Bionomics of

Platynota flavedana Clemens and *P. idaeusalis* (Walker) (Lepidoptera: Tortricidae) in Virginia Apple Orchards

by

Paul J. David

Dissertation submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of
DOCTOR OF PHILOSOPHY
in
Entomology

APPROVED:

R. L. Horsburgh, Chairman

J. A. Barden

J. L. Eaton

G. I. Holtzman

R. L. Pienkowski

March, 1985
Blacksburg, Virginia

BIONOMICS OF *PLATYNOTA FLAVEDANA* CLEMENS AND *P. IDAEUSALIS* (WALKER) (LEPIDOPTERA:TORTRICIDAE) IN VIRGINIA APPLE ORCHARDS

by

Paul J. David

Committee Chairman: Robert L. Horsburgh

Entomology

(ABSTRACT)

The effects of pheromone trap placement on male moth catches of both species were studied. For *P. flavedana*, traps hung at 2.1 and 3.0 meters captured the greatest number of moths. Trap heights of 1.2, 2.1, and 3.0 meters caught the greatest number of *P. idaeusalis* moths. The outside-the-canopy trap position captured more *P. flavedana* moths, while the within-canopy trap location caught the greatest number of *P. idaeusalis* moths. Traps placed in the west portion of the tree captured the greatest number of *P. flavedana* moths. *P. idaeusalis* moth catches were not influenced by compass quadrants. Trap design and pheromone dispenser and rate influenced trap catches of *P. flavedana*.

Development of P. flavedana and P. idaeusalis on a meridic diet was observed at constant temperatures in the laboratory. Lower developmental threshold values for egg, larval, and pupal stages of P. flavedana were: 10.6, 8.6, 9.0°C, respectively. Lower developmental threshold values of 9.7, 7.0, and 8.5°C were estimated for P. idaeusalis egg, larval, and pupal stages, respectively. An average of 101.5 $^{\circ}D_{10.6}$, 379.6 $^{\circ}D_{8.6}$, and 126.0 $^{\circ}D_{9.0}$ were required for development of egg, larval, and pupal stages of P. flavedana, respectively. P. idaeusalis required 104.7 $^{\circ}D_{9.7}$, 442.7 $^{\circ}D_{7.0}$, and 132.2 $^{\circ}D_{8.5}$ to complete development in the egg, larval, and pupal stages, respectively. Differences in rate of development were observed between food sources for both species.

Within-tree spatial distribution of egg masses and fruit damage resulting from larval feeding for both species was investigated. P. flavedana egg masses were mostly found in the southern portion of the tree below 1.8 meters. Egg masses of P. idaeusalis were observed in greatest numbers in the southern and eastern quadrants of the tree below 2.8 meters. Fruit damage caused by larvae of both species was greatest in the lower portion of the tree. Wind dispersal of first-instar larvae between trees is believed to have influenced fruit damage distribution.

The seasonal activity of P. flavedana and P. idaeusalis was monitored. Degree-day accumulations for first moth catch, first and peak egg deposition, and first and peak egg hatch of both generations are presented.

ACKNOWLEDGEMENTS

I would like to thank my advisor, Bob Horsburgh, for his support, both financially and otherwise, during my studies at VPI. His friendship, expertise, guidance, and enthusiam throughout the course of this project has been invaluable. I would also like to acknowledge him for his treatment of his students as collegues and not as subordinates; this was very much appreciatd by the author.

I also thank John Barden, John Eaton, Stephen Myers, and Robert Pienkowski for serving on my graduate committee. Their helpful suggestions throughout this study and reviews of this manuscript were appreciated.

A special thanks goes to my remaining committee member, Goldie Holtzman. His statistical advise in the early stages of this project was greatly appreciated. Also, his many days spent on statistical analyses of part of the data in Chapter V made interpretation of the results significantly easier and more accurate.

and his summer crews, , and Sherry Smith of the Winchester Fruit Research Laboratory all deserve special thanks as do all the Frederick County and Nelson County fruit growers for their cooperation on many aspects of this study.

I thank my parents, , for their encouragement and support.

Finally, I would like to thank my wife, , for all of her love, encouragement, support, and assistance during the course of my graduate studies. She certainly made our stay at VPI much more bearable and enjoyable, especially during the tough times.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figures

Figures page

Chapter I

INTRODUCTION

Apples are an economically important commodity in the United States. The 1982 commercial apple crop in this country was estimated to be 8,100 million pounds with a value of 803.7 million dollars. In 1982, Virginia, ranking fifth in total production among the states, produced 500 million pounds of apples. The value of the state's crop was set at 48.5 million dollars (Anon. 1983).

Because consumers demand fresh-market apples to be virtually blemish free, an economic injury level (EIL) of 1% damaged fruit at harvest is used (Croft et al. 1983). Because of this low EIL, growers rely heavily on pesticides to achieve a high level of pest control. Many Virginia growers make 10-18 applications of pesticides to their crop each year (VPI and SU 1984a). Many of these sprays are often protective in nature and some may not be required when low pest densities are present. In such instances their primary purpose is to provide growers with "peace of mind." In addition to the high costs of synthetic chemicals and their application, excessive pesticide sprays, insecticides in particular, can result in environmental contamination, secondary pest outbreaks, genetic resistance, pest resurgence,

or have adverse effects on nontarget organisms. Despite the many potentially negative effects of pesticides, they remain one of the most powerful tools available for the management of crop pests (Metcalf 1975).

In the apple production system, insecticides are and will probably remain the mainstay for controlling phytophagous insects in the foreseeable future. However, the emphasis in many current apple pest management programs is toward a spray-as-needed approach (e.g. codling moth in Michigan and Washington). To successfully use this approach, the biology and ecology of the pests and beneficial species associated with them must be intensely studied. Research results can then be used to develop methods to more precisely time pesticide applications (Hoyt et al. 1983).

Platynota flavedana Clemens is one of the most important pests of apple in Virginia (Thomas 1976). Bobb (1972) reported damage caused by larvae of this leafroller to be as high as 75% in several commercial apple orchards in the Piedmont region of Virginia. Experiments conducted during the 1970's focused on controlling the larval and adult stages of this pest; results indicated that the level of control achieved was not commercially acceptable (Bobb 1972, Thomas 1976, 1979). Horsburgh et al. (1980), in preliminary testing, demonstrated that methomyl applied as an ovicide showed

promise in controlling this pest. David (1982), after extensive testing of this material, found it to be highly ovicidal against many important apple pests such as aphids, Aphis spp. and Dysaphis plantaginea (Passerini); redbanded leafroller, Argyotaenia velutinana (Walker); and P. flavedana. Currently, commercial fruit producers using methomyl in combination with insecticides having longer residual activity (e.g. azinphosmethyl, methyl parathion) can achieve satisfactory control of P. flavedana if sprays are properly timed (VPI and SU 1984b). The optimal time to control this pest is during the egg or first instar. Many of these insecticides, however, are also extremely toxic to important beneficial species and may have a disruptive effect on the orchard ecosystem and thus disrupt established pest management programs (Asquith and Hull 1979).

P. idaeusalis (Walker), the tufted apple budmoth, is an important leafroller which feeds on apples in Virginia orchards. P. flavedana and P. idaeusalis have very similar life cycles and, presently, for commercial control purposes are managed as a complex. Bobb (1971) and Thomas (1976) suggested that P. flavedana was the predominant species in Virginia. Consequently, most of the research conducted in the state during the 1970's dealt with P. flavedana, little attention was paid to P. idaeusalis. However, David (1982)

concluded that P. flavedana was not the predominant species in all regions of the state. His data indicated that there is a mix of P. flavedana and P. idaeusalis in most orchards with P. flavedana being the predominant species in the Piedmont region of Virginia, while P. idaeusalis is more dominant in the upper Shenandoah Valley region.

In order to provide information which will assist in the management of P. flavedana and P. idaeusalis the objectives of this research were: (1) evaluate various pheromone dispensers, concentrations, and sticky traps for P. flavedana male moth attraction and capture, and study the effects of within-tree pheromone trap placement on male moth catches of P. flavedana and P. idaeusalis, (2) derive developmental threshold data for P. flavedana and P. idaeusalis, (3) determine the within-tree spatial pattern of P. flavedana and P. idaeusalis egg masses and fruit damage and if tree-to-tree larval dispersal occurs for both species, (4) relate the seasonal activity of P. flavedana and P. idaeusalis to degree-day accumulations.

Chapter II

LITERATURE REVIEW

The Tortricids, P. flavedana and P. idaeusalis are widely distributed throughout the United States; P. idaeusalis has also been reported to occur in some parts of Canada (Chapman and Lienk 1971). While both of these species are widely distributed, they cause economic damage to deciduous tree fruits only in the eastern United States (Hoyt et al. 1983). Of the two species, P. idaeusalis seems to be the most widespread causing greater damage. However, where P. flavedana occurs it has the potential to produce considerable damage. Bobb (1972) reported fruit injury caused by P. flavedana to be as high as 75% in several commercial apple orchards.

Although the variegated leafroller is the often used common name of P. flavedana, it has not been accepted by the Common Names Committee of the ESA. An acceptable common name for this species is needed. The approved common name of P. idaeusalis is the tufted apple budmoth (Chapin 1984). Both P. flavedana and P. idaeusalis have collected several synonyms in the taxonomic literature since they were first described by Clemens (1860) and Walker (1863), respectively. Comprehensive taxonomic reviews of P. flavedana and P.

idaeusalis have been compiled by Thomas (1976) and Koethe (1977), respectively.

The two species are charcterized as being general feeders and have been found on a number of plants other than apple. P. flavedana has been observed feeding on sixteen different host plants (Thomas 1976), and P. idaeusalis on twenty-one (Bode 1975).

Although P. flavedana and P. idaeusalis had been found to be occasional pests of deciduous tree fruits as early as 1948 (Summerland and Hamilton 1954) and 1919 (Frost 1923), respectively, economic injury was not observed until the late 1960's and early 1970's (Bode et al. 1973, Bobb 1972). Consequently, the literature on these leafrollers is limited. However, presently, there are several active research projects under way on various aspects of the biology and control of these pests.

General life histories have been studied for both species. The life history of P. flavedana on rose (Hamilton 1940), strawberry (Wilde and Semel 1966), and apple (Bobb 1972 and Thomas 1976) have been reported. Seasonal development of P. idaeusalis has been reported on apple in both Michigan (Hogmire and Howitt 1979) and Pennsylvania (Frost 1923, Koethe 1977). Their life cycles are similar, but P. idaeusalis generally appears a few days earlier than P.

flavedana each spring. For P. flavedana in Virginia apple orchards, there are two generations per year. The species overwinters in the ground cover as second to fourth instar larvae. First generation adults begin to emerge in early- to mid-May and flights continue until July. Eggs are laied in masses of 36-100. Eggs in individual masses overlap one another like shingles. Each female lays an average of four masses on smooth, upper leaf surfaces. The first generation oviposition period runs from late-May until late-June. Second generation moth flights commence in mid-July and flights continue until late-September or October. Egg masses of this generation can be found from late-July or early-August until mid-September (Bobb 1972, also see Appendix 2). Larvae of P. idaeusalis have been demonstrated to diapause from late fall until early spring. Photoperiod and thermoperiod have been suggested to influence diapause induction and termination (Rock et al. 1983, Rock and Shaffer 1983, Rock 1983).

While basic life history studies of both species have been conducted, little information on developmental thresholds is available. Data for P. flavedana are lacking, but Berkett et al. (1976) studied the developmental rates of P. idaeusalis larvae and pupae at constant temperatures. The authors concluded that 32.2°C was probably the upper devel-

opmental threshold for the species, but failed to speculate on a lower developmental threshold.

Sex pheromone components of P. flavedana and P. idaeusalis have been isolated (Hill et al. 1977 and Hill et al. 1974, respectively). Some work has been done with comparing sticky traps and sex attractants for P. idaeusalis (Bode et al. 1973), but the potential uses of pheromone traps has not been exploited for these species as they have been for other deciduous fruit pests. Pheromone traps have been used or suggested for use as tools for timing sprays against many pests including: the codling moth, Cydia pomonella (L.), (Alford et al. 1979, Batiste et al. 1973, Hagley 1973, Madsen and Vakenti 1972, 1973, Riedl et al. 1976, Riedl 1980a, Rock et al. 1978, Vakenti and Madsen 1976, Westigard and Graves 1976); the oriental fruit moth, Grapholita molesta (Busck), (Bailey 1980, Phillips 1973, Rice et al. 1982, 1984); San Jose scale, Quadraspidiotus perniciosus (Comstock), (Mague and Reissig 1983, Rice et al. 1982); and the tortricid, Adoxophyes orana (Fischer von Roslerstamm) (Minks and DeJong 1975).

The importance of standardization of monitoring techniques when using pheromone traps has been well documented for the codling moth (Riedl et al. 1979, Riedl 1980b, McNally and Barnes 1980, 1981, 1984) and San Jose scale (Hoyt et al.

1983). Little work on such standardization has been conducted for either P. flavedana or P. idaeusalis. Brown (1984) studied the efficiency of pheromone traps in relation to saturation of the sticky surface of the traps by male P. idaeusalis moths. Results suggested that if pheromone traps are to be used as population density indicators, careful attention must be paid to proper maintance of the sticky surface of the traps. Bode et al. (1973) compared two types of commercial sticky traps and six formulations of pheromone for P. idaeusalis. They found that a 1:1 mixture of pheromone plus synergist impregnated in a rubber septum resulted in the greatest trap catches for this species. Results of their sticky trap study demonstrated significant differences in numbers of moths caught by each trap design, Pherocon 1C and Sectar. The Pherocon 1C trap captured greater numbers of moths. However, while trap catches differed numerically, general population trends (e.g. peak moth catch) were similarly portrayed by both designs.

Chemical control of these leafrollers has been the focus of many studies conducted since the early 1970's (Bobb 1972, Thomas 1976, 1979, Travis et al. 1981, Rock and Shaltout 1983, David and Horburgh 1985; also numerous reports have appeared annually in Insecticide and Acaracide Tests Vol 1-9). Experiments on microbial control of these insects

have been conducted using Bacillus thuringiensis and a nuclear polyhedrosis virus. Both materials considerably reduced leafroller damage to fruit at harvest, compared to untreated trees, but failed to provide economic control (Croft and Bode 1983). A large number of parasites of P. flavedana and P. idaeusalis have been collected (Thomas 1976 and Koethe 1977). Unfortunately, parasites are not able to regulate populations of either species in commercial apple orchards. Parasitization rates rarely exceed five percent (Hoyt et al. 1983).

Timing of sprays appears to be one of the most important factors influencing the degree of success in leafroller control. A significant amount of evidence has been accumulated to indicate that control efforts should be directed at the egg or early, first-instar larval stages of these leafrollers because control becomes increasingly more difficult thereafter (Hill and Thomas 1976, David 1982, Rock and Shaltout 1983). Preliminary studies on using degree-days as an index for timing sprays against these leafrollers have been reported, but the approach has not been validated under field conditions (David 1982). Phenology models using degree-days have also been published for several other deciduous tree fruit pests, but validation of their effectiveness as tools for timing sprays under field conditions have not

been reported (the codling moth: Riedl et al. 1976, Jorgensen et al. 1979, Cranham 1980; oriental fruit moth: Croft et al. 1980, Rice et al. 1982; European red mite, Panonychus ulmi (Koch),: Trottier and Herne 1979; western cherry fruit fly, Rhagoletis indifferens Curran,: AliNiazee 1976, 1979; apple maggot, Rhagoletis pomonella (Walsh),: Reissig et al. 1979, Laing and Heraty 1984; San Jose scale: Jorgensen et al. 1981, Rice et al. 1982, Mague and Reissig 1983; and spotted tentiform leafminer, Phyllonorycter blancardella (Fabricius),: Johnson et al. 1979). The usefulness of degree-days as a validated method for timing insecticide applications has been demonstrated for the codling moth, oriental fruit moth, and apple maggot (Trottier 1980, Rice et al. 1984).

Chapter III

EFFECTS OF PHEROMONE TRAP DESIGN, PHEROMONE DISPENSER AND RATE, AND WITHIN-TREE TRAP PLACEMENT ON P. FLAVEDANA AND P. IDAEUSALIS MALE MOTH CAPTURES IN VIRGINIA APPLE ORCHARDS

INTRODUCTION

The tortricids, P. flavedana and P. idaeusalis are serious pests of apples in Virginia. There are two generations of these leafrollers per year in the state. Bobb (1972) and Thomas (1976) described the life history of P. flavedana in Virginia. The phenology of P. idaeusalis has been described in Michigan (Hogmire and Howitt 1979) and Pennsylvania (Koethe 1977). Sprays to control these pests must be directed at the egg or newly-hatched, first-instar larval stage. Once the larvae build their leaf nests, control becomes increasingly more difficult (David 1982, Rock and Shaltout 1983). Extensive field trials have demonstrated some efficacious insecticides for controlling these insects (VPI and SU 1984b). However, timing of sprays is one of the most important factors influencing successful leafroller control.

Pheromone based monitoring systems are being developed to assist in timing insecticide applications directed against these leafrollers in Virginia (see Chapter 6). Such systems have been used successfully to time sprays against

other deciduous tree fruit pests (Madsen and Vakenti 1973, Hagley 1973, Minks and DeJong 1975, Vakenti and Madsen 1976, Westigard and Graves 1976, Rock et al. 1978, Alford et al. 1979, and Bailey 1980). The importance of standardizing monitoring techniques has been well documented for the codling moth, C. pomonella, (Riedl et al. 1979, Riedl 1980b, McNally and Barnes 1980, 1981, 1984) and San Jose scale, Q. perniciosus, (Hoyt et al. 1983). Presently little work in this area has been conducted for P. flavedana and P. idaeusalis. However, in one study, Bode et al. (1973) illustrated that pheromone trap design and pheromone formulation significantly influenced P. idaeusalis male moth attraction and capture. The importance of maintance of the sticky surface of pheromone traps was well illustrated by Brown (1984) for P. idaeusalis.

