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# SPRING EMERGENCE OF THE CODLING MOTH, *LASPEYRESIA POMONELLA* (L.) AND THE POSSIBILITY OF FORECASTING IT IN CENTRAL POLAND*

ABSTRACT: Usefulness of the sum of effective temperatures' method for forecasting the spring emergence of codling moth – *Laspeyresia pomonella* was investigated in central Poland. The threshold of developmental temperature and the sum of effective temperatures were estimated for the Polish strain. Factors affecting the reliability of the method are discussed.

KEY WORDS: Lepidoptera, *Laspeyresia pomonella*, orchards, laboratory and field experiments, forecasting, sum of effective temperatures' method.

Contents



## 1. INTRODUCTION

The most commonly used method for forecasting the emergence of the codling moth is the sum of effective temperatures. It depends on the accuracy of the threshold developmental temperature, the accurate date of larval development following the diapause and precise estimations of the sum of effective temperatures necessary for termination of larval development under Polish climatic conditions.

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The termination of diapause of codling moth and the beginning of spring development of larvae are conditioned by the number of days with appropriately low temperature. Geier (1963) has observed a close relation between the number of days with low temperature and the adult eclosion and its duration. The longer is the cold period, the earlier is the emergence of codling moth and shorter the duration. After 20 days of keeping larvae at 4.5°C only 40% developed into pupae. After 90 days about 90% became pupae (Peterson and Hammer 1968). These data are consistent with observations of Wildbolz and Riggenbach (1969). The development of diapausing larvae started after 3 months of keeping at 4°C or under conditions of 18 hrs day. Under field conditions the diapause of codling moth can terminate in the middle or at the end of November (Russ 1966), or in December (Saringer 1971, 1975).

Larvae of codling moth develop according to climatic conditions of a given region and the threshold developmental temperature of a given ecological race. When summing effective temperatures the scientists use different thresholds of developmental temperatures: 9°C (Savescu 1963, Suta and Floru 1972); 10°C (Schneider, Vogel and Wildbolz 1957, Touzeau 1966, 1970, Popov 1968) and 11°C (Glenn 1922, Hagley 1973). The majority of scientists take the first day after January 1 with temperature higher than the threshold developmental temperature as the beginning for summing the effective temperatures.

The emergence of first codling moths under climatic conditions of Switzerland occurs at the sum of effective temperatures 100°C (Schneider, Vogel and Wildbolz 1957), in Austria at the sum of 150°C (Müller and Russ 1969) and in France at the sum of 300°C (Gendrier and Reboulet 1970). Under climatic conditions of Poland in 1974 first codling moth males in sex-pheromone baited traps were recorded at the sum of effective temperatures 34–68°C, and the emergence of first moths from larvae collected in corrugated paper bands was observed at the sum from 65 to 144°C depending on the region (Niemczyk 1974).

The sum of effective temperatures provides also the optimum date of treatment for codling moth control. In Switzerland spraying of orchards is recommended during the main emergence of moths at the sum 300–450°C (Wildbolz 1965), in Soviet Union at the sum 230°C (Ščerbakov 1967) and in Bulgaria at the sum 218°C (Vasev 1961).

Usefulness of the sum of effective temperatures' method for forecasting the spring emergence of codling moth was investigated under conditions of central Poland.

## 2. MATERIAL AND METHODS

The studies on the beginning of larval development after the diapause were conducted in 1975 in Skierniewice. Therefore in the autumn of the preceding year 800 cocoons with larvae of codling moth were collected and kept in unheated insectary. Every fortnight (January 21, Fabruary 8 and 22 and March 8) some cocoons were placed in thermostatic chambers having constant air temperature 15 and 20°C and relative humidity about 70%. At each date and temperature a sample consisted of 100 cocoons. During the emergence of codling moth their number and sex were recorded, and afterwards dead larvae and pupae were counted including larvae continuing the diapause. The duration of post diapause larval development is expressed by the number of days between placing the larvae in the thermostat and the day of emergence of 10, 50 and 90% of moths.

