A thermal unit summation model for the phenology of *Rhagoletis completa* (Diptera: Tephritidae)

ABDULMAJID KASANA and M.T. ALINIAZEE

DEPARTMENT OF ENTOMOLOGY, OREGON STATE UNIVERSITY, CORVALLIS, OR 97331

ABSTRACT

Predictions of various biological events in the life cycle of the walnut husk fly, *R. completa* Cresson in the Willamette Valley of Oregon were made using a thermal unit summation model. The model was based on data from a 3-year field study and was tested in 1993. The model was found to be more accurate than calendar dates at predicting several aspects of its phenology including adult emergence, female sexual maturity, and oviposition.

Key words: Insecta, Diptera, Tephritidae, walnut husk fly, *Rhagoletis completa*, thermal unit summation model, IPM, Oregon

INTRODUCTION

Temperature-based models predicting pest phenology have become the basis of many agricultural pest management programs (e.g., AliNiazee 1976, 1979, Higley *et al.* 1986, Jones *et al.* 1989, 1991). These models have been widely used in many applications. For example, crop damage forecasting, studies of climatic limits to species distribution, population dynamics, the timing of insecticide applications and predicting pest development at different localities (AliNiazee 1976, Baker and Miller 1978).

The efficacy of chemical control of insects can be greatly influenced by the timing of spray applications. If timing is good, the control is optimized. Seasonal growth and development of insects in a geographical region can vary as much as 2 to 3 weeks from year to year, depending on climatic conditions, particularly temperature. With the walnut husk fly (WHF), *Rhagoletis completa* Cresson, variation in emergence could complicate pest control decisions, therefore, a temperature-based model of its phenology would be a useful tool in developing and implementing an IPM program for this insect.

Few data are available on the phenology of WHF (Kasana and AliNiazee 1996). The aim of the present study was to formulate and test a thermal unit summation model to predict phenological events of this key pest of walnuts in North America.

MATERIALS AND METHODS

The study consisted of 2 parts: developing a thermal unit summation model, and subsequently testing it. The model was based on data gathered during 1990-92, using Pherocon AM aerial traps (Trece Inc., Salinas, California). Traps (4 in 1990 and 8 in 1991 & 1992) were placed 2 m above ground level in trees that were heavily infested in the previous season, and the numbers of trapped flies were recorded three times per week (Kasana and AliNiazee 1995). Captured flies were also sexed and placed in small plastic vials with alcohol and brought to the laboratory for dissection to determine sexual maturity of the females.

The data on oviposition, egg hatch, larval development and pupal formation were derived from field observation over three years. One week after the first female was trapped, we sampled for the occurrence of oviposition. One-hundred nuts were collected randomly from all sides of trees and brought to the laboratory to check for infestation. Ten nuts, randomly selected, were dissected to determine egg hatch and larval development (Kasana and AliNiazee 1996).

Daily minimum and maximum temperatures were obtained from a weather station (OSU, Hyslop Farm) approximately 6 km from the study sites and at approximately the same elevation. Both air (107 cm above ground) and 5.08 cm soil temperatures were used.

The thermal units (day-degrees) were calculated using the method described by Baskerville and Emin (1969) employing a sine curve approximation from maximum and minimum temperature, with a lower threshold of 5°C. No upper threshold was used because the daily maximum temperature rarely exceeded the upper developmental threshold of 34°C as determined in an earlier study (Kasana and AliNiazee 1994). The lower developmental threshold of 5°C was also used in earlier models (AliNiazee 1976, 1979) for *R. indifferens* and for *R. cerasi* (Boller 1966). Additionally, a detailed laboratory study of WHF (Kasana and AliNiazee 1994) established a lower developmental threshold of 5°C using the X-intercept method.

The model calculations of thermal units (TUs) were initiated on March 1. This date was chosen as it provided the least amount of variation (assessed by coefficient of variation) and has been used by earlier researchers for temperate-climate fruit flies (e.g., AliNiazee 1976, Reissig *et al.* 1979, Jones *et al.* 1989, 1991).