The studies reported in this paper were conducted to evaluate various pheromone dispensers, concentrations, and sticky traps for P. flavedana male moth attraction and capture. Also, the effects of within-tree pheromone trap placement on male moth catches of P. flavedana and P. idaeusalis were studied.

MATERIALS AND METHODS

Experiments were conducted over both generations of these leafrollers during the 1982-84 growing seasons in commercial apple orchards. In all experiments except the first two, the effect of various parameters on trap catches were studied in separate experiments for both P. flavedana and P. idaeusalis. The Zoecon Corporation (Palo Alto, Calif.) Pherocon 1C sticky trap was used in all experiments except the trap design study where several different models were evaluated. Zoecon's commercially available pheromone preparation was used for P. idaeusalis (Hill et al. 1974). Except for the first two experiments, a rubber septum impregnated with 2.5 mg of P. flavedana pheromone (Hill et al. 1977) prepared by Zoecon was the attractant used for this species. In all experiments, pheromone dispensers were allowed to "air out" for 24-48 hours prior to use in the field. Extensive use of these pheromone preparations have shown that when dispensers are first removed from storage vials or packages, they are extremely active and can lead to exaggerated trap catches during the first 24-36 hours if placed directly in the field (David, personal observation). All traps were hung 1.7 meters above ground, except in the height study. Pheromone dispensers and sticky trap liners were changed every three weeks. The sticky surface of the traps was thoroughly stir-

red after moths were removed to renew the catch surface as suggested by Riedl (1980).

Trap Design Study

Experiments were conducted to evaluate the effect of trap design on P. flavedana male moth captures. Three traps were evaluated: Pherocon II, Pherocon 1CP, and Pherocon 1C (Zoecon Corp.). These traps have been described and illustrated, in detail, by AliNiazee (1983). Traps were set out in a completely randomized experimental design replicated three times. A spacing of 30 m between traps was used. The pheromone wick used was a Beem cap impregnated with 5.0 mg of P. flavedana pheromone prepared by Zoecon Corp. Traps were checked weekly.

Pheromone Dispenser and Rate Study

Two types of pheromone dispensers, the Beem cap and the rubber septum, were evaluated. Illustrations of both dispensers have been published (Sharp and Cross 1980). The two dispensers were charged with three different loads of P. flavedana pheromone - 2.5 mg, 5.0 mg, and 10.0 mg. A total of six combinations were evaluated. Pheromones were prepared by Zoecon Corp. Traps were hung out in a 6 X 6 Latin square design with a spacing of approximately 30 m between traps within a row and 30 m between rows.

Trap Height

To study the effect of height on moth catches, traps were hung at heights of 0.3, 1.2, 2.1, 3.0, and 3.9 m above ground from a three meter pole strapped to the tree trunk. Five, one-pole replicates were used. Replicates were spaced 40 m apart. The average tree height was 4.1 m.

Tree Compass-quadrant Trap Orientation

In this study traps were placed in the east, south, north, and west quadrants of the same tree. Five replicates were used per treatment. Replicates were spaced 30 m apart.

Within-canopy Trap Placement

The effect of trap placement inside and outside the tree canopy was studied using two experiments. In experiment one, one trap was hung on the edge of the canopy and one trap was hung in the center of the tree along the trunk of the same tree. In experiment two, traps were placed in different trees, but they occupied the same relative canopy locations within the tree. Each experiment was replicated five times and replicates or treatments were separated by 30 m.

In the first four experiments data were subjected to analysis of variance and Duncan's (1951) multiple range test

to determine differences between treatments. T-tests were used to determine significance between treatments in the within-canopy trap placement study (paired t in expt.1, two-sample t in expt.2).

RESULTS AND DISCUSSION

Trap Design Study

The Pherocon 1C trap captured significantly more P. flavedana males than either the Pherocon 1CP or the Pherocon II traps during both generations (Table 1). Differences were found among all three designs in generation two at the 10% level. Bode et al. (1973) compared the Sectar (= Pherocon II) and Pherocon 1C trap for capture of P. idaeusalis. They also found that the Pherocon 1C trap captured more males. These results concur with those for other species (AliNiazee 1983, Danko and Jubb 1983).

While the Pherocon 1C trap has a greater total sticky surface than do the other traps studied, its greater efficiency cannot be solely attributed to this difference. AliNaizee (1983) found no significant relationship between retentive surface and total catch. He suggested that the efficiency of a trap design may be related to attractant plume characteristics, behavior of the male in response to the plume, the convenience of trap for entrance and landing, and the capturing efficiency of the sticky surface.

Table 1. Effect of trap design on P. flavedana male moth catches.

Trap design[a]	$\bar{X}$ no. of moths caught[b]	
	1st generation	2nd generation[c]
Pherocon 1C	80.9 a	108.4 a
Pherocon 1CP	27.0 b	57.9 b
Pherocon II	22.2 b	35.4 b

[a]Zoecon Corp., Palo Alto, Calif.

[b]Means followed by the same letter in the same column are not significantly different ($P < 0.05$); Duncan's (1951) multiple range test.

Sustained efficiency of the sticky surface of the traps remains a concern where estimation of population density is the main objective. Brown (1984) found, using a trap with a sticky surface of 450 cm^2, that efficiency was reduced after only 20 P. idaeusalis moths were caught. McNally and Barnes (1984), using the Pherocon 1C trap, found similar results in studies conducted with the codling moth. Riedl (1980) suggested that this problem may be partially overcome by thoroughly stirring the catch surface after moths have been removed and by regular replacement of the sticky liners (after 4 weeks or sooner if excessively soiled).

Although the Pherocon 1C trap captured greater numbers of moths, all traps indicated general population trends (e.g., peak moth catch) (Figure 1). Depending on the intent of a particular trapping system, the Pherocon II trap may be most suitable for pest management programs because of its ease of use and maintenance. Jubb and Danko (1982) compared all three Pherocon traps and suggested that the Pherocon II trap may be the preferred trap for use in pest management programs because of its ease of use. The trap selected for a program should be determined by its intended use. If pheromone traps are to be used as biofix points (e.g. first moth catch) (Riedl et al. 1976) then the Pherocon II trap may be most suitable for the aforementioned reasons (assum-

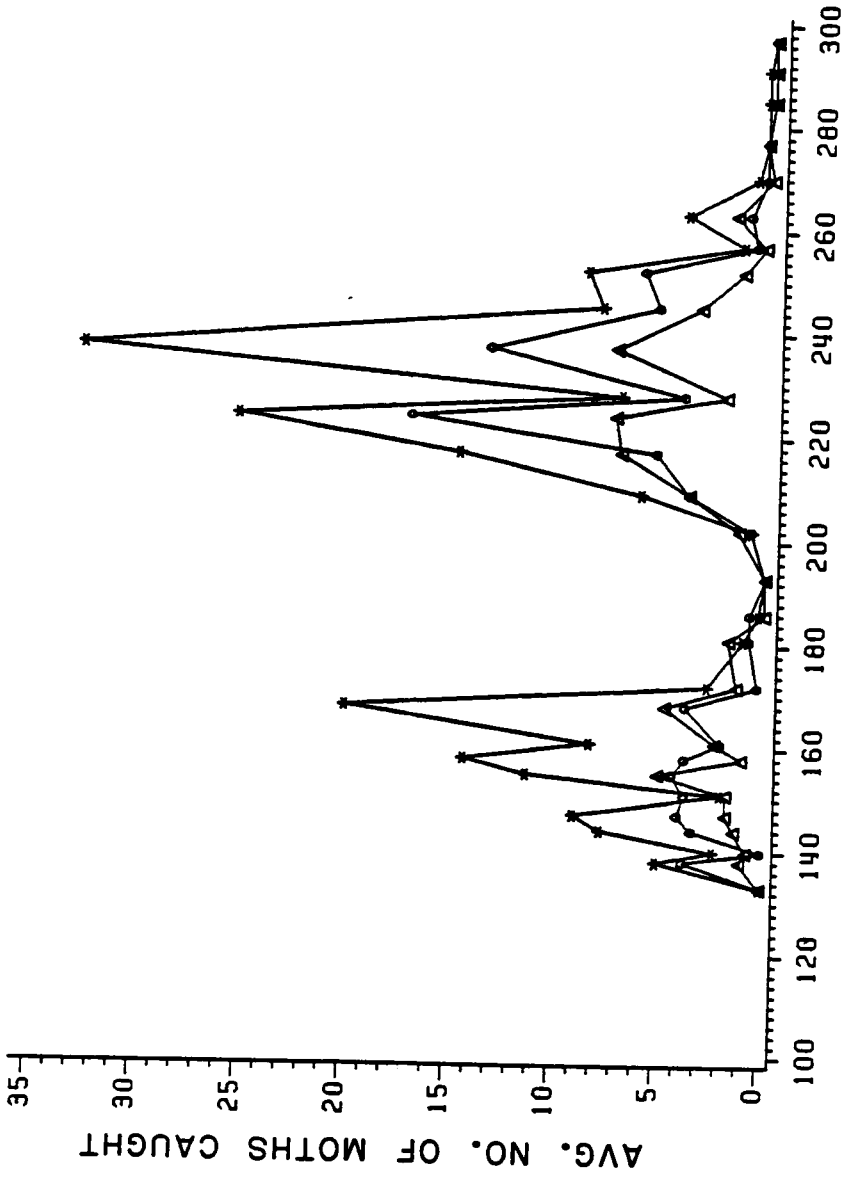

Fig. 1. Pheromone trap evaluation study, 1982. * = Pherocon 1C; O = Pherocon 1CP; Δ = Pherocon II.

ing equal efficiency in first moth catch between designs (Figure 1)). However, if the numbers of moths caught are important (e.g. mass trapping) or precisely defined peaks are desired (Bode et al. 1973) then the Pherocon 1C trap would be the best trap of those evaluated.

Pheromone Dispenser and Rate Study

No significant differences ($P > 0.10$) were found among the various pheromone dispenser/rate combinations (avg moth catch = 26.1) during the first generation of P. flavedana. In the second generation, the rubber septum impregnated with 2.5 mg of pheromone captured the most moths but not significantly different from the 2.5 mg/Beem cap and the 5.0 mg/rubber septum combinations (Table 2). These data suggest that the pheromone rate/dispenser combinations can significantly influence trap catches for this species.

Data in Table 2 and in Chapter 6 (Figure 10 julian date 185-250) illustrate a problem experienced using pheromone traps for monitoring P. flavedana during the early part of the second generation. There appears to be either reduced male responsiveness to the pheromone traps or reduced efficiency of the traps during this generation as compared the first. Egg mass sampling data (David, unpublished data) indicated a much higher population present in the orchard than

Table 2. Effect of pheromone rate and dispenser on *P. flavedana* male moth catches.

Rate[a] (mg)	Dispenser	$\bar{X}$ no. moths caught[b,c]	
2.5	Septum	23.1	a
2.5	Beem cap	16.8	ab
5.0	Septum	15.7	abc
5.0	Beem cap	10.9	bc
10.0	Septum	10.3	bc
10.0	Beem cap	6.8	c

[a] E11-14:OH/Z11-14:OH, 85:15. Prepared by Zoecon Corp., Palo Alto, Calif.

[b] Second generation.

[c] Means followed by the same letter are not significantly different ($P < 0.05$); Duncan's (1951) multiple range test.

suggested by pheromone trap catches. A similar phenomenon has been observed for the codling moth (Madsen and Vakenti 1972, Riedl et al. 1976). The factors responsible for this observed pattern are not known. Consequently, when monitoring for P. flavedana, efforts should be directed toward maximizing trap catches. No such problem has been observed with P. idaeusalis as trap catches are normally great enough for interpretation.

Trap Height

For P. flavedana, the trap height of 2.1 m above ground captured the greatest number of moths in both generations as compared to the other positions, but the 0.3, 1.2, 2.1, and 3.0 m traps did not differ statistically in generation one and the 2.1 and 3.0 m positions did not differ during generations two (Table 3). While the heights of 2.1 and 3.0 m above ground captured the most P. flavedana moths in generation two, slightly lower trap heights such as 1.7 to 1.8 m above ground would be more convenient for maintenance. The 2.1 m position also captured more P. idaeusalis moths in both generations, but not significantly different from the 1.2, 3.0, and 3.9 m heights in generation one and the 1.2 and 3.0 m heights in generation two.

Table 3. Effect of trap height on P. flavedana and P. idaeusalis male moth catches.

Height (m)	$\bar{X}$ No. of moths caught[a,b]			
	P. flavedana		P. idaeusalis	
	1st gen.[c]	2nd gen.	1st gen.	2nd gen.
3.9	3.4 a	4.2 a	31.6 ab	15.6 a
3.0	35.5 b	22.9 b	54.3 b	83.6 bc
2.1	59.2 b	24.8 b	64.9 b	110.6 c
1.2	42.5 b	7.4 a	48.0 ab	104.0 c
0.3	29.3 b	7.2 a	24.6 a	49.6 b

[a]Average total catch per generation per species.

[b]Means followed by the same letter in the same column are not significantly different ($P < 0.05$); Duncan's (1951) multiple range test.

[c]Generation.

In experiments presented in this paper, with the possible exception of the pheromone dispenser/rate study, higher trap catches are presumed to be due to the influence of air currents on the pheromone plume (Hoyt et al. 1983), but many other factors (e.g. temperature, light intensity, male flight behavior) could possibly play an important role as illustrated by AliNaizee (1983). In this experiment, traps at different heights were placed in direct competition with each other. Different findings may have resulted if individual traps were hung in separate trees.

Tree Compass-quadrant Trap Orientation

No significant differences ($P > 0.10$) were found in the number of P. idaeusalis moths caught for either generation among traps placed in compass quadrants. For P. flavedana, the trap placed in the west portion of the tree captured a greater number of the moths than traps in the other quadrants in both generations (Table 4). Thus from these results, it appears that tree quadrant has a variable effect, influencing P. flavedana trap catches but not those of P. idaeusalis.

Table 4. Effect of tree compass-quadrant trap placement on P. flavedana male moth catches.

Quadrant	$\bar{X}$ No. of moths caught[a,b]	
	1st gen.[c]	2nd gen.
East	29.6 ab	10.5 ab
North	27.9 a	12.9 a
South	23.8 a	7.5 b
West	41.5 b	20.0 c

[a]Average total catch per generation.

[b]Means followed by the same letter in the same column are not significantly different ($P < 0.05$); Duncan's (1951) multiple range test.

[c]Generation.

Within-canopy Trap Placement

In experiment one (traps in the same tree) for P. flavedana, the outside or edge of canopy traps captured a greater number of moths than did the inside or within canopy traps in the first generation, but no significant differences were found between locations in generation two (Table 5). In experiment two (traps in different trees), no significant differences were found between the two locations for either generation. However, during the second generation, outside traps captured a greater number of moths than did traps placed inside the tree canopy (Table 5).

In the case of P. idaeusalis in experiment one, no statistical differences were found between trap locations for either generation (Table 5). The inside trap during generation two, however, did capture a greater number of moths than did the outside trap. For both generations in experiment two, the inside the canopy traps captured more moths (Table 5).

These experiments show that traps placed on the edges of the canopy produce the greatest trap catches for P. flavedana. For P. idaeusalis, where the management objective may not be to maximize trap catch, the outside-the-canopy trap position may be the preferred location because of its ease of maintenance. In experiments where the effect of

Table 5. Effect of trap placement within the tree canopy on P. flavedana and P. idaeusalis male moth catches.

Experiment	$\bar{X}$ No. of moths caught[a,b]			
	P. flavedana		P. idaeusalis	
	Inside	Outside	Inside	Outside
		1st gen.[c]		
1 (same)[d]	30.2 a	46.8 b	117.5 a	123.0 a
2 (different)[e]	61.7 a	57.5 a	154.9 a	117.5 b
		2nd gen.		
1 (same)	12.9 a	17.8 a	134.9 a	91.2 a
2 (different)	18.6 a	30.9 a	144.5 a	67.6 b

[a]Average total catch per experiment per species for a given generation.

[b]Means within a row for a given species followed by the same letter are not significantly different ($P < 0.10$); t-test.

[c]Generation.

[d]Traps of a replicate placed in the same tree.

[e]Traps of a replicate placed in different trees.

lateral, as well as vertical, distribution of pheromone traps are studied, wind movements through the canopy probably influences pheromone plumes. Tree shape, land topography, weather conditions, and horticultural practices (e.g. pruning, training, and spacing) may also influence these plumes and thus affect male moth attraction and capture.

These data demonstrate that many factors can influence pheromone trap catches of P. flavedana and P. idaeusalis. As suggested by Riedl et al. (1979), monitoring procedures should be standardized in a program to allow generation of data which are interpretable, reproducible, and comparable to results from different years and locations. Consistent placement and proper maintenance of traps are key elements in standardization. Based on data presented in this paper and other studies (Riedl et al. 1979, Riedl 1980b, McNally and Barnes 1980, 1981, 1984, and David, personal observation), a standardized method is recommended. For both species we recommend that pheromone dispensers be "aired out" for 24-48 hours prior to placement in the field. Three traps spaced 30-50 m apart should be used per orchard or block. Pheromone dispensers and sticky traps should be replaced every 4 weeks. Traps should be checked weekly and moths should be removed from the sticky surface. The catch surface should be stirred thoroughly after moths are removed

to restore its efficiency or replaced if excessively soiled. For P. flavedana where maximizing trap captures is an objective, the Pherocon 1C trap baited with a rubber septum impregnated with 2.5 mg of pheromone is recommended. Traps should be hung in a consistent location in the tree, we suggest in the western, outer portion of the canopy, approximately 1.7 m above ground. The Pherocon 1C trap baited with standard P. idaeusalis pheromone is recommended for this species. Traps should be hung approximately 1.7 m above ground in the outside portion of the canopy.

As suggested earlier, monitoring programs should be developed to generate the information required for a particular pest management program. The monitoring techniques just elucidated are based on needs in Virginia. Elements of these programs can be modified to provide for local needs and limitations. The key element in monitoring programs for these leafrollers appears to be consistency.

