Prediction of Apple Maggot Fly[1] Emergence from Thermal Unit Accumulation[2]

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ABSTRACT

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The minimum temperature threshold for the development of apple maggot pupae, *Rhagoletis pomonella,* was 6.4°C. From 1951–75 the 1st flies emerged in cages over infested apples on the avg on June 15 near Highland, NY and on June 23 in Geneva, NY. The avg accumulated air temperature thermal units (T.U.'s) from Mar. 1 using a threshold of 6.4°C until 1st emergence were 614±53 and 641±48, respectively, at the 2 locations. The annual deviations between the actual first emergence and the date when the avg T.U.'s were accumulated ranged from 1–8 days with an avg of 3.5 at Geneva and from 1–14 days with an avg of 5.7 days at Highland. From 1975–77 the mean T.U. accumulation and the 99% confidence interval developed at Geneva was used to predict emergence in 5 locations in Wayne Co. The deviations between the observed emergence and dates in which the appropriate number of T.U.'s was accumulated averaged 3.5 and 0.8 days, respectively.

The apple maggot, *Rhagoletis pomonella,* a serious pest in New York State apple orchards, is currently controlled by insecticide sprays applied periodically when adults are active from late June–Sept. A reliable estimate of the start of adult emergence is essential because growers begin control sprays 7–10 days later, which is the normal pre-oviposition period of females. Emergence is currently estimated by daily observations and collection of flies in cages placed over areas seeded with infested fruit the previous fall. Cages are difficult to set up and tedious to maintain. Furthermore, this method does not predict emergence but only records the event after it has occurred.

Accumulated thermal units have been used to predict the seasonal development and emergence of various insects (Strong and Apple 1958, Eckenrode and Chapman 1971, Eckenrode et al. 1975, Sevacherian et al. 1977), including other *Rhagoletis* species (Jubb and Cox 1974, AliNiazee 1975). In this study, we determined the developmental temperature threshold for apple maggot pupae and used iterative analysis to compare field collected emergence data from several seasons and 2 locations in New York State so that thermal unit accumulations could be used to predict the initial emergence of apple maggot flies.

Materials and Methods

Developmental Threshold Temperature of Apple Maggot Pupae

Infested 'Wealthy' apples were collected from the field and placed over moist sand in an insectary. Pupae were sifted from the sand Nov. 7 and stored at a constant temperature of 1°C for 5 mo. Lots of 600 were removed and spread evenly over 1.27 cm of dry sand in an opaque cylindrical plastic container ca. 11 cm diam and 7.5 cm high. A layer of sand 2.5 cm thick was placed over the pupae and moistened with 115 ml of distilled water. Saran wrap fastened with a rubber band was placed over the top of the containers to maintain the RH near 100% during the test. Containers were placed under a loose aluminum foil cover to shield pupae from radiant energy. One container of pupae was kept at each of 5 constant temperatures ± 2°C: 10°, 15.5°, 18.3°, 21.1°, and 26.7° in biotrons at 16:8 LD. Flies were removed from the containers daily until emergence was completed. The minimum temperature threshold for pupal development was calculated by fitting a linear regression line to the percent development/day calculated for the emergence of the 1st fly at the various temperatures and extrapolating to determine the x-intercept. This method was used to determine the developmental threshold of apple maggot pupae in Canada (Reid and Laing 1976) and also for various life stages of other insects (Chiang and Sisson 1968, Eckenrode and Chapman 1971, Litsinger and Apple 1973, Obrycki and Tauber 1978).

Thermal Unit Determination

Records of apple maggot fly emergence were obtained from 1951–75 in central NY State at Geneva, and in southern NY in the Hudson Valley at Poughkeepsie in 1954–62 and Highland 1963–75 from cages described by Glass (1960) and Dean and Chapman (1973). Although multiple cages were maintained at each site, data from these were combined to give one annual record for each location. Air temperature and rainfall were recorded during this period from weather stations ca. 400 m from the emergence cages at Geneva, 1–5 m in Poughkeepsie, and 600 m (1962–72) or 30–60 m (1973–75) at Highland.

Thermal units (T.U.'s) were calculated as follows:

$$\text{T.U.} = \frac{\text{daily max air temp} + \text{daily min air temp}}{2} - \text{Dev. Thresh. Temp (6.4°C)}$$

Annual T.U.'s to 1st emergence using all combinations of beginning dates from Jan. 1–June 1, and threshold temperatures from −17.8° to 10°C were compared. The annual deviations between the observed emergence and the date when the avg number of T.U.'s

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were accumulated were determined for each combination.

