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TEMPERATURE-DEPENDENT DEVELOPMENT AND DEGREE-DAY MODEL OF EUROPEAN LEAF ROLLER, *ARCHIPS ROSANUS*

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Abstract: The effect of temperature on the duration of larval, prepupal, and pupal development of the European leaf roller, *Archips rosanus* L. (*Lepidoptera*: *Tortricidae*) was studied at four constant temperatures (18, 22, 26, and 30°C) where *Malus communis* L. (apple, Stark Crimson) was used as food. Significant positive linear relationships were observed between development rate and temperature for all life stages. Minimum developmental threshold temperatures were estimated as 5.5–6.7°C for first stages, 5.8–5.7°C for second stages, 5.1–6.3°C for prepupae, and 8.1–6.3°C for pupae, male and female, respectively. Lower threshold of complete development of adult was estimated as 6.05°C (male) and 6.0°C (female). Median development values of degree-days (DD) for first stages, second stages, prepupae, pupae and complete preimaginal development were 57.5–55.2, 55.2–66.2, 33.1–33.9, 137–175.4 and 476.2–526 for male and female, respectively. A degree-day model was developed using from the laboratory data for predicting the first emergence of the pest and spray application time. Estimated degree-day model predicted the emergence within 3–7 days of that observed at the field site in both 2001 and 2002. Accordingly, the degree-day model will be useful to predict the first emergence dates, optimum spray period and to provide a starting point to catches in pheromone traps in the summer for *A. rosanus*.

Key words: Leaf rollers, *Archips rosanus*, degree-day, apple, Turkey

INTRODUCTION

Turkey is one of the most important apple producer countries of Europe and the Middle East, with a 2.5 million tones annual yield. (DIE 2001). Pests of apple are mainly lepidopterean species, particularly codling moth *Cydia pomonella* (L.) (*Lepidoptera*: *Tortricidae*), and European leaf roller *Archips rosanus* (L.) (*Lepidoptera*: *Tortricidae*).

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In addition there are two species of mites, *Tetranychus urticae* Koch. and *Panonychus ulmi* Koch. (*Acarina*: *Tetranychidae*) and other lepidopteran species e.g. *Yponomeuta malinellus* Zell. (*Lepidoptera*: *Yponomeutidae*), *Aporia crataegi* (L.) (*Lepidoptera*: *Pieridae*), inhabiting the apple orchards (Yıldırım 1957; Özbek *et al.* 1995).

The European leaf roller, *A. rosanus*, first recorded in Turkey in 1901 (Staudinger and Rebel 1901), is a native species to the Palearctic region but it is distributed all over the world except the far east and Siberia. It feeds on many hosts, including fruit trees, forest trees with wide leaf as *Quercus, Arbutus*, *Tamarix* e.g. and some weeds (Bradley *et al.* 1973; AliNiazee 1977; Ulu 1983; Doganlar 1987). *A. rosanus* is a primary or sometimes secondary pest on apple orchards depending on the year and the location (Mayer and Beirne 1974; AliNiazee 1977). The European leaf roller is univoltine, in Cakit Valley its life cycle starts with the larvae hatching from overwintering eggs in late February (Doganlar 2003). The young larvae move to opening buds and feed on both sides of new leaves. Sometimes they web, enveloping buds and young foliage to form feeding nests. The larval period is about 6–8 weeks. Pupation takes place within the rolled and webbed leaves. (Baggiolini 1956; Kapidani and Duraj 1991; Grichanov *et al.* 1994; Moreas and Netti 1996). In Southern Turkey pupation occurs at the end of May and early June. Adult emergence begins in the second week of June, and usually continues through mid- August. Adults live for 2–4 weeks. Egg laying takes place mainly in June and July with an average of 71.66 ±17.10 eggs per female (Doganlar 2003); the egg masses usually are found on tree trunks and major branches. The pest feeds on a large variety of shrubs and trees (Markelova 1957; AliNiazee 1983; Ulu 1983; Doganlar 2003).

If necessary, *A. rosanus* population levels can be reduced by spraying trees when first and second instar larvae are present. Mating disruption and mass trapping techniques during flight period of moths may also help reduce population levels.