The effect of trap density on trap catch was not studied in these experiments. This may be an important element in a comprehensive monitoring and predictive system for these leafrollers and needs to be investigated.

Chapter IV

DEVELOPMENT OF P. FLAVEDANA AND P. IDAEUSALIS AT CONSTANT TEMPERATURES IN THE LABORATORY

INTRODUCTION

The leafrollers, P. flavedana and P. idaeusalis are serious pests of apples in Virginia (Hill and Thomas 1976). To control these leafrollers successfully with efficacious insecticides, sprays must be applied when the insects are in the egg, or early first-instar larval stage. After this, control becomes increasingly more difficult (David 1982, Rock and Shaltout 1983). Studies have been conducted in Virginia to relate the seasonal activity of both species to degree-day accumulations in an effort to time insecticide applications more accurately (see Chapter 6).

Developmental thresholds are essential in degree-day monitoring. The development of P. idaeusalis larvae and pupae has been studied in Pennsylvania (Berkett et al. 1976). No reports have been seen on the development of P. flavedana in relation to temperature. One objective of this study was to determine developmental thresholds for the egg, larval, and pupal stages of P. flavedana and P. idaeusalis in the laboratory. Data for P. idaeusalis were compared to that

generated in Pennsylvania. Also, since both species are polyphagous (Bode 1975, Thomas 1976), the second objective of this study was to determine the influence of host on rate of development.

MATERIALS AND METHODS

Developmental Threshold Determination

First-generation egg masses of *P. flavedana* and *P. idaeusalis* were collected in commercial apple orchards and brought to the laboratory where they were monitored until hatch. Larvae, less than 12 hours old, were placed singly into capped, 30-ml plastic cups containing a semi-synthetic diet (Shorey and Hale 1965). Cups, containing the neonate larvae, were reared in growth chambers at each of eight constant temperatures (±1°C): 12.8, 15.6, 21.1, 23.9, 26.7, 29.4, 32.2, and 35.0°C, with a 16:8 hr. (L:D) photoperiod. Larvae were examined daily and the number of days required to complete the larval and pupal stages were recorded.

To study the developmental rates of eggs, larvae of both species were field collected and reared to the pupal stage on the semi-synthetic diet described previously. Pupae were then transferred to oviposition cages (ca. 25 cm wide, 15 cm deep, and 15 cm high (Glass and Hervey 1962)) containing waxed paper sheets (ca. 16 cm by 8 cm). Moths

were provided with a 10% sucrose solution and were maintained at 23.9 ±2°C with a 16:8 (L:D) photoperiod. After a brief preoviposition period, females oviposited on the waxed paper.

Egg masses, less than 9 hours old, were cut from the waxed-paper sheets and placed individually into shell vials. Egg were incubated under high humidity at 12.8, 15.6, 21.1, 23.9, 26.7, 29.4, 32.2 ±1°C. Vials were examined every 24 hours and the number of days required for hatch were recorded.

The variations of the average rate of development (1/average number of days of development) were plotted as a function of temperature and were analyzed by linear regression and graphical techniques. The 32.2 and 35.0°C average rates of development were deleted from the analysis for all stages of P. flavedana and the egg and pupal stages of P. idaeusalis because averages for 32.2°C were close to those of 29.4°C. This indicates that the upper developmental threshold is near 30.0°C. No larvae of either species survived to the pupal stage at 35°C. Developmental thresholds for the various life stages of both species were calculated using the x-intercept method of Arnold (1959).

Varied Host Experiments

Newly-hatched P. idaeusalis and P. flavedana larvae, less than 12 hours old, were obtained from field collected egg masses which were maintained in the laboratory. These larvae were placed, singly, into plastic cages containing leaves of one of three different host plants. Cages consisted of a screen-topped, 185 ml vial inverted over a 150 ml vial filled with water. Vials were attached via plastic caps which were stapled together. Leaf petioles were wrapped in cotton and inserted through a 1 cm hole in the stapled caps into the water-filled vial. A smaller version of this cage was illustrated by McCaffrey (1981).

Host leaves used were: apple, Malus domestica; strawberry, Fragaria xananassa; and dewberry, Rubus spp. The semi-synthetic diet described previously (see page 32) was also used in this study. Apple leaves were obtained from an abandoned, mature, unsprayed tree of an unknown cultivar. Leaves of strawberry were harvested from two-year-old plants maintained in a field plot. Dewberry leaves were obtained from plants growing in an abandoned apple orchard. A leaf analysis was conducted for all hosts during the course of the study and results can be found in Appendix 1.

Leaves used in the experiment were changed every 5-7 days to maintain freshness. To minimize disruption of the

larvae during changes, the portion of the old leaf-nest or spin-up containing the larvae was transferred to the fresh leaf cluster.

Two experiments were conducted with apple. Larvae of both species characteristically cut the leaf petiole during their development (Thomas 1976). Field observations indicate that larvae typically will cut the petiole when they are approximately fourth instar. To learn whether larvae could develop to the adult stage on drying leaves without access to additional fresh leaves, larvae were provided with a fresh source of apple leaves throughout the course of one study. In the second experiment, fresh apple leaves were provided until the larvae reached the fourth instar, after which petiole cuts were simulated by removing the petioles from water and the larvae were allowed to develop on the drying leaves. In all experiments in this test, insects were reared at 23.9 ± 2°C with a 16:8 hr (L:D) photoperiod. Vials were checked daily and the number of days required to complete development from larva to adult were recorded. Data were subjected to analysis of variance and Duncan's (1951) multiple range test was used to determine differences in developmental times among hosts for each species.

RESULTS AND DISCUSSION

Developmental Threshold Determination

No significant differences in the time required to complete development were found between males and females of either species in these experiments (t-tests; $P > 0.05$). Similar findings were reported by Berkett et al. (1976) for *P. idaeusalis* in Pennsylvania. As a result, data were pooled before subsequent analyses and are presented as an overall stage average.

Table 6 contains the average time required to complete development for the egg, larval, pupal, larval plus pupal, and egg to adult stadia for both species at the seven constant temperatures used. As previously stated, we were unable to successfully rear larvae to the pupal stage at 35.0°C. Larvae reared at this temperature did not settle down and feed as those at the other temperatures did. Instead, the larvae wandered, relentlessly, around the vial until they died.

Between 15.6 and 32.2°C, the time required to complete development for all stages of both species were similar. In general, *P. flavedana* required slightly more time to complete development. At 12.8°C, *P. flavedana* required significantly more time to complete development in all stages than did *P. idaeusalis*. For *P. flavedana* there is only a margi-

Table 6. The duration in days of the stages of P. flavedana and P. idaeusalis at different constant temperatures.

Temp (°C)	n[a]	Egg $\bar{X}$ ± SE	n	Larval $\bar{X}$ ± SE	n	Pupal $\bar{X}$ ± SE	n	Larval + Pupal $\bar{X}$ ± SE	Total egg to adult $\bar{X}$ ± SE
					P. flavedana				
12.8	13	34.23±0.71	34	94.91±1.29	34	30.00±0.34	34	124.91±1.29	159.14±1.47
15.6	41	19.05±0.14	41	46.41±0.34	39	18.18±0.18	39	64.61±0.34	83.66±0.37
21.1	29	11.07±0.09	41	33.02±0.26	41	10.71±0.15	41	43.73±0.26	54.79±0.28
23.9	26	9.00±0.14	49	25.22±0.27	49	9.76±0.18	49	34.98±0.29	43.98±0.32
26.7	16	6.06±0.14	44	19.50±0.22	42	6.57±0.14	42	26.12±0.24	32.18±0.28
29.4	11	5.09±0.09	39	17.82±0.19	39	6.05±0.13	39	23.95±0.22	29.04±0.24
32.2	15	5.13±0.09	44	17.43±0.21	44	5.75±0.16	44	23.18±0.20	28.30±0.23
					P. idaeusalis				
12.8	41	28.66±0.32	42	84.05±1.21	42	27.60±0.29	42	111.64±1.22	140.30±1.26
15.6	22	17.14±0.12	53	46.98±0.32	52	17.81±0.19	52	64.83±0.30	81.96±0.32
21.1	18	10.00±0.00	40	33.08±0.24	38	10.79±0.18	38	43.87±0.23	53.87±0.23
23.9	23	7.96±0.13	39	26.26±0.16	39	9.03±0.15	39	35.28±0.18	43.24±0.23
26.7	21	5.71±0.10	38	20.74±0.15	37	7.32±0.15	37	28.08±0.33	33.80±0.21
29.4	34	5.18±0.10	35	19.60±0.33	35	5.89±0.20	35	25.49±0.33	30.66±0.35
32.2	15	5.20±0.11	34	17.85±0.24	34	6.29±0.13	34	24.15±0.24	29.35±0.26

[a]Egg masses (50-180 eggs per mass).

nal decrease in developmental time at 32.2 versus 29.4°C suggesting that the upper developmental threshold is being approached. A similar phenomenon for P. idaeusalis in the egg and pupal stages is suggested by these data. Based on these results, the upper developmental threshold for P. flavedana and the egg and pupal stages of P. idaeusalis is probably approached at 30°C. Since P. idaeusalis larvae could not be successfully reared at 35°C and developmental rates do begin to taper off at 32.2°C for the larval, larval plus pupal, and total (egg to adult) stages, 32.2°C is considered as the approximate upper developmental threshold for these stages. Berkett et al. (1976) also suggested this value for the upper threshold based on their data for P. idaeusalis.

Table 7 contains regression equations, r^2 values, standard errors of the regression coefficient, estimated lower and upper developmental threshold values, and degree-day (°C and °F) requirements for the various stadia of both species. The coefficients of determination, r^2, were high for all stages of both species with the lowest value being 0.96. This suggests a good fit of the data to the linear model (Table 7).

As suggested from the data in Table 6, the estimated lower developmental thresholds for P. flavedana are higher

Table 7. Regression equations of rate of development in relation to temperature, developmental threshold estimates, and degree-day requirements for stages of P. flavedana and P. idaeusalis.

Stage	Regression equation[a]	SE of regression coefficient	r^2	Lower developmental threshold[b] (°C)	Upper developmental threshold[c] (°C)	$\bar{X}$ °D ± SE[d] (°C)	$\bar{X}$ °D ± SE[d] (°F)
			P. flavedana				
Egg	y=-0.278112+0.005443x	0.000545	0.961	10.6	30.0	101.5±5.8	182.1±10.7
Larval	y=-0.071192+0.001498x	0.000104	0.981	8.6	30.0	379.6±12.2	681.7±22.4
Pupal	y=-0.212476+0.004415x	0.000397	0.969	9.0	30.0	126.0±4.2	229.9±6.7
Larval + Pupal	y=-0.053160+0.001115x	0.000076	0.982	8.7	30.0	506.1±14.2	907.7±26.4
Egg to adult	y=-0.045015+0.000929x	0.000066	0.980	9.1	30.0	607.2±17.6	1084.0±33.3
			P. idaeusalis				
Egg	y=-0.265275+0.005362x	0.000383	0.980	9.7	30.0	104.7±3.9	187.7±7.3
Larval	y=-0.056611+0.001268x	0.000067	0.986	7.0	32.2	442.7±11.2	796.1±20.3
Pupal	y=-0.201681+0.004264x	0.000258	0.986	8.5	30.0	132.2±3.9	237.7±7.2
Larval + Pupal	y=-0.042843+0.000955x	0.000047	0.988	7.2	32.2	538.7±11.9	1052.3±22.0
Egg to adult	y=-0.036608+0.000803x	0.000043	0.986	7.5	32.2	699.2±14 1	1251.2±25.1

[a]Regression equation is y = b + mx where y is the reciprocal of the number of days and x is temp in °F.

[b]Calculated by using x-intercept method.

[c]Determined graphically.

[d]Calculated multiplying degree-days per day by number of days required to complete development per temperature per stage for each species.

for all stages than those of P. idaeusalis. Because of the lower base temperatures, P. idaeusalis requires more °D to complete development than does P. flavedana even though P. flavedana requires more calander days to complete development.

For P. idaeusalis, differences in number of days required to complete development can be found between our data and those of Berkett et al. (1976) from Pennsylvania. Results are similar above 21.1°C, however at 21.1 and 15.6°C, their data indicate significantly more days required to complete the larval and pupal stages. We found that the larval plus pupal stadia required an average of 64.8 days to complete; they reported a requirement of 99.3 days. These differences did influence the shape of the developmental curves and thus the estimated lower base temperatures. Plotting rate of development per day versus temperature for the larval plus pupal stadia Berkett et al. found that the logistic model best fit their data; our data were best described by a linear model.

There may be several reasons for the differences in developmental rates found between the two studies. One reason may be different strains or biological races of P. idaeusalis. A second possible reason is that different semi-synthetic diets were used. Diet influenced rate of development

of several other pest species (Lamb and Loschiavo 1981, Day and Robinson 1981, Conti and Waddill 1982, Pitre and Hogg 1983; also see Varied Host Experiment section). Berkett et al. removed shed head capsules and exuviae from the diet cups when larvae were examined. These removals may have disturbed the larvae or damaged their silken nests thus diverting energy from growth to avoidance reactions or nest repair. Also, these examinations may have disrupted feeding by the larvae, perhaps influencing growth. The cumulative effect of these disruptions over the duration of the larval stage may have been important. In our studies, larvae were not disturbed during their development. Finally, a combination of the above speculations and possibly others may have accounted for the differences observed.

Varied Host Experiments

Host influenced rate of development from larva to adult for both species (Table 8). Both species developed fastest on the semi-synthetic diet and less rapidly on strawberry, apple, and dewberry, respectively.

Days required to complete development were similar in the two apple experiments for both species. These data suggest that larvae do not need to leave their leaf shelter after the petiole is cut to find fresh food. Whether the

Table 8. Development of P. flavedana and P. idaeusalis on several different hosts.

Host[a]	$\bar{X}$ no. of days from larva to adult[b,c]	
	P. flavedana	P. idaeusalis
Artificial diet	30.6 a	31.8 a
Strawberry	34.6 b	38.1 b
Apple - fresh	36.1 c	43.0 c
Apple - petiole cut simulated	36.8 c	43.6 c
Dewberry	42.7 d	44.4 c

[a]Artificial diet (Shorey and Hale 1965); strawberry, Fragaria xananassa; apple, Malus domestica; dewberry, Rubus spp.

[b]Constant 23.9±1°C

[c]Means followed by the same letter in the same column are not significantly different ($P < 0.05$); Duncan's (1951) multiple range test.

larvae stopped feeding during this time or fed on the drying leaf was not determined. In either case, these results have control implications. If the larvae do not leave their shelters during these later stages of their development, they probably will not come in contact with toxicants during this time unless insecticides penetrate the leaf nest. Thus, insecticide sprays may not be effective at this time.

The reasons why larvae cut the leaf petiole at this particular time are not known, but it may not be a haphazard event. If petiole cut was simulated in the laboratory when larvae of both species were early third instar, they failed to develop to the pupal stage. Consequently, if larvae do not feed on additional leaves after petiole cut, then this cut may be timed to coincide with a certain point in their development. It may be hypothesized that the drying leaf serves as a protective barrier against parasites, or predators, and may act as a barrier against pesticide penetration. This may also be a defensive mechanism against slow-acting defensive chemicals secreted by the plant which are toxic (Kogan 1975) to the developing larvae. It is also possible that the larvae may cut the petiole(s) to stop leaf transpiration and increase temperatures within its leaf nest. Such a temperature rise has the potential to increase the rate of development. Ferro et al. (1979), studying ap-

ple leaves, illustrated that transpiration can significantly affect temperature within the leaf boundary layer. Further research in these areas is required before the purpose of leaf petiole cutting can be fully understood.

Results of these experiments indicate that host can influence rate of development for both species. Since both species feed on numerous host plants during the growing season, the potential for a wide range of developmental rates and subsequent adult emergence times is enhanced. Variability in pheromone trap catch numbers experienced for these species may be partly attributable to their feeding on alternate hosts (see Chapter 6). Additional research in the area of host influence on developmental rates of these pests may allow us to interpret pheromone trap data with greater accuracy and reliability in the future.

The influence of host on fecundity was not studied in these experiments. However, host has been reported to influence fecundity of several pest species (Day and Robinson 1982, Drolet and McNeil 1984). Experiments in this area for both P. flavedana and P. idaeusalis may prove productive.

Chapter V

WITHIN-TREE SPATIAL PATTERN OF EGG MASSES AND FRUIT DAMAGE OF P. FLAVEDANA AND P. IDAEUSALIS IN VIRGINIA APPLE ORCHARDS

INTRODUCTION

P. flavedana and P. idaeusalis are two of the most important arthropod pests of apples in Virginia. While both species are pests in the state, they are generally not both a serious problem in an individual apple growing region. P. idaeusalis is the predominant species in the upper Shenandoah Valley, while P. flavedana predominates in the Piedmont region (David 1982).

Life history studies of P. flavedana, in Virginia, have been reported (Bobb 1972, Hill and Thomas 1976). The life cycles of P. flavedana and P. idaeusalis are quite similar in Virginia and each has two generations per year (Hill and Thomas 1976).

To control these pests, orchards should be sampled regularly during egg deposition and hatch periods to determine proper timing for spray application. Sprays must be timed to coincide with egg deposition and hatch periods for maximum effectiveness.

There is very little information available on the spatial distribution and dispersal of leafrollers and budmoths in general (Hoyt et al. 1983) and information is lacking for P. flavedana and P. idaeusalis. One objective of the studies reported in this paper was to determine the within-tree spatial pattern of egg masses and larval damage to fruit for P. flavedana and P. idaeusalis. A second was to determine whether tree-to-tree dispersal of larvae of the pests occurred.

