

1982

Pest management strategies for the alfalfa blotch leafminer, *Agromyza frontella* (Rondani) (Diptera: Agromyzidae), in Massachusetts.

Alfred Jeffery Alicandro
University of Massachusetts Amherst

Follow this and additional works at: <https://scholarworks.umass.edu/theses>

Alicandro, Alfred Jeffery, "Pest management strategies for the alfalfa blotch leafminer, *Agromyza frontella* (Rondani) (Diptera: Agromyzidae), in Massachusetts." (1982). *Masters Theses 1911 - February 2014*. 3038.

Retrieved from <https://scholarworks.umass.edu/theses/3038>

This thesis is brought to you for free and open access by ScholarWorks@UMass Amherst. It has been accepted for inclusion in Masters Theses 1911 - February 2014 by an authorized administrator of ScholarWorks@UMass Amherst. For more information, please contact scholarworks@library.umass.edu.

*

UMASS/AMHERST

*



312066 0230 3745 6

PEST MANAGEMENT STRATEGIES FOR THE ALFALFA BLOTCH
LEAFMINER, AGROMYZA FRONTELLA (RONDANI) (DIPTERA: AGROMYZIDAE),
IN MASSACHUSETTS

A Thesis Presented

By

ALFRED JEFFERY ALICANDRO

Submitted to the Graduate School of the
University of Massachusetts in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE

May 1982

Department of Entomology

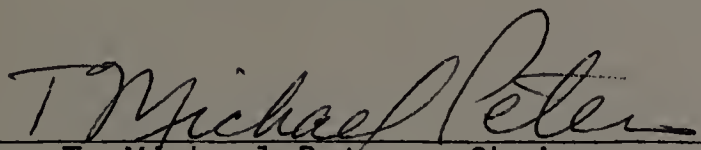
PEST MANAGEMENT STRATEGIES FOR THE ALFALFA BLOTCH LEAFMINER,
AGROMYZA FRONTELLA (RONDANI) (DIPTERA: AGROMYZIDAE),
IN MASSACHUSETTS

A Thesis Presented

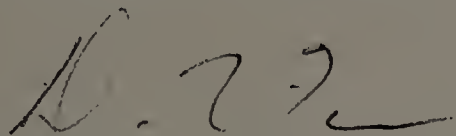
By

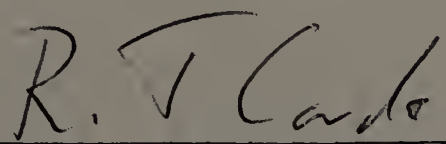
ALFRED JEFFERY ALICANDRO

Approved as to style and content by:


Dr. T. Michael Peters, Chairperson


Dr. Joseph S. Elkinton, Member


Dr. David N. Ferro, Member


Dr. R. T. Cardé, Department Head
Department of Entomology

DEDICATION

This thesis is dedicated to Elizabeth Ann Alicandro, my patient and loving wife, for all the encouragement she has provided and faith she has shown during our years together; to my son Ryen, for the sense of purpose he has unknowingly added to all my endeavours; and to my parents, Mr. and Mrs. Vincent P. Alicandro, for more than I could ever communicate.

ACKNOWLEDGEMENTS

I would like to thank Dr. T. Michael Peters for all his guidance during my thesis research; Dr. David N. Ferro and Dr. Joseph S. Elkinton for their advice concerning research aspects and manuscript preparation; and Dr. John T. Andaloro for inspiring several aspects of research.

In addition I would like to express my sincere gratitude to the following individuals:

Mr. Les Chromack, for conducting maintenance of alfalfa research stands; the Feed, Seed, and Fertilizer Lab., West Exp. Sta., Univ. of Mass., for conducting alfalfa protein analyses; Bob Alper, Mark Lee, Mike Bruno, and Sue Dec, for contributing long hours to field research activities; Mr. Lee Totman, Ms. Barbara Crowley, and the Melnick family, cooperating growers in several research activities; and Mr. David Adamski, for peer review and support. Finally, I would like to thank Melanie Fletcher-Howell for the typing of this manuscript.

ABSTRACT

PEST MANAGEMENT STRATEGIES FOR THE ALFALFA BLOTCH
LEAFMINER, AGROMYZA FRONTELLA (RONDANI) (DIPTERA:
AGROMYZIDAE), IN MASSACHUSETTS

(May 1982)

Alfred Jeffery Alicandro B.S., University of Massachusetts

Directed by: Professor T. Michael Peters

Sampling techniques for the alfalfa blotch leafminer (ABL), Agromyza frontella (Rondani) (Diptera: Agromyzidae) were evaluated in 1979. Eclosion traps were the optimal method for determining the effect of modified crop harvests on ABL density. The sweep-net, although unable to distinguish between population increases due to eclosion vs. immigration, was considered useful in qualitative studies of leafminer population dynamics and phenology. Directional flight traps noted significant inter-plot movements of flies from cut to uncut plots at harvest.

The feasibility of harvest schedule modifications to control the ABL was investigated in 1980. ABL development was well-synchronized to alfalfa growth under a standard 10% bloom harvest schedule. Early harvest of the first or second crop regrowths resulted in effective leafminer control (91 to 99% reduction). Harvest modifications also influenced the developmental rate of soil-dwelling pupae, by influencing crop canopy and soil microclimate. Instituting harvest control during

the second crop regrowth was found unacceptable, as full-season total hay yields and crude protein levels were significantly reduced. In contrast, modified first harvests produced forage yields and quality similar to that of the standard harvest schedule. Optimal conditions for ABL-induced damage were considered, and the basis for a dynamic ABL-alfalfa economic injury level model was developed.

The practice of field-curing alfalfa hay after harvest increased survival of third instar ABL larvae; windrow simulation experiments showed that ca. 32% of third instars may complete their development and form pupae while hay is field-curing.

Several methods were compared at forecasting ABL seasonality during 1978-1979-1980. The phytophenological indicator forecasts provided by Prunus pensylvanica and by Berberis thunbergii were more useful than calendar date, "ABL-days", cumulative degree-day, and crop development indices at forecasting ABL adult peaks for the first three generations. Forecasts were considered useful in scheduling leafminer sampling programs and in planning cultural control strategies for the fly. The conceptual basis and history of phytophenological indicators was considered and protocols for their use in pest management were outlined.

TABLE OF CONTENTS

DEDICATION		iii
ACKNOWLEDGEMENT.		iv
ABSTRACT		v
LIST OF TABLES		viii
LIST OF FIGURES.		ix
Chapter I.	INTRODUCTION	1
Chapter II.	EVALUATION OF METHODS FOR ASSESSING POPULATION RESPONSES OF THE ALFALFA BLOTCH LEAFMINER, <u>AGROMYZA</u> <u>FRONTELLA</u> (RONDANI), TO MODIFIED CROP HARVEST SCHEDULES.	
	Introduction	3
	Materials and Methods	4
	Results	9
	Discussion	14
Chapter III.	THE IMPACT OF CROP HARVEST SCHEDULES ON THE ALFALFA BLOTCH LEAFMINER, <u>AGROMYZA</u> <u>FRONTELLA</u> (RONDANI), AND IMPLICATIONS FOR CROP MANAGEMENT	
	Introduction	15
	Materials and Methods	16
	Results	22
	Discussion	35
Chapter IV.	THE INFLUENCE OF FIELD-CURING HAY ON SURVIVAL OF THE ALFALFA BLOTCH LEAFMINER, <u>AGROMYZA</u> <u>FRONTELLA</u> (RONDANI).	
	Introduction	44
	Materials and Methods	44
	Results and Discussion	46
Chapter V.	FORECASTING <u>AGROMYZA</u> <u>FRONTELLA</u> (RONDANI) SEASONALITY WITH PHYTOPHENOLOGICAL INDICATORS.	
	Introduction	49
	Materials and Methods	53
	Results and Discussion	58
BIBLIOGRAPHY		81

LIST OF TABLES

Chapter II.