The importance of the seasonal prediction of the occurrence of insects for developing control strategies has led to multiple formulations of mathematical models that describe the developmental rate in relation to temperature. For degree-days models to be relevant for pest management, a comparison of heat units required in the laboratory and the estimates in the field are necessary. Under field conditions, the generation time can vary with microclimatic factors, population genetics and host quality (Pitcairn *et al.* 1992). Knowledge of the variation in generation time of field populations is consequently essential for the development of a phenological model (Pitcairn *et al.* 1992). To develop a useful degree-days model, it is also necessary to predict the occurrence of the first emergence and timing of the maximum flight period of *A. rosanus* moths in the orchards.

The aims of this research were to develop a degree-day model concerning different biological stages and to determine the lower threshold temperatures, required degree-days and development times of *A. rosanus*. This data will be used for predicting optimum time in the control strategy of the pest.

MATERIALS AND METHODS

Experiments were performed using a colony initiated from the eggs collected from Horticulture Research Center (POZMER) of Çukurova University in Alpu district (Cakit Valley, Adana).

All experiments were conducted in climatic chambers with 60 ±10% RH, the experimental temperatures 18, 22, 26 and 30 ±1ºC using a photoperiod of 16:8 (L:D) h. The eggs were collected with a piece of bark from apple trees and the egg masses then were removed. Each egg mass was divided into several parts so that each experimental treatment contained eggs from each mass. Each group of eggs was placed in a 62.8 ml small polyethylene dish with moist cotton. Egg development was observed daily and the date of hatching recorded. Emerged larvae were individually placed into 157 ml vials that contained a small piece of apple leaf (Stark Crimson variety). They were then placed in the experimental chambers and fed ad libitum. The populations were observed daily until pupation. The development time of all preimaginal stages in all experimental conditions were recorded separately. The pupae were placed in "Sigma 12 well plate" with a piece of moistened cotton. The day of adult emergence and sex were recorded.

Difference in development time of *A. rosanus* biological stages of two sexes (fed on Stark Crimson) in different temperatures were compared using Uni-ANOVA, the means were separated by Duncan's test using SPSS 10.0 software at the significance level $p \leq 0.05$.

Regression Model

For each developmental stage the mean development time and mean rate at each temperature were calculated. The relationship between the temperature (T) and the mean developmental rate ($r = 1/d$) was determined using linear models. The relationship between T and r was determined using linear regression where

$$r = \mathrm{a} + \mathrm{bT}$$

The lower developmental threshold (t_b) and the degree-day requirements were estimated as

$$t_b = -a / b$$

and degree-days (DD)

$$DD = 1 / b$$

Calculations were made using the SPSS 10.0 (SPSS Institute, 2000) and Excel (Microsoft Corporation).

RESULTS

Development times decreased with increasing temperature (Table 1); lower temperatures slowed the development of European leaf roller. For instance, complete development for larvae-adult of *A. rosanus* took 39.93 ±0.58 days at 18°C and 19.71 ±0.30 at 30°C for males. The same period for females of *A. rosanus* was calculated to be 44.93 ±0.58 at 18°C and 21.92 ±0.38 at 30°C. This trend was observed matched through all stages of development. The maximum development rate for both sexes appeared to be 30°C for all stages.

Table 1. Mean number of days ± SE to complete larval, prepupal, pupal and 1st instars to adult development and No. of (n) in each stage for *A. rosanus* at four constant temperatures