MATERIALS AND METHODS

Egg Mass Sampling

Three orchards in Frederick Co., Va. where P. idaeusalis was the predominant species and three orchards in Nelson Co., Va. where P. flavedana was the predominant species were sampled during 1982-83. The Frederick Co. orchards were sampled in 1984 as well. Species composition of the orchards was determined by past history, pheromone trap catches, and larval sampling. Due to topography, tree rows in the Frederick Co. research orchards ran from north to south and in Nelson Co. they ran from east to west. All orchards sampled were commercially operated. In each orchard, at the beginning of each generation, ten new trees bearing at least one egg mass were randomly selected for

study. All trees were spur Delicious cultivar, approximately 3.9 m tall and 15 years old. Tree spacing was approximately 4.6 m between trees within a row and 6.1 m between rows.

Trees were divided into 32 sections using flagging tape. Each tree was divided vertically into four strata: 0-0.9 m, 0.9-1.8 m, 1.8-2.7 m, and 2.7-3.7 m. Trees were further divided into the four quadrants of the compass. Finally, the tree canopy was divided into inside and outside foliage. To achieve approximately equal volumes of foliage in this final division, 70% the distance from the tree trunk was considered inside and the rest outside. (The cross-sectional area is proportional to the square of the diameter.)

Trees were examined visually for egg masses which both species lay on the upper leaf surface. Sampling was conducted when egg hatching for a given generation ceased. This allowed detection of egg masses because hatched egg masses are white and easily seen whereas unhatched egg masses are greenish-yellow and are thus camouflaged on the leaves. To collect accurate second generation data, trees were examined at the beginning of the oviposition period for that generation. At that time, all first generation egg masses were removed. Data were recorded as the number of egg masses per section of foliage.

Fruit Damage Sampling

During the 1983-84 growing seasons, five trees were randomly selected in one of the Frederick Co. orchards sampled in the egg mass study and one of the Nelson Co. study orchards. All the fruit on each of these trees were examined. Trees were partitioned as in the egg mass study (page 47), except that only two vertical strata were used: 0-1.8 m and 1.8-3.7 m above ground. In each tree section the number of fruit and fruit damaged by first and second generation P. flavedana (Nelson Co.) and P. idaeusalis (Frederick Co.) larvae were recorded.

Data in both studies were analyzed using the multivariate log-linear heirachical-modeling approach of Bishop, Feinberg, and Holland (1975). Also see Feinberg (1980) for further discussion. The effects and interactions of explanatory variables were dropped from the model if they were not significant at the 0.05 level. In the Egg Mass and Fruit Damage Sampling sections of the Results and Discussion, the term significant is used in this sense exclusively.

Larval Dispersal Study

During 1983-84 tree-to-tree larval dispersal was determined for both P. flavedana (Nelson Co.) and P. idaeusalis (Frederick Co.). Four, 2.3 liter, wire-mesh, cylindrical traps (ca. 16.5 cm high and 13.3 cm in diameter) were hung between adjacent apple trees within a row. Traps were suspended, vertically, from a common rope which was attached to a horizontal rope secured to two, 3 m poles which were strapped to the trunks of the adjacent trees. The traps were hung at heights of 1, 2, 3, and 4 m above ground. Trees were approximately 4 m tall. Each trap was covered with a close-fitting plastic bag, the vertical surfaces (ca. 690 cm^2) of which were sprayed with Tangle Trap® adhesive. The lower end of the rope supporting the cylindrical traps was attached to a square, horizontal plywood trap (ca. 690 cm^2) which was also covered with plastic and sprayed with adhesive. The plywood trap was nailed to a stake so that its horizontal surface was 15 cm above ground. These methods have been modified from those described by Beckwith and Burnell (1982).

Ten replicates were used per orchard. Traps were sprayed with adhesive approximately one week before first oviposition of both the first and second generation. Experiments were evaluated two to three weeks after the last egg

hatch, for a given generation, of both species. Using a 3.5X binocular magnifier, the number of larvae caught per trap were counted. Samples of the larvae were taken to the laboratory where head capsule measurements were made to determine the instar. Data were subjected to analysis of variance and Duncan's (1951) multiple range test was used to determine differences among mean counts for the trap heights.

RESULTS AND DISCUSSION

Egg Mass Distribution

Temporal Variation of Egg Mass Counts

Significantly more egg masses per tree were found for P. idaeusalis (TABM) than P. flavedana (VLR) for each generation except for the second generation of 1983 (Figure 2). The 1984 data for P. flavedana in Figure 2 represent the average number of egg masses found per tree during both first and second generations. No significant differences in numbers of egg masses per tree were found during the first and second generations of P. idaeusalis during 1982 and 1983. During 1984, populations of P. idaeusalis climbed significantly higher than in previous years. This may be explained by a reduced number of insecticide applications because of a very light crop load (R. Edwards per. commun.).

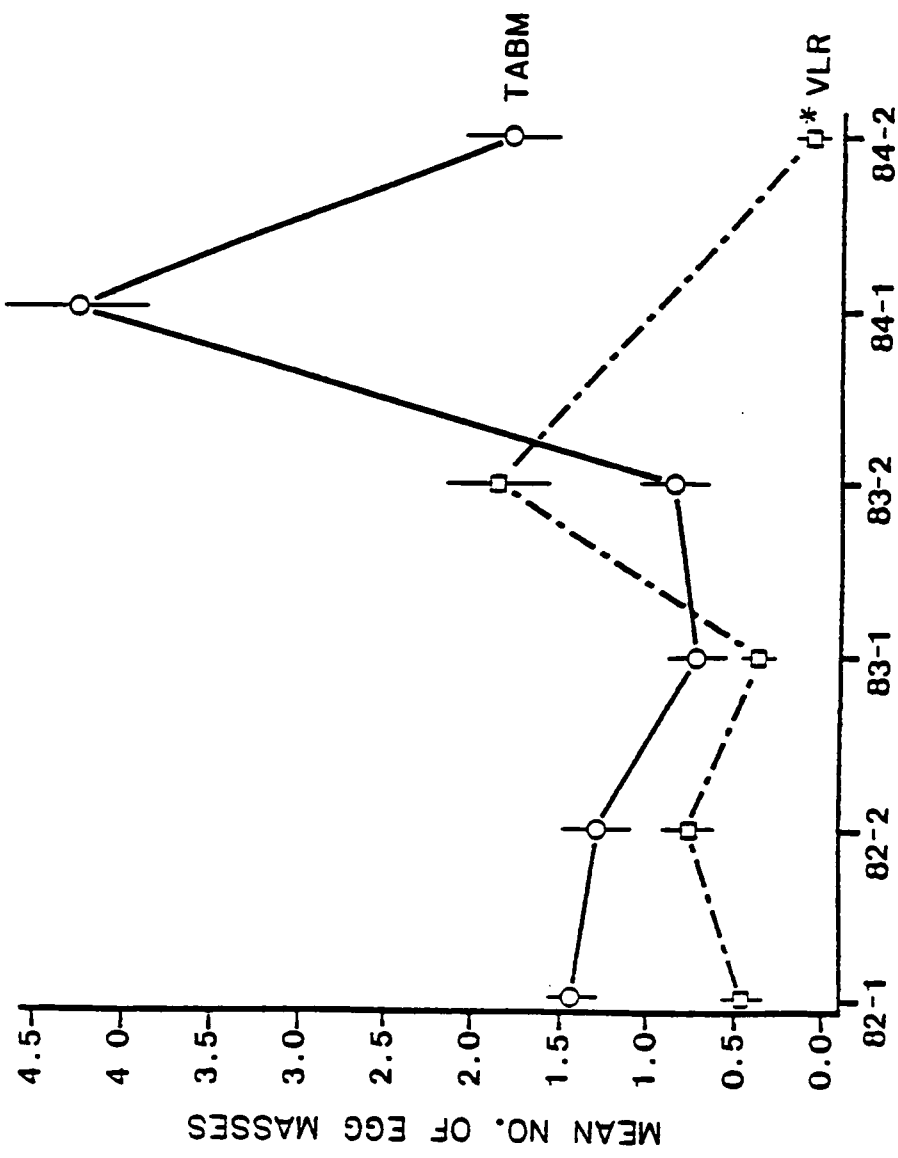

Fig. 2. Average (±1SE) egg mass count per tree. TABM = P. idaeusalis; VLR = P. flavedana; * 1984 total count of generation 1+2 for VLR.

P. flavedana egg mass counts were significantly greater in the second generation than in the first during both 1982 and 1983.

In the Nelson Co. orchard used for the 1984 fruit damage sampling, the average P. flavedana first and second generation egg mass counts were 0.1 per tree (Figure 2). These data did not lend themselves to further analysis. The crop in this orchard during 1984 was extremely good, consequently the grower (W. Flippin, per. commun.) made approximately 30% more insecticide applications than he did in previous years. As a result, leafroller populations were reduced to very low levels in the 1984 growing season.

Within-tree Spatial Pattern of Egg Masses

No significant differences were found between orchards, within a county, in terms of spatial pattern of egg masses over the course of the study. Also, no significant differences were observed in the spatial pattern of egg masses between years for either species. Consequently, data from all orchards and years (1982-83) were pooled, within a county, for further analysis (see Figure 3). Significant differences were found in egg mass distributions between generation one and two for P. idaeusalis during 1982 and 1983, but no differences were found between generations for P.

flavedana. As a result, data for generations of P. flavedana were pooled. Although 1984 P. idaeusalis, egg populations were two to three times as high as those of 1982-83 no significant differences were found in terms of spatial pattern of egg masses as compared to previous years. However, as will be discussed later, no significant differences were found for spatial pattern between generations, contrary to the results of 1982-83.

Since tree rows ran in opposite directions for both species in the study, we were unable to definitively determine whether differences observed between quadrants could be attributed exclusively to the species effect. Both species have been observed to oviposit only at night (Bobb 1972, David, personal observation) suggesting that row direction may possibly have a minimal effect.

DEPTH. Twice as many egg masses of P. idaeusalis were found in the outside portion (avg = 1.1) of the canopy versus the inside portion (avg = 0.5). For P. flavedana, seven times as many egg masses were found in the outside portion versus (avg = 0.7) versus the inside portion (avg = 0.1). For subsequent analyses the data for the inside and outside portions of the canopy were combined. From these data for both species, it appears that in a program where detection of the presence or absence of egg masses is the major con-

cern (e.g. to confirm events predicted by degree-day accumulations), a considerable amount of time may be saved by sampling just the outside portion of the tree.

HEIGHT. In the Nelson Co. orchards (Figure 3), significantly more egg masses were found in the 0-0.9 m portions of the tree versus all other strata. This was particularly noticeable in the southern and eastern portions of the tree. Fewer egg masses were found in the 0.9-1.8 m portion, very few in the 1.8-2.7 m portion, and none above 2.7 m. These data indicated that the majority of the egg masses (96%) in the Nelson Co. study sites were found below 1.8 m which suggests that sampling efforts should be concentrated in this portion of the tree.

A significantly greater percentage of egg masses in Frederick Co. during 1982-83 were found below 1.8 m during both generation one and two (78% and 89%, respectively) (Figure 3). Some egg masses were found in the 1.8-2.7 m portions and during generation one a few egg masses were found above 2.7 m. While egg masses could be found throughout the tree, the majority of them were found below 1.8 m. Most of these egg masses were found in the 0.9-1.8 m section during generation one, but in generation two the majority were in the 0-0.9 m portion of the tree.

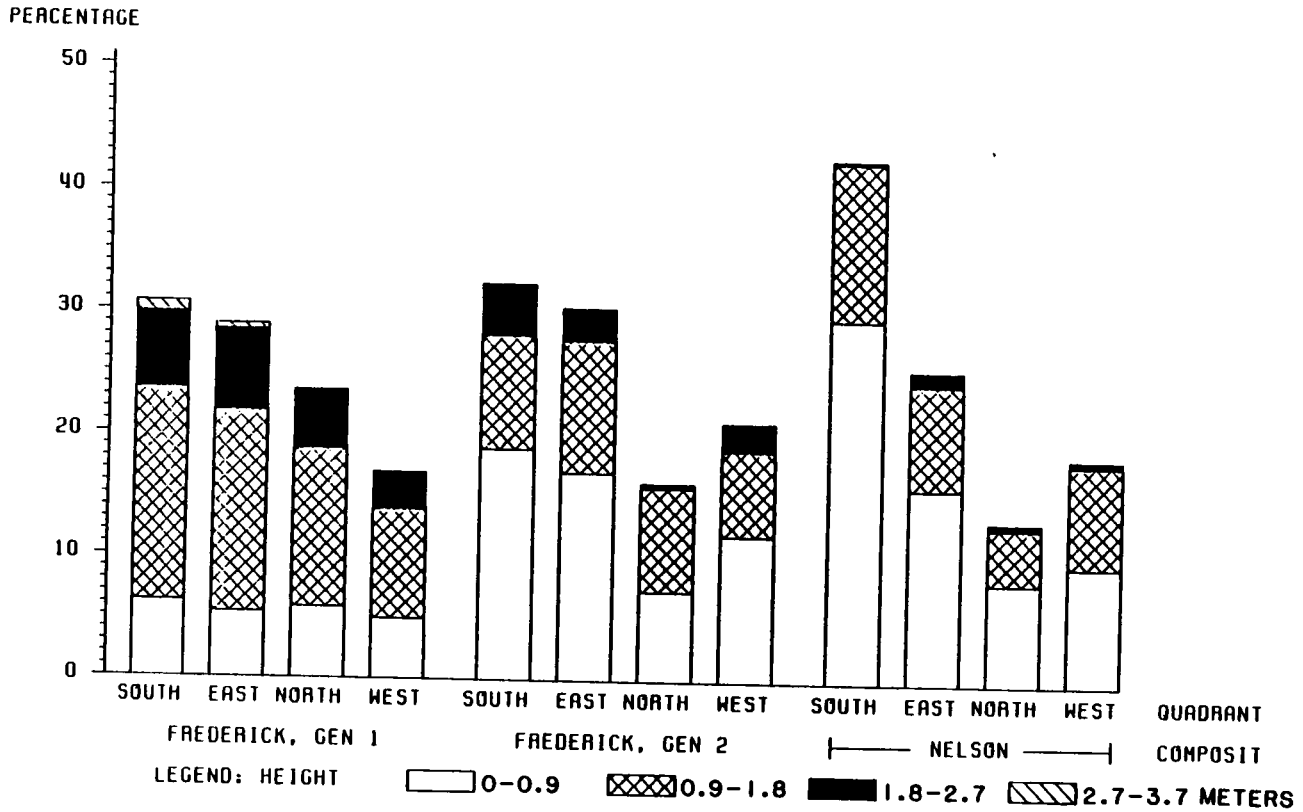

Fig. 3. Within-tree spatial pattern of egg masses in Frederick Co. (P. idaeusalis) and Nelson Co. (P. flavedana), 1982-83 composite. Percentage = 100 X count in section/total count in all sections. GEN = generation. Nelson Co. data a composite of gen. 1 and 2.

We found that the within-tree distribution of foliage changed drastically throughout the growing season with the lower portion of the tree becoming increasingly more dense because the increasing fruit weight pulled the branches down. Consequently, there was more foliage in the lower portion of the tree during the second generation egg laying period. In 1984, there was an extremely poor fruit set in the Frederick Co. study orchards; most trees had little or no fruit on them. These trees were sampled for eggs over both generations to see whether fruit load influenced spatial pattern of egg masses. There were no significant differences between generations in terms of distribution of egg masses by height (Figure 4). The influence of fruit weight on foliage distribution within the tree canopy may partially explain the greater number of egg masses lower in the tree during the second generation of P. idaeusalis in Frederick Co. In Nelson Co., the vertical distribution of egg masses of P. flavedana was apparently not significantly affected by fruit weight during the second generation because it oviposits in the lower portion of the tree.

QUADRANT. In Nelson Co., significantly more P. flavedana egg masses were found in the southern portion of the trees than in other quadrants (Figure 3). Of the egg masses found, 69 percent were found in the southern and eastern

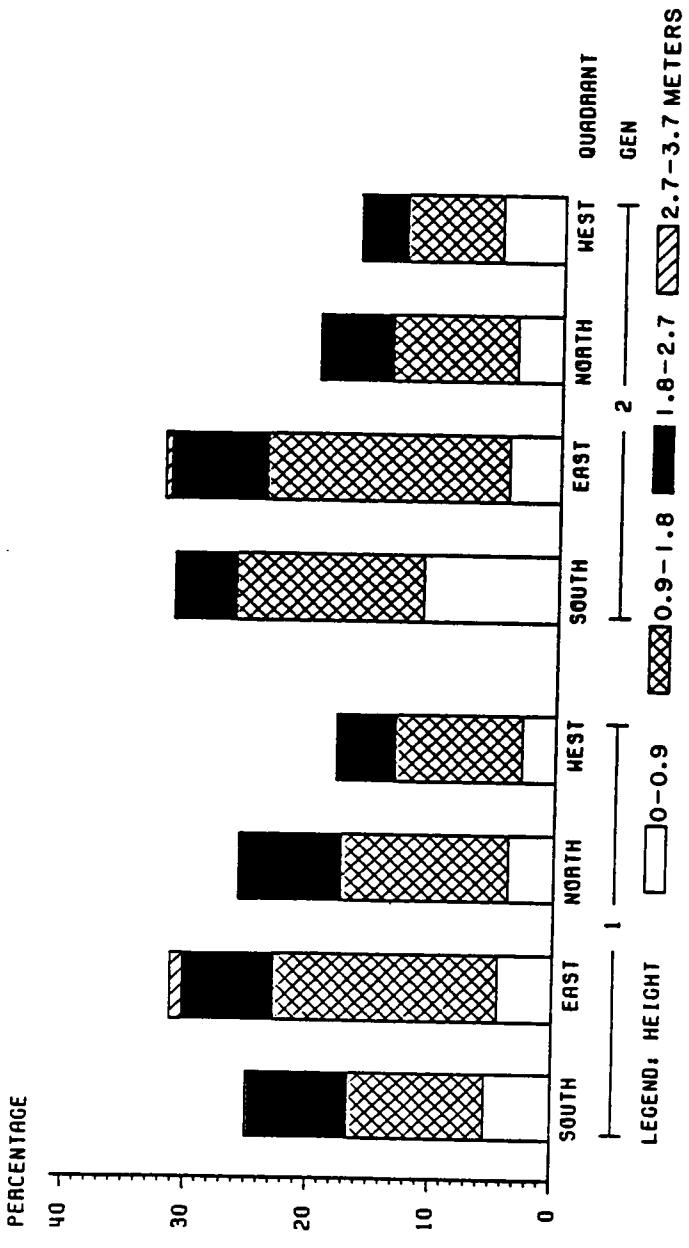

Fig. 4. Within-tree spatial pattern of egg masses in Frederick Co. (P. idaeusalis), 1984. GEN = generation. Percentage = 100 X count in section/total count in all sections.

quadrants of the trees. Significantly fewer egg masses were found in the northern and western quadrants than the southern and eastern portions of the tree.