The threshold developmental temperature of larvae and the sum of temperatures necessary for the emergence of codling moth were calculated on the basis of recorded dates of the emergence of first codling moths and the mean daily air temperatures. Records from 12 Quarantine and Plant Protection Stations in central Poland and nearest meteorological stations for the period of 1965–1967 were used in this purpose. Results were statistically elaborated by linear regression method, similarly as Hunter-Jones (1970) when calculating the threshold of developmental temperature of eggs of desert locust. Hyperbolic relation $\left(Y = \frac{100}{X}\, b + a\right)$ between the number of days of larval development ($X$) and mean air temperature for this period ($Y$) was used. Equation of hyperbola was transformed into linear one by introducing a variable $z = \frac{100}{X}$, determining the daily development rate. Thus equation $Y = bz + a$, where parameter $b$ determines the threshold of larval development and parameter $a$ multiplied by 100 the sum of effective temperatures necessary for the termination of larval development. On the basis of literature following assumption were made: (a) 8 thresholds of developmental temperature: 6.0, 8.0, 9.0, 9.5, 10.0, 10.5, 11.0 or 12.0°C, (b) two thermal criteria: mean daily temperature and maximal daily temperature, and (c) two time criteria for the start of air temperature summing one or three consecutive days with temperature higher than the assumed threshold of developmental temperature. Then 23 analyses of linear regression were made counting the correlation coefficients and parameters of regression equation. As the most correct threshold of developmental temperature was accepted the one for which the results of mathematical calculations are nearest to the theoretical assumptions.

The sum of effective temperatures necessary for the emergence of codling moth was calculated also summing mean daily temperatures above the threshold of developmental temperature 10°C. These data allowed to calculate the correlation coefficient and parameters of equation regression for the relations between the sum of effective temperatures ($y$) and the mean temperature for the period of larval development ($x$). On the bases of own observations carried out in Skierniewice, apart from the sum of effective temperatures necessary for the emergence of first moths sums of temperatures were also calculated for the emergence of 10, 50 and 90% of moths. Observations on the emergence were conducted in the years 1973–1976 under insectary conditions, with the exception of 1974 when observations were conducted in the orchard. Air temperature was recorded by a meteorological station in Skierniewice about 1 km from the place of investigations. During the emergence the number and sex of moths were recorded daily. In successive years of investigations the numbers of moths were as follows: 30 in 1973, 614 in 1974, 429 in 1975 and 884 in 1976. Using the graphical method (probability graphs for normal distribution – Zając 1976) the mean emergence of 10, 50 and 90% of moths and number of days of main emergence were calculated for the years 1974–1976. The main emergence was the time between the emergence of 10 and 90% of all moths. Cumulative probability curve was obtained by plotting the sums of the number of moths in 3–6 day intervals.

## 3. RESULTS AND DISCUSSION

Larvae of codling moths from the experiment in January 25, 1975, completed their diapause and their further storage under field conditions did not affect the per cent of moth emergence. The date of beginning of larval development afterwards did not affect also the number of larvae still in diapause (Table I). Till the beginning of the development larvae remained at least 110 days at 0 to 10°C, which was sufficient for diapause termination by wintering codling moths. This is consistent with the data of Peterson and Hamner (1968), Wildbolz and Riggenbach (1969). During post-diapause larval development air temperature was a decisive factor. At 15°C 1.4% of larvae remained in the diapause for the following year. At 20°C all larvae finished their development. At this temperature the mortality of larvae and pupae was slightly lower than at 15°C.

Table I. Per cent of moths (A), dead larvae and pupae (B) and larvae continuing the diapause (C) in the experiment on breaking the diapause of codling moth – Skierniewice, 1975

| Date of starting the development | A | | B | | C | | Number of days of a temperature 0–10°C during wintering |
|---|---|---|---|---|---|---|---|
| | 15°C | 20°C | 15°C | 20°C | 15°C | 20°C | |
| January 25 | 82.3 | 90.4 | 16.5 | 9.6 | 1.2 | 0.0 | 111 |
| February 8 | 84.6 | 92.3 | 15.4 | 7.7 | 0.0 | 0.0 | 118 |
| February 22 | 82.2 | 84.3 | 17.8 | 15.7 | 0.0 | 0.0 | 122 |
| March 8 | 84.9 | 88.1 | 13.7 | 11.9 | 1.4 | 0.0 | 136 |

The initiation date of larval development did not affect its duration, thus the effect of temperature was examined according to mean values (Table II). At 15°C post-diapause larval development lasted much longer than at 20°C. Emergence of 10, 50 and 90% of moths at 15°C on the average took place after 76, 89 and 103 days, and at 20°C after 43, 53 and 59 days. The duration of main emergence, i.e., of 80% of moths, at 15°C, was on the average 27 days and at 20°C – only 16 days, although the emergence of moths had the character of bimodal distribution.