Biological Stages	Development Time (Days ± SE)							
	Male				Female			
	18°C	22°C	26°C	30°C	18°C	22°C	26°C	30°C
1st instars	4.30 ± 0.19	3.83 ± 0.19	2.72 ± 0.13	2.33 ± 0.11	4.65 ± 0.10	4.08 ± 0.20	2.86 ± 0.16	2.40 ± 0.14
	(20)	(24)	(22)	(24)	(20)	(24)	(22)	(25)
2nd instars	4.30 ± 0.20	3.40 ± 0.12	3.00 ± 0.16	2.17 ± 0.12	5.20 ± 0.35	4.33 ± 0.20	3.10 ± 0.19	2.75 ± 0.13
	(20)	(22)	(22)	(23)	(20)	(24)	(20)	(24)
3rd instars	4.82 ± 0.32	3.57 ± 0.17	2.75 ± 0.17	2.40 ± 0.11	5.05 ± 0.29	4.05 ± 0.21	3.05 ± 0.15	2.53 ± 0.16
	(17)	(21)	(20)	(20)	(18)	(20)	(20)	(18)
4th instars	4.87 ± 0.11	3.68 ± 0.11	2.82 ± 0.21	2.45 ± 0.17	5.67 ± 0.14	4.38 ± 0.13	3.74 ± 0.21	2.87 ± 0.21
	(17)	(18)	(17)	(17)	(17)	(18)	(18)	(17)
5th instars	6.12 ± 0.21	4.98 ± 0.11	4.22 ± 0.11	3.12 ± 0.13	7.15 ± 0.17	4.55 ± 0.16	4.88 ± 0.20	3.68 ± 0.19
	(17)	(18)	(17)	(17)	(16)	(18)	(17)	(16)
prepupa	2.33 ± 0.19	2.12 ± 0.09	1.70 ± 0.11	1.26 ± 0.11	2.40 ± 0.21	2.16 ± 0.11	1.88 ± 0.08	1.27 ± 0.20
	(15)	(18)	(17)	(15)	(15)	(18)	(17)	(14)
pupa	13.26 ± 0.33	9.58 ± 0.27	8.35 ± 0.19	5.95 ± 0.29	15.66 ± 0.31	10.38 ± 0.32	9.23 ± 0.30	7.35 ± 0.24
	(15)	(17)	(14)	(14)	(15)	(18)	(13)	(14)
1st instars to adult	39.93 ± 0.58	29.11 ± 0.45	24.00 ± 0.37	19.71 ± 0.30	44.93 ± 0.58	31.50 ± 0.47	26.30 ± 0.53	21.92 ± 0.38

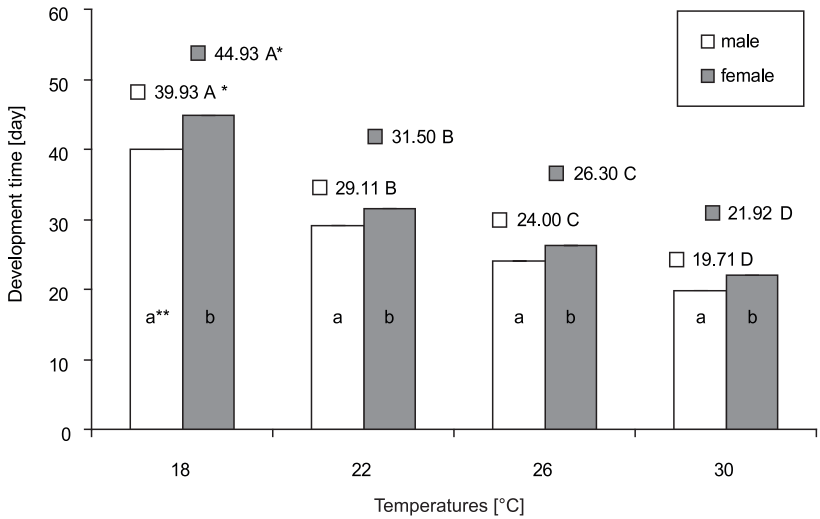

Fig. 1. Mean number of days to complete preimaginal development of *A. rosanus*
* Means followed by a different letter differ significantly at $p \leq 0.05$ (Duncan's test).
** Means followed by a different letter differ significantly (Student t-test, $p \leq 0.05$)

Table 2. Parameter estimates from regression of development rate (1/day) on temperature (°C), estimated lower thresholds of development temperature (T_0), and cumulative degree-days (DD) required for development of male and female of *Archips rosanus**

Sex	Stages	Y-Intercept	Slope	R^2	T_0 [°C]	DD [°C-day]
Male	larva					
	1st instars	–0.0952	0.0174	0.95	5.5	57.5
	2nd instars	–0.1042	0.0181	0.93	5.8	55.2
	3rd instars	–0.1097	0.0178	0.99	6.2	56.2
	4th instars	–0.1048	0.0173	0.99	6.1	57.8
	5th instars	–0.0743	0.0127	0.95	5.8	78.7
	prepupa	–0.1553	0.0302	0.91	5.1	33.1
	pupa	–0.0591	0.0073	0.95	8.1	137.0
	larva-adult	–0.0127	0.0021	0.99	6.05	476.2
Female	larva					
	1st instars	–0.1190	0.0177	0.96	6.7	56.5
	2nd instars	–0.0860	0.0151	0.97	5.7	66.2
	3rd instars	–0.1116	0.0168	0.99	6.6	59.5
	4th instars	–0.0780	0.0139	0.97	5.6	71.9
	5th instars	–0.0652	0.0111	0.95	5.9	90.1
	prepupa	–0.1590	0.0295	0.85	5.4	33.9
	pupa	–0.0360	0.0057	0.97	6.3	175.4
	larva-adult	–0.0114	0.0019	0.99	6.00	526.3