In 1984, ten trees were examined for egg masses of P. flavedana in Nelson Co. As previously mentioned, P. flavedana egg mass counts were extremely low. While data were not appropriate for statistical analysis, all egg masses were found below 1.8 m and the majority of them were found in the southern portion of the tree (see Figure 8).

In Frederick Co., for P. idaeusalis, a similar phenomenon was observed with a significantly greater percentage of the egg masses being found in the southern and eastern quadrants of the tree versus the northern and western portions during both generations in 1982-83 (Figure 3). The same trend was also observed in 1984 even though populations were significantly higher than those observed in previous years (Figure 4). No significant differences were observed between the numbers of eggs found in the southern and eastern portions of the tree for both generations throughout the course of this study. MacLellan (1962) observed that eggs of the codling moth were mainly laid in the southeast portion of apple trees in the first generation of this pest, but oviposition showed a more uniform distribution during the second generation.

Neuenschwander and Michelakis (1979), studying olive trees, found significant differences in temperatures in different parts of the olive tree canopy. At daily maximum temperatures, shade air temperatures on the north side of the tree were only slightly above temperatures in the interior of the tree. However in the sunny southern side of the tree, differences were found to be as high as 8.1°C between the outside and the cooler inside portion of the canopy. The outer portions of the tree were only slightly warmer than the inside of the tree at sunrise. However, temperature at the leaf surface may differ greatly from air temperature. As Ferro et al. (1979) illustrated, many factors (e.g. environmental, horticultural) can influence leaf surface temperature. It is possible that oviposition of P. flavedana and P. idaeusalis females is influenced by temperature. Females may deposit their eggs within the tree canopy where the eggs would be exposed to greater temperatures and thus have faster developmental rates. However, further studies on the influences of temperature, leaf microclimate, and radiation on ovipositional behavior are necessary to test this hypothesis.

The color of unhatched egg masses of both species blends in quite well with apple leaves, thus eggs are difficult to locate. Samples may underestimate actual population

size by 30-50% (David, unpublished data). However, effective control of these leafrollers requires that sprays be directed at the egg or newly-hatched larvae, consequently, sampling is necessary. Further studies need to be conducted on the within-orchard dispersion of egg masses for both species before a satisfactory sampling program can be developed. This could yield a sequential sampling plan. Until those studies are conducted, a grower or scout sampling for egg masses, assuming a fixed amount of time is available, probably should sample more trees less intensely rather than fewer trees more intensely. Since the majority of the egg masses in our study sites for both species were found below 1.8 m in the outside, southern and eastern portions of the canopy, sampling should be concentrated in these areas. Focusing on these areas rather than the whole tree, a scout would be able to examine a greater number of trees in a fixed amount of time and get a reliable determination of the presence, absence, or density of the eggs.

Larval Dispersal

No significant ($P > 0.10$) differences were found between trap heights for either species or either generation during 1983 and 1984 in terms of number of first-instar larvae caught. The average number caught per generation per

trap during the study ranged from 0.2-4.8 for P. idaeusalis and 0.3-0.8 for P. flavedana. The horizontal plywood traps were removed from the study due to excessive contamination of the trap surface by debris produced by various cultural practices (e.g. mowing, tree-hoeing, broadcast fertilizer application). However, several larvae were counted on these traps indicating that some individuals may land in the ground cover.

Thomas (1976) found that in later stages of their development P. flavedana larvae moved within the tree canopy. The movement was usually the result of environmental conditions which resulted in the loosening of the silken mooring of the insect. This caused it to fall to the next lower branch. Thus it appears that once first-instar larvae settle into a habitat, there is little directed movement to new habitats unless they are disturbed in some way.

This study indicates that dispersal of first-instar larvae between trees probably occurs just after eclosion. While numbers of larvae caught per trap were small, when trap size is related to tree size, these numbers become significant. Consequently, there appears to be a considerable redistribution of larvae just after eclosion. Environmental conditions (e.g. rain, wind speed, temperature) occurring during that time probably greatly influence the redistribu-

tion of larvae. This phenonmenon may be of considerable importance in sampling programs and interpretation of data based on the larval stage of these leafrollers.

Fruit Damage Distribution

Temporal Variation of Fruit Damage

In Frederick Co., fruit damage at harvest caused by P. idaeusalis larvae was 11% in 1983 and 42.3% in 1984. P. flavedana larvae in the Nelson Co. site caused 3.8% damage in 1983 and 0.4% in 1984.

No significant differences were found in terms of total fruit frequency per tree between the various quadrants during both 1983 and 1984 except during 1983 in Frederick Co. for the 1.8-3.7 m section of the canopy. In this year, significantly more fruit were found in the south (avg = 161) and east (avg = 128) quadrant than in the north (avg = 81) and west (avg = 75) quadrant. To minimize this effect, damage was converted to a percent; total fruit damaged within a section was divided by total fruit within the section.

Within-tree Spatial Pattern of Fruit Damage

DEPTH. Significant differences were observed for the within-tree distribution of fruit damage for both species. Of the 11% fruit damage caused by P. idaeusalis larvae in

the Frederick Co. site during 1983, 40% was found in the inside portion of the tree canopy and 60% was found in the outside portion. During 1984, 45% of the 42.3% total damage was found in the inside section and 55% was found in the outside portion of the canopy. In the Nelson Co. site during 1983, of the 3.8% total damage caused by P. flavedana larvae, 58% was found in the outside section and 42% was found inside. P. flavedana damage to fruit in 1984 was negligible and too low for analysis (see Figure 6). For the P. idaeusalis fruit damage and the 1983 P. flavedana fruit damage, the inside and outside portions of the canopy were combined for subsequent analyses of spatial patterns.

HEIGHT. In Frederick Co., a significantly greater percentage of the fruit were damaged in the lower (0-1.8 m) portion of the tree versus the upper (1.8-3.7 m) portion during both 1983 and 1984 (Figures 5 and 6, respectively). Similar percentages of damaged fruit were found in the 0-1.8 m and 1.8-3.7 m strata in Nelson Co. during 1983 (Figure 5).

QUADRANT. In Frederick Co., significantly more fruit were damaged in the southern, western, and eastern sections of the tree versus the northern portion in both 1983 and 1984. Similar percentages of fruit were damaged in the south and east sections in 1983, but significantly more fruit were damaged in the eastern quadrant of the trees dur-

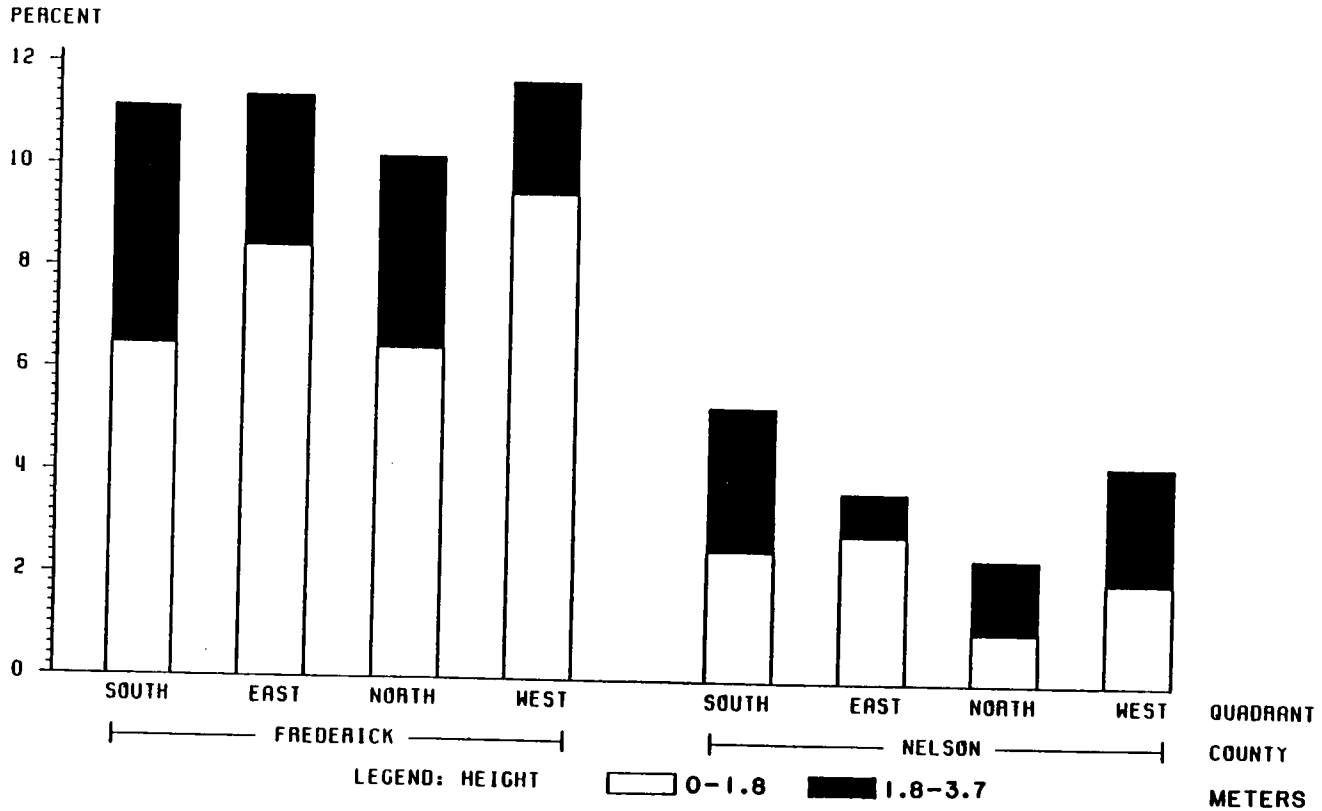

Fig. 5. Within-tree spatial pattern of fruit damage caused by P. idaeusalis (Frederick Co.) and P. flavedana (Nelson Co.), 1983. Percent = 100 X fruit damaged within section/total fruit within section.

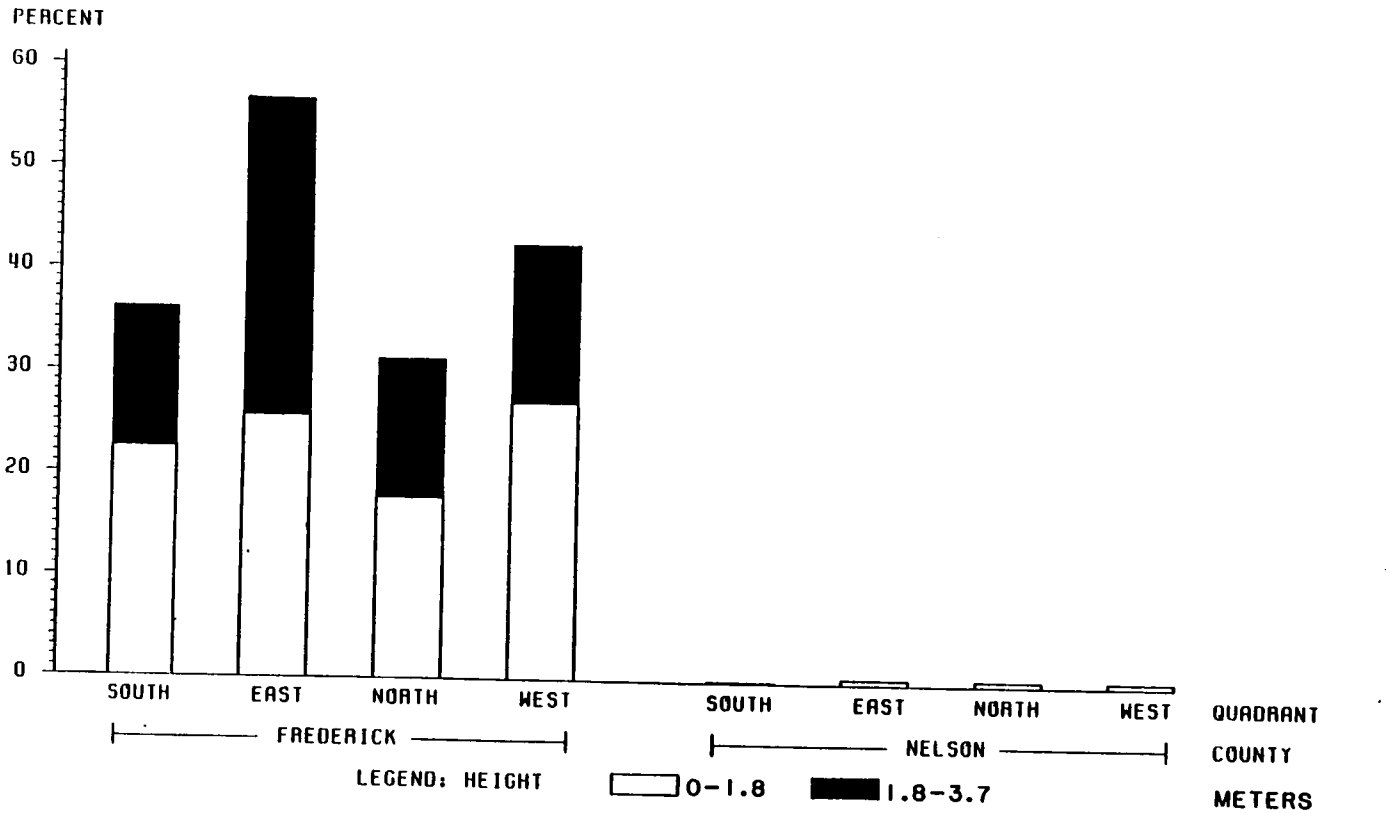

Fig. 6. Within-tree spatial pattern of fruit damage caused by P. idaeusalis (Frederick Co.) and P. flavedana (Nelson Co.), 1984. Percent = 100 X fruit damaged within section/total fruit within section.

ing 1984 (Figures 5 and 6). Significantly more fruit were damaged by P. idaeusalis larvae in the western portions of the tree during both years as compared to the northern section.

Significantly more fruit damage was found in the southern and western quadrants of the tree versus the northern and eastern portions in the Nelson Co. site during 1983 (Figure 5). A significantly greater proportion of the fruit was damaged in the southern versus the eastern sections of the trees. Similarly, a significantly greater percentage of damaged fruit was found in the western quadrant as compared to the northern portion of the tree (Figure 5).

There is an apparent but not significant relationship between the number of egg masses within a quadrant and the percent of damaged fruit within that quadrant. Figures 7 and 8 isolate the within-tree distribution of egg masses in orchards sampled for fruit damage in the two counties during 1983 and 1984, respectively. In Figure 6 for Frederick Co., significantly more fruit were damaged in the east portion of the tree, also there were significantly more egg masses in the eastern quadrant (Figure 8). However, while a direct relationship does appear to exist between egg mass number and fruit damage, there are also significant and similar amounts of damage in portions of the trees where no egg masses

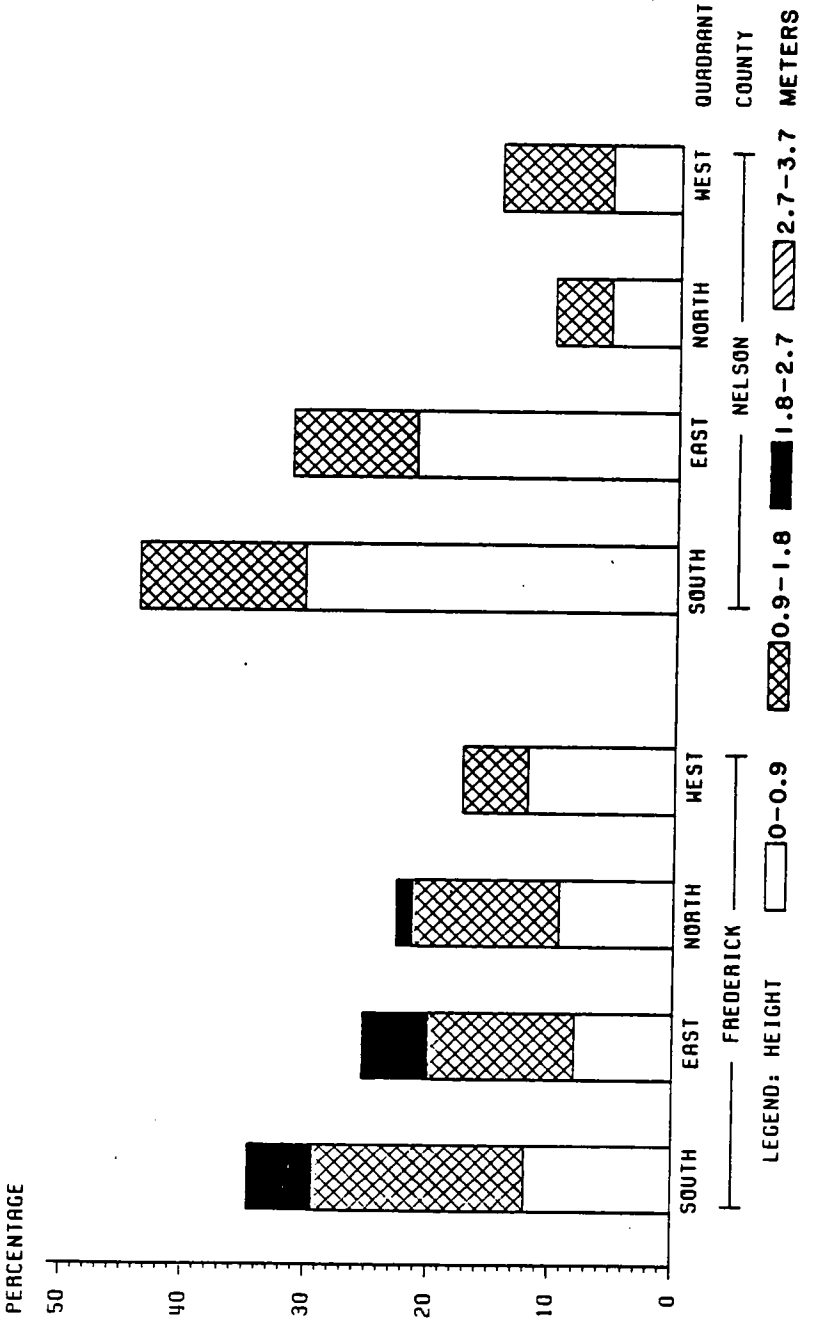

Fig. 7. Within-tree spatial pattern of egg masses in the Frederick Co. (P. idaeusalis) and Nelson Co. (P. flavedana) orchards where fruit damage was sampled, 1983. Generation one plus two composites. Percent = 100 X count in section/total count in all sections.

