EFFECTIVENESS OF THE CALIFORNIAN PROGNOSIS MODEL "BUGOFF 2" FOR CYDIA POMONELLA L. (LEPIDOPTERA, TORTRICIDAE) UNDER CENTRAL EUROPEAN CONDITIONS.

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Abstract

During 1985 and 1988, the effectiveness of the codling moth prognosis model BUGOFF 2 was studied in Dossenheim, West Germany. Bugoff 2 was developed at the University of California, Berkeley, USA to determine the egg hatch of the codling moth, *Cydia pomonella* L., under field conditions. At weekly intervals the egg laying behaviour was observed on 150 apple fruit clusters collected from unmanaged crops. A new staining method with toluidine blue/sodium biborate was used for visualization codling moth eggs on the apples and leaves collected. Air temperature was continuously recorded to determine the heat units used by Bugoff 2.
The results of this study were similar in both years. In the first generation of the codling moth we found a good agreement between our field observations and the forecasts given by the model. However a considerable difference was found in the second generation: under our climatic conditions the egg hatch was about 3 weeks earlier than estimated in the forecast. This time divergence is due to the overestimation of the developmental rates of codling moth in the heat unit table of Bugoff 2, if the maximum value of air temperature exceeds the upper limit for development. Influence on these results due to differences between air and microenvironmental temperatures experienced by codling moth are also discussed. In our further studies Bugoff 2 will be adapted to meteorological and phenological data of different European latitudes (Italy, West Germany and Norway).

1. Introduction

The verification of a prognosis model in variable climatic conditions is the final test for its use in practice.
Cydia pomonella (*Cp*), a major apple, pear, and walnut pest, has been studied intensively since beginning of this century. One of the principal aims of these studies has been the determination of climatic factors influencing codling moth development as support for IPM. Although relative humidity (Shelford, 1927), the photoperiod (Riedl and Croft, 1978a), the food quality (Geiger and Breise, 1978; Hathaway et al., 1971), and other factors affect the developmental rate of *Cp*, temperature alone was used for construction of simulation models and timing of treatment measures (Bloesch et De Siebenthal, 1988; Brunner et al., 1982; Riedl et al., 1976).
In a bulletin from the University of California, Berkeley, a new codling moth prediction model was published by Falcon et al. (1983). In their opinion, this model, named BUGOFF 2, proved an exellent success when used for the determination of time applications for *Cydia pomonella* granulosis virus (*Cp*GV). The prognosis of Bugoff 2 is also based on daily minimum and maximum air temperatures recorded in a weather shelter. The model used a special table to convert recorded temperatures into heat units (HU), whilst considering temperature dependence of *Cp* development. The forecast consists in determining the time of egg hatch for every *Cp* generation. Before proceeding with the

daily accumulation of HU towards egg hatch, 3 conditions should be fulfilled:
a) *Cp* is caught in a pheromone trap,
b) blooming has reached its final stage (90-100% of normal petal fall), and
c) the temperature sunset is 15.6°C or higher for 3 nights within a 7-day period. The first of the 3 nights is used to start temperature accumulation towards egg hatch.
In the framework of a *Cp*GV spray programme the effectiveness of the Bugoff 2 model was tested for 2 years (1985 and 1988) in Dossenheim by Heidelberg, W-Germany. In 1986 and 1987 no experiments were carried out. The results of the study are reported in this paper.

2. Material and methods

2.1. Phenological observations

2.1.1. Egg laying activity

Observation of *Cp* egg laying activity was carried out on collected fruit clusters (FC) from unmanaged orchards of the Research Centre for Plant Protection in Fruit Crops in Dossenheim.
During the sampling season (May-September, 1985 and 1988) every week a total of 150 FCs with 300 apples was randomly collected from 2 orchards. Detailed features of these orchards are described elsewhere (Blago und Dickler, in press).
In 1985, individual leaves and apples were examined for *Cp* eggs under artificial light. Egg development was examined using the 3 easily identifiable broad stages: white stage, red ring and black head.
The mean physiological time values (calculated with data from Wyniger, 1956) were used to determine the egg hatch:
- 75.5 degree-days (DD, in °C) towards egg hatch of the white stage,
- 44.2 DD towards egg hatch of the red ring and
- 11.4 DD towards egg hatch of the black head.