*regression ($p < 0.05$) are based on mean rates over four temperatures (18–30°C)

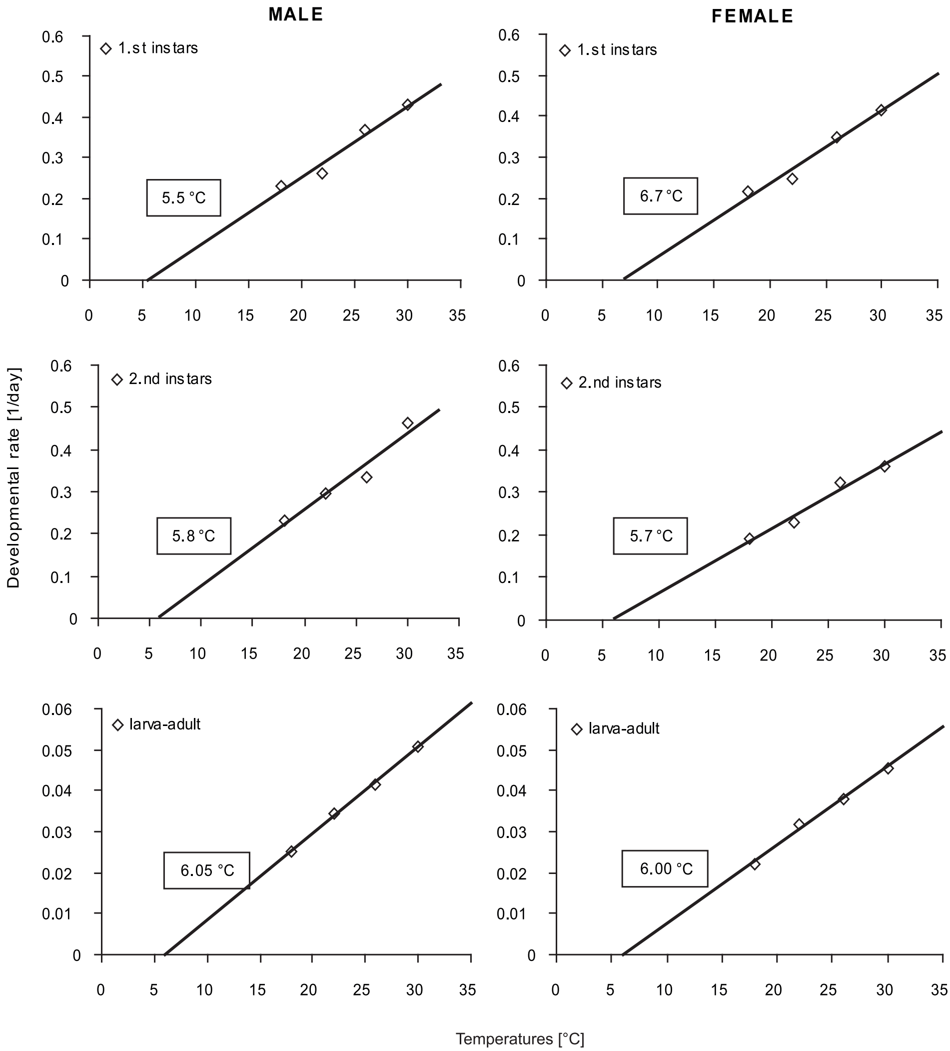

Fig. 2. Developmental rate [1/day] of *Archips rosanus* as a function of temperature [°C] and threshold temperatures

For each temperature, complete preimaginal development (larva to adult) was longer for female of *A. rosanus* than male (Student t-test, $p \leq 0.05$). There were significant differences in development time of both sexes among four temperatures. (Male: $F = 362.3$; df = 3.55; $p < 0.0001$; Female: $F = 383.69$; df = 3.56; $p < 0.0001$) (Fig. 1).