1. Inter-plot movements of ABL adults at harvest during 1979 at Amherst, MA 11
2. Influence of harvest schedule on second generation ABL adult density at Amherst, MA in 1979 12

Chapter III.

3. Description of harvest schedules evaluated at Amherst, MA in 1980 19
4. Cumulative ABL adult emergence densities for each generation under 4 crop harvest schedules at Amherst, MA in 1980 24
5. The relationship between first harvest timing and ABL survival at 4 commercial stands in MA during 1980 29
6. Inter-plot movements of ABL adults at harvest at Amherst, MA during 1980 30
7. Total number of blotch mines per stem at each harvest for 3 harvest schedules at Amherst, MA in 1980 33
8. Total dry matter (TDM) and crude protein (CP) yields of alfalfa harvested under 3 schedules at Amherst, MA in 1980 36

Chapter IV.

9. Cumulative first generation ABL adult densities under 4 first harvest treatments at Amherst, MA in 1980 48

Chapter V.

10. Degree-days (centigrade) between peak adult densities of the first 3 ABL generations at Amherst, MA during 1978-1979-1980 65
11. Flowering dates of 30 plant species in Amherst, MA during 1978-1979-1980 66
12. Comparison of indices for forecasting ABL adult population peaks at Amherst, MA during 1978-1979-1980 74
13. Comparison of indices for forecasting overwintering generation ABL adult peaks at 5 sites in western MA in 1980 77

LIST OF FIGURES

Chapter II.

1. Experimental plot design for assessing ABL response to harvest schedule modifications 5
2. Design of directional flight trap used to monitor adult ABL inter-plot movements 8
3. ABL adult population dynamics under 3 harvest schedules at Amherst, MA in 1979 10

Chapter III.

4. Relationship of ABL adult and third instar larvae phenology to crop growth under a standard harvest schedule at Amherst, MA in 1980 23
5. Effect of first harvest timing on subsequent alfalfa regrowth, peak daily soil temperatures, and first generation adult emergence profiles at Amherst, MA in 1980 27
6. Crop growth patterns under 4 harvest schedules at Amherst, MA in 1980 34
7. Major factors influencing potential crop damage from the ABL during the second alfalfa growth period 42

Chapter V.

8. Geography of 1980 study sites 54
9. Accumulated degree-days (centigrade) at Amherst, MA during 1978-1979-1980 and 32-year norm values 59
10. ABL adult population dynamics at Amherst, MA during 1978-1979-1980 62
11. Phenology of ABL adults and indicator plants at 5 sites in western MA during 1980 71

C H A P T E R I

INTRODUCTION

The presence of the alfalfa blotch leafminer (ABL), Agromyza frontella (Rondani), in North America was first detected in Hampshire County, Massachusetts during 1968 (Miller and Jensen 1970). Extending its range at approximately 80 kilometers per season (Mellors and Helgesen 1978), the leafminer has spread north into the Canadian provinces of Ontario, Quebec, and the Maritimes (Bereza 1977), west to Ohio, and south to West Virginia (Hendrickson and Barth 1978).

The general biology of the ABL has been considered in great detail (Dureseau and Jeandell 1977; Hendrickson and Barth 1978). Adults emerge synchronously in the spring from the overwintering pupal stage when the vernal growth of alfalfa, Medicago sativa L., is quite young. Three to four relatively distinct generations occur annually in Massachusetts (Andaloro 1981). Infestations are usually most severe during the second generation, as the native complex of hymenopterous parasites (Hendrickson and Barth 1979a) and the induction of diapause (Mellors and Helgesen 1980) limit third and fourth generations, respectively. Damage to alfalfa is caused by the feeding perforations made by female flies ("pinholes") and by the leafmining activities of the three larval instars. Guppy (1981) determined that in leaflets infested with a single mine, ca. 27% of the leaflet surface is encompassed.

Although the ABL is endemic to and widespread in Europe (Spencer 1973), it is not considered economically important (Dureseau and Jeandell 1977). In contrast, much higher densities are common in North America (Plummer and Byers 1981; Andaloro 1981), resulting in several reports of economic crop loss (Anonymous 1972; Richard and Gagnon 1976). This inter-continent difference may be due to the reduced rate of hymenopterous parasitism in North America (Hendrickson and Barth 1979a) as compared to Europe (Dureseau and Jeandell 1977). Precise economic injury levels for the ABL have not been determined (Byers and Valley 1978; Thompson 1981).

Andaloro (1981) reported that crop harvest schedules may influence ABL bionomics, and suggested that a modification of harvest time (Spencer 1974; Bremer 1976) may be useful for controlling the fly in Massachusetts. However, harvest schedules are an integral component of alfalfa management, directly influencing crop yields, quality, and stand persistence (Smith 1978). In addition, harvesting practices may affect the biology of many members of the alfalfa insect community (van den Bosch and Stern 1969; Andaloro 1981). Thus, before implementing such a control strategy, the impact of modified harvests on both ABL pest status and overall crop production was investigated (Chapters II, III, and IV). In order to efficiently schedule sampling activities for the leafminer, the value of phytophenological indicators in forecasting ABL seasonality was also investigated (Chapter V).

CHAPTER I I

EVALUATION OF METHODS FOR ASSESSING POPULATION RESPONSES OF THE ALFALFA BLOTCH LEAFMINER, AGROMYZA FRONTELLA (RONDANI), TO MODIFIED CROP HARVEST SCHEDULES

Introduction

The alfalfa blotch leafminer (ABL), Agromyza frontella (Rondani), is a recently introduced pest of alfalfa in the northeastern United States and eastern Canada. In Massachusetts, first and second generation leafminer infestations may exceed 100 adults per sweep and 30-40% mined leaflets (Andaloro 1981). This highly visible damage has caused considerable grower concern and prompted our investigations of pest management alternatives for the fly.

Despite their established efficacy (Spencer 1974; Bremer 1976; Thompson 1981), the use of insecticides to control the ABL is restricted by the low unit-value of the crop and ongoing biocontrol programs for both the ABL (Hendrickson and Barth 1979b) and the alfalfa weevil, Hypera postica (Gyllenhal). Properly timed harvests have been successfully evaluated for ABL control. By harvesting when the leafminer population is primarily in the early larval instar stage, the formation of soil-dwelling pupae is minimized. This in turn results in reduced recruitment into the adult stage and ca. 95% control in subsequent fly density (Spencer 1974; Bremer 1976). However, it is well known that alfalfa harvest schedules are an integral component of overall crop management (Smith 1978), directly influencing forage yields, quality, and stand persistence. In addition, harvest practices may affect the

biology of many members of the alfalfa insect community (van den Bosch and Stern 1969). Thus, before implementing a harvest schedule modification to control the ABL, additional information on the effect of this practice on crop production and pest management was needed.

In Chapter III, a season-long analysis of the effect of harvest modifications to control the ABL is presented; equal consideration is given to crop response and possible impacts on other insect species. The intent of this study was to evaluate sampling methods for the ABL under an experimental plot design in which adjacent plots were harvested by differing schedules. These results would then provide baseline data for the full-season analysis in 1980 (Chapter III).