Table II. Number of days from the date of the beginning of development of codling moth larvae to the emergence of 10, 50 and 90% of moths and the number of days of the main emergence (time of emergence of 10–90% of moths) – Skierniewice, 1975

Number of days was determined on the basis of probability graphs for normal distribution. At 20°C the emergence of moths has a bimodal character, in the first period about 10% of all moths emerged

| Date of starting the development | 10% | | 50% | | 90% | | Main emergence | |
|---|---|---|---|---|---|---|---|---|
| | 15°C | 20°C | 15°C | 20°C | 15°C | 20°C | 15°C | 20°C |
| January 25 | 67 | 45 | 84 | 53 | 99 | 60 | 32 | 14 |
| February 8 | 85 | 44 | 96 | 54 | 108 | 61 | 23 | 17 |
| February 22 | 73 | 39 | 89 | 52 | 105 | 58 | 32 | 19 |
| March 8 | 79 | 44 | 88 | 51 | 99 | 57 | 20 | 13 |

Under variable temperature conditions (Table III) the duration of main emergence was 17 and 19 days in 1974 and 1975, respectively, although in 1974 the emergence was about one month later than in 1975. In both years air temperature preceding the emergence and mean temperature were similar during the main emergence. In 1976 the spring emergence of codling moth was much longer and had two periods, and total duration of main emergence of two subpopulations lasted 29 days. That year mean monthly air temperature preceding the emergence was much lower than in the two previous years. Similarly the mean air temperature during the main emergence of the first subpopulation was lower than in the previous years. These results confirm the conclusion of the laboratory experiment that developmental temperature after the diapause affects the duration of moth emergence.

Table III. Characteristics of spring emergence of codling moth pupulation under conditions of real temperatures: field experiment, Skierniewice

| Year of investigations | Mean monthly temperature before the emergence | Date of moth emergence | | | Main emergence – days | Mean daily temperature during the main emergence |
|---|---|---|---|---|---|---|
| | | 10% | 50% | 90% | | |
| 1974 | 14.9 | July 2 | July 10 | July 18 | 17 | 16.1 |
| 1975 | 14.6 | June 4 | June 13 | June 22 | 19 | 16.8 |
| 1976[a] | | | | | | |
| I period | 12.5 | June 4 | June 10 | June 16 | 13 | 13.5 |
| II period | | June 21 | June 28 | July 6 | 16 | 17.8 |

[a]Dates of emergence were determined on the basis or probability graphs for normal distribution; this year the emergence of moths had a bimodal character, in the first period about 20% of all moths emerged.

Correlation coefficients show a correlation between the mean daily post-diapause development rate of codling moth larvae and the mean temperature for this period (Table IV). The smallest deviations of the threshold of developmental temperature from the one assumed theoretically was obtained in variant A, where mean daily temperatures were summed when temperature in three consecutive days exceeded the assumed threshold of developmental temperature.

At theoretical values 8–12°C the threshold of developmental temperatures differed not more than by 5% and the least deviation was at the theoretically assumed 10°C. Thus 9.97°C should be assumed as the threshold of developmental temperature for codling moth population occurring under conditions of central Poland. This is consistent with the value given by other scientists (Schneider, Vogel and Wildbolz 1957, Touzeau 1966, 1970, Popov 1968).

Parameter *a* of the regression equation multiplied by 100 indicates (Table IV) that the theoretical sum of effective temperatures necessary for the emergence of first codling moths is 100.3°C, assuming the threshold of developmental temperatures 10°C and the mean daily temperature as thermal criterion and three consecutive days with a temperature above the threshold of developmental temperatures as the time criterion. The latter was not taken into consideration in summing the effective temperatures by other scientists, except Touzeau (1966) who has mentioned its usefulness.

Table IV. Correlation coefficients and parameters of regression equation for the relation: mean daily larval development rate-mean temperature during that period, and the deviation in per cents of estimated threshold of developmental temperature for codling moth from the theoretical threshold Variant A – thermal criterion – mean daily temperature, time criterion – three consecutive days with a temperature above the assumed threshold. Variant B – thermal criterion – mean daily temperature, time criterion – one day with a temperature above the threshold. Variant C – thermal criterion – maximal daily temperature, time criterion – three consecutive days with a temperature above the threshold. Variant D – thermal criterion – maximal daily temperature, time criterion – one day with a temperature above the threshold. *a* – multiplied by 100 – sum of effective temperatures, *b* – threshold of developmental temperature