In the range of temperatures used, the lower temperature threshold (T_0) and degree-days (DD) required for the development of ELR were adequately determined by the linear model, as shown by a high coefficient of determination obtained for all the developmental stages except prepupa (Male:$R^2 > 0.91$; Female:$R^2 > 0.95$) (Table 2). Development rate (1/day) from larvae to adult were linear with the temperature (Fig. 2), and similar trends were observed for all larval, prepupal and pupal stages in both sexes (Table 2). Based on a regression of development rate and all temperatures between 18 and 30°C (the linear portion), *A. rosanus* has a minimum temperature threshold for male between 5.1 and 8.1°C and for female 5.4 and 6.7°C, depending on life stage (Table 2). The lower thresholds in both sexes were for prepupal stages, while the upper values were for the pupal stage of male and first instars larva of female. Lower threshold of complete development to adult was 6.05°C (male) and 6.00°C (female). Using the inverse of the slopes of the regression lines it was calculated that male sex of *A. rosanus* requires 305.4, 33.1, 137 and 476.2 degree-days for larval, pre-pupal, pupal and complete development, respectively; the same calculations have shown that female sex of *A. rosanus* needs 344.3, 33.9, 175.4, 526.3 degree-days for larval, prepupal, pupal and complete development, respectively (Table 2).

DISCUSSION

Temperature is one of the major factors influencing the developmental rate of insects, and there are several models to describe this relationship (Campbell *et al.* 1974; Logan *et al.* 1976; Schoolfield *et al.* 1981; Briere *et al.* 1999). The linear degree day model was used in this study, as it allowed a direct estimation of the DD required and the developmental threshold for the leaf roller species. This study documented the effect of temperature on instars-specific duration, complete preimaginal development time (first instars-adult) and survivorship of *A.rosanus.* This is important to provide the understanding of the pest biology to be used to control it in the field. As expected, duration of larval, pupal, and total life cycle durations all decreased with the increase in temperature (18–30°C) (Table 1). The optimal temperature range for *A. rosanus* instar-spesific duration (Table 1) and complete preimaginal development was observed between 22 and 26°C. Although survivorship was higher at 22°C than at any other temperature, total development times were the shortest at 30°C. The total preimaginal development times observed at 26°C during this study are similar to development times of 17–27 days for *A. rosanus* on filbert leaves, reported by AliNiazee (1977). However, the larval development times of 25 days reported at 20°C for *A. rosanus* (Balachowsky 1966) were comparatively longer than the results obtained from this study. In the aforementioned study, the host plants and climatic conditions were not clearly indicated. This may be attributed to the effect of different hosts and experimental procedure. The larval development times found at 18 and 22°C in this study are similar to development times of *A. rosanus* larvae on cherry leaves, stated by Ulu (1983).

Markelova (1957) and AliNiazee (1977) reported a developmental threshold of temperature to be 8°C for *A. rosanus.* Based on the current data, the developmental threshold determined from the regressions of first instars of *A. rosanus* was 5.5 and 6.7°C, for male and female, respectively. Minimum thresholds for full development from first instars to adults were 6.05 and 6.00°C (Table 2) for male and female, respectively. These differences may be the result of variations in environmental conditions other than temperature, such as species of food plants or the photoperiod and dissimilarity in experimental methods between this study and the previous ones.

It was found that the developmental thresholds were not similar between life stages of *A. rosanus.* Depending on the life stages developmental thresholds for male ranged between 5.1 and 8.1°C and for female between 5.4 and 6.7°C (Table 2). Differences in developmental thresholds between life stages are not uncommon (Hanula *et al*. 1987). Nordin and O'Canna (1985) reported a temperature threshold of 14°C for eggs of the red headed type of fall webworm, *Hyphantria cunea* (Drury), but the developmental threshold of larvae and pupae varied between 11 and 12°C. The similar result was reported by Butler and Wardecker (1971) for *Lygus hesperus* Knight showed that the different lower threshold temperatures occur among the egg and different nymphal stages.

When necessary, *A. rosanus* population levels might be reduced by spraying trees when first and second instars larvae are present. Since 3rd–5th larval stages roll the leaves and feed inside, insecticides can not reach to them (AliNiazee 1983; Kapidani and Duraj 1991; Doganlar 2003). Thus, determining the first and second larval stages is very important for a successful control of the pest.