RESULTS AND DISCUSSION

The TU requirements for emergence of different population levels based on aerial trap catches are given in Table 1. A thermal unit summation model was developed based on three year (1990-92) fly catch data in aerial traps (Table 1). The model, using air temperatures, predicts the emergence of WHF at accumulations of 1050, 1517, 1751, 1895 and 2198 TUs for first, 10%, 50%, 90% and 100% fly emergence levels, respectively. Different TU values were derived for soil temperatures. A comparison of reliability of calendar dates vs. model predictions as predictors of fly emergence at various percent population levels is also given in Table 1. Considering the variation in the fly catch dates, the data suggest that using TUs was a much more reliable method than using calendar dates to predict emergence, especially for 10% and 50% adult levels, while TUs were only slightly better than calendar dates in predicting the first emergence. Predictions using temperature above and below ground were almost equal compared with aerial traps, therefore, we recommend using a model based on air temperature data.

The TU requirements for various other biological events in the life cycle of WHF are given in Table 2. The TU summation method was more accurate than calendar dates for forecasting almost all biological events, especially for female sexual maturity and first oviposition. The first oviposition is a critical event for the IPM decision-making process because the first insecticide sprays should be applied at or before this event.

Although this study considered both air and ground temperatures, the use of soil temperature might be difficult. Very few farmers are likely to have access to soil temperatures needed for prediction. We therefore, suggest using aerial trap data and air temperature for practical applications.

As expected, different TU accumulations occurred at different dates in different study years. An analysis of the weather pattern suggests that the winter and spring of 1990 were normal, but they were colder in 1991 and warmer in 1992. This might explain the

Table 1.

Thermal unit (TU) requirements and comparison of estimates (Calendar vs. TU) of emergence of *R. completa* at various population emergence levels in the Willamette Valley, OR.

	First				10%				50%				90%				100%			
			DFMID				DFMID				DFMID				DFMID				DFMID	
Year	Date	TU	CD	TU	Date	TU	CD	TU	Date	TU	CD	TU	Date	TU	CD	TU	Date	TU	CD	TU
Pherocon AM trap																				
Air temperature																				
1990	7/11	1066	2	1	8/10	1573	2	3	8/27	1807	3	4	9/05	1929	2	2	10/1	2262	6	10
1991	7/17	941	8	9	8/19	1450	11	4	9/04	1669	11	4	9/11	1762	8	11	10/9	2124	14	7
1992	7/01	1142	8	8	7/27	1527	12	0	8/12	1777	12	1	8/26	1994	8	6	9/11	2209	14	0
Soil temperature																				
1990	7/11	1583	2	0	8/10	2303	2	2	8/27	2636	3	3	9/05	2800	2	1	10/1	3240	6	6
1991	7/17	1458	8	7	8/19	2203	11	2	9/04	2500	11	4	9/11	2631	8	8	10/9	3108	14	5
1992	7/01	1693	8	6	7/27	2234	12	1	8/12	2590	12	1	8/26	2895	8	6	9/11	3191	14	1

Thermal units above 5° were accumulated from March 1. DFMID= Deviation from means in days, CD= Calendar date.

Table 2.
Thermal unit (TU) requirements and comparison of methods (calendar vs. TU) of estimating various biological events in the life cycle of *R. completa* in the Willamette Valley, OR.

Year	Mature female		DFMID		Oviposition		DFMID		Larva		DFMID		Larval exit		DFMID	
	Date	TU	CD	TU	Date	TU	CD	TU	Date	TU	CD	TU	Date	TU	CD	TU
Pherocon AM trap																
			Air temperature													
1990	7/23	1272	2	3	7/31	1393	0	0	8/10	1573	4	4	9/10	2006	6	5
1991	7/29	1124	8	6	8/08	1284	8	5	8/16	1401	10	7	9/13	1786	9	13
1992	7/13	1305	8	5	7/22	1457	9	6	7/27	1527	10	2	8/25	1978	10	3

(First occurrence spans Mature female through Larval exit.)