Validation of Prediction

Apple maggot activity was monitored from 1975–77 in Wayne Co., NY, which contains more acres of apples than any other county in the state, to determine if avg T.U. accumulations developed at Geneva and in the Hudson Valley could be used to predict initial emergence elsewhere in NY. Several yellow sticky traps (Reissig 1975) were deployed ca. 2 wk before anticipated emergence in each of 5 heavily infested abandoned orchards during the 3-yr tests and checked daily throughout the season. Cumulative T.U.'s were calculated as previously described from nearby weather stations maintained by the NY State Apple Pest Management Program. The deviations between the observed 1st emergence in Wayne Co. and dates when the avg T.U.'s and the C.I. 99 developed at Geneva were accumulated are shown in Table 2.

Results

Determination of Developmental Threshold Temperature

The minimum temperature threshold for the development of apple maggot pupae calculated from the emergence of the 1st fly at various temperatures was 6.4°C. The standard error of prediction was <0.5%/day (Fig. 1).

Thermal Unit Determination

The most satisfactory predictions at Geneva and in the Hudson Valley (C.I.=99) were obtained by accumulating T.U.'s from Mar. 1 using the pupal development base temperature of 6.4°C. However, varying this base ± 5°C made the prediction only slightly less accurate. Emergence at the Geneva site was more accurately predicted by the accumulation of T.U.'s than by the avg

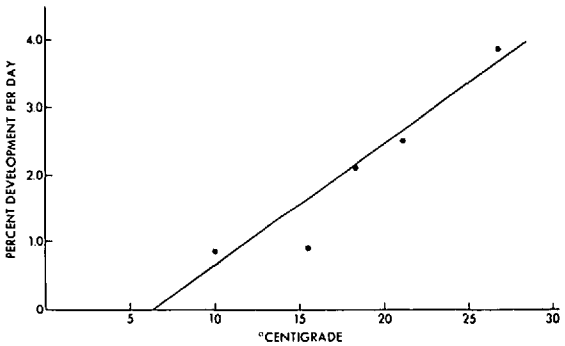

FIG. 1.—Relationship of apple maggot, *Rhagoletis pomonella*, pupal development to temperature.

Table 1.—Actual and predicted emergence dates of apple maggots from 1951–75 in Geneva and Highland, NY.

	Geneva				Highland			
	1st emergence				1st emergence			
Year	Date	T.U.'s	Dev. of pred.[a] (days)[b]	Dev. cal. day	Date	T.U.'s	Dev. of pred.[a] (days)[b]	Dev. cal. day
1951	6/27	702	4	−4	—			
1952	6/19	610	−4	4	—			
1953	6/19	583	1	4	—			
1954	6/22	669	3	1	6/16	654	3	−1
1955	6/18	693	−1	5	6/15	722	9	0
1956	6/29	640	1	−6	6/26	751	9	−11
1957	—				6/10	582	−2	5
1958	—				6/16	591	−4	1
1959	—				6/10	648	1	5
1960	—				6/13	545	−7	2
1961	—				6/22	636	1	−7
1962	—				6/16	765	12	−1
1963	—				6/16	627	1	−1
1964	6/24	670	−5	−1	6/10	485	−11	5
1965	6/23	594	−5	0	6/09	466	−14	6
1966	6/24	564	−5	−1	6/14	538	−6	1
1967	6/21	567	8	2	6/20	592	−2	−5
1968	7/02	756	1	9	6/13	530	−9	2
1969	6/27	667	−5	−4	6/13	525	−8	2
1970	6/15	575	2	8	6/10	658	2	5
1971	—				6/22	673	3	−7
1972	—				6/14	515	−8	1
1973	—				6/11	589	−2	4
1974	—				6/20	766	10	−5
1975	6/25				6/18	650	2	−3
Avg	6/23	641	3.5	4.1	6/15	614	5.7	3.6
Thermal Unit C.I.99=	593, 690				560, 667			

[a] Deviations between the observed emergence and the date when the avg T.U.'s were accumulated.
[b] (−) signs indicate actual emergence occurred later than the predicted date.

calendar date of 1st emergence (dev. 3.5 vs. 4.1 day), while in the Hudson Valley the calendar date was more accurate (dev. 5.7 vs. 3.6 day) (Table 1). The avg calendar date for the emergence of the 1st fly was one wk earlier in the Hudson Valley (June 15) than in Geneva (June 23). However, the avg T.U. accumulation was only slightly lower in the Hudson Valley (614±53) than in Geneva (641±48).