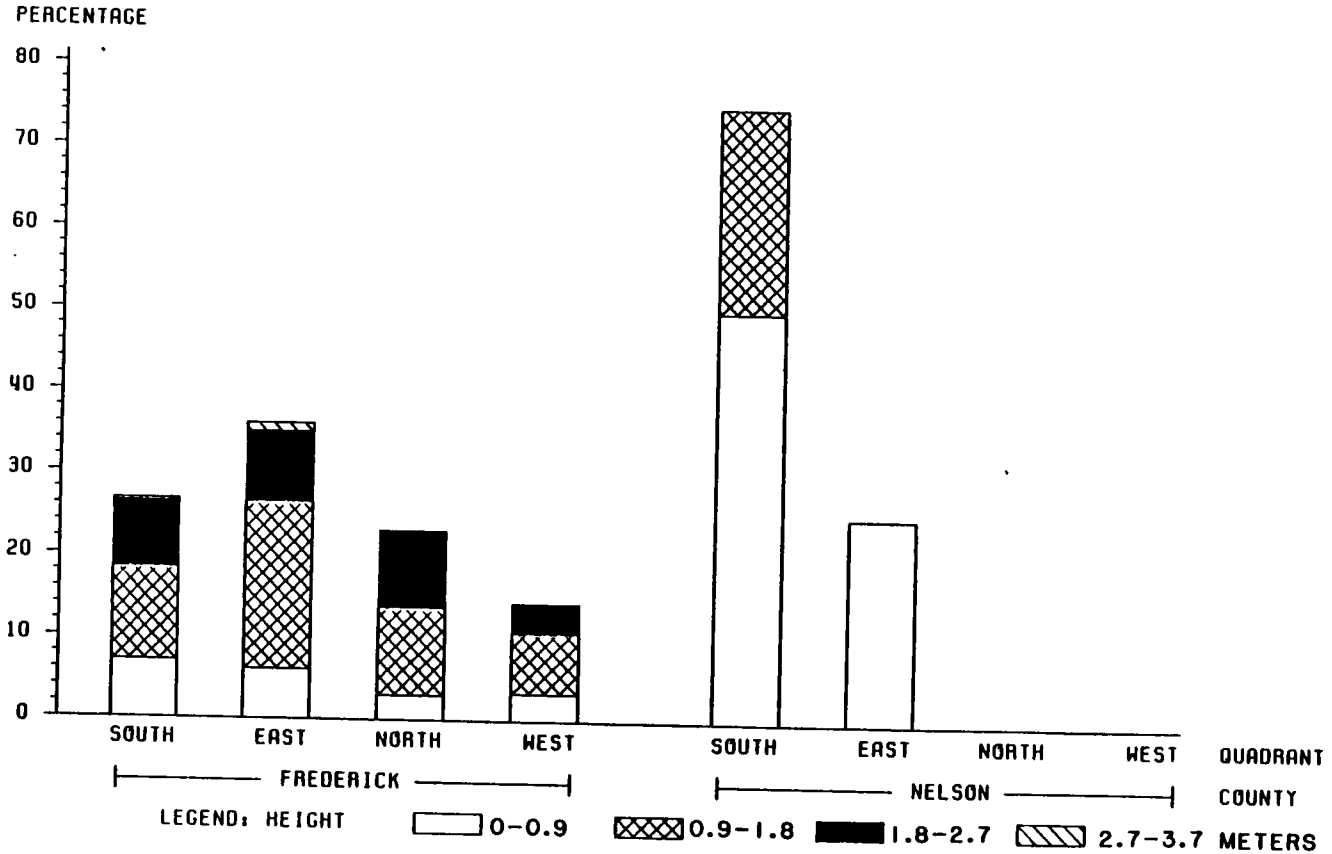

Fig. 8. Within-tree spatial pattern of egg masses in the Frederick Co. (P. idaeusalis) and Nelson Co. (P. flavedana) orchards where fruit damage was sampled, 1984. Generation one plus two composites. Percent = 100 X count in section/total count in all sections.

were found as compared to areas preferred for oviposition. In Nelson Co. during 1983, Figure 7 indicates that no egg masses of P. flavedana were found above 1.8 m in the trees, while Figure 5 shows that 3.1% of the fruit above 1.8 m were damaged. These results support those of the larval dispersal study because: 1) there appears to be a significant amount of dispersal of first-instar larvae of both species and 2) this movement significantly influences within-tree distribution of larvae and subsequent fruit damage.

Results of these studies suggest that egg masses in Nelson Co. (P. flavedana) and in Frederick Co. (P. idaeusalis) can be found mostly below 1.8 m above ground in the southern and eastern, outside portions of apple trees. Fruit damage distribution observed for both species in the study orchards appeared to be directly related to the distribution of egg masses with greater damage being found in quadrants of the tree where more egg masses were found. However, dispersal of first-instar larvae between trees appeared to alter the within-tree distribution of fruit damage for both species. Data generated in these studies is part of that necessary for the development of a comprehensive sampling plan for these destructive pests.

Chapter VI

SEASONAL ACTIVITY OF P. FLAVEDANA AND P. IDAEUSALIS IN VIRGINIA APPLE ORCHARDS

INTRODUCTION

The tortricid leafrollers, P. flavedana and P. idaeusalis, are two of the most important pests of apples in Virginia. Preliminary studies have suggested that P. flavedana is the most important leafroller species in the Piedmont region of the state while P. idaeusalis predominates in the upper Shenandoah Valley (David 1982). Currently, insecticides are used extensively to control these pests. Use of an efficacious material (VPI and SU 1984b), and proper timing of sprays are the most important factors in successful leafroller control. For these pests, insecticide applications should be directed at the egg or newly-hatched, first-instar larval stages (David 1982, Rock and Shaltout 1983). Once the larvae build their leaf nests, control becomes increasingly more difficult.

Pesticide applications have traditionally been timed against early-season, tree-fruit pests based on tree phenology with a variable degree of success (Herne and Trottier 1975, Trottier and Herne 1979, Hull and Starner 1983). However for mid- to late-season pests, tree phenology is less

useful and sprays are either applied on a regular schedule (VPI and SU 1984a) or are timed for particular pests using calendar days. Using a schedule, sprays are often protective in nature and may not be required. The calendar method when used by experienced growers can be fairly reliable against certain pests (e.g. San Jose scale) in typical years. However in years where the season has been warmer or cooler than average, this method involves considerable guesswork and can yield disappointing results.

Degree-days have been used successfully or proposed for use as a tool for timing sprays against several tree fruit pests (e.g. Hagley 1973, Riedl et al. 1976, Johnson et al. 1979, Trottier 1980, Jorgensen et al. 1981, Rice et al. 1984). The purpose of this study was to relate male moth flights, egg deposition, and hatch periods of both P. flavedana and P. idaeusalis to degree-day accumulations.

MATERIALS AND METHODS

A variable number of orchards in Frederick Co. were monitored for male moth flights and sampled for egg masses of P. idaeusalis during 1982-84. The number of orchards monitored were: 6 in 1982, 8 in 1983, and 3 in 1984. Although all study orchards were sampled for egg masses during the early parts of the oviposition periods for both generations,

some did not have adequate numbers (e.g. less than two egg masses per thirty trees at the peak oviposition period) for analysis and were deleted from the egg mass monitoring portion of the study. Consequently, the number of orchards sampled for egg masses during the study were: 4 in 1982, 5 in the first generation and 2 in the second generation of 1983, and 1 in 1984. For P. flavedana, two orchards in Nelson Co. were monitored for male flights and sampled for egg masses during 1982 and 1983.

Male moth flights were monitored in each orchard using the Pherocon 1C sticky trap (Zoecon Corp.) baited with a sex attractant. For P. flavedana, the attractant used was a rubber septa impregnated with 2.5 mg of sex pheromone (Hill et al. 1977), prepared by Zoecon Corp. With P. idaeusalis, Zoecon's standard, commercially-available sex pheromone (Hill et al. 1974) and dispenser was used. Traps were hung 1.7 m above ground in the outside portion of the tree canopy. Sticky liners and pheromone dispensers were changed every three weeks or sooner if necessary. In 1982, three of each type of trap were used per orchard; while in 1983 and 1984, five of each trap were used per orchard. Pheromone traps were deployed in the study orchards from mid-April until late-October.

To determine the egg deposition and hatch periods of both species, thirty trees, which were randomly selected and tagged during the dormant stage of bud development, were sampled weekly or more frequently during the season. The foliage of the trees was examined visually for egg masses to a height of 1.8 m above ground. In a seperate study the majority of the egg masses of both species were found within 1.8 m of the ground (see Chapter 5). Egg hatch was monitored by observing tagged egg masses.

Hygrothermographs contained in modified Stevenson Screen weather stations were used to monitor temperature within the study orchards. A weather station was placed at each of the study sites except for one orchard in Frederick Co. during both 1982 and 1983. The weather data for this orchard were obtained from an adjacent site approximately 0.4 km away at a similar altitude. Degree-days were calculated from daily minimum and maximum temperatures according to the sine-wave method of Baskerville and Emin (1969). For P. flavedana, the lower and upper developmental thresholds used were: 9.1 and 30.0 °C, respectively. The lower and upper developmental thresholds used for P. idaeusalis were: 7.5 and 32.2 °C, respectively (see Chapter 4). (Weather, pheromone trap, and sampling data collected during this study are on file at the Winchester Fruit Research Laboratory.)

To determine 10, 50, and 90% moth catch degree-day estimates, average weekly moth catches per species per generation for each orchard were converted to cummulative percent of total moth catch. The probit of the cumulative percent catch was plotted against the $\log_{10}$ of the degree-day accumulation. Using the Statistical Analysis System (SAS Inst. Inc. 1982), equations of the form $Y = b + mx$ were fit to the data; "Y" is the probit of the cumulative emergence estimate, "b" is the intercept of the regression line, "m" is the regression coefficient, and "x" is the $\log_{10}$ of the cumulative number of degree-days. Using the appropriate "Y" emergence value, the equations could be solved for "x" or $\log_{10}$ degree-days.

RESULTS AND DISCUSSION

Figures 9 and 10 illustrate the typical pattern of male moth flights and egg deposition for P. idaeusalis and P. flavedana, respectively, in a given orchard. These figures are used to illustrate basic population trends. The julian date of event occurrence and the magnitude of moth catches and egg mass numbers may differ from year to year and from site to site.

For P. idaeusalis, peak oviposition occurs 10 to 21 days after peak moth flights during generation one. While

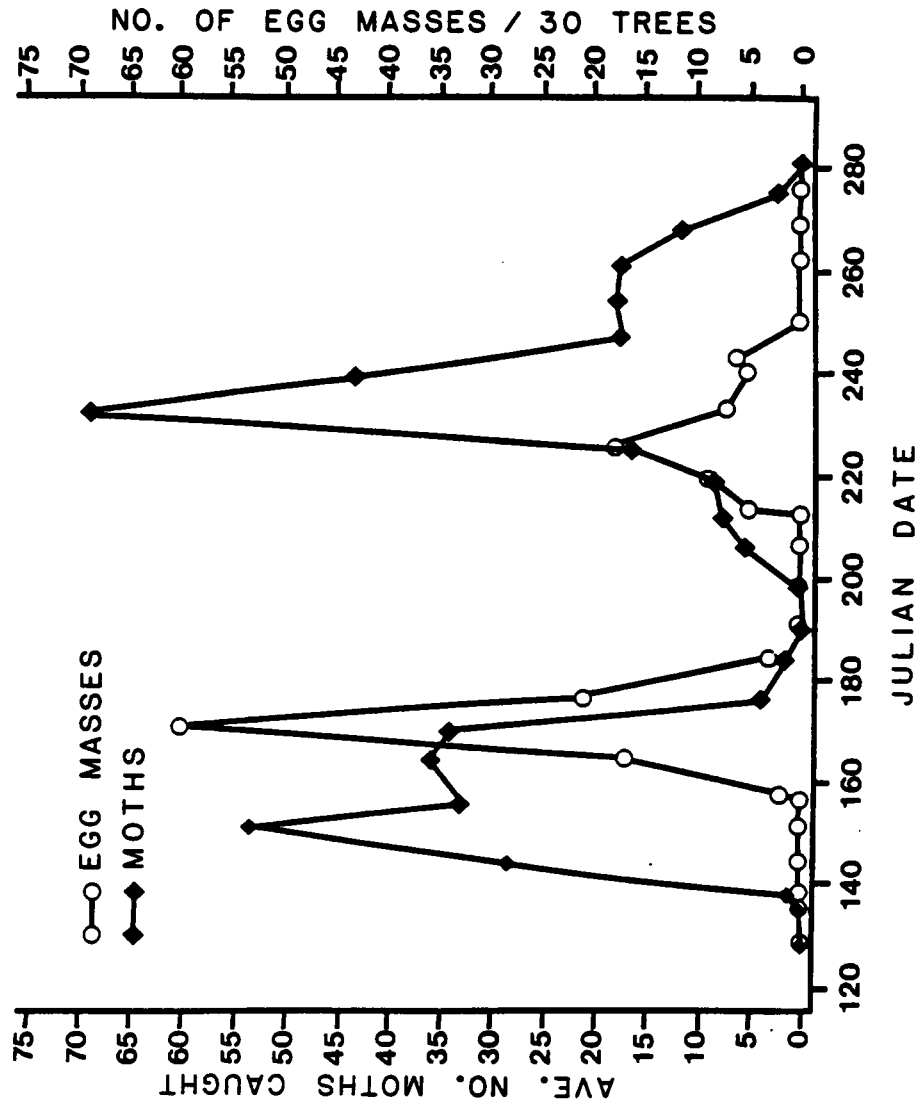

Fig. 9. Male moth flight and egg deposition periods of P. idaeusalis, 1984. Solenberger orchard, Frederick Co.

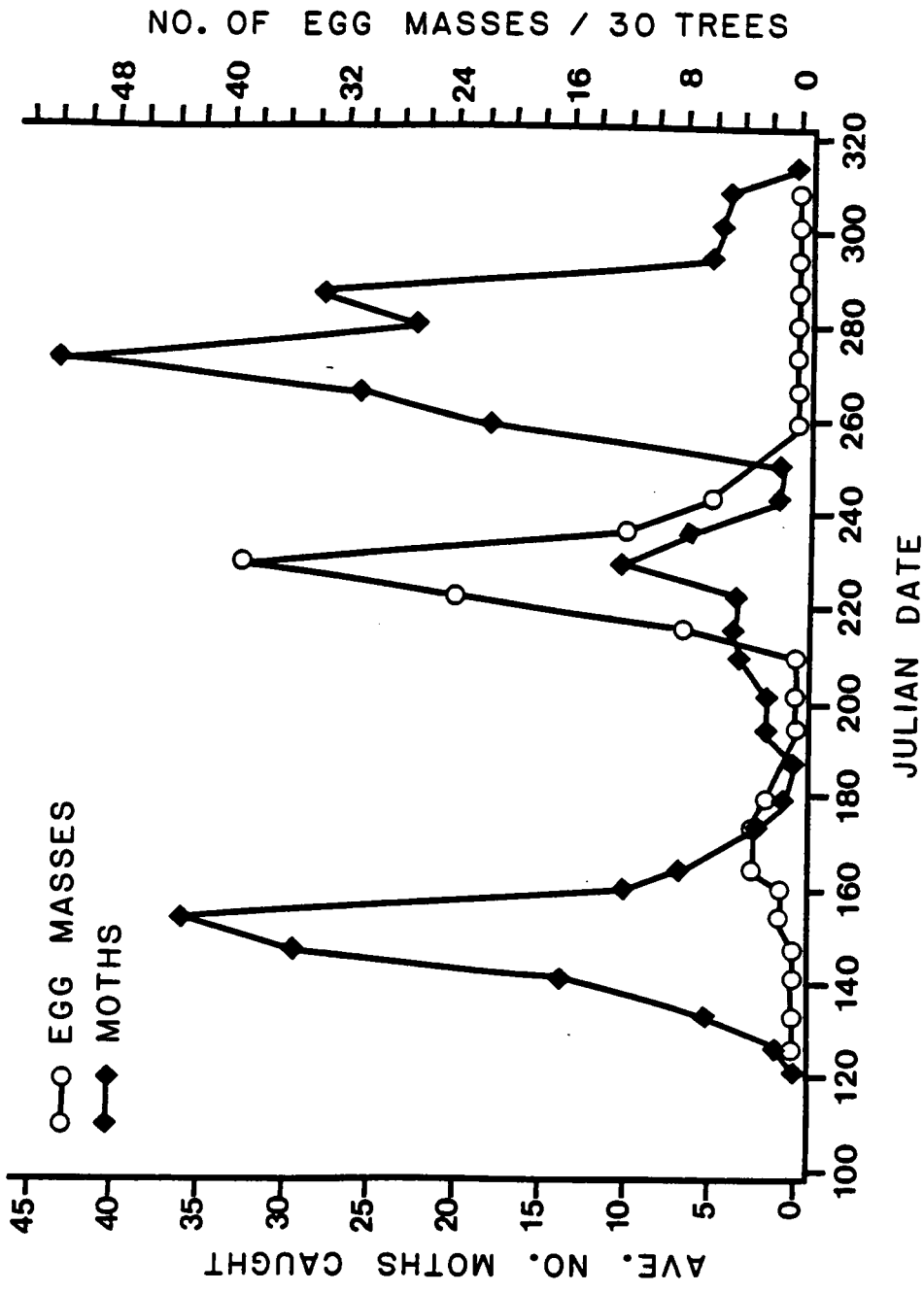

Fig. 10. Male moth flight and egg deposition periods of P. flavedana, 1983. Seaman orchard, Nelson Co.

in generation two, peak oviposition occurred approximately 7-10 days prior to peak moth flights. Riedl et al. (1976) observed a similar phenomenon for second generation codling moth activity. He also cited a personal communication with W. M. Bode (Penn. State Univ.) stating that Bode also observed a similar phenomenon with P. idaeusalis in Pennsylvania. Riedl suggested that for the codling moth this finding may be due to a reduced efficiency of the pheromone traps in capturing male moths during the second generation. This hypothesis may also hold true for P. idaeusalis and needs to be investigated. However, another possible explanation for this second generation phenomenon may be found in the study reported in Chapter 4. P. idaeusalis, along with P. flavedana, is polyphagous. As illustrated in Chapter 4, significant differences in rates of development from larva to adult were found for P. idaeusalis feeding on several different hosts. While the effect of host on fecundity was not studied for P. idaeusalis, there may be significant differences as observed for other species (Day and Robinson 1981, Conti and Waddill 1982). Thus it is possible that some individuals caught during the later half of the second generation flight period (e.g. after julian date 230) were emerging from less or more suitable hosts and while influencing the magnitude of the trap catches, they may have a reduced fec-

undity and contribute little to the egg mass population. However, further studies need to be conducted in this area before the validity of these hypotheses is determined.