Wyniger (1956) found the incubation period of a *Cp* egg to be 85.5 DD (10 °C base temperature). Daily DDs were calculated with the exact mean value of air temperature.
In 1985 the egg hatch was determined by using the average time for development of weekly sampled eggs.

A more accurate method for identifying *Cp* eggs on leaves and fruits was developed in 1988. Collected fruit clusters were immersed for 30 min in a 0.035% toluidine blue and sodium biborate aqueous solution. After washing FCs codling moth eggs (also those of other pests or useful species) were stained dark violet, whereas hydrophobic leaves and apple surfaces remained uncolored (Blago und Dickler, in press). As it was impossible to recognize developmental stages on stained eggs, they were separated from leaves or fruit surfaces and transferred in a drop of HCl (32%) on slide. Acid decolorized the eggs immediately and the exact developmental stage (see below) could clearly be distinguished by stereomicroscopy (light from below). This method facilitates *Cp* egg detection, particulary if oviposition activity is low.
In weekly observations we found an average of only 1.54 eggs/50 FCs in the 1st generation, and 2.40 eggs in the 2nd.
Approximations of egg development used in first year of study were not accurate enough because the span of time covered by the white, the red ring, and the black head stage is too long to enable a close estimation of egg hatch. Hence, in 1988, a total of 12 stages was determined by observing embryogenesis in about 6000 reared *Cp* eggs at 2-hours intervals. Eggs were incubated at 26°C and 80% r.h.. For each stage DDs were also calculated for the time of

oviposition and egg hatch (table 1). Our 12 stages and the related DDs reveal close similarities to data reported by Richardson et al. (1982). Therefore, a description of our stages can be omitted.

2.1.1.1. Correction of field data

Particulary in colder springs, we noted that eggs laid at the same time could be found within a period of 2-3 weeks. To avoid double or triple counting of these eggs, the number of eggs found in a defined stage was divided through the number of observations made during the time necessary for their complete development. An example of this correction procedure is shown in table 2: in our observation on 27 May we found 3 eggs belonging to stage 10 and 12; determining their oviposition and egg hatch time we could see that it was nearly the same as the 2 eggs (stage 5 and 6) found in a previous observation. The same is valid for the 2 eggs (stage 12) found on 13 June and the 4 eggs (stage 5 and 6) found on 3 June.

2.1.2. Flight activity

Early *Cp* flight was established using 2 Biotraps baited with Codlemone septa (Hoechst, Frankfurt, W-Germany) and placed in the 2 trial-orchards. During the week before first male catch, orchards were visited daily in order to accurately determine early male moth activity.

2.1.3. Blooming

The 90-100% percentage of normal petal fall was observed daily on the varieties Cox Orange and Golden Delicious. The calculated average time for this percentage was used to start Bugoff 2.

2.2. Temperature recording

An automatic weather station, type "DAT 1000" (Adamchewski, 7129 Zaberfeld, W-Germany), placed in an open space in the center of the experimental orchards of the Institute in Dossenheim, was used to monitor temperature data continuously. Measurements of the weather station and microenvironmental temperatures were taken with the help of small sensores, (length 10 mm, diameter 1.3 mm; type: GX 613, platinum 100, errors +/- 0.1°C; Drisen & Kern, 2000 Tangstedt, W-Germany). The internal registration of data took place every 5 sec, whereas the output hourly produced the min., max. and mean values of temperature. Air temperature for Bugoff 2 was recorded in the weather shelter 2 m above the ground. Furtheremore, microenvironmental temperatures were investigated to determine the correlation between standard input of Bugoff 2 (weather shelter temperature) and typical microclimate of *Cp*. In connection with the present study only the measurements listed below are relevant:

- the crown on the north and south side of the tree (position of 2 sensores: 2 m above ground and 1 m away from trunk of a 15 year old Golden Delicious, MM106 root stock, bush form)
- in the apple on the north and south side of the crown (the 2 sensores were embedded in a sterile cavity of the apple; diameter: 1 mm, depth: 15-25 mm).

The microclimatic recording was carried out in the 2 orchards used for FC collection.

2.3. The model Bugoff 2

Based on the instructions of the bulletin by Falcon et al. (1983) we developed a prediction computer program to simplify the use of Bugoff 2.

Table 3 shows the heat unit algorithm used by Bugoff 2 to transform daily min. and max. temperatures into developmental rates of *Cp*. Sunset at Dossenheim was determined using data from the W-German Weather Service - Offenbach. Phenological and weather data were elaborated on a HP-UX and an Altos-MsDos computer. *Grafic illustrations* were produced with the Signum AS-Heidelberg program on a Atari computer.