Validation of Prediction

During the 3-yr test in Wayne Co., the deviations between the observed and predicted 1st emergence of apple maggots averaged 3.6 days (Table 2). This was quite similar to the deviations occurring at Geneva where the T.U. avg was developed from the emergence cage data. The C.I. 99 was quite accurate in estimating the emergence in Wayne Co. since 3 of the actual dates were within this interval, and the avg deviations among the 5 sites were less than one day. Also, no flies emerged prior to the lower C.I. 99 limit, which suggests that this provides adequate advance notice of 1st emergence, which can be validated later by deploying traps within given sites.

Discussion

Slightly different minimum development temperature thresholds have been used to calculate T.U.'s for pupae of various *Rhagoletis* species infesting cherries. A 5°C threshold has been used for *R. indifferens* and *R. cerasi* (AliNiazee 1975, Boller 1964) and Jubb and Cox (1974) used 4.4°C for *R. fausta* and *R. cingulata*. The developmental threshold reported here for apple maggot pupae, 6.4°C, is quite similar to the 5.5°C base temperature that Maxwell and Parsons (1969) used to calculate thermal accumulations for this species, but is lower than the 8.7°C threshold reported for pupae from a Canadian population (Reid and Laing 1976). Future studies should be done in other areas to determine if the temperature requirements for the development of *Rhagoletis* pupae vary not only among species but also among allopatric populations of the same species adapted to different climates.

In this study, and others attempting to relate the emergence of *Rhagoletis* species to temperature, deviations between the actual and predicted 1st emergence based on T.U. accumulation usually averaged several days over a period of years at any given location (Maxwell and Parsons 1969, Jubb and Cox 1974), although AliNiazee (1975) obtained slightly better predictions of the 1st emergence of the western cherry fruit fly using soil temperatures 5 cm below the surface. These deviations are probably partially caused by factors other than temperature which also affect the emergence pattern of the flies. The most important other variables for apple maggots are soil type, rainfall, amount of sunlight, and host variety in which the larvae developed (Glass 1960, Dean and Chapman 1973, Neilson 1976). Thus, the annual emergence of apple maggots varies considerably among orchards within an area and even in various locations within a single orchard. This is illustrated by the large variations in 1st emergence recorded among adjacent cages in the same orchard (Glass 1960, Dean and Chapman 1973).

New York apple growers have previously received information about apple maggot emergence only from the 2 sites described in this study where emergence cages were maintained. Emergence predictions could only be based on the avg calendar dates which vary considerably between the 2 areas. The similarity of the avg accumulated T.U.'s required for 1st emergence at the 2 widely separated locations and the accuracy of prediction obtained using the average Geneva T.U.'s in the validation tests in Wayne Co. indicate that emergence can be predicted with this system anywhere in the state where weather information is available. When the lower limit of accumulated T.U.'s in the C.I. 99 is reached, growers in an area can be alerted that apple maggot emergence is imminent so that apple maggot traps (Reissig 1975) can be deployed in nearby abandoned orchards to detect emergence and monitor activity more specifically. This system will require considerably less labor than the maintenance of multiple emergence cage sites, and should provide growers with more specific information in localized areas so that control measures can be timed more accurately.

Table 2.—Prediction of initial emergence of apple maggot flies in Wayne Co., NY, using accumulated T.U.'s.

Site no.	Year	Actual emergence	T.U.	Deviation[a] of prediction (days) from Avg T.U.[b,c]	Deviation[a] of prediction (days) from C.I. 99[b,c]
1	1975	June 30	675	−2	0
2	1976	June 23	609	+3	0
3	1976	June 28	752	−6	−3
4	1977	June 18	601	+3	0
5	1977	June 21	702	−4	−1
Avg:				3.6	0.8

[a] Deviations between the observed emergence and the date when the appropriate number of T.U.'s were accumulated.
[b] Avg T.U. (641) and C.I. 99 (593–690 T.U.) were developed from observations in Geneva, NY.
[c] (−) signs indicate actual emergence occurred later than the predicted date.

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