In the current study, in Cakit Valley (Pozmer, Adana) from where the egg masses were collected to initiate the laboratory population, first instar larvae were observed on 29 March in both years. On that date for 2001 and 2002 mean temperatures were 6.3 and 6.2 and cumulative degree-day from 1st January were 32 and 40 DD respectively (Doganlar 2003). After 8 days from emergence of first instars, the second instar larvae of *A. rosanus* were observed in 2001 and this period took 11 days in 2002. Required degree-day for completing the development of 1st instars were 65 DD and 71 DD for 2001 and 2002, respectively. It took 135 DD and 151 DD for respective years for second instar larvae to complete the development (Doganlar 2003). In the current study, development thresholds for first instars were 5.5 and 6.7 and calculated degree-days for complete development were 57.5 and 56.5 DD for males and females, respectively. According to results of this study, the best control period of *A. rosanus* were calculated as 112.7 DD in case of males and 122.7 DD in case of females. The model developed can predict the control period with the accuracy of ± 0.5°C and ±23–29 DD. Estimated development threshold could be used in conditions of Cakit Valley (Pozmer, Adana), but there is a 3–5 day difference between the estimated DD and the real DD. Considering the control period takes 12–17 days for the pest in this region, the difference between the estimated DD and the real DD can be considered as acceptable.

In Cakit Valley (Pozmer, Adana) the first adult emergence dates were determined as 18th May in 2001, and 9th June in 2002 and cumulative effective temperatures were 512 and 560 DD in respective years (Doganlar 2003). Similarly, complete development duration in laboratory conditions was 476.2 and 526.3 DD for male and female, respectively. This case might be explained by the differences between the conditions of field and laboratory. However, the model calculate approximately the first emergence of adults with a 4–7 day difference, thus it could be used to predict the complete development duration of *A. rosanus*.

Accordingly, the degree-day model will be useful in further efforts to predict first emergence dates of *A. rosanus*, optimum spray periods and to provide a starting point for catches with pheromone traps in the summer.

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POLISH SUMMARY

UZALEŻNIONY OD TEMPERATURY I STOPNIODNI MODEL ROZWOJU ZWÓJKI RÓŻÓWECZKI

W artykule przedstawiono wyniki badania wpływu temperatur oraz stopniodni na czas trwania rozwoju poszczególnych etapów stadium larwalnego oraz stadium bezpośrednio poprzedzającego przepoczwarczenie i stadium poczwarki zwójki różóweczki *Archip. Rosanus* L. (*Lepidoptera, Tortricidae*). Badania były wykonywane w 4 stałych temperaturach (18, 22, 26 i 30°C), a larwy żywiono liśćmi jabłoni (*Malus communis* L.) odmiany Stark Crimson. Zaobserwowano istotną, dodatnią zależność pomiędzy tempem rozwoju wszystkich stadiów rozwojowych szkodnika a temperaturą. Minimalne progi temperatury dla ich rozwoju wynosiły: 5,5–6,7°C dla pierwszych stadiów, 5,8–5,7°C dla następnych stadiów, 5,1–6,3°C dla stadium poprzedzającego przepoczwarczenie, 8,1–6,3°C dla stadium poczwarki, odpowiednio dla osobników męskich i żeńskich.

Dolny próg dla pełnego rozwoju osobników dorosłych wynosił 6,05°C (osobniki męskie) i 6,0°C (osobniki żeńskie). Średnie wartości stopniodni dla pierwszych i następnych stadiów oraz stadium poczwarki i stadium poprzedzającego przepoczwarczenie, stadium poczwarki i stadium bezpośrednio poprzedzającego wykształcenie się owada dorosłego wynosiły: 57,5–55,2; 55,2–66,2; 33,1–33,9; 137–175,4 i 476,2–526, odpowiednio dla osobników męskich oraz żeńskich. Model stopniodni mający na celu ustalenie pierwszego pojawu szkodnika i zastosowania opryskiwania opracowano wykorzystując dane uzyskane w laboratorium. Przy jego pomocy można było przewidzieć pojaw szkodnika z dokładnością do 3–7 dni w stosunku do pojawu obserwowanego w warunkach naturalnych w latach 2001 i 2002. Model ten będzie więc użyteczny do prognozowania terminów pierwszego pojawu szkodnika, optymalnego okresu wykonania oprysku a także wskaże on termin rozpoczęcia zakładania pułapek feromonowych na *A. rosanus*.