| Variant | Theoretical threshold of developmental temperature ($^{o}$C) | Correlation coefficient | Parameters of equation | | Deviation (%) |
|---|---|---|---|---|---|
| | | | *a* | *b* | |
| A | 6.0 | 0.341** | 0.918 | 8.965 | 49.4 |
| | 8.0 | 0.641** | 1.626 | 8.200 | 2.5 |
| | 9.0 | 0.698** | 1.383 | 8.678 | 3.6 |
| | 9.5 | 0.650** | 1.167 | 9.219 | 3.0 |
| | 10.0 | 0.478** | 1.003 | 9.971 | 0.3 |
| | 10.5 | 0.498** | 0.620 | 10.983 | 4.6 |
| | 11.0 | 0.590** | 0.674 | 11.071 | 0.7 |
| | 12.0 | 0.535** | 0.555 | 12.111 | 0.9 |
| B | 9.0 | 0.720** | 1.941 | 7.497 | 16.7 |
| | 9.5 | 0.703** | 1.845 | 7.682 | 19.1 |
| | 10.0 | 0.684** | 1.661 | 8.086 | 19.1 |
| | 10.5 | 0.686** | 1.681 | 8.070 | 23.1 |
| | 11.0 | 0.642** | 1.502 | 8.491 | 22.8 |
| C | 9.0 | 0.330** | 1.255 | 13.540 | 50.4 |
| | 9.5 | 0.330** | 1.262 | 13.539 | 42.5 |
| | 10.0 | 0.327** | 1.230 | 13.610 | 36.1 |
| | 10.5 | 0.405** | 1.490 | 13.274 | 26.4 |
| | 11.0 | 0.362** | 1.164 | 13.862 | 26.0 |
| D | 9.0 | 0.341** | 2.052 | 12.015 | 33.5 |
| | 9.5 | 0.294* | 1.635 | 12.705 | 33.7 |
| | 10.0 | 0.306* | 1.672 | 12.654 | 26.5 |
| | 10.5 | 0.281* | 1.324 | 13.266 | 26.3 |
| | 11.0 | 0.301* | 1.300 | 13.392 | 21.8 |

*Significant correlation coefficient at a level $P = 0.05$. **Significant correlation coefficient at a level $P = 0.01$.

Under our climatic conditions three consecutive days with mean daily temperature above 10$^{o}$C occur most frequently in April and sometimes in March. Thus it is not always necessary to trace air temperatures from the beginning of year as suggested by other scientists.

Observations of the emergence of first moths in the years 1965–1973 by 12 Quarantine and Plant Protection Stations show that the mean sum of effective temperatures

(Table V) was 138.4°C and mean temperature for larval development after the diapause 12.4°C. Thus obtained sum of effective temperatures approximated that given by Müller and Russ (1969), but the components of this average according to the year and place of observations ranged between 36.9 and 234.0°C. One of the reasons for such a high variability were thermal conditions during the spring development of larvae. This is suggested by the existence of a relation between the sum of effective temperatures ($y$) and the mean daily temperature during larval development after the diapause ($x$). Correlation coefficient for the years 1965–1973 is $r = 0.289^x$, and regression equation is $y = 6.26\,x + 60.77$.

**Table V. Sums of effective temperatures of larval development of codling moth obtained from mean daily temperatures over 10°C till the emergence of first moths**

| Year of investigations | Number of observations[a] | Range of the sum of effective temperatures | Range of the mean temperature for the development period |
|---|---|---|---|
| 1965 | 3 | 36.9–157.1 | 11.3–13.7 |
| 1966 | 6 | 72.1–155.1 | 12.4–16.1 |
| 1967 | 4 | 127.4–194.4 | 11.3–12.4 |
| 1968 | 9 | 131.0–217.7 | 10.2–12.4 |
| 1969 | 7 | 139.2–184.7 | 14.4–16.4 |
| 1970 | 8 | 91.7–188.3 | 12.0–16.0 |
| 1971 | 9 | 95.2–232.7 | 9.8–16.8 |
| 1972 | 8 | 44.4–234.0 | 9.6–17.7 |
| 1973 | 9 | 68.7–157.8 | 9.5–13.8 |
| Average | | 138.4 | 12.4 |

[a]Observations of the emergence of first moths were conducted by Quarantine and Plant Protection Stations.

Other reasons of this large variability of the sum of effective temperatures are probably: the population differentiation (different ecological races), differences of air temperature caused by the distance between the observation point of moth emergence and the place of temperature reading, different exposure of larvae to direct solar radiation, and incorrect dates of the emergence of the first moth due to small cocoon sample or insufficient knowledge of observers. According to four years of investigations (1973–1976) in Skierniewice the mean sum of effective temperatures 143.2°C was necessary up to the day of emergence of first moth; for 10% of moths 176.1°C; for 50% of moths 225.8°C and for 90% of moths 282.8°C (Table VI). It should be pointed out that the sum of temperatures necessary for the emergence of the first moth according to these data approximates the sum of effective temperatures according to the data from the Quarantine and Plant Protection Stations for years 1966–1973.

Results of investigations indicate that forecasting of spring emergence of codling moth is possible on the basis of the sum of effective temperatures. But in order to obtain a good forecast the sum of effective temperatures should be corrected according to mean daily temperature for the period of larval development following the diapause and other

Table VI. Sums of effective temperatures of development of codling moth larvae from mean daily temperatures over $10^{o}C$ till the emergence of first 10, 50 and 90% of moths, Skierniewice, 1973–1976

| Year of investigations | Sums of effective temperatures till the moment of emergence of: | | | |
|---|---|---|---|---|
| | the first moth | 10% of moths | 50% of moths | 90% of moths |
| 1973 | 123.1 | 146.7 | 188.8 | 244.5 |
| 1974 | 162.3 | 229.2 | 264.9 | 321.9 |
| 1975 | 139.6 | 145.5 | 193.5 | 266.0 |
| 1976 | 147.7 | 182.8 | 256.1 | 298.6 |

sources of error should be eliminated. Thus the mean daily temperature should be known for the period between the day when the threshold of developmental temperature is exceeded and the day of the earliest emergence of the first moth, which under Polish conditions took place on May 11. Then the obtained value ($x$) should be substituted in the equation $y = 6.26\ x + 60.77$ to calculate the sum of effective temperatures ($y$) when the emergence of first codling moth should take place. Thus the emergence of codling moth can be forecasted up to several days earlier with an almost 100% accuracy.

The sum of effective temperatures allows also to determine the best period for the control of codling moth. Assuming that the spraying should be done during the main emergence, precisely at the moment of emergence of 50% of moths, the date of spraying should be determined by the sum of effective temperatures equal 225.8°C, which approximates the value given by Ščerbakov (1967) and Vasev (1961). However, it requires a verification under field conditions at varying numbers of codling moth population.

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## 4. SUMMARY

Forecasting of spring emergence of codling moth – *Laspeyresia pomonella* is possible using the sum of effective temperatures in central Poland. The flight of codling moth begins when accumulated temperatures (over $10^{o}C$) summed since January 1 reach the value of 140 degree-days (°C), 50% of moths emerge at 230 degree-days (°C) (Table VI). There is a considerable variability of results and the accumulated degree-days depend on temperature fluctuations during the larval development in spring. The regression equation for the corrected sum of effective temperatures ($y$) takes for $y = 6.26\ x + 60.77$, where $x$ = current sum of effective temperatures till May 11 (under conditions of central Poland). The lower threshold temperature for the post-diapause development of codling moth larvae equals 9.97°C. The post-diapause larval development begins when after January 1 there are three consecutive days with temperature higher than the threshold of developmental temperature (Table IV).

## 5. POLISH SUMMARY

W warunkach Polski środkowej istnieje możliwość prognozowania terminu wylotu motyli wiosennego pokolenia owocówki jabłkóweczki i optymalnego terminu jej zwalczania na podstawie sumowania dziennych temperatur efektywnych. Lot motyli owocówki rozpoczyna się przeciętnie przy sumie dziennych temperatur efektywnych około 140°C, a wylot 50% motyli zachodzi przy sumie ok. 230°C (tab. VI). Suma temperatur efektywnych podlega znacznej zmienności i jej wartość zależy w głównej mierze od przebiegu temperatur powietrza w okresie rozwoju larw wiosną. Równanie regresji dla obliczenia poprawionej sumy temperatur ($y$) ma postać $y = 6.26\ x + 60.77$, gdzie $x$ = rzeczywista suma temperatur efektywnych do 11 maja (w warunkach Polski środkowej). Wartość zera fizjologicznego rozwoju larw owocówki jabłkóweczki wynosi 9.97°C. Rozwój larw po zakończeniu diapauzy następuje wówczas, jeżeli po 1 stycznia w ciągu trzech kolejno następujących po sobie dniach średnia temperatura dobowa będzie wyższa, niż wartość zera fizjologicznego rozwoju (tab. IV).

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