Thermal units above 5° were accumulated from March 1. DFMID = Deviation from means in days, CD = Calendar date.

Table 3.
Model validation; a comparison of model predicted vs. actual dates of the beginning of various population levels/ biological events in the life cycle of *R. completa* under field conditions, Willamette Valley, OR, 1993.

	Flies captured/ biological events																				
	First			10%			50%			90%			100%			Mature female*			Oviposition*		
			Error (days) ±			Error (days) ±			Error (days) ±			Error (days) ±			Error (days) ±			Error (days) ±			Error (days) ±
Events	Date	TU		Date	TU		Date	TU		Date	TU		Date	TU		Date	TU		Date	TU	
P	7/9	1050	-	8/13	1517	-	8/31	1751	-	9/9	1895	-	10/6	2198	-	7/25	1233	-	8/3	1378	-
A	7/9	1043	0	8/04	1387	6	8/23	1657	5	9/3	1798	7	10/1	2132	5	7/23	1211	2	8/1	1324	3

P = predicted, A = actual, * = first occurrence early emergence of the first fly in 1992 (June 29). In 1990, the emergence was 13 days later (July 11) than in 1992, and in 1991, the emergence was 19 days later (July 17).

Although the effect of pupal exposure to cold during the winter months was not analyzed in this paper, it has been suggested previously (Brown and AliNiazee 1977, AliNiazee 1988) that the duration of cold experienced by pupae may also affect TU requirements for development after diapause, and this could have a significant impact on the year-to-year variation of fly emergence in the field. Neilson (1962) reported that development of *R. pomonella* (Walsh) after diapause was rapid if the preceding cold period was 40 weeks or more. An effect of the length and intensity of cold period on phenology has also been reported for *R. indifferens* (Brown and AliNiazee 1977) and *R. cerasi* (Baker and Miller 1978). Smith and Jones (1991) investigated the effects of cold on *R. pomonella* emergence, and reported that pupae exposed to a longer cold period (79-191 days) required fewer TUs for emergence compared with those enduring shorter cold periods. AliNiazee (1988), in a detailed discussion of the subject, suggested that beyond a certain minimum (3-4 months) length of cold exposure had little effect either on the date of emergence or percentage of the emergence level of many *Rhagoletis* flies. In addition to temperature, other factors such as rainfall, amount of sunlight, soil type and host variety might also influence the adult emergence of *Rhagoletis* flies (Glass 1960, Dean and Chapman 1973, Neilson 1976).

The predictions of the models derived from aerial trap data and air temperature were tested during 1993 and were found more accurate than calendar dates. For example in 1993, the model predicted first adult emergence on July 9, female sexual maturity on July 25, and oviposition on August 3. The actual events in the field occurred on July 9, July 23 and August 1, respectively, (Table 3).

In summary, the TU summation model presented here predicts occurrence in the field of various biological events including fly emergence levels, dates of occurrence of mature females and first oviposition. These predictions are more accurate in the field than calendar dates and the model is therefore an improvement over the current practice which depends on calendar dates for applying insecticides. Similar programs have been successfully used with other *Rhagoletis* species including *R. indifferens* (AliNiazee 1976 & 1979, Jones *et al.* 1991), *R. cingulata* and *R. fausta* (Jubb and Cox 1974), and *R. pomonella* (e.g., Maxwell and Parsons 1969, Reissig *et al.* 1979, Jones *et al.* 1989).

REFERENCES

AliNiazee, M. T. 1976. Thermal unit requirements for determining adult emergence of the western cherry fruit fly (Diptera: Tephritidae) in the Willamette Valley of Oregon. Environmental Entomology. 5: 397-402.

AliNiazee, M. T. 1979. A computerized phenology model for predicting biological events of *Rhagoletis indifferens* (Diptera: Tephritidae). The Canadian Entomologist. 111: 1101-1109.