Materials and Methods

Experimental plot design. Investigations were conducted during 1979 on a 0.30 hectare stand of Saranac cultivar alfalfa. The stand had been summer-seeded in 1978 and one full-bloom harvest was made in that year. Three harvest schedule treatments were investigated to compare ABL population response and to evaluate leafminer sampling methods. The stand was subdivided into six equal plots, two per treatment, with harvested aisles maintained between plots (Figure 1). All plots, except for the unharvested control, were first cut between VI-6 and VI-9, when the crop was between 60 and 75% bloom. After this initial harvest, each plot was fertilized with 0-10-40 with boron at the rate of 448 kilograms per hectare. Variations in harvest schedule were instituted during the second harvest period. The second harvest of the standard

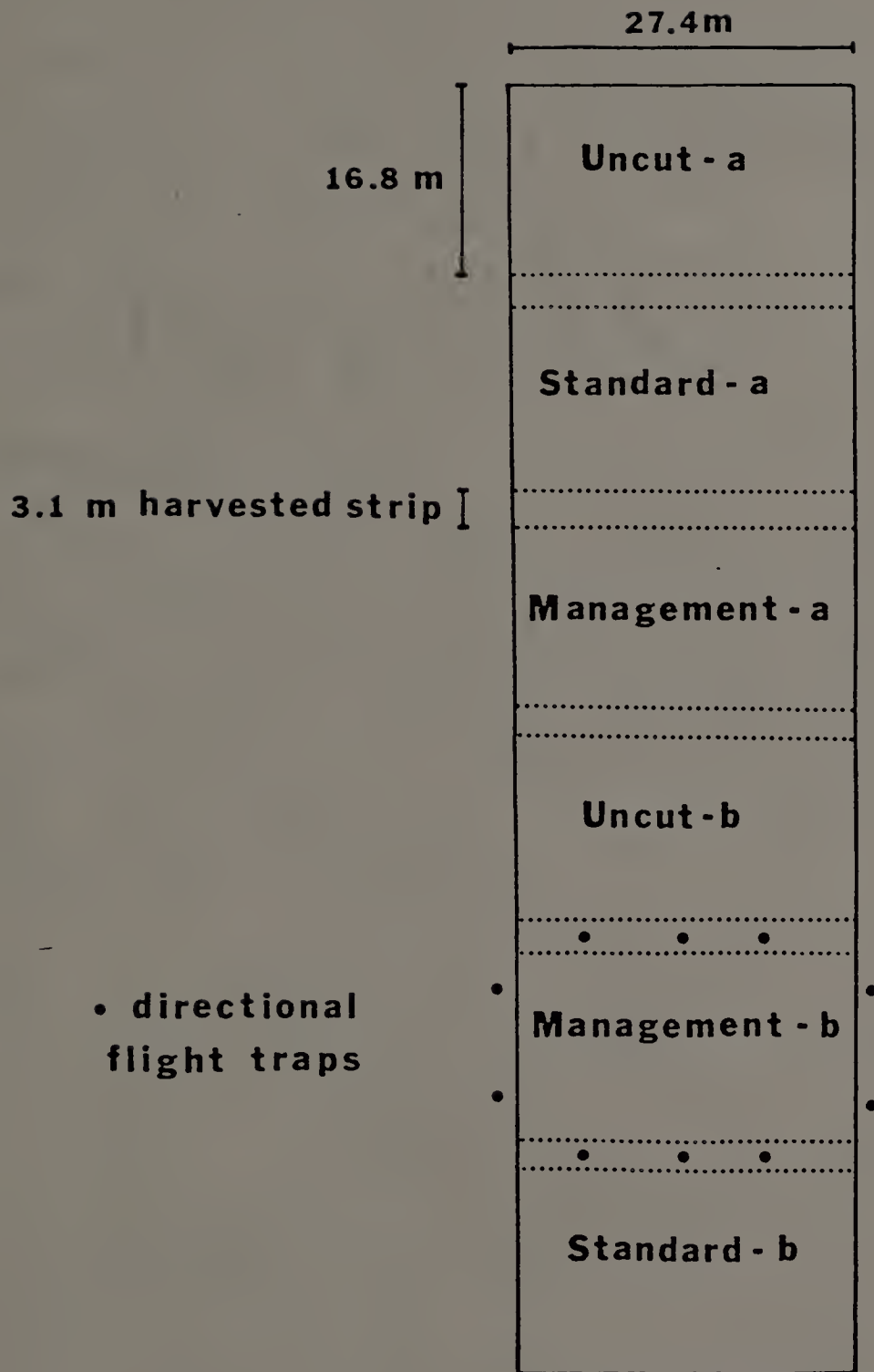


Figure 1. Experimental plot design for assessing ABL response to harvest schedule modifications. Closed circles represent locations of directional flight traps used to monitor inter-plot fly movements.

harvest treatment was conducted at 10% crop bloom, generally considered the optimal crop management practice (Smith 1978). In contrast, the management treatment plots were harvested during the second harvest period on the basis of leafminer phenology, without regard for crop development. Second harvests in the management treatment were instituted at the appearance of linear, early instar ABL mines (Spencer 1974; Bremer 1976). The unharvested control plots again were left uncut during this period. Following this variable second harvest treatment, all plots, including the unharvested control, were cut on IX-11-81. Thus, uniform fall regrowth periods were provided.

ABL sampling. The tendency of leafminer adults to aggregate on upper portions of alfalfa stems (Bremer 1976) facilitated the use of the sweep-net in monitoring adult population dynamics. Furthermore, Plummer and Byers (1981) reported the sweep-net to be as effective as the D-vac in sampling adults, except at very low densities. A standard 38 cm sweep-net with a 0.9 m handle was used to collect adult ABLs by taking 180 degree arc sweeps through the top 20-25 cm of crop growth. At an alternating 3 and 4 day interval, three 5-sweep samples were collected per plot. Sampling was restricted to between noon and 3 p.m. to minimize possible diurnal variations in activity noted for other alfalfa insects (Saugstad et al. 1967). Collected insects were killed with ethyl acetate and frozen until counting.

The minimal overlap between ABL generations enables adult emergence density to serve as a measure of leafminer abundance during the season (Mellors and Helgesen 1980). An eclosion trap modified

from Mellors and Helgesen (1980) was used to monitor recruitment into the adult stage during the second generation (i.e. third emergence). Traps consisted of inverted white plastic flower pots with the interior surface coated with a thin layer of diluted sticky Tack-TrapTM. The four drainage holes were covered with fine Saran screening to prevent escape of emerging adults and the entrance of contaminants. Approximately one week before the onset of second generation adult emergence, 20 traps were placed 2.5 cm into the ground in both the management and standard harvest treatments; traps were left in place until sweep samples indicated that the second generation emergence period had ended. As each trap covered 0.018 square meters of soil surface, counts were transformed to a per square meter basis.

In order to monitor the activity patterns of adult ABLs at harvest, a directional flight trap (see Southwood 1966) was developed. Each trap consisted of a paired set of 14 cm diameter plastic petri dish covers mounted onto wooden paint stirrers, in a "lollipop" fashion (Figure 2). The surface of each cover was coated with a thin layer of diluted sticky Tack-TrapTM and pairs were placed back-to-back into the soil. Traps intercepted flies moving between 20.5 and 35.5 cm above the soil surface. Ten pairs of traps were established around the management-b and standard-b plots for the two-day intervals before and after second harvest. Traps were placed two meters from the field edge, parallel to the edge, in the manner illustrated in Figure 1. In the lab, counts of ABL adults on each surface were made to provide estimates of net fly movement.