Figure 10 illustrates a problem experienced with using pheromone traps to monitor for P. flavedana during the early part of the second generation (julian dates ca. 190-260). As indicated by the egg mass counts, a significantly higher moth population than suggested by pheromone trap counts must have inhabited this orchard. These results are typical of those observed for this species during the study. While increased female fecundity during the second generation may be a partial explanation for this phenomenon, it does not appear to be the total explanation. As suggested in Chapter 3, there appears to be a reduced efficiency of the pheromone traps during this generation. Similar observations were reported for second generation monitoring of the codling moth as compared to the first (Madsen and Vakenti 1972, Riedl et al. 1976). The reasons for this phenomenon need to be investigated. Based on these results, it appears that if moth catches in pheromone traps are to be used as biofix points (Riedl et al. 1976) then data from the first generation should be used to predict second generation activity (e.g. oviposition) because second generation pheromone trap catches are unreliable.

The large peak at approximately 250-310 julian days (Figure 10) was originally believed to be that of a third generation of P. flavedana on apple, but based on the results of studies conducted in Chapter 4 and field sampling of larvae on apple trees during this time, this is currently not believed to the the case. P. flavedana is polyphagous and larvae have been found in the orchard ground cover feeding on various plants (Thomas 1976, David, personal observation). Results of Chapter 4 indicate significant differences in rate of development depending on host. A search of the apple foliage in late September (ca. 270 julian days) during 1983 indicated that larvae were from 1st-3rd instar suggesting that the source of adult males was probably not from apple (David, unpublished data). Thus evidence suggests that these late individuals are perhaps either second generation adults emerging from less suitable hosts or third generation adults emerging from more suitable hosts other than apple. Field studies are needed to confirm this observation. For the purpose of this study, the second generation moth flight period was considered to run from first moth catch of this generation in July until the last moth catch in October.

The late individuals, i.e. those of late September and October, were of little consequence to the current year's

crop in the study orchards because it had already been picked. These individuals also appear to contribute little to the size of the overwintering larval population because very few (i.e. one egg mass per 30 trees) or no egg masses were found during this time. We were unable to obtain feral females during this time to determine if they posessed viable eggs, but this area needs to be investigated. However, since P. flavedana has been reported to oviposit only at night (Bobb 1972, David, personal observation), it is possible that evening temperatures, averaging 8.3°C (47°F), were below the thresholds for flight and/or oviposition. The influence of host on the phenlogy of both P. flavedana and P. idaeusalis has not been studied, but needs to be investigated. An understanding of the influence of host on phenology and fecundity may allow us to interpret pheromone trapping data more effectively and thus allow these data to be more useful in the future.

The average number of degree-days required for first moth catch, 10%, 50%, and 90% of total moth catch per generation for P. flavedana and P. idaeusalis can be found in Table 9 and 10, respectively. Rock and Shaffer (1983) estimated that larval diapause of P. idaeusalis terminated between mid-April and early May in North Carolina. Based on their results, we used a conservative estimate of April 1 to

Table 9. Degree-day estimates for P. flavedana moth flights.

Event	$\bar{X}$ no. of $^{\circ}D_{9.1}^{30.0}$ ± SE		
	1982[a]	1983[a]	Overall (95% CI[b])
	1st generation[c]		
1st moth[d]	205±6	345±40	275±44 (137-414)
10% catch	374±39	465±32	420±33 (314-525)
50% catch	529±71	601±27	565±37 (446-684)
90% catch	749±125	778±15	765±52 (599-930)
	2nd generation[e]		
1st moth	1589±78	1403±62	1496±67 (1282-1711)
10% catch	2178±88	1953±72	2066±80 (1811-2320)
50% catch	2581±88	2483±156	2532±79 (2282-2782)
90% catch	3059±85	3159±281	3109±123 (2716-3501)

[a]Based on two orchards.

[b]CI = confidence interval.

[c]°D accumulated from April 1.

[d]Biofix I (1st male moth(s) caught with no significant interruption in trap catches thereafter).

[e]°D accumulated from biofix I for a given site and year.

Table 10. Degree-day estimates for P. idaeusalis moth flights.

Event	$\bar{X}$ no. of $^{\circ}D_{7.5}^{32.2}$ ± SE			
	1982[a]	1983[b]	1984[c]	Overall (95% CI[d])
		1st generation[e]		
1st moth[f]	412±30	443±17	296±13	406±18 (367-445)
10% catch	508±31	558±23	470±35	525±18 (487-562)
50% catch	732±33	726±29	640±43	713±20 (670-756)
90% catch	1055±33	945±41	871±53	971±28 (910-1030)
		2nd generation[g]		
1st moth	1601±42	1591±69	1558±76	1589±35 (1515-1664)
10% catch	1933±57	1916±46	1945±65	1927±30 (1864-1991)
50% catch	2293±61	2233±45	2240±53	2257±32 (2191-2324)
90% catch	2720±66	2603±55	2581±38	2645±37 (2566-2724)

[a]Based on six orchards.

[b]Based on eight orchards.

[c]Based on three orchards.

[d]CI = confidence interval.

[e]°D accumulated from April 1.

[f]Biofix I (1st male moth(s) caught with no significant interruption in trap catches thereafter).

[g]°D accumulated from biofix I for a given site and year.

begin degree-day accumulations for P. idaeusalis and also for P. flavedana.

Comparing the overall averages, P. flavedana accumulated fewer degree-days from April 1 to first moth emergence than did P. idaeusalis during the first generation. The first male moth(s) caught in the pheromone traps with no significant interuption in the catches thereafter was considered to be biofix I for a given species (Riedl et al. 1976). P. flavedana required slightly fewer accumulated degree-days from biofix I to second generation adult emergence than did P. idaeusalis (Table 9 and 10).

Looking at the variablilty of degree-days (in terms of ±1 standard error of the mean (SE)) versus calendar days (in terms of difference between earliest and latest date event occurred) for P. flavedana first moth catch of generation one, we found approximately 6 days for degree-days and 9 for calendar days, for generation two we observed approximately 5 days for degree-days and 7 calendar days. In calculating variablilty for degree-days, we assumed an average of 15 degree-days per day in early-May, 20-22 degree-days per day in late-May, and 25-28 degree-days per day for June through August. The earliest and latest calendar date required for an observed phenological event for both species can be found in Appendix 2. In the case of P. idaeusalis, degree-days var-

ied by approximately 2 and 3 days for first and second generation first moth catches, respectively, versus 12 and 14 calendar days for the generations, respectively. The P. idaeusalis degree-day estimates are less variable than those of P. flavedana, probably, because of a larger sample size (overall 17 versus 4 orchards, respectively).

Tables 11 and 12 contain the degree-day estimates for first egg deposition, peak egg deposition, first egg hatch, and peak egg hatch periods of both generations for P. flavedana and P. idaeusalis, respectively. Degree-day values for the various events for P. idaeusalis and first generation P. flavedana are accumulations from first moth catch of the respective generation. Due to the unreliability of second generation moth catches for P. flavedana as discussed previously, degree-day estimates for the second generation's oviposition and hatch events are accumulations from the first moth catch of the first generation (biofix I).

The overall average number of degree-days from first moth catch to first egg mass are quite similar for both species during generation one and two (ca. 350 degree-days for P. flavedana in generation two) with second generation egg masses being found at slightly fewer degree-days after first moth catch than those of generation one. This suggests a preoviposition period of similar duration for both species.

Table 11. Degree-day estimates for egg deposition and hatch periods of P. flavedana.

Event	$\bar{X}$ no. of $^{\circ}D_{9.1}^{30.0}$ ± SE		
	1982[a]	1983[a]	Overall (95% CI[b])
	1st generation[c]		
1st egg mass	436±48	399±10	417±23 (345-490)
Peak egg deposition	581±82	631±92	606±52 (440-773)
1st egg hatch	610±54	582±43	596±29 (503-689)
Peak egg hatch	764±112	912±5	838±62 (639-1036)
	2nd generation[c]		
1st egg mass	1800±80	1892±11	1846±42 (1712-1981)
Peak egg deposition	1959±85	2345±108	2152±125 (1755-2549)
1st egg hatch	1959±85	2133±43	2046±64 (1844-2249)
Peak egg hatch	2161±85	2584±75	2373±131 (1957-2788)

[a]Based on two orchards.

[b]CI = confidence interval.

[c]°D accumulated from biofix I (1st male moth(s) caught with no significant interruption in trap catches thereafter) per site per year.

Table 12. Degree-day estimates for egg deposition and hatch periods of P. idaeusalis.

Event	$\bar{X}$ no. of $^{\circ}D_{7.5}^{32.2}$ ± SE[a]			
	1982[b]	1983[c]	1984[d]	Overall (95% CI[e])
	1st generation			
1st egg mass	485±36	323±6	369	392±29 (327-458)
Peak egg deposition	681±30	464±14	741	619±52 (502-736)
1st egg hatch	741±18	464±14	589	623±57 (495-751)
Peak egg hatch	844±20	630±2	871	777±48 (670-885)
	2nd generation			
1st egg mass	365±9	391±26	319	366±12 (337-394)
Peak egg deposition	636±29	784±30	637	678±32 (600-757)
1st egg hatch	691±19	551±11	637	643±27 (577-709)
Peak egg hatch	832±25	979±25	963	893±32 (814-971)

[a] $^{\circ}D$ accumulated from first moth catch per site for a given generation and year.

[b] Based on four orchards.

[c] Based on five orchards in generation one and two orchards in generation two.

[d] Based on one orchard.

[e] CI = confidence interval.

Egg hatch generally required similar to more degree-days (ca. 0-70) to occur in the field than were required at constant temperatures in the laboratory (Tables 11 and 12, see Chapter 4). Neuenschwander and Michelakis (1979) also observed a similar phenomenon for eggs of Dacus oleae.

Comparing variability in degree-days (using ±1 SE) versus calendar days for first egg mass prediction we found for P. flavedana in generation one approximately 2 and 11 days, respectively, and for generation two, approximately 3.5 and 9 days for degree-days and calendar days, respectively. Similarly for P. idaeusalis variabilities of approximately 3 and 7 days for generation one and for generation two, 1 and 13 days variability for degree-days and calendar days, respectively. Degree-days, in general, estimated occurrence of events with less variability than did calendar days (recorded for the actual events).

While variability of degree-days is less than that of calendar days, it is still significant and needs to be reduced through refinement in monitoring techniques. As Hogmire and Howitt (1979) suggest for P. idaeusalis in their study, variability between orchards and years with respect to degree-day accumulations may be partially due to the fact that only one environmental parameter, air temperature, was monitored. Many other environmental parameters such as soil

temperature, photoperiod, and rainfall may significantly influence development of these insects. This is especially true for the overwintering larvae in the gound cover (Hogmire and Howitt 1979, Rock et al. 1983, Rock and Shaffer 1983, Rock 1983). The leaf microclimate, where the insect lives, can differ significantly from ambient conditions as illustrated by Ferro et al. (1979). Such differences can significantly alter the rate of development of the insect from what is expected and result in greater variability. As Riedl (1980) points out, a considerable amount basic biological data is required to construct even a simple predictive model, such as a degree-day model. Greater degrees of resolution in a model will require more data. Unfortunately, much of this basic biological information which is required for a complete model is lacking for P. idaeusalis and P. flavedana. As our knowledge of the biology of these species is expanded so should our ability to predict their seasonal activity.

Welch et al. (1978) suggested that requirements of a research model and those of an extension model are quite different. Research models focus on intricate details of the phenology of a pest with a level of precision not required for extension models. Extension models need to focus on key events and may require somewhat lesser degrees of ac-

curacy. This is especially true in the case of P. flavedana and P. idaeusalis. Accuracy is always an objective, however, models with a lesser degree of accuracy may still be useful in assisting growers in timing sprays. Insecticides most frequently used by growers to control these leafrollers have an effective residual life of 7-10 days (VPI and SU 1984b). Consequently, the residual life of the insecticides may counteract the variability of our degree-day predictions. Using first egg hatch of P. idaeusalis during generation two for example, we find a 95% confidence interval (CI) size of 132 degree-days (Table 12). If a grower desires to apply an insecticide timed for first egg hatch, he could apply the material at the lower value for the 95% CI (577 degree-days). Adequate residues of the material should still be present on the foliage at the greater 95% CI value, 132 degree-days (ca. 6 days) later, to provide effective control of newly emerging larvae assuming no adverse weather conditions (e.g. excessive rainfall) occurs during the interval.

Growers usually apply two complete or 3-4 half sprays (alternate middles) of insecticides to their crop to control each generation of these leafrollers in Virginia. The timing of the first and the last spray can determine the success of their efforts to control these pests. For example

if they apply the first spray too long after first hatch, some of the larvae may have already begun feeding on the fruit. Until now, sprays, as mentioned previously, have been applied on a protective or calendar basis. Based on this study, degree-days appear to offer a significant advantage over methods previously employed to predict the seasonal phenology of and to time sprays against P. flavedana and P. idaeusalis. However, this degree-day approach still needs to be verified with field plot work.

LITERATURE CITED

Alford, D. V., P. W. Carden, E. B. Dennis, H. J. Gould, and J. D. R. Vernon. 1979. Monitoring codling moth and tortrix moths in United Kingdom apple orchards using pheromone traps. Ann. Appl. Biol. 91: 165- 178.

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. Environ. Entomol. 5: 397-402.

_____. 1979. A computerized phenology model for predicting biological events of Ragoletis indifferens (Diptera: Tephritidae). Can. Entomol. 111: 1101-1109.

_____. 1983. Monitoring the filbertworm, Melissopus latiferreanus (Lepidoptera: Olethreutidae), with sex attractant traps: Effect of trap design and placement on moth catches. Environ. Entomol. 12: 141-146.

Anonymous. 1983. Agricultural Statistics 1983. United States Department of Agriculture. Washington, D.C. 558 pp.

Arnold, C. Y. 1959. The determination and significance of the base temperature in a linear heat unit system. Proc. Am. Soc. Hort. Sci. 74: 430-445.

Bailey, P. 1980. Oriental fruit moth in South Australian peach orchards: monitoring moth activity and abundance and estimating first egg hatch. Z. ang. Entomol. 89: 377-386.

Baskerville, G. L. and P. Emin. 1969. Rapid estimation of heat accumulations from maximum and minimum temperatures. Ecology 50: 514-517.

Batiste, W. C., A. Berlowitz, W. H. Olson, J. E. Detar, and J. L. Joss. 1973. Codling moth: estimating time of first egg hatch in the field - a supplement to sex-attractant traps in intregated control. Environ. Entomol. 2: 387-391.

Beckwith, R. C. and D. G. Burnell. 1982. Spring larval dispersal of the western spruce budworm (Lepidoptera: Tortricidae) in north-central Washington. Ibid. 2: 387-391.

Berkett, L. P., P. D. Mowery, and W. M. Bode. 1976. Rate of development of Platynota idaeusalis at constant temperatures. Ann. Entomol. Soc. Am. 69: 1091-1094.

Bishop, Y. M. M., S. E. Feinberg, and P. W. Holland. 1975. Discrete multivariate analysis: theory and practice. The MIT Press, Cambridge.

Bobb, M. L. 1972. Observation's on the biology and control of Platynota flavedana. J. Econ. Entomol. 65: 1486-1487.

Bode, W. M., D. Asquith, and J. P. Tette. 1973. Sex attractants and traps for tufted apple budmoth and redbanded leafroller males. Ibid. 66: 1129-1130.

Bode. W. M. 1975. The tufted apple budmoth in Pennsylvania, 1974. Penn. Fruit News. 54: 50-53.

Brown, M. W. 1984. Saturation of pheromone sticky traps by Playtnota idaeusalis (Walker) (Lepidoptera: Tortricidae). J. Econ. Entomol. 77: 915-918.

Chapin, J. B. 1984. Proposed additions, additions, and corrections to the list of common names of insects and related organisms (1982 revision). Bull. Entomol. Soc. Am. 30: 57.

Chapman, P. J. and S. E. Lienk. 1971. Tortricid fauna of apple in New York (Lepidoptera: Tortricidae); including an account of apples' occurrence in the state especially as a naturalized plant. Special publication, New York State Agricultural Experiment Station, Geneva.

Clemens, B. 1860. Contributions to American lepidopterology. No. 6. Acad. Natur. Sci. (Phila.) Proc. 12: 345-362.

Cranham, J. E. 1980. Monitoring codling moth (Cydia [Laspeyresia] pomonella L.) with pheromone traps. EPPO Bull. 10: 105-107.

Croft, B. A., M. F. Michels, and R. E. Rice. 1980. Validation of PETE timing model for the oriental fruit moth in Michigan and central California (Lepidoptera: Olethreutidae). Great Lakes Entomol. 13: 211-217.

Croft, B. A., D. C. Elfving, and J. A. Flore. 1983. IPM and fruit-tree physiology and growth. pp. 67-92. In B. A. Croft and S. C. Hoyt [eds.], Integrated management of insect pests of pome and stone fruits. John Wiley & Sons, New York.

Croft, B. A. and W. M. Bode. 1983. Tactics for deciduous fruit IPM, pp. 219-270. In B. A. Croft and S. C. Hoyt [eds.], Integrated management of insect pests of pome and stone fruits. John Wiley & Sons, New York.

Conti, L. and V. Waddill. 1982. Development of velvetbean caterpillar, Anticarsia gemmatalis (Lepidoptera: Noctuidae), on several winter hosts. Environ. Entomol. 11: 1112-1113.

Danko, L. and G. L. Jubb, Jr. 1983. Field evaluation of pheromone-baited traps for monitoring grape berry moth (Lepidoptera: Olethreutidae). J. Econ. Entomol. 76: 480-483.

David, P. J. 1982. Ovicidal activity of methomyl on eggs of pest and beneficial insects and mites associated with apples in Virginia. M.S. thesis, Virginia Polytechnic Institute and State University, Blacksburg.

David, P. J. and R. L. Horsburgh. 1985. Ovicidal activity of methomyl on eggs of pest and beneficial insects and mites associated with apples in Virginia. J. Econ. Entomol. 78:(in press).

Day, A. and J. F. Robinson. 1982. Comparative survival, development, and fecundity of the pickleworm reared on an artificial diet and three cucurbit hosts. J. Ga. Entomol. Soc. 16: 518-521.

Drolet, J. and J. M. McNeil. 1984. Performance of the alfalfa blotch leafminer, Agromyza frontella (Diptera: Agromyzidae), on four alfalfa varieties. Can. Entomol. 116: 795-800.

Duncan, D. B. 1951. A significance test for differences between ranked treatments in an analysis of variance. Va. J. Sci. 2: 171-189.

Feinberg, S. E. 1980. The analysis of cross-classified categorical data, 2nd ed. The MIT Press, Cambridge.

Ferro, D. N., R. B. Chapman, and D. R. Penman. 1979. Observations on insect microclimate and insect pest management. Environ. Entomol. 8: 1000-1003.

Frost, S. W. 1923. A new apple bud-moth in Pennsylvania. J. Econ. Entomol. 15: 304-307.

Glass, E. H. and G. E. R. Hervey. 1962. Continuous rearing of the red-banded leafroller, Argyrotaenia velutinana. Ibid. 55: 336-340.

Hagley, E. A. C. 1973. Timing sprays for codling moth (Lepidoptera: Olethreutidae) control on apple. Can. Entomol. 15: 1085- 1089.

Hamilton, C. C. 1940. Control of the leafroller, Platynota flavedana Clem. on roses. J. Econ. Entomol. 33: 364-368.

Herne, P. H. C. and Trottier. 1975. Relationships between hatching of eggs of European red mite and fruit bud development in Ontario peach and apple orchards. Proc. Entomol. Soc. Ont. 106: 4-8.

Hill, A., R. Carde, A. Comeau, W. Bode, and W. Roelofs. 1974. Sex pheromones of the tufted apple bud moth (Platynota idaeusalis). Environ. Entomol. 3: 249-252.

Hill, A. S., R. T. Carde, W. M. Bode, and W. L. Roelofs. 1977. Sex pheromone components of the variegated leafroller moth, Platynota flavedana. J. Chem. Ecol. 3: 369-376.

Hill, C. H. and J. H. Thomas. 1976. Leafrollers and their control. Va. Fruit. 64(3): 32-38.

Hogmire, H. W., Jr. and A. J. Howitt. 1979. The bionomics of the tufted apple budmoth, Platynota idaeusalis in Michigan. Ann. Entomol. Soc. Am. 72: 121-126.

Horsburgh, R. L., J. P. McCaffrey, M. P. Parrella, and L. F. Ponton. 1980. Apple, ovicidal effects of Lannate-L, 1979. Insectic. Acaric. Tests. 5: 17-18.

Hoyt, S. C., J. R. Leeper, G. C. Brown, and B. A. Croft. 1983. Basic biology and management components for insect IPM. pp. 93-151. In B. A. Croft and S. C. Hoyt [eds.], Integrated management of insect pests of pome and stone fruits. John Wiley & Sons, New York.

Hoyt, S. C., P. H. Westigard, and R. E. Rice. 1983. Development of pheromone trapping techniques for male San Jose scale (Homoptera: Diaspididae). Environ. Entomol. 12: 371-375.

Hull, L. A. and V. R. Starner. 1983. Effectiveness of insecticide applications timed to correspond with the development of rosy apple aphid (Homoptera: Aphididae) on apple. J. Econ. Entomol. 76: 594-598.

Johnson, E. F., R. Trottier, and J. E. Laing. 1979. Degree-day relationships to the development of Lithocolletis blancardella (Lepidoptera: Gracillariidae) and its parasite Apanteles ornigis (Hymenoptera: Braconidae). Can. Entomol. 111: 1177-1184.

Jorgensen, C. D., M. E. Martinsen, and L. J. Westover. 1979. Validating Michigan State University's codling moth model (MOTHMDL) in an arid environment : a test in Utah. Great Lakes Entomol. 12: 203-212.

Jorgensen, C. D., R. E. Rice, S. C. Hoyt, and P. H. Westigard. 1981. Phenology of the San Jose scale (Homoptera: Diaspididae). Can. Entomol. 113: 149-159.

Jubb, G. L. Jr. and L. Danko. 1982. Comparison of four trap designs for monitoring grape berry moth, Endopiza viteana. Melsheimer Entomol. Ser. 32: 1-4.

Koethe, R. W. 1977. Seasonal life history, distribution and parasitism of Platynota idaeusalis (Lepidoptera: Tortricidae) in Pennsylvania apple orchards. M.S. thesis, Pennsynvania State University, University Park.

Kogan, M. 1975. Plant resistance in pest management, pp. 103-146. In R. L. Metcalf and W. H. Luckman [eds.], Introduction to insect pest management. John Wiley & Sons, New York.

Laing, J. E. and J. M. Heraty. 1984. The use of degree-days to predict emergence of the apple maggot, Rhagoletis pomonella (Diptera: Tephritidae), in Ontario. Can. Entomol. 110: 1123-1129.

Lamb, R. J. and S. R. Loschiavo. 1981. Diet, temperature, and the logistic model of developmental rate for Tribolium confusum (Coleoptera: Tenebrionidae). Ibid. 113: 813-818.

MacLellan, C. R. 1962. Mortality of codling moth eggs and young larvae in an integrated control orchard. Ibid. 94: 655-666.

Madsen, H. F. and J. M. Vakenti. 1972. Codling moths: female-baited and synthetic phermone traps as population indicators. Environ. Entomol. 1: 554-557.

_____. 1973. Codling moths: use of Codlemone-baited traps and visual detection of entries to determine need of sprays. Ibid. 2: 677-679.

Mague, D. L. and W. H. Reissig. 1983. Phenology of the San Jose scale (Homoptera: Diaspididae) in New York state apple orchards. Can. Entomol. 115: 717-722.

McCaffrey, J. P. 1981. Bionomics of the anthocorid, Orius insidiosus (Say) in Virginia apple orchards. Ph.D. dissertation, Virginia Polytechnic Institute and State University, Blacksburg.

McNally, P. S. and M. M. Barnes. 1980. Inherent characteristics of codling moth phermone traps. Environ. Entomol. 9: 538-541.

_____. 1981. Effects of codling moth phermone trap placement, orientation and density on trap catches. Ibid. 10: 22-26.

_____. 1984. Improving codling moth trap catches. Calif. Agric. 38(10): 18-19.

Metcalf, R. L. 1975. Insecticides in pest management. pp. 235-273. In R. L. Metcalf and W. H. Luckman [eds.], Introduction to insect pest management. John Wiley & Sons, New York.

Minks, A. K. and D. J. DeJong. 1975. Determination of spaying dates for Adoxophyes orana by sex pheromone traps and temperature recordings. J. Econ. Entomol. 68: 729-732.

Neuenshwander, P. and S. Michelakis. 1979. Determination of the lower thermal thresholds and day-degree requirements for eggs and larvae of Dacus oleae (Gmel.) (Diptera: Tephritidae) under field conditions in Crete, Greece. Bull. Soc. Entomol. Suisse. 52: 57-74.

Phillips, J. H. H. 1973. Monitoring for oriental fruit moth with synthetic sex phermones. Environ. Entomol. 2: 1039-1042.

Pitre, H. N. and D. B. Hogg. 1983. Development of the fall armyworm on cotton, soybean, and corn. J. Ga. Entomol. Soc. 18: 182-187.

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. Environ. Entomol. 8: 51-54.

Rice, R. E., W. W. Barnett, D. L. Flaherty, W. J. Bentley, R. A. Jones. 1982. Monitoring and modeling oriental fruit moth in California. Calif. Agric. 36(1): 11-12.

Rice, R. E., D. L. Flaherty, and R. A. Jones. 1982. Monitoring and modeling San Jose scale. Ibid. 36(1): 13-14.

Rice, R. E., C. V. Weakley, and R. A. Jones. 1984. Using degree-days to determine optimum spray timing for the oriental fruit moth (Lepidoptera: Tortricidae). J. Econ. Entomol. 77: 698-700.

Riedl, H., B. A. Croft, and A. J. Howitt. 1976. Forecasting codling moth phenology based on pheromone trap catches and physiological time models. Can. Entomol. 108: 449-460.

Riedl, H., S. A. Hoying, W. W. Barnett, and J. E. Detar. 1979. Relationship of within-tree placement of the pheromone trap to codling moth catches. Environ. Entomol. 8: 765-769.

Riedl, H. 1980a. Monitoring and forecasting methods for codling moth management in the United States and Canada. EPPO Bull. 10: 241-252.

_____. 1980b. The importance of pheromone trap density and trap maintenance for the development of standardized monitoring procedures for the codling moth (Lepidoptera: Tortricidae). Can. Entomol. 112: 655-663.

Rock, G. C., C. C. Childers, and H. J. Kirk. 1978. Insecticide applications based on Codlemone trap catches vs. automatic schedule treatments for codling moth control in North Carolina apple orchards. J. Econ. Entomol. 71: 650-653.

Rock, G. C. and A. D. Shaltout. 1983. Toxicities of three synthetic pyrethroids and selected orchard insecticides to the tufted apple budmoth, Playnota idaeusalis (Lepidoptera: Tortricidae). Ibid. 76: 1384-1389.

Rock, G. C., P. L. Shaffer, and A. D. Shaltout. 1983. Tufted apple budmoth (Lepidoptera: Tortricidae): photoperiodic induction of larval diapause and stages sensitive to induction. Environ. Entomol. 12: 66-70.

Rock, G. C. and P. L. Shaffer. 1983. Tufted apple budmoth (Lepidoptera: Tortricidae): effects of constant daylengths and temperatures on larval diapause development. Ibid. 12: 71-75.

Rock, G. D. 1983. Thermoperiodic effects on the regulation of larval diapause in the tufted apple budmoth (Lepidoptera: Tortricidae). Ibid. 12: 1500-1503.

SAS Institute Inc. 1982. SAS user's guide: statistics, 1982 edition. SAS Inst. Inc., Cary, North Carolina.

Sharp, J. L. and J. H. Cross. 1980. Longevity and attractivity to male lesser peachtree borer of E,2-ODDA evaporated from various dispensers. Environ. Entomol. 9: 818-820.

Shorey, H. H. and R. L. Hale. 1965. Mass rearing of larvae of nine noctuid species on a simple artificial medium. J. Econ. Entomol. 57: 52-54.

Summerland, S. A. and D. W. Hamilton. 1954. A leafroller, Platynota flavedana Clem., attacking peaches. Ibid. 47: 941.

Thomas, J. H. 1976. Biology and control of a leafroller, Platynota flavedana Clemens (Lepidoptera: Tortricidae) in Virginia apple orchards. M.S. thesis, Virginia Polytechnic Institute and State University, Blacksburg.

_____. 1979. An evaluation of Bacillus thuringiensis for leafroller control in Virginia apple orchards. Ph.D. dissertation, Virginia Polytechnic Institute and State University, Blacksburg.

Travis, J. W., D. Asquith, and P. D. Mowery. 1981. Bioassay study of commercial formulations of several insecticides on Playtnota idaeusalis. J. Econ. Entomol. 74: 328-330.

Trottier, R. and D. H. C. Herne. 1979. Temperature relationships to forecast hatching of overwintered eggs of the European red mite, Panonychus ulmi (Acarina: Tetranychidae). Proc. Entomol. Soc. Ont. 110: 53-60.

Trottier, R. 1980. Early warning system for apple pest management in Canada. EPPO Bull. 10: 253-257.

Vakenti, J. M. and H. F. Madsen. 1976. Codling moth (Lepidoptera: Olethreutidae): monitoring populations in apple orchards with sex pheromone traps. Can. Entomol. 108: 433-438.

Virginia Polytechnic Institute and State University. 1984a. Virginia Spray Bulletin for commercial tree fruit growers. VPI and SU Ext. Div. Publ. 456-419.

_____. 1984b. Tree fruit production supplement. VPI and SU Ext. Div. Publ. 456-421.

Walker., F. 1863. List of the specimens of lepidopterous insects in the collection of the British Museum. Cat. Brit. Mus. 28: 324.

Welch, S. M., B. A. Croft, J. F. Brunner, and M. F. Michels. 1978. PETE: an extension phenology modeling system for management of multi-species pest complex. Environ. Entomol. 7: 482-494.

Westigard, P. H. and K. L. Graves. 1976. Evaluation of pheromone baited traps in a pest management program on pears for codling moth control. Can. Entomol. 108: 379-382.

Wilde, G. and M. Semel. 1966. The life history of Platynota flavedana, a leafroller of strawberry. J. Econ. Entomol. 59: 1037-1041.

APPENDICES

Appendix 1. Leaf analysis report[a] for plants used in the varied host experiment (Chapter 4).

Host	%					ppm				
	N	P	K	Ca	Mg	B	Zn	Mn	Cu	Fe
Apple	2.20	0.18	1.60	1.80	0.31	29	18	54	6	76
Strawberry	1.83	0.33	1.68	1.72	0.26	37	21	215	6	62
Dewberry	1.37	0.09	0.96	1.00	0.52	25	14	135	3	48

[a]Conducted by the Soil Testing and Plant Analysis Laboratory, Cooperative Extension Service, VPI&SU, Blacksburg. July 15, 1984.

Appendix 2

Field observations of *P. flavedana* and *P. idaeusalis* phenology, 1982-84.

Field observations of P. flavedana phenology.

Event	Earliest - latest date event observed[a] 1982	1983
	1st generation	
1st moth catch	5/4-5/4	5/6 -5/13
50% moth catch[b]	5/24-5/26	5/28-5/29
1st egg mass	5/26-5/26	6/3 -6/6
Peak egg deposition	5/31-6/3	6/13-6/17
1st egg hatch	6/3 -6/3	6/13-6/13
Peak egg hatch	6/9 -6/15	6/25-6/28
	2nd generation	
1st moth catch	7/19-7/19	7/13-7/20
50% moth catch[b]	9/12-9/17	8/27-9/26
1st egg mass	7/27-7/27	8/3 -8/5
Peak egg deposition	8/3 -8/3	8/17-8/27
1st egg hatch	8/3 -8/3	8/10-8/17
Peak egg hatch	8/11-8/11	8/27-9/4

[a]Two orchards observed.

[b]Estimated.

Field observations of P. idaeusalis phenology.

Event	Earliest - latest date event observed[a]		
	1982	1983	1984
	1st generation		
1st moth catch	5/10-5/17	5/17-5/22	5/15-5/18
50% moth catch[b]	5/29-6/3	6/4 -6/11	6/3 -6/12
1st egg mass	6/3 -6/5	6/8 -6/10	6/6[c]
Peak egg deposition	6/11-6/16	6/15-6/16	6/19[c]
1st egg hatch	6/16-6/20	6/15-6/22	6/13[c]
Peak egg hatch	6/21-6/22	6/22-6/23	6/25[c]
	2nd generation		
1st moth catch	7/19-7/26	7/18-8/1	7/17-7/25
50% moth catch[b]	8/23-8/31	8/19-8/25	8/18-8/23
1st egg mass	8/2 -8/2	8/9 -8/15	8/1[c]
Peak egg deposition	8/9 -8/16	8/25-8/29	8/13[c]
1st egg hatch	8/16-8/16	8/15-8/22	8/13[c]
Peak egg hatch	8/23-8/23	9/1 -9/6	8/27[c]

[a]Pooled observations from 2-8 orchards.

[b]Estimated.

[c]One site observed.

The vita has been removed from the scanned document