression line could be expressed by the following equation:

$$y=70.67+314.92x \quad (2)$$

The regression lines differed slightly but significantly among the three orchards (Iwata, Hosoe, and Mikkabi) in the western district in terms of their slope (ANCOVA, $F=6.277$, $p=0.004$). However, the regression lines for the Iwata and Mikkabi orchards did not differ significantly in their slope, as determined from Eq. (2) (ANCOVA, $F=0.004$

and 3.610, $p=0.949$ and 0.060, respectively). These results indicate that the intervals between generations in Iwata and Mikkabi were equal to those in the five orchards of the central district of Shizuoka Prefecture.

DISCUSSION

Tatara (1994) and Shibao (1996) investigated the occurrence of *S. dorsalis* using sticky traps in citrus orchards or vineyards at 1-week intervals, and they concluded that it was impossible to estimate the peak day by calculating the total effective temperature after the 2nd generation in June because the succeeding generations overlapped. However, other research has shown that the duration of de-

Fig. 3. Relationship between the generation number (x) and the total effective temperature (y) on peak days of the occurrence of *S. dorsalis* adults in the citrus orchards from 1999 to 2001. Dotted lines indicate 95% confidence intervals.

velopment between oviposition and adult emergence was approximately 2 weeks at 29.5 or 30.0°C (Tatara, 1994; Shibao, 1996); this indicates that the 1-week duration between censuses was too long to detect the generations during the summer. Therefore, the estimation of each peak day using data collected every few days should be considered, as was done successfully in the present study.

Overwintering adults of *S. dorsalis* emerge from dormancy in late March (Okada and Kudo, 1982), and the 1st generation adults can be found in early May (Masui, 2007b). Adult immigration into citrus orchards reaches a peak approximately six times from early May to mid-September, and the peak time coincides with the time of adult emergence

from host plants surrounding the orchards (Masui, 2007a). This study enabled estimation of the peak days of adult immigration into citrus orchards from May to September by calculating the total effective temperature and by analyzing trap data collected every few days. In addition, the results indicated that adult immigration times can be estimated simultaneously over a wide area, because the immigration times for the five citrus orchards in the central district of Shizuoka Prefecture could be uniformly estimated using data from the AMeDAS station in Shimizu. This result suggests that in the future, it will be possible to predict adult immigration times by means of real-time calculation of total effective temperature. Further, the prediction

will permit timely control of infestations by means of insecticide application or application of the reflective sheet mulching that has also been used to control *S. dorsalis* (Muraoka, 1991; Tatara, 1992; Tsuchiya et al., 1995).

The slight difference in the intervals between generations observed in different orchards might be due to environmental differences such as the local ambient temperature, which affects the developmental rate, and the different shoot-elongation periods of the local vegetation, which affects the propagation of *S. dorsalis*. Thus, in some cases, meteorological observations in smaller areas (i.e., closer to each orchard) or modification of the regression equation may be required to predict the peak day of adult immigration more accurately.

The intervals (290 to 334 degree-days) between successive peaks of adult immigration that were estimated in this study were slightly larger than the total effective temperature (265 degree-days) from oviposition to adult emergence that was reported by Tatara (1994). However, this discrepancy is reasonable because the preoviposition period in *S. dorsalis* females is 1 d, and the egg-laying period can be longer than 20 d at 25°C (Tatara, 1994). Hence, the generation number and peak days of adult occurrence can be estimated more correctly by applying the generation intervals observed in the field.

Using Eq. (2), the peak days of adult immigration for each generation could be tentatively estimated using data from the Shimizu AMeDAS station in 1993 and 1998, when the average temperatures throughout the year were the lowest and highest temperatures recorded between 1987 and 2006, respectively. On this basis, the peak days of adult immigration in the 1st generation were estimated to be May 28, 1993 and May 7, 1998; these peak days differed by 21 d. In contrast, the peak days in the 6th generation were estimated to be September 28, 1993 and August 23, 1998; these peak days differed by a larger amount (36 d). Thus, the present prediction equation may be useful to detect peak days that vary greatly among years and among generations, and to estimate the optimal timing for chemical control of *S. dorsalis* in citrus orchards.

Global warming is now occurring, and its effects on the occurrence of pest insects are receiving increased attention. Two different approaches have been applied to project the influence of global

warming on insects—estimating an increase in the number of generations using a formula based on effective temperature (Yamamura and Kiritani, 1998) and examining a change in the phenology and occurrence of pests using field survey data collected in years with an unusually high temperature (Yamaguchi et al., 2001). Although the influence of global warming on *S. dorsalis* populations is presently unclear, the regression line obtained in the present study would be helpful in predicting the changes in the life cycle of *S. dorsalis* caused by global warming if census data can be related to the actual field conditions.

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