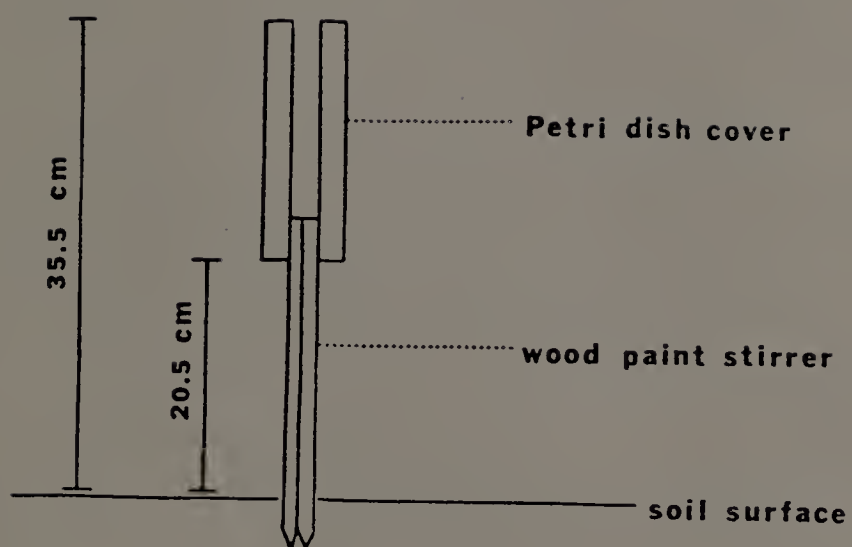


Figure 2. Design of directional flight trap used to monitor adult ABL inter-plot movements during 1979 at Amherst.

At second harvest, the total number of blotch mines per alfalfa stem was determined. This included mines occupied by live third instars, by dead third instars, and abandoned mines. Bremer (1976) determined that at densities greater than 10 larvae/stem, 25-stem samples yielded a 12% coefficient of variation. As densities encountered in this study were considerably greater, a 20-stem sample was collected from each plot at harvest.

Results

The timing of first harvest minimized interference with first generation leafmining activities. This allowed the buildup of high pupal densities and resulted in high ABL adult population densities during the second alfalfa regrowth in all three treatments (Figure 3). Although sweep-net counts indicated lower population densities in the unharvested plot, this was probably due to interference by the tangled and lodged growth of this treatment.

The second harvest of the management treatment plots occurred on VII-6, when ABL adults were still very abundant. Following this harvest, a rapid increase in adult densities was noted in both the unharvested and standard treatment plots (Figure 3). Thus a distinctly bimodal adult activity pattern was observed, contrary to the findings of Andaloro (1981). Directional flight trap data suggested that this second peak was due to emigration of flies from the harvested management plots (Table 1).

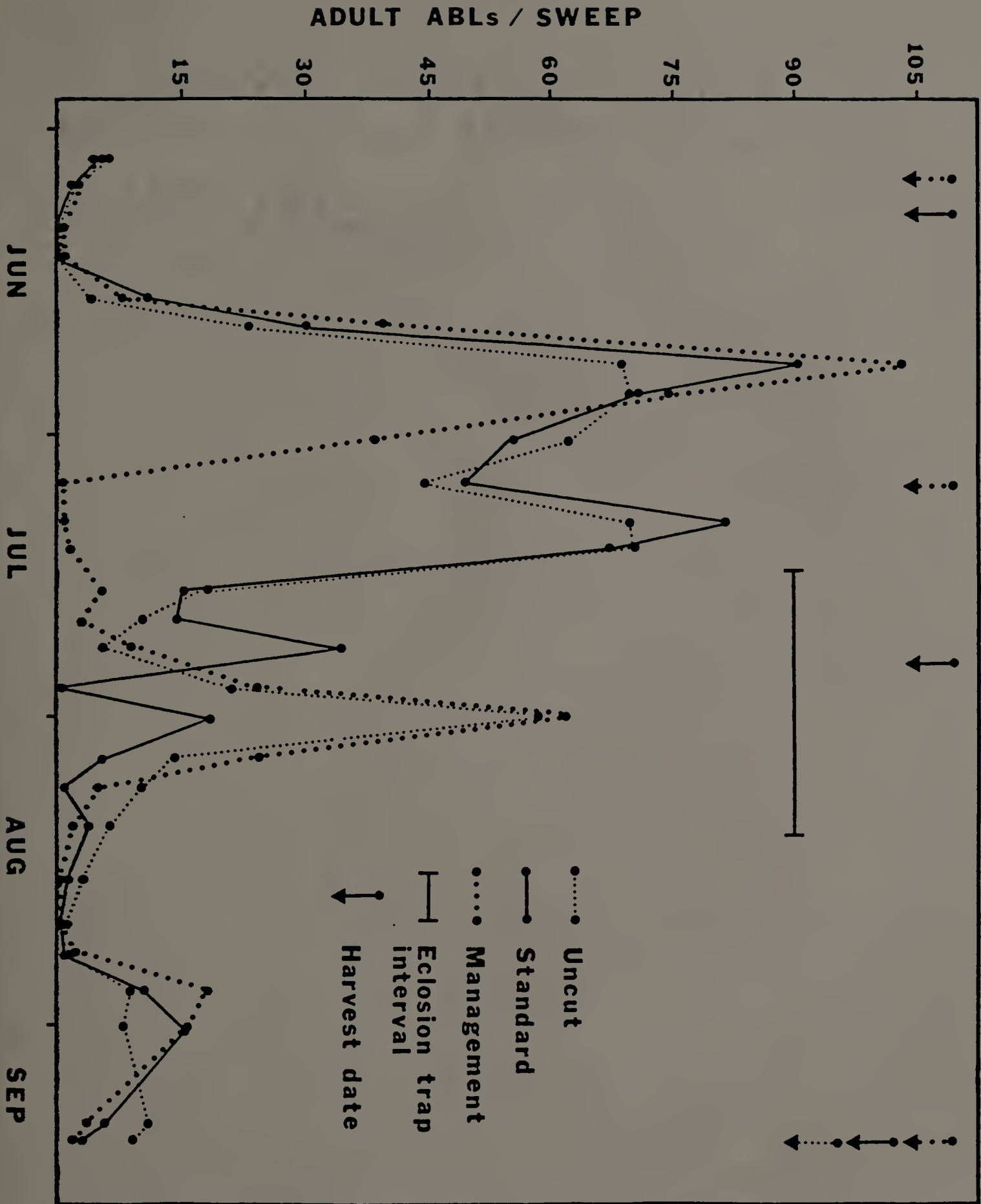


Figure 3. ABL adult population dynamics under three harvest schedules at Amherst, MA in 1979. The horizontal bar indicates the period in which eclosion traps were utilized.

Table 1. Inter-plot movements of ABL adults at harvest during 1979 at Amherst, MA.

Harvested Plot	Harvest Date	Sampling Interval	Adult ABLs/trap ¹	
			Immigrants ²	Emigrants ³
Management-b	VII/6	VII/4-VII/6	15.4 ± 4.4a	13.5 ± 4.2a
		VII/6-VII/8	9.6 ± 2.5a	15.4 ± 4.5b
Standard-a	VII/24	VII/22-VII/24	0.2 ± 0.3a	0.3 ± 0.3a
		VII/24-VII/26	12.0 ± 5.4a	23.1 ± 6.7b

¹mean values with 95% confidence intervals; horizontal values followed by the same letter are not significantly different at $p < 0.05$ (t-test).

²adults trapped on sticky surfaces facing away from harvested plot

³adults trapped on sticky surfaces facing toward harvested plot

Table 2. Influence of harvest schedule on second generation ABL adult density at Amherst, MA in 1979.