3. Results and discussion

The 3 conditions required before accumulating daily HU towards egg hatch were fulfilled on 15 May for 1985 and on 6 May for 1988. Results from the 2-year study obtained with the Bugoff 2 model under climatic conditions of Dossenheim are shown in figures 1 and 2 . A superficial analysis already indicated that similar results were obtained in both years.
Comparing the egg hatch forecast with the field observation the latter was found to be delayed by an average of only 1.2 days in 1985, and 1.5 days in 1988, respectively (table 4). The positive difference does not affect the application of *Cp* control measures. Similarly, the negative differences calculated for the early 1st generation in 1988 should have no influence on the efficacy of a spray program: particularly at this time adverse weather conditions and predation produce high mortality of searching first instar *Cp* (Jackson, 1982). In addition, the data of both years showed an intersection of field and prediction curves in approximately 50% of the egg hatch.
On the contrary, our analysis in figures 1 and 2 indicates that, for the 2nd generation, the Bugoff 2 forecast occurred about 3 weeks later than field observations both in 1985 and in 1988. Average physical and physiological time differences between prognosis and field data were always negative and nearly constant (table 4). To our mind this discrepancy is due to overstimated developmental rates of *Cp* when using the table of Bugoff 2 (table 3) at times where the maximum value of air temperature exceeds the upper limit for development.
Falcon et al. (1983) stated this limit to be 33.3°C, yet, in our opinion, its effect was not accurately assessed in the HU table, where the developmental rate of *Cp* increases continually with rising temperatures (table 3). We think that this trend could only be adequate for max. temperatures lower than 30-33°C (depending on life stages), but not for temperatures above this limit. It is well known from literature (Glenn, 1922; Shaffer and Gold, 1985; Shelford, 1927; Wyniger, 1956) that the development of *Cp* is repressed by rearing temperatures above 30-33°C.
Sensitivity studies by Gold et al. (1987) also demonstrated a drastic decrease in the enhancement of the developmental rate when the max. temperatures go across the upper limit for only a few hours a day.

An intrinsic error for a simplified model like Bugoff 2 is the sole use of the min. and max. temperatures. This method disregards the period of time during a day in which the insect is exposed to high temperatures adverse to its development. Rock and Shaffer (1983) showed the graphs of correlation between temperature and developmental rate used for the codling moth in PETE model (Riedl and Croft, 1978b; Welch et al., 1978) and those determined by Glenn (1922) and Shelford (1927). The PETE model is similar to Bugoff 2, yet developmental rates of the former remain constant when temperatures exceed the upper limit. Despite this factor the PETE model is not likely to succeed when used in strongly variable latitudes, considering the real decrease of the functions established by Glenn (1922), Shelford (1927) and Wyniger (1956).

Another source of error when implementing Bugoff 2 is the difference between the weather station temperature used for the forecast and that of the microenvironment. In our studies on correlation between temperature values of weather shelter (X) and those of the apple crown (Y), we established the following regression equations for the time period April-August:

$Y = 0.957X + 0.313$ ($r = 0.96$) for min. temperature,
$Y = 1.035X + 1.87$ ($r = 0.97$) for max. temperature, and
$Y = 0.993X + 1.152$ ($r = 0.98$) for mean temperature.

These equations revealed: a) almost no difference among values of min. temperature; b) the max. temperature of the crown was always 2-3°C higher, and c) that the crown mean temperature was about 1°C higher than the shelter temperature. This difference was even higher when air temperatures were compared with those measured in the apple. Even if the max. air temperature does not reach the upper limit for *Cp* development, the temperatures withing the apples exceed this limit considerably (table 5). This effect was even more striking for apples exposed on the south side of the crown. Here the max. temperature could reach 42°C compared to 30°C recorded on the weather shelter. Our results agree with those obtained in Hungary by Jermy (1964), who cautioned against the exclusive use of air temperature to forecast *Cp* activity. The dynamic variations between microenvironmental temperatures and those of a weather station, as well as their negative effect on the prediction of a model, was emphasized by Gold et al. (1987).