AliNiazee, M. T. 1988. Diapause modalities in some *Rhagoletis* species. In: M. T. AliNiazee [Editor], Ecology and Management of Economically Important Fruit Flies. Agricultural Experiment Station Oregon State University Special Report 830: 111 pp.

Baker, C. R. B. and G. W. Miller. 1978. The effect of temperature on the post-diapause development of four geographical populations of the European cherry fruit fly (*Rhagoletis cerasi*). Entomologia Experimentalis et Applicata. 23: 1-13.

Baskerville, G. C. and P. Emin. 1969. Rapid estimation of heat accumulation from maximum and minimum temperatures. Ecology. 50: 514-516.

Boller. E. F. 1966. Drei Jahre Erfahrung in der Zeitpunktsprognose für die Kirschenfliegenbekämpfung mittles Bodentemperaturen. Schweizerische Zeitschrift für Obstund Weinbau. 75: 63-67.

Brown, R. D. and M. T. AliNiazee. 1977. Synchronization of adult emergence of the western cherry fruit fly in the laboratory. Annals of the Entomological Society of America. 70: 678-680.

Dean, R. W. and P.J. Chapman. 1973. Bionomics of the apple maggot in eastern New York. Search Agriculture. (Geneva, NY). 3: 1-62.

Glass, E. H. 1960. Apple maggot fly emergence in western New York. New York Agricultural Experiment Station Bulletin. 789: 29 pp.

Higley, L. G., L. P. Pedigo and K. R. Ostlie. 1986. DEGDAY: a program for calculating degree-days, and assumptions behind the degree-day approach. Environmental Entomology. 15: 999-1016.

Jones, V. P., D. W. Davis, S. L. Smith and D. B. Allred. 1989. Phenology of the apple maggot associated with cherry and hawthorn in Utah. Journal of Economic Entomology 82: 788-792.

Jones, V. P., D. G. Alston, J. F. Brunner, D. W. Davis and M. D. Shelton. 1991. Phenology of the western cherry fruit fly (Diptera: Tephritidae) in Utah and Washington. Annals of the Entomological Society of America. 84: 488-492.

Jubb, G. L. Jr. and J. A. Cox. 1974. Seasonal emergence of two cherry fruit fly species in Erie County, Pennsylvania: a 25-year summary. Journal of Economic Entomology. 67: 613-615.

Kasana, A. and M. T. AliNiazee. 1994. Effect of constant temperatures on development of the walnut husk fly, *Rhagoletis completa.* Entomologia Experimentalis et Applicata. 73: 247-254.

Kasana, A. and M. T. AliNiazee. 1995. Adult flight dynamics of the walnut husk fly (Diptera: Tephritidae) in the Willamette Valley of Oregon. Pan-Pacific Entomologist. 71: 142-148.

Kasana, A. and M. T. AliNiazee. 1996. Seasonal phenology of the walnut husk fly, *Rhagoletis completa* Cresson (Diptera: Tephritidae). The Canadian Entomologist. 128: 377-390.

Maxwell, C. W. and C. Parsons. 1969. Relationships between hour-degree F soil temperature summations and apple maggot adult emergence. Journal of Economic Entomology. 62: 1310-1313.

Neilson, W. T. A. 1962. Effects of temperature on development of overwintering pupae of the apple maggot, *Rhagoletis pomonella* (Walsh). The Canadian Entomologist. 94: 924-929.

Neilson, W. T. A. 1976. The apple maggot (Diptera: Tephritidae) in Nova Scotia. The Canadian Entomologist. 108: 885-92.

Reissig, W. H., J. Barnard, R. W. Weires, E. H. Glass and R. W. Dean. 1979. Prediction of apple maggot fly emergence from thermal unit accumulation. Environmental Entomology. 8: 51-54.

Smith, S. L. and V. P. Jones. 1991. Alteration of apple maggot (Diptera: Tephritidae) emergence by cold period duration and rain. Environmental Entomology. 20: 44-47.