	Harvest Treatment	
	Standard	Management
Total blotch ¹ mines/stem at second harvest	42.6 ± 11.7a	5.3 ± 1.8b
Second generation ^{1,2} adults/m ²	2341.7 ± 550.6a	227.8 ± 112.8b

¹mean values with 95% confidence intervals; horizontal values followed by the same letter are not significantly different at $p < 0.01$ (t-test).

²eclosion trap data

At summer temperatures of 20-25⁰C, development from the egg to the pupal stage of the ABL takes ca. 9-12 days (Mellors and Helgesen 1978). Thus by installing eclosion traps on VII-15, nine days after the management second harvest, the development of pupal progeny of immigrant flies was minimized in the standard treatment plots. Eclosion trap data indicated that the early harvest of the management treatment reduced second generation ABL adult density by 90.3% as compared to the standard treatment, due to the prevention of larval development (Table 2).

The second harvest of the standard treatments was conducted at 10% crop bloom; this was 18 days after the second harvest of the management treatment plots. Again, this harvest interfered with adult population dynamics as it occurred during the second generation adult emergence period (i.e. the third emergence) (Figure 3). A bimodal peak in adult activity was observed in the standard treatment plots, as populations crashed after harvest and remained low until sufficient regrowth appeared. Despite the reduction in adult emergence density indicated by eclosion traps, ABL adult populations in the management treatment were very high. Directional flight traps again suggested this was due to emigration of flies from the harvested standard treatment plots (Table 1).

Sweep samples indicated little difference in adult densities during the third generation adult emergence period (Figure 3). Apparently, inter-plot movement of flies at harvest had neutralized the variable impact of harvest timing in the management and standard treatments. The

low densities of this generation are probably due to the induction of diapause in third generation pupae (Mellors and Helgesen 1980).

Discussion

The results of this study clarify the role of the sweep-net and the eclosion trap in analyzing ABL population dynamics. The population dynamics of a species are determined primarily by four factors: rates of natality, mortality, emigration, and immigration. The eclosion trap is sensitive to only the first factor, natality, or recruitment into the adult stage. Thus it was ideal for estimating absolute abundance of ABL adult generations, as is necessary in the construction of life tables (Mellors and Helgesen 1980). In contrast, the sweep-net provided an instantaneous estimate of adult activity levels. As sweep-net catches vary with many factors (Southwood 1966), it has limited value in analyzing inter-generation survival rates. This was particularly evident in the present study, in which the interplot movements of flies rendered sweep-net data useless in terms of assessing the impact of modified harvests on ABL survival. However, as it is sensitive to all the factors influencing population density, the sweep-net is useful in qualitative studies of ABL population dynamics and phenology. When used in concert with directional flight traps, population increases due to eclosion and immigration may be qualitatively isolated.

CHAPTER III

THE IMPACT OF CROP HARVEST SCHEDULES ON THE ALFALFA BLOTCH LEAFMINER AND IMPLICATIONS FOR CROP MANAGEMENT

Introduction

The alfalfa blotch leafminer (ABL), Agromyza frontella (Rondani), is a recently introduced herbivore of alfalfa in the northeastern United States and eastern Canada. Although the ABL is not considered economically significant in its native Europe (Dureseau and Jeandell 1977), its pest status in North America remains uncertain (Byers and Valley 1978; MacCollum et al. 1980; Thompson 1981). In Massachusetts, first and second generation ABL infestations may exceed 100 adults per sweep and 30-40% mined leaflets (Andaloro 1981). This highly visible damage has resulted in considerable grower concern and prompted our investigation of pest management alternatives for the fly.

Despite their established efficacy (Spencer 1974; Bremer 1976; Thompson 1981), the use of insecticides to control the ABL is restricted by the low unit-value of the crop and ongoing biological control programs for both the ABL (Hendrickson and Barth 1979b) and the alfalfa weevil, Hypera postica (Gyllenhal). As properly timed harvests have been proven effective at breaking the leafminer's life-cycle (Spencer 1974; Bremer 1976), we considered this cultural control strategy a preferred management option. However, it is well-known that harvest schedules are a key factor in alfalfa management, directly influencing forage yields, quality, and stand maintenance (Smith 1978). In

addition, alfalfa harvest practices may affect the biology of many members of the alfalfa insect community (van den Bosch and Stern 1969). Thus, in order to evaluate the role of modified harvests in ABL pest management, a more complete understanding of the impact of such a practice on crop production was required. In this study, ABL bionomics and alfalfa growth under a standard harvest schedule and modified harvest schedules were compared.

Materials and Methods

Investigations were conducted during 1980 at a university research plot in Amherst and at four commercial stands in western Massachusetts. At the Amherst site, one full-bloom harvest was conducted in 1978 and three 10% bloom harvests in 1979. Each of the commercial stands was between 2-5 years old; crop management practices before 1980 were unknown. All sites were pure stands of Saranac cultivar alfalfa in which no insecticides had previously been used. The location of each plot is more fully described in a concurrent study of ABL phenology (Chapter V).

The full-season impact of three harvest schedules and an unharvested control treatment were observed at the Amherst site. A 0.30 ha stand was divided into four plots, each 16.8 m by 27.4 m, with 3.0 m harvested strips maintained between adjacent plots. Three harvests were conducted under each harvest schedule treatment; the fourth regrowth was left uncut. Harvested alfalfa was allowed to field-dry for 2-3 days

after each cutting. After the initial harvest, each plot was fertilized with 0-10-40 with boron at the rate of 448 kg/ha.

For each treatment the timing of harvests was determined by either crop growth-stage or ABL development, as described in Table 3. The commonly recommended strategy of harvesting at 10% crop bloom is represented by the standard treatment, in which the crop was managed without regard for the leafminer. Two management schedules were designed to implement ABL control. The management-1 and management-2 treatments instituted ABL control during the first and second harvest growths, respectively. Both management harvests were timed to prevent the buildup of soil-dwelling pupal populations. Thus, the appearance of linear mines (first and second instars) was used as a cue to time management harvests (Spencer 1974; Bremer 1976). The unharvested treatment permitted observation of leafminer survival and phenology in the absence of periodic host removal.

ABL development and survival. The mature third instar larva, or blotch miner stage, was selected for monitoring larval phenology, as the development of this stage is critical in relation to ABL survival at harvest (Andaloro 1981). Bremer (1976) determined that at densities greater than 10 larvae/stem, 25-stem samples yielded a 12% coefficient of variation. As densities encountered in this study were considerably greater, a 20-stem sample was utilized to monitor third instar development. Stems were collected at random along diagonal transects through stands at 6-12 day intervals, as dictated by developmental rates and

Table 3. Description of harvest schedules evaluated at Amherst, MA in 1980.

<u>Harvest Schedule</u>	<u>Event Used to Time Harvest</u>		
	<u>first</u>	<u>second</u>	<u>third</u>
Management-1	appearance of early ABL instars (1st generation)	10% crop bloom	10% crop bloom
Management-2	10% crop bloom	appearance of early ABL instars (2nd generation)	10% crop bloom
Standard	10% crop bloom	10% crop bloom	10% crop bloom
Unharvested	not cut	not cut	not cut

harvest schedules. In the lab, the total number of live third instars/stem was determined.

The minimal overlap between ABL generations permits the use of adult emergence density as a measure of absolute abundance for each generation (Mellors and Helgesen 1980). An eclosion trap modified from Mellors and Helgesen (1980) was used to monitor recruitment into the adult stage. Traps consisted of inverted white plastic flower pots whose drainage holes were covered with fine Saran screening. The interior surface was coated with a thin layer of diluted sticky Tack-TrapTM, and traps were placed 2.5 cm into the ground. One week before the onset of emergence was anticipated for each generation, 20 traps were randomly placed in each plot and left in place until sweep samples indicated eclosion had subsided. Thus traps measured cumulative recruitment into the adult stage for each generation. As each trap covered 0.018 m^2 of soil surface, counts were transformed to a per square meter basis.

Adult ABL dynamics in the standard treatment plot was monitored with a standard 38 cm sweep-net. Three 5-sweep samples were collected on an alternating three and four day basis. In conjunction, the first generation emergence profile of adults in each plot was monitored with a modified eclosion trap. The Saran screening over one of the four drainage holes was replaced with a 1-ounce clear plastic "mustard cup." Only the interior surface of the "mustard cup" was coated with sticky Tack-TrapTM, rather than the entire flower pot. Ten of these traps were placed in each plot and "mustard cups" were replaced at 2-day intervals. Thus adult eclosion was more closely monitored. Measurements of peak

daily soil temperature in each plot were recorded. At 2.00 p.m., a Taylor soil-dial thermometer reading was made at 2.5 cm below the soil surface. This provided a comparison of pupal microclimates between treatments, as ca. 90% of ABL pupae are found within the top 5 cm of soil (Guppy 1981).

Satellite plot observations. The relationship between crop phenology, commercial harvest schedules, and ABL development was observed at the four commercial sites in Western Massachusetts. At each site, three 5-sweep samples were collected on an alternating three and four day interval to monitor adult activity during the first two harvest periods. One 20-stem sample was collected weekly to monitor larval development. Ten eclosion traps were installed at each site to measure first generation cumulative adult density. At harvest, the stage of crop development was characterized in terms of alfalfa flower phenology.

Adult dispersal. Previous studies comparing adjacent small-plot harvest schedules illustrated the potential for dispersal of flies at harvest from cut to uncut plots (Chapter II). In order to assess such fly movements between plots in this study, the directional flight trap previously described (Chapter II, Figure 2) was used. For 3-day intervals before and after each harvest, sixteen pairs of directional flight traps were placed around the harvested field in the following manner: five in each 3 m harvested aisle between plots and 3 on the outside edge of the rectangular plot. By comparing adult catches on the inside (i.e., toward the field being cut) and the outside surface of each pair,

an estimate of the net direction and magnitude of fly movement was obtained (Southwood 1966).

Crop damage. The feeding activity of third instar ABL larvae is considered the most serious damage caused by the leafminer, resulting in a ca. 27% loss of leaflet surface per blotch mine (Guppy 1981). Thus the density of blotch mines was used as the principal measure of ABL damage in this study. At each harvest, the total number of blotch mines (occupied, dead, or abandoned) per stem was recorded from a 20-stem sample. Estimates of pinholing damage (i.e., female feeding perforations) were made by determining pinhole density per leaflet (n=10).

Crop growth and yields. Crop growth response to the three harvest schedule treatments was monitored using the 20-stem samples collected for larval abundance estimates. In the lab, the mean height and percentage bloom of samples was determined.

In order to determine the suitability of the Amherst site for yield comparisons between harvest treatments, stand density analyses were conducted in early spring (IV-25) before the onset of ABL activity. Sixteen 0.31 m ring samples (7.5×10^{-6} ha each) were randomly collected from each plot and stems over 10 cm counted.

Yield comparisons were conducted by randomly collecting sixteen ring samples (4.1×10^{-5} ha each) per plot at each harvest. Samples were oven-dried at 70°C for 36 hours before weighing. Three 50 mg subsamples were selected per treatment for crude protein determinations by the Kjehdal method (Horwitz 1970).

Results

ABL development and survival. Adult ABL activity was well synchronized to alfalfa growth patterns under the standard harvest schedule in this study. Four distinct generations were observed, one during each crop regrowth period, before a killing frost on X-10 (Figure 4). These results agree with the findings of Andaloro (1981) at four sites in western Massachusetts during 1977-1978.

Alfalfa stands were ca. 25 cm high when overwintered flies emerged in early- to mid-May, thereby providing ample host material for female feeding and oviposition. Although the 10% bloom harvest on VI-6 prevented complete development of the leafminer population, sufficient pupae accrued to provide a ca. 2.6-fold increase in first generation adult density as compared to overwintered levels (Table 4). A similar synchrony between crop and pest development was noted for the second harvest period, as the interval between harvests (39 days) and peak adult densities (40 days) were nearly identical. Despite high second generation larval densities, leafminer abundance declined precipitously during the third harvest period. As a sharp increase in the incidence of dead larvae was noted during the second regrowth, this decline was probably due to the native hymenopterous parasite complex (Hendrickson and Barth 1979a). Similarly, the low densities during the final crop regrowth were probably attributable to heavy late-season parasitism (Hendrickson and Barth 1979a) and the induction of diapause in third generation pupae (Mellors and Helgesen 1980).

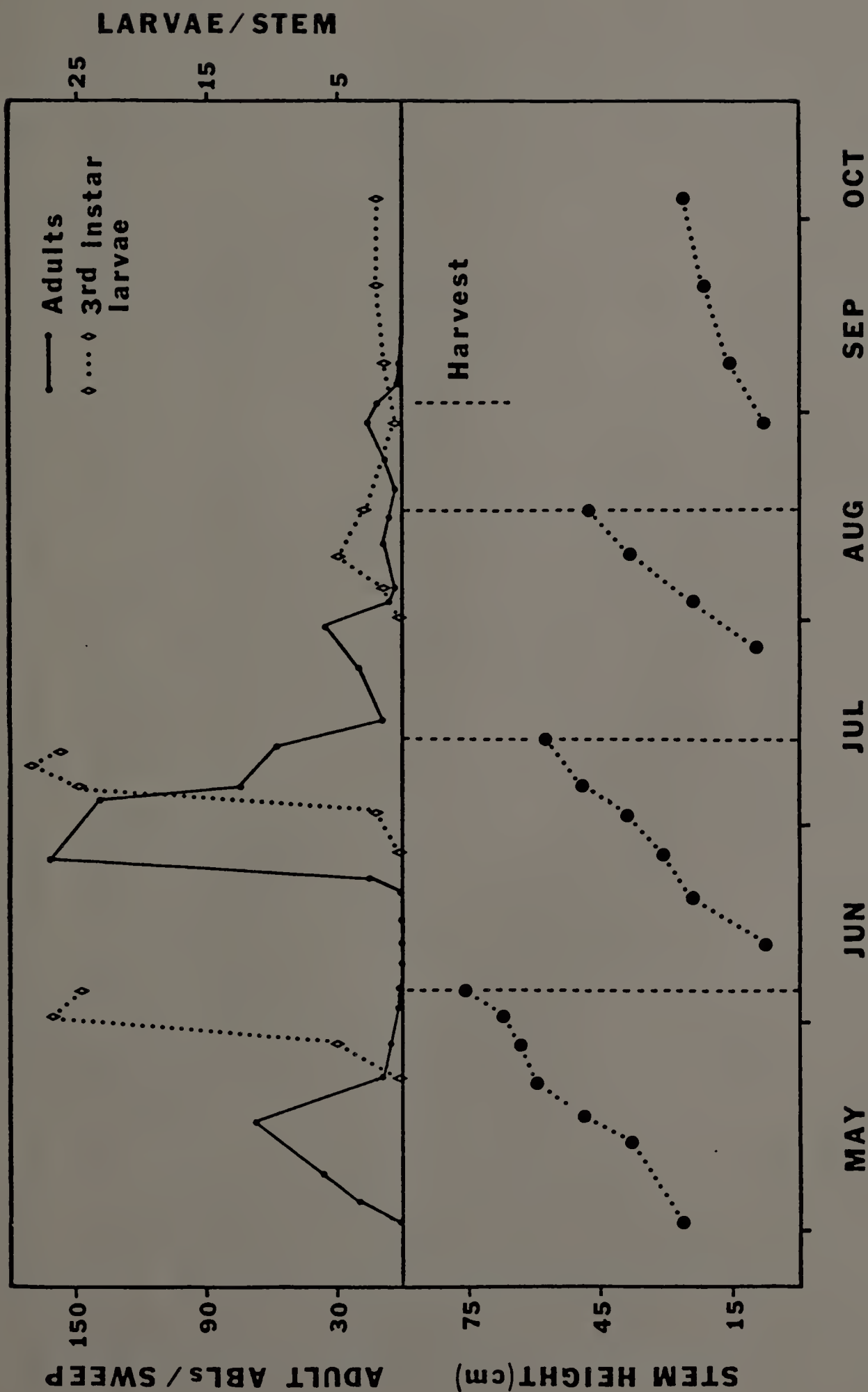


Figure 4. Relationship of ABL adult and third instar larvae phenology to crop growth under a standard harvest schedule at Amherst, MA in 1980.

Table 4. Cumulative ABL adult emergence densities for each generation under four crop harvest schedules at Amherst, MA in 1980.

<u>ABL Generation</u>	<u>(Adult ABLs/m²)¹</u>			
	<u>Harvest Schedule</u>			
	<u>Uncut</u>	<u>Standard</u>	<u>Mgt.-1</u>	<u>Mgt.-2</u>
overwintering	972.3a	894.5a	1022.3a	1039.0a
first	2872.4a	2333.5b	16.7c	2422.4b
second	<u> </u> ²	577.8a	23.9b	50.0b
third	<u> </u> ²	150.0a	8.3b	5.6b

¹ values followed by the same letter are not significantly different at 5% level by Duncan's multiple range test (horizontal comparison)

² not determined

Although a full-bloom management schedule was not investigated at the Amherst site, leafminer development in the uncut plot is of value in estimating the impact of such a practice. At full-bloom of the spring growth (ca. VI-17), third instar populations had declined to 2/stem from a peak of 26.6/stem on VI-2. Thus a full-bloom cut would have permitted almost 100% completion of first generation leafmining activities and produced first generation adult densities comparable to those of the uncut treatment (Table 4). The development of alfalfa and the ABL in the uncut treatment was not monitored after the emergence of first generation adults, as the lack of fresh crop regrowth limited leafminer survival.

Both the management-1 and -2 early harvest treatments provided effective leafminer control (Table 4). The management-1 first harvest was conducted fourteen days before 10% crop bloom. This minimized pupation of first generation ABLs, resulting in a significant 99.3% decrease in subsequent first generation adult density as compared to the standard treatment. These results agree closely with the findings of Spencer (1974) and Bremer (1976). Similarly, the early second harvest of the management-2 plot, 11 days before second regrowth 10% crop bloom, caused a significant 91.4% reduction in second generation adult densities as compared to the standard treatment.

The harvest schedules evaluated also influenced the developmental rate of soil-dwelling pupae. Crop development was similar under harvest schedule treatments during the first harvest period. However, differences in first harvest cutting date produced marked variation in the

second crop regrowth (Figure 5, top third). As alfalfa canopy acts as a modifier of temperature and humidity (Pinter et al. 1975), these variations in regrowth influenced the soil microclimate experienced by pupal populations. On warm sunny days, peak soil temperatures (-2.5 cm depth) under canopies of 16 cm or less exceeded peak ambient air temperatures (Figure 5, middle third). Conversely, the dense shading of the uncut plot (70+ cm) reduced peak soil temperatures to as much as 9.5 °C below air levels. Little difference in temperature were noted between growths of 25-40 cm, as these intermediate canopies presumably had similar microclimates. On overcast days, smaller differences between soil and ambient air temperatures were noted.

Abandonment of leafmines by pre-pupal first generation ABLs was first noted on V-25 and continued in the uncut treatment until VI-19; peak mine abandonment occurred between VI-4 and VI-12. Thus in the early cut management-1 plot, harvested on V-23, surviving pupae were exposed to elevated temperatures in relation to the standard and uncut treatments. Similarly, following the 10% bloom harvest of the standard plot on VI-6, the highest soil temperatures were noted in this plot (Figure 5, middle third). Mellors and Helgesen (1978) reported an 8.4 day reduction in duration of the pupal stage between 20 and 25 °C. In this study the consistently lower soil temperatures of the uncut plot resulted in a significant 2-day delay in peak emergence of first generation leafminer adults (Figure 5, bottom third) as compared to the standard harvest treatment. Peak soil temperatures under eclosion pots varied little from normal soil readings (1-2 °C maximum difference);

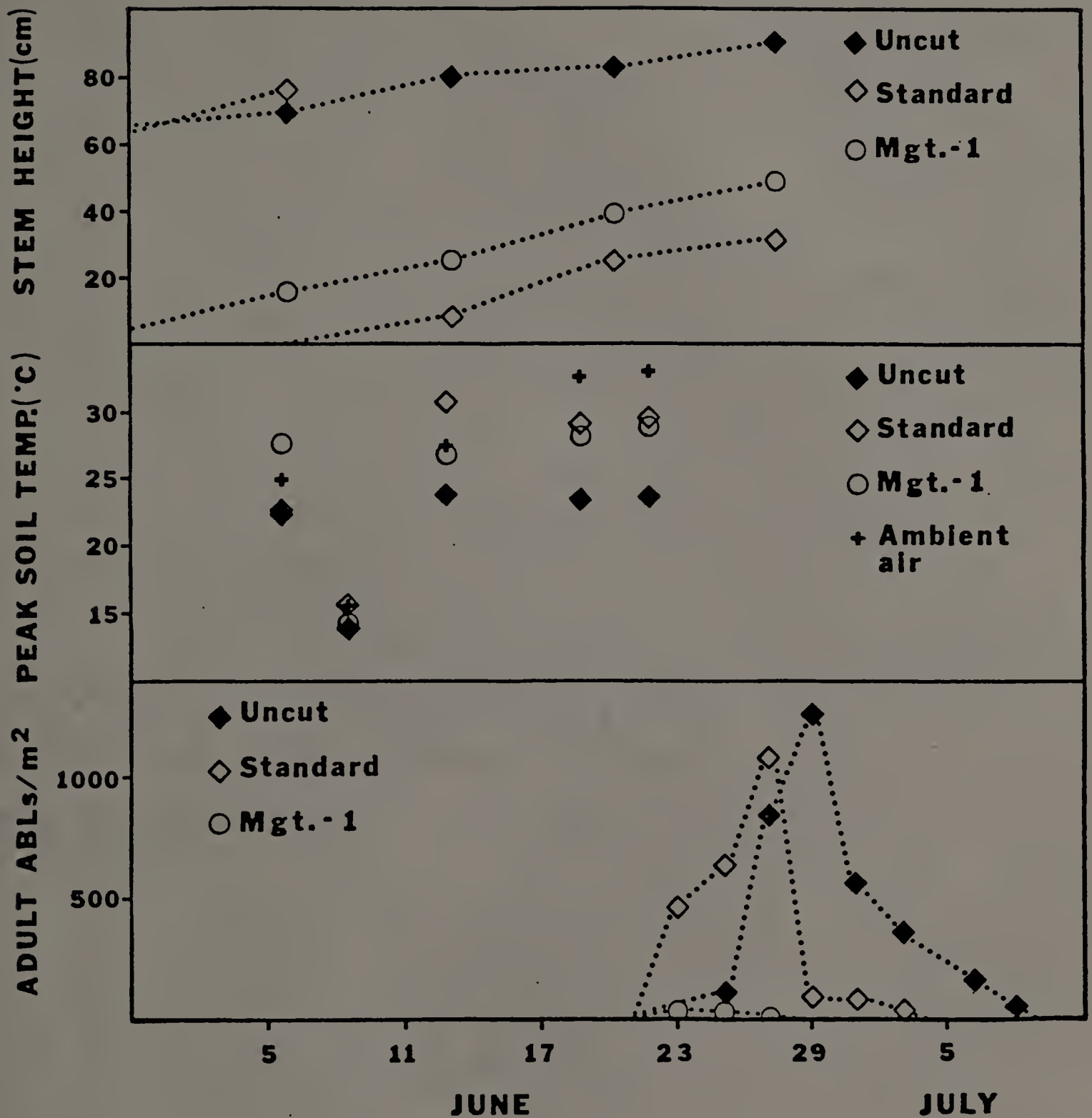


Figure 5. Effect of first harvest timing on subsequent alfalfa regrowth, peak daily soil temperatures, and first generation adult emergence profiles at Amherst, MA in 1980.

differences were probably even less during non-peak temperature periods. Although the emergence density in the management-1 plot was minimal, the rate of pupal development apparently was similar to that of the standard treatment.

The emergence density of third generation adults was not investigated, as densities in both management treatments were quite low and few larvae completed their development in the old growth of the unharvested plot.

Satellite plot observations. Observations at four commercial stands in western Massachusetts during the first two harvest periods confirm the results of Amherst harvest treatments (Table 5). First harvests were conducted between early and full bud at three of the sites, thereby reducing the buildup of first generation ABL pupae. In contrast, the 10% bloom harvest at Greenfield resulted in uninterrupted first generation ABL development and subsequent elevated adult densities during the second regrowth.

Adult dispersal. Overwintering generation adult numbers had already declined by the management-1 first harvest and remained low during the initial management-2 and standard harvests at 10% crop bloom (Figure 4). Thus, no net movements of flies between plots were noted by directional flight traps (Table 6). In contrast, the early second harvest of the management-2 plot on VII-3 occurred when adult densities were still quite high (Figure 4). This sudden removal of feeding and oviposition sites resulted in a net movement of adults to the adjacent unharvested plot,

Table 5. The relationship between first harvest timing and ABL survival at four commercial stands in western Massachusetts during 1980.

	SITE			
	Greenfield	Conway	S.D. I	S.D. II
Crop growth stage at first harvest	10% bloom	full bud	early bud	full bud
Total blotch mines/stem at first harvest ¹	30.0a ²	0.0b	1.4c	1.0c
Cumulative adults/m ² (generation 1) ¹	1034.9a	11.6b	4.1b	17.9b

¹horizontal values followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test

²probably an underestimate, as harvest was conducted three days after last sampling date.

Table 6. Inter-plot movements of adult ABLs at harvest during 1980 at Amherst, Ma.

Plot	Harvest Date	Sampling Interval	Adult ABLs/trap ¹	
			Immigrants	Emigrants
Management-1	5/23	5/21-5/23	4.8 ± 1.9	5.3 ± 1.5
		5/23-5/25	2.7 ± 1.1	3.2 ± 1.1
Standard & Management-2	6/6	6/4-6/6	0.2 ± 0.2	0.1 ± 0.2
		6/6-6/8	0.0 ± 0.0	0.3 ± 0.2
Management 2	7/3	7/1-7/3	21.4 ± 4.2	26.9 ± 6.9
		7/3-7/5	12.8 ± 2.4	24.0 ± 5.9*
Management-1	7/7	7/5-7/7	20.7 ± 4.1	21.1 ± 3.8
		7/7-7/9	4.9 ± 2.3	4.3 ± 2.0
Standard	7/15	7/13-7/15	5.8 ± 3.7	7.1 ± 4.4
		7/15-7/17	6.4 ± 2.6	8.5 ± 4.8
Management-1 and -2	8/14	8/12-8/14	2.2 ± 1.2	1.4 ± 0.7
		8/14-8/16	1.1 ± 1.0	1.9 ± 1.4
Standard	8/23	8/21-8/23	4.4 ± 3.6	2.4 ± 1.8
		8/23-8/25	3.9 ± 2.7	5.2 ± 3.9

¹mean values ± 95% confidence intervals

* indicates significant net movement of flies at $p < 0.01$ (t-test)

management-1. However, the second harvest of the management-1 plot four days later precluded the development of progeny from immigrant females. No other significant interplot fly movements were noted. Thus, crop damage and yield estimates were not influenced by ABL dispersal between treatments.

Crop damage. The total number of blotch mines/harvested stem was greatest during the first harvest of the standard treatment (Table 7). However, adult densities were clearly highest during the second crop regrowth, as indicated by both sweep-net peaks (Figure 4) and cumulative emergence densities (Table 4). The use of blotch mine density as a measure of ABL damage probably resulted in an underestimate of damage levels during the second crop regrowth. This may be due to several factors: 1) larval competition in multiple-mined leaflets, resulting in increased mortality (Guppy 1981) and smaller third instars and 2) higher larval mortality due to increased feeding by female flies ("pinholing") (Dureseau and Jeandell 1977). During the second regrowth, an average of 101.2 pinholes/leaflet were observed, with individual leaflets sustaining over 200 pinholes. Guppy (1981) estimated that 86 pinholes/leaflet was equivalent to 2% of the total leaflet surface area. The low damage levels observed during the third and fourth regrowths of the standard treatment was attributable to the impact of increased late-season parasitism (Hendrickson and Barth 1979a) and the induction of diapause in third generation pupae (Mellors and Helgesen), respectively.

The early harvests of the management treatments virtually

Table 7. Total number of blotch mines per stem at each harvest for three harvest schedules at Amherst, MA in 1980.

Harvest	Total number blotch mines/ harvested stem ¹		
	Harvest Schedule		
	Standard	Management-1	Management-2
1	63.7a	0.2b	67.9a
2	51.3a	0.4b	0.1b
3	15.4a	0.1b	0.2b

¹horizontal values followed by the same letter are not significantly different at the 5% level by Duncan's multiple-range test.

eliminated ABL damage during subsequent crop regrowths (Table 7). The low incidence of blotch mines observed in either treatment following the modified harvest was due to either rapid third instar development in field-drying hay (Chapter IV) or occasional immigrant females.

Crop growth and yields. No significant differences (Duncan's multiple range test, $p < 0.05$) in stand density were noted between the three harvest schedule plots; the mean number of stems/m² for all treatments was 549.0. Thus, the Amherst site was considered suitable for conducting yield comparisons between harvest schedule treatments.

Under the standard 10% bloom harvest schedule, alfalfa growth (Figure 6) and total hay and crude protein yields (Table 8) were greatest at first harvest. Yields decreased with each successive regrowth, partly due to the severe drought in Massachusetts during 1980. However, full-season yields were nearly identical to those reported by Smith (1978) under a 3-cut, 10% bloom harvest schedule in Wisconsin.

Both management schedules resulted in varying crop growth patterns and yields for each harvest. As the management-1 and -2 modified harvests were conducted 14 and 11 days, respectively, before 10% bloom of the standard treatment, each reduced yields significantly during the truncated growth period. However, these early cuts produced a higher quality forage than the standard treatment.

As both second and third harvest yields of the management-1 schedule exceeded those of the standard treatment, full-season yields did not differ significantly between the two treatments. In contrast,