4. Conclusions

All results were obtained in Dossenheim, located at 49°25' north latitude. The prognosis model Bugoff 2 was developed using phenological and meteorological data sampled in Berkeley at about 37°5' north latitude. In California the summer air temperature frequently rises above the upper limit for *Cp* development. Without correction of the temperature above 33°C as stated in Bugoff 2 (table 3), the egg hatch curve for the 2nd generation in Berkeley consequently results in a higher number of HU compared to our observations in central Europe (figures 1 and 2) where the max. value of air temperature never rises above this limit. An indirect confirmation of our hypothesis is shown by the egg hatch of the 1st generation. Almost no difference results between model forecast and observations because in spring and early summer the air temperature rarely rises above 33°C both in Dossenheim and Berkeley. Consequently, the Bugoff 2 model could successfully be applied in regions where the above-mentioned limit is irrelevant. In these climatic conditions our results (figures 1 and 2) could be used to forecast the egg hatch of the 2nd generation of codling moth as well. On compiling the complete data of the 2-year study (figure 3), we observed no difference using the physiological time scale of Bugoff 2. The minor deviations shown in figure 3 are due to different methods used to determine egg hatch (see 2.1.1.). Up to now the data reported in figure 3 also could be confirmed by the results obtained in Dossenheim in current years. In our climatic conditions the interval of highest activity (from 10 to 90%) for egg hatch of the 2nd generation of *Cp* is established between 1062 and 1323 HU (figure 3). A final review of this adaptation of Bugoff 2 and its possible application in temperate regions will follow after conclusion of further studies carried out in warmer (Italy), colder (Norway) and similar (other regions in W-Germany) climatic conditions than those in Dossenheim.

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Table 1 - Degree-days (DD, °C) used to determine oviposition and hatch time of codling moth egg. Description of stages by Richardson et al. (1982).

Stages	DD as of oviposition	DD towards egg hatch	Stages	DD as of oviposition	DD towards egg hatch
I	0.3	85.2	VII	28	57.5
II	1.7	83.8	VIII	37.3	48.2
III	4	81.5	IX	48.3	37.2
IV	8	77.5	X	57.3	28.2
V	16	69.5	XI	66.7	18.8
VI	20	65.5	XII	78.7	6.8

Table 2 - Examples of corrected numbers of codling moth eggs sampled by 50 fruit clusters from an unmanaged orchard. (A and B = corrected number of eggs for oviposition and hatch, respectively; horizontal lines: day of sampling; * number of sampled eggs)

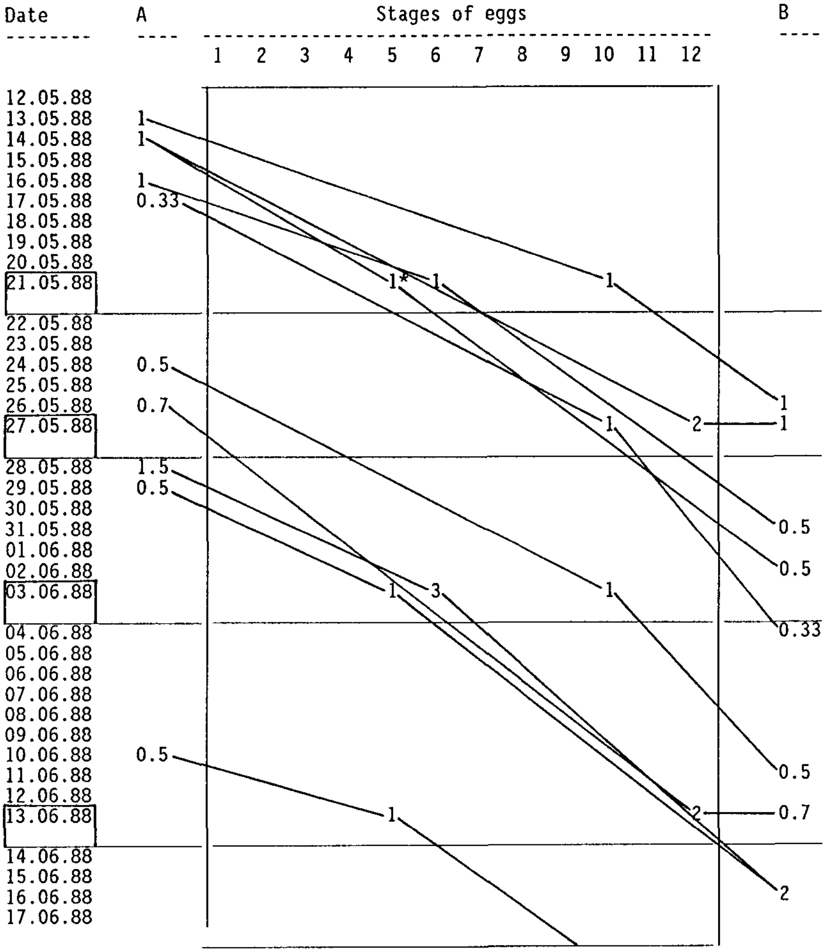

Table 3 - Heat unit algorithm used in BUGOFF 2 to forecast egg hatch of Cydia pomonella. Temperature values in Fahrenheit. (Falcon et al., 1983)

MAX TEMP	MINIMUM TEMPERATURES 30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72
102	18	18	18	18	19	20	20	20	21	22	22	23	24	25	26	27	28	29	30	31	32	32
100	17	18	18	18	19	19	20	20	21	21	22	23	24	25	25	26	27	28	29	30	31	32
98	17	17	17	18	18	19	19	19	20	21	21	22	23	24	25	26	27	28	29	30	31	32
96	16	16	17	17	18	18	18	19	19	20	21	21	22	23	24	25	26	27	28	29	30	31
94	16	16	16	17	17	17	18	18	19	19	20	21	22	23	24	25	26	27	28	29	30	31
92	15	15	15	16	16	17	17	17	18	19	19	20	21	22	23	24	25	26	27	28	29	30
90	14	14	14	15	15	16	16	16	17	18	18	19	20	21	22	23	24	25	26	27	28	29
88	13	13	14	14	14	15	15	15	16	17	17	18	19	20	21	22	23	24	25	26	27	28
86	12	12	13	13	13	14	14	15	15	16	16	17	18	19	20	21	22	23	24	25	26	27
84	11	11	12	12	12	13	13	14	14	15	15	16	17	18	19	20	21	22	23	24	25	26
82	10	11	11	11	11	12	12	13	13	14	14	15	16	17	18	19	20	21	22	23	24	25
80	10	10	10	10	11	11	11	12	12	13	13	14	15	16	17	18	19	20	21	22	23	24
78	9	9	9	9	10	10	10	11	11	12	12	13	14	15	16	17	18	19	20	21	22	23
76	8	8	8	8	9	9	9	10	10	11	11	12	13	14	15	16	17	18	19	20	21	22
74	7	7	7	8	8	8	8	9	9	10	10	11	12	13	14	15	16	17	18	19	20	21
72	6	6	7	7	7	7	8	8	8	9	9	10	11	12	13	14	15	16	17	18	19	20
70	5	6	6	6	6	6	7	7	7	8	8	9	10	11	12	13	14	15	16	17	18	
68	5	5	5	5	5	6	6	6	6	7	7	8	9	10	11	12	13	14	15	16		
66	4	4	4	4	4	5	5	5	5	6	6	7	8	9	10	11	12	13	14			
64	3	3	3	4	4	4	4	4	5	5	5	6	7	8	9	10	11	12				
62	2	3	3	3	3	3	3	3	4	4	4	5	6	7	8	9	10					
60	2	2	2	2	2	2	2	3	3	3	3	4	5	6	7	8						
58	1	1	1	1	1	2	2	2	2	2	2	3	4	5	6							
56	1	1	1	1	1	1	1	1	1	1	2	2	3	4								
54	0	0	0	0	0	0	0	0	0	1	1	1	2									
52	0	0	0	0	0	0	0	0	0	0	0	0										

Table 4 - Physical and physiological time differences between predictions of BUGOFF 2 model and field observations of codling moth egg hatch in Dossenheim-Heidelberg, W-Germany.

	1985 Day differences		Heat unit differences	
% egg hatch	1st brood hatch	2nd brood hatch	1st brood hatch	2nd brood hatch
10	+ 2	- 14	+ 4	- 220
20	+ 1	- 13	+ 3	- 243
40	+ 1	- 14	+ 9	- 201
60	- 1	- 16	- 9	- 227
80	+ 2	- 23	+ 37	- 245
90	+ 2	- 26	+ 19	- 254
mean values	+ 1.16	- 17.66	+ 10.5	- 231
1988				
10	- 5	- 10	- 28	- 164
20	- 4	- 12	- 27	- 157
40	0	- 17	- 10	- 204
60	+ 3	- 19	+ 26	- 178
80	+ 6	- 27	+ 91	- 204
90	+ 9	- 36	+ 136	- 222
mean values	+ 1.5	- 20	+ 31	- 188.1

Table 5 - Differences between weather shelter and apple temperatures in the warmest time of the year in Dossenheim-Heidelberg, W-Germany.

Date	Air temperature			Apple temperature (north)			Apple temperature (south)		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
02.08.88	13.9	27.8	21.2	15.6	35.6	23.8	15.6	37.4	23.0
03.08.88	14.1	23.8	19.0	15.0	30.2	21.1	15.1	31.3	20.6
04.08.88	7.5	18.9	13.9	8.1	21.4	14.7	7.9	26.5	15.2
05.08.88	11.6	22.0	16.6	11.1	32.6	19.5	10.6	33.8	19.0
06.08.88	10.8	23.4	17.0	10.1	26.5	18.3	-	-	-
07.08.88	13.5	27.0	20.5	13.3	33.7	22.8	-	-	-
08.08.88	15.7	29.3	22.2	15.3	37.9	24.8	-	-	-
09.08.88	14.7	29.2	21.8	14.4	34.6	24.2	-	-	-
10.08.88	15.5	28.0	21.8	15.1	32.9	24.0	-	-	-
11.08.88	18.5	29.6	23.8	17.7	33.2	25.5	17.5	41.8	25.6
12.08.88	14.4	26.6	20.1	14.1	32.1	22.0	13.9	36.5	22.3
13.08.88	17.2	26.9	22.0	16.8	32.2	24.0	16.6	37.9	23.7
14.08.88	12.1	25.5	19.2	11.4	32.0	21.4	11.0	35.2	21.5
15.08.88	15.4	29.8	23.5	15.1	34.7	26.3	15.2	42.2	26.2
16.08.88	14.2	30.2	22.3	13.6	35.3	24.1	13.4	40.7	24.9
17.08.88	11.8	24.4	18.0	10.7	28.6	19.4	10.2	36.1	20.1
18.08.88	9.5	25.6	17.2	8.8	30.4	19.4	8.4	41.3	20.3

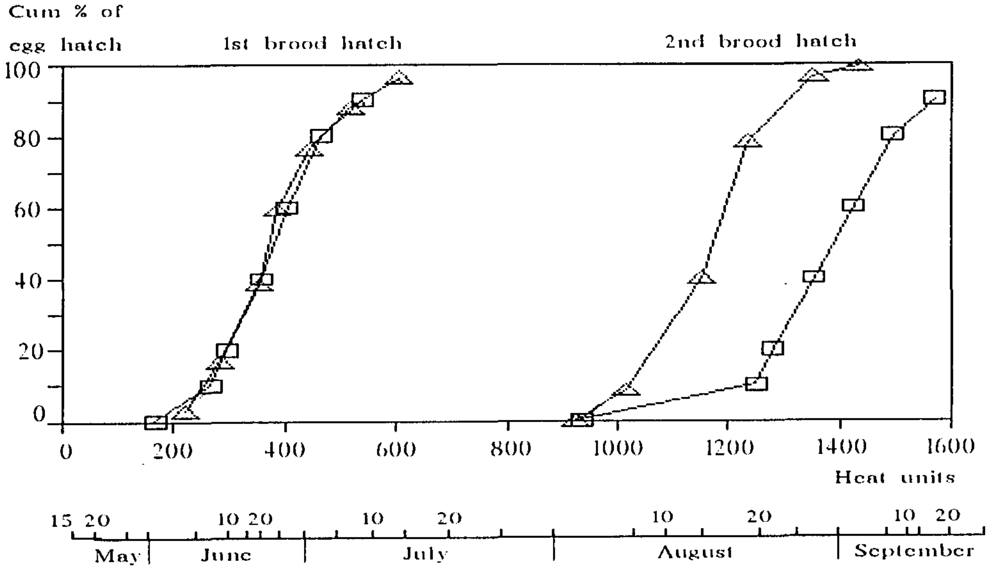

Fig 1 - Bugoff 2 prediction (▭) and field observation (△) of codling moth egg hatch in Dossenheim (W-Germany), 1985.

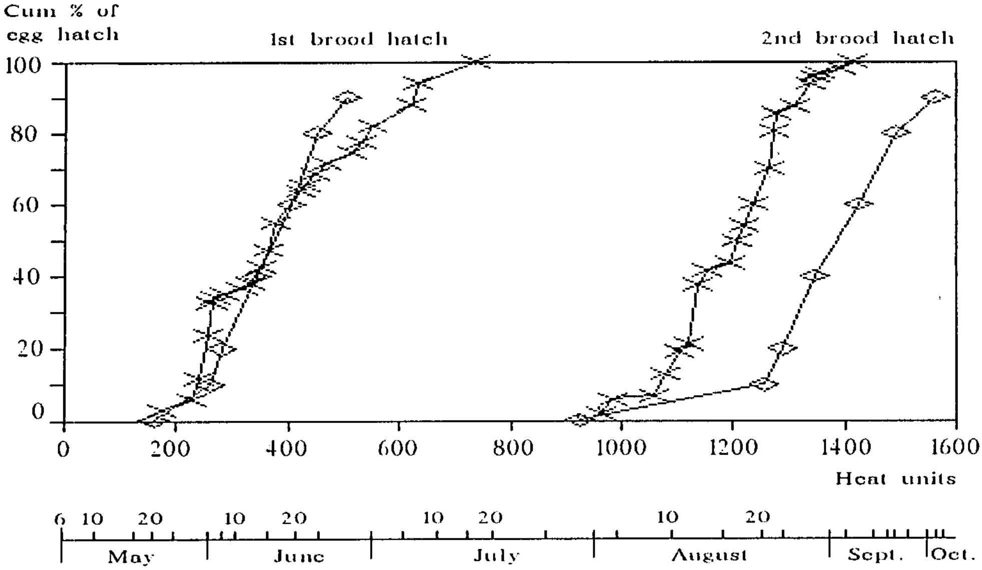

Fig. 2 - Bugoff 2 prediction (<>) and field observation (><) of codling moth egg hatch in Dossenheim (W-Germany), 1988.

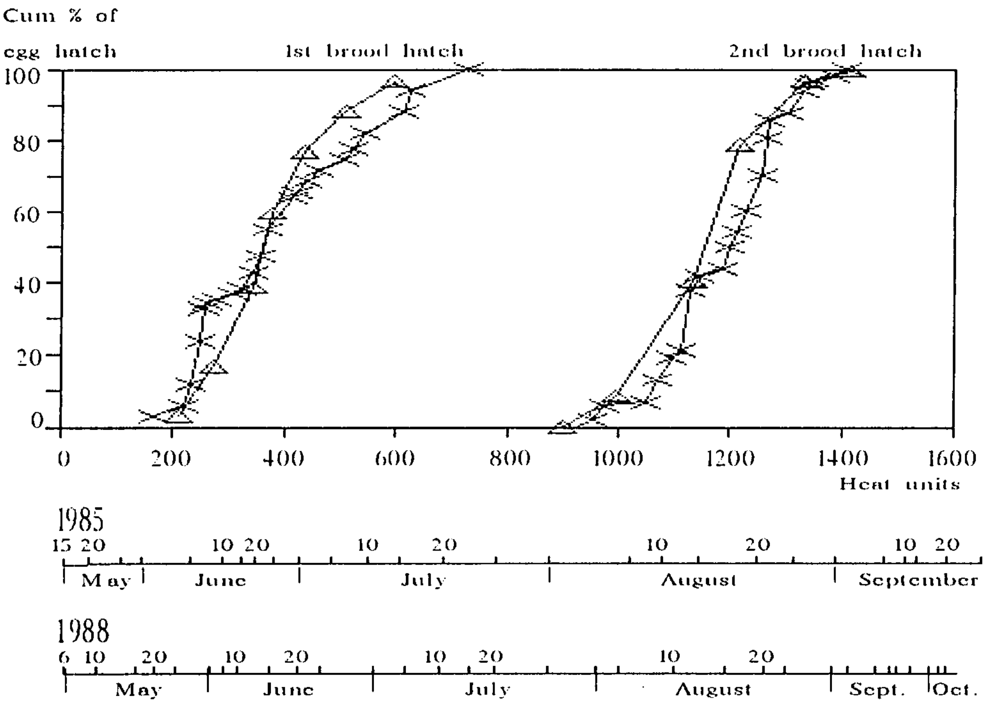

Fig. 3 - Field observations of codling moth egg hatch in 1985 (△) and 1988 (><) on the heat units scale of Bugoff 2.