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DEVELOPMENT OF A PREDICTIVE PHENOLOGICAL MODEL FOR THE SPRING GENERATION OF THE OLIVE SCALE, *PARLATORIA OLEAE* (COLVEE), IN ISRAEL: PRELIMINARY RESULTS

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ABSTRACT

The onset and rate of oviposition and egg-hatching in the spring generation of the olive scale, *Parlatoria oleae* (Colvee) (Coccoidea: Diaspididae), were investigated during 1992 and 1993 in the Upper Galilee, Israel. A regional predictive phenological model was developed for both phenological events. Fifty percent oviposition was calculated to occur at approximately 176 degree-days accumulated from January 1st, while 50% egg-hatching occurred at approximately 303 degree-days. During 1993 the model accurately predicted the timing of the phenological events, with a maximal deviation of 5 days from the predicted dates. It is suggested that this model can be successfully applied to optimize pesticidal treatments against olive scale crawlers.

KEYWORDS: Coccoidea, Diaspididae, *Parlatoria oleae*, degree-days, egg-hatching, integrated pest management, olive scale, oviposition, phenological models.

INTRODUCTION

The olive scale, *Parlatoria oleae* (Colvee) (Homoptera: Coccoidea: Diaspididae), is an important armored scale-insect pest of deciduous fruit trees, olives and ornamentals in Central Asia, the Mediterranean Basin and several regions of the United States (Applebaum and Rosen, 1964; Kozar, 1990). In Israel, mated olive scale females produced during fall overwinter without laying eggs and oviposit during the following spring (Cohen and Nestel, 1993). Based on prevailing climatic conditions, 2-3 generations are produced per year in Israel (Applebaum and Rosen, 1964).

The rate at which physiological processes in insects proceed is highly dependent on temperature (see e.g. Wall et al., 1992). This attribute has been used in the generation of phenological models that predict the time of occurrence of biological events in the life history of insect populations (Risch, 1987). Theoretically, predictive degree-day models (i.e. models that associate developmental rate with the summation of heat units above a threshold temperature) constitute powerful tools enabling the management of insect pests by integrated pest management (IPM) programs. However, their potential has been seldom exploited and only few such models have actually found their way into field application (Pruess, 1983).

Several factors seem to be responsible for the low level of application of predictive degree-day models. In some cases, estimation of model parameters was performed under laboratory and semi-natural conditions (Rijks, 1987), thus producing incomplete models that failed to consider important environmental variables (Wagner and Willers, 1992). This fact has led to unsuccessful field application of predictive models as a result of their low accuracy in forecasting phenological events of insect pest populations. An additional factor is that some field models have been developed from limited data (often from a single location) and may not hold at other locations (Pruess, 1983). Therefore, current efforts in the development of phenological models are being directed at the estimation of model parameters under field conditions and on regional scales (see, e.g. Horton et al., 1992). The present paper reports preliminary results of such an attempt. During the last two years we have investigated, under Israeli field conditions, the relationship between accumulation of thermal units and the onset of oviposition and egg-hatching in the spring generation of olive scale. The study takes into account and integrates the variability in the onset of these phenological events that may result from topographic and climatic differences that exist within the investigated region. The basic idea behind this study has been to develop a degree-day model that will forecast the time of crawler emergence in the spring generation of the olive scale. This model is expected to provide the farmer with a management tool that will enhance the control of olive scale by accurately timing the application of insecticides.

MATERIAL AND METHODS

Region and sampling plots

The study was conducted in the Upper Galilee region in northern Israel. The region is composed of an inner valley (the Hula Valley) and a hilly sector. The Hula Valley lies at an elevation of ca. 70 m above sea level, whereas the hills may reach elevations of 850 m. The region is located at a distance of approximately 50 km from the Mediterranean Sea. Deciduous fruits are a major crop in the region. Apples and pears are cultivated at most elevations, whereas plums and nectarines are mainly produced in the valley. At low elevations (Kefar Blum meteorological station, 75 m) average temperatures during the winter months oscillate between 11.0°C and 14.6°C, while temperatures at high elevations (Har Kenaan station, 934 m) oscillate between 6.6°C and 10.5°C (Israel Meteorological Service, 1983). During spring, temperatures at low elevations range from 17.5°C to 24.2°C, at high elevations between 14.2°C and 22.3°C.

Five apple orchards (four in 1992), located at different elevations, were selected for this study. During 1992 sampling was carried out at Amir (80 m above sea level), Kefar Gil'adi (320 m), Yiftah (420 m) and Yir'on (720 m). During 1993, an additional apple orchard was sampled at Sasa (820 m). Meteorological data (maximal and minimal daily temperatures) were obtained from two sources: thermographs located in some of the orchards (Kefar Gil'adi, Yiftah and Yir'on) and data from digitalized meteorological stations located close to two of the orchards (Amir and Yir'on).

Sampling

Apple trees infested with female olive scale were identified in all of the studied orchards, and five trees were selected in each orchard and marked for continuous sampling. Sampling was performed 2–3 times a week from mid-February to mid-May, 1992 and 1993, and consisted of removing infested spurs (4–5 spurs/tree) from all the trees. Live adult females were examined under a stereoscopic microscope after removal of the scale cover, and their developmental stage (non-laying female, female with egg-masses and female with emerging crawlers) was registered. A minimum of 150 living females per plot and sampling date was used for estimation of the developmental stage of the population.

Calculation of degree-days and data analysis

Based on a previous study by Applebaum and Rosen (1964), we established the developmental threshold base for accumulating degree-days (D.D.) at 10°C. Degree-days for each experimental plot were calculated from the daily maximal and minimal temperatures with the Sine Wave function (Allen, 1976). Accumulation of D.D. followed two schemes: (1) accumulation from an arbitrary date, and (2) accumulation from a "biofix" (i.e. a biological event that serves as a sign to initiate the accumulation of D.D.).

In the first case we started to accumulate D.D. from the 1st of January. This date was selected since it is expected that due to the low temperatures during that time of the year accumulation of D.D. would be small or negligible, providing a higher certainty that effective D.D. are not omitted from the model. In the second case, in 1993 we investigated the possibility of using apple-tree phenology as a biofix. Fifty percent budburst was quantified in all sampling trees by inspecting 100 buds/tree (25 buds/tree-section and direction). When this phenological stage was reached in each plot, quantification and accumulation of D.D. were initiated.

The rate at which olive scale populations developed (percent oviposition and percent egg-hatching) in each one of the investigated plots was matched with the corresponding accumulation of D.D. according to these two schemes. The number of D.D. until 50% oviposition and 50% egg-hatching was determined by visual approximation. A subsequent treatment of the results included utilization of linear models. Data from all the elevations were pooled and the linear association between percent oviposition, percent egg-hatching and the accumulation of D.D. was calculated. The "zero" point for both percent oviposition and percent egg-hatching was established by using the sampling date preceding the onset of the event.

RESULTS

The percent of oviposition and egg-hatching in olive scale populations, for 1992 and 1993, as a function of Julian date and elevation, is shown in Fig. 1. Oviposition and egg-hatching in both years started earlier at low elevations than at high ones. During both years, the first orchard to show oviposition and hatching was Amir. It was followed by Kefar Gil'adi, Yiftah, Yir'on and, in 1993, by Sasa. The approximate dates when 50% oviposition and 50% egg-hatching occurred during the two years in all the orchards are shown in Table 1. Chronological differences were found both between orchards and between years. On an elevation gradient, 50% of the biological events of a given population were reached earlier at low elevations than at high ones. The sequence at which each orchard reached a given population stage was inversely associated

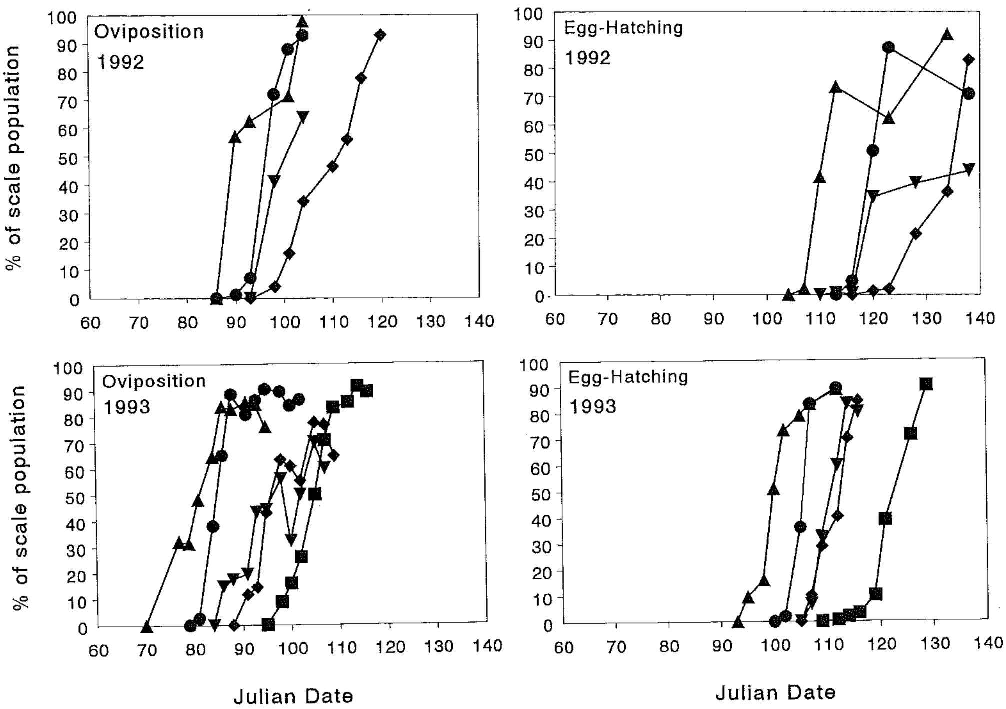

Fig. 1. Rate of oviposition and egg-hatching in olive scale (*Parlatoria oleae*) populations in Israel as a function of Julian date and elevation during 1992 and 1993. Orchards: ▲, Amir (80 m); ●, Kefar Gil'adi (320 m); ▼, Yiftah (420 m); ◆, Yir'on (720 m); and ■, Sasa (820 m).

TABLE 1

Approximate date when 50% of the olive scale (*Parlatoria oleae*) population, residing in different orchards of Northern Israel, reached a given phenological stage during 1992 and 1993

Plot (elevation)	50% egg-laying	50% egg-hatching
1992		
Amir (80 m)	March 31	April 24
Kefar Gil'adi (320 m)	April 6	April 30
Yiftah (420 m)	April 12	May 16
Yir'on (720 m)	April 23	May 16
1993		
Amir (80 m)	March 23	April 10
Kefar Gil'adi (320 m)	March 26	April 16
Yiftah (420 m)	April 7	April 22
Yir'on (720 m)	April 6	April 23
Sasa (820 m)	April 15	May 3

with the location of the orchard on the elevation gradient. On the other hand, 50% of the biological events occurred, in all orchards, earlier in 1993 than in 1992.

Table 2 shows the approximate amount of D.D. accumulated from January 1st until 50% of the biological events of the population, for all the orchards and for the two years. The accumulation of thermal units until 50% oviposition in 1992 ranged from 115 to 170 D.D. (average: 143.8), whereas that until 50% egg-hatching ranged from 210 to 320 D.D. (average: 253.8). During 1993 the variability between orchards was smaller: 147–185 D.D. (average: 172.4) until 50% oviposition and 270–315 D.D. (average: 293.4) until 50% egg-hatching. Average number of D.D. between 50% oviposition and 50% egg-hatching was 110 for 1992 and 121 for 1993.

TABLE 2

Accumulation of degree-days from January 1st to a given olive scale (*Parlatoria oleae*) phenological event as a function of elevation

Plot (elevation)	D.D. until 50% oviposition	D.D. until 50% egg-hatching	D.D. between 50% oviposition and 50% egg-hatching
1992			
Amir (80 m)	165	220	55
Kefar Gil'adi (320 m)	170	320	150
Yiftah (420 m)	115	210	95
Yir'on (720 m)	125	265	140
Average ± S.D.	143.8 ± 27.8	253.8 ± 50.2	110 ± 43.8
1993			
Amir (80 m)	185	312	127
Kefar Gil'adi (320 m)	165	315	150
Yiftah (420 m)	185	275	90
Yir'on (720 m)	147	270	123
Sasa (820 m)	180	295	115
Average ± S.D.	172.4 ± 16.4	293.4 ± 20.6	121 ± 21.7

The effect of using tree phenology as a starting date (biofix) upon the number of D.D. accumulated until the occurrence of the two biological events is shown in Table 3. Degree-days from 50% budburst until 50% oviposition ranged from 51 to 101 (average: 76.8), D.D. accumulated until 50% egg-hatching ranged from 176 to 217 (average: 197.8), and average number of D.D. from 50% oviposition to 50% egg-hatching was 121.

Table 4 shows the resultant linear models, correlation coefficients and coefficients of determination for the pooled data of 1992 and 1993. The correlation between accumulation of D.D. and phenological events (oviposition and egg-hatching) was high in all cases. Better correlations and coefficients of determination were obtained for 1993 and for the model based on the January 1st starting date than for 1992 and for the biofix-based model. Predicted values with the January 1st model were very close for 1992 and 1993 (Tables 2 and 4).

TABLE 3
Accumulation of degree-days from 50% budburst in apple trees to a given olive scale (*Parlatoria oleae*) phenological event as a function of elevation (1993)

Plot (elevation)	D.D. until 50% oviposition	D.D. until 50% egg-hatching
Amir (80 m)	52	179
Kefar Gil'adi (320 m)	51	201
Yiftah (420 m)	86	176
Yir'on (720 m)	94	217
Sasa (820 m)	101	216
Average ± S.D.	76.8 ± 23.7	197.8 ± 19.6

TABLE 4
Association between accumulation of degree days (x) and phenological events (y) in spring populations of olive scale (*Parlatoria oleae*) for 1992 and 1993: accumulation of degree days was started on January 1st and when 50% of the apple trees showed budburst

Phenological event	Linear model	r	r^2	Predicted value at 50% of y (D.D.)
Accumulation of D.D from January 1st				
1992				
% oviposition	$y = 0.5x - 30.5$	0.80	0.64 (N = 24)	161.0
% egg-hatching	$y = 0.3x - 44.0$	0.70	0.50 (N = 23)	313.0
1993				
% oviposition	$y = 0.6x - 55.8$	0.85	0.72 (N = 51)	176.0
% egg-hatching	$y = 0.6x - 132.1$	0.80	0.64 (N = 33)	303.5
Accumulation of D.D. from budburst of apple tree				
1993				
% oviposition	$y = 0.6x - 2.8$	0.80	0.64 (N = 51)	88.0
% egg-hatching	$y = 0.7x - 92.4$	0.82	0.67 (N = 33)	203.4

DISCUSSION

Deviations from the predicted number of D.D. accumulated until the biological events (based on the annual regression lines, Table 4) were greater during 1992 than during 1993. For example, in 1992 the largest deviation from the predicted value of D.D. accumulated until 50% oviposition (at Yiftah) was 46 D.D., or 29% of the predicted value, whereas in 1993 (at Yir'on) it was only 29 D.D., or 16% of the predicted value (compare Tables 2 and 4). Similarly, the largest deviation from the predicted number of D.D. accumulated until 50% egg-hatching was 110 D.D., or 33% of the calculated value in 1992 (Yiftah), and only 33.5 D.D., or 11% in 1993 (Yir'on) (compare Tables 2 and 4). The higher variability in both oviposition and hatching during 1992 was mainly contributed by the results obtained at Yiftah. During that year the olive scale population at Yiftah showed an unusual behavior: only 70% of the females oviposited, and egg-hatching, which extended over a long period of time, never reached the 50% level (Fig. 1). Therefore, in order to calculate the 50% egg-hatching point for this population we had to extrapolate the value from the scatterplot. This resulted in a less accurate estimate of the value and consequently increased the variability for that year. During 1993 the olive scale population at Yiftah and all other plots did not show this irregular behavior, which resulted in a more accurate estimation of the biological events and a reduced variability in the system.

The use of apple-tree phenology as a biofix was less accurate in predicting the biological events than utilization of January 1st as a starting date. The variability in D.D. accumulated until oviposition was higher with the biofix (Table 3) than with the arbitrary date (Table 2, 1993). The variability in D.D. accumulated until egg-hatching was similar with the two models. In addition, deviations from the predicted value (Table 4) were more extreme when using the biofix than with the arbitrary date: oviposition with the biofix deviated from the predicted value by 36 D.D. (42% of the calculated value), whereas the largest deviation with the arbitrary date was only 16% of the predicted value (29 D.D.) (compare Tables 2–4). Deviation from the predicted egg-hatching was slightly higher with the biofix (13%) than with the arbitrary date (11%).

The use of budburst in the study of insect–host interactions has been suggested in the past (Valentine, 1983). However, utilization of tree phenology to predict insect biological events can be problematic. Besides the relationship that exists between temperate-tree phenology and spring warming, budburst timing may also be influenced by winter chilling and photoperiod (Hunter and Lechowicz, 1992). Thus, at locations where the occurrence of winter chilling is uncertain, the timing of budburst may not correlate with spring warming. In the present study, greater deviations from the expected number of D.D. accumulated until oviposition (calculated with the biofix) were observed in plots located at low elevations (Amir, Kefar Gil'adi). These plots probably did not get the number of chilling days required to stimulate budburst during 1993, which resulted in biased predictions. A similar situation can occur at higher elevations in unusually warm winters. Delayed budbursts, that do not correlate with spring warming, have been registered in temperate regions (Hunter and Lechowicz, 1992). In fact, during 1994 the winter in Israel was warmer than usual, and there are indications that budburst at low elevations (e.g. Amir) may have occurred after the olive scale population had started to oviposit. This would, of course, disqualify utilization of apple-tree budburst as a reliable biofix, creating the need to investigate other possible phenological events to be used as biofix. Alternatively, utilization of the arbitrary date as a starting point should be justified. These possibilities are currently being investigated.

The deviation, in days, between the predicted and observed date when 50% hatching occurred was low for all orchards. This was calculated with the results of 1993. The number of D.D. accumulated between 50% oviposition and 50% egg-hatching (Table 2) were divided by the number of days that elapsed between the two events (Table 1), providing the average number of D.D. accumulated per day during this period for each of the orchards. These values were then utilized to calculate the approximate number of days by which the observed phenological event deviated from the predicted date (based on the regression line in Table 4). This was done by dividing, for each one of the orchards, the difference in D.D. between the observed and predicted values by the corresponding average daily accumulation of D.D. The results showed that the deviation from the expected date of 50% egg-hatching was always less than 5 days: Amir, +1.2 days; Kefar Gil'adi, +1.6 days; Yiftah, –4.8 days; Yir'on, –4.7 days; and Sasa, –1.3 days. These deviations between the observed and the expected are well within the accepted range of a good predictive phenological model, and are very similar to the results obtained with other phenological models that predict egg-hatching in scale insects (e.g. McClain et al., 1990: San José scale; Potter et al., 1989, Hendricks and Williams, 1992: obscure scale).

Utilization of the systems approach with scale insects, for both management and research purposes, has been limited (Brown and Potter, 1990). Management models developed through this approach may find a broad application in IPM of scale insects. Forecasting biological events of scale insect populations may reduce the use of pesticides by accurately predicting the timing of a susceptible stage. One of the possible derivations of the present study is the application of the predictive phenological model to the control of olive scale. The scale in Israel is controlled with dormant oils in winter and insect growth regulators (IGRs) in spring (Cohen and Oppenheim, 1991). In order for IGRs to be effective against scale insects, it is necessary to apply them during periods of crawler emergence (Potter et al., 1989). A predictive model that would accurately forecast the period of emergence of crawlers during spring could thus greatly enhance the effectiveness of insecticides, leading to reduced scouting and application costs. The olive scale spring egg-hatching model being developed in this study shows good predictive capabilities. Moreover, the preliminary results of this study indicate that the model may be utilized in an entire region, a feature that is highly desirable in IPM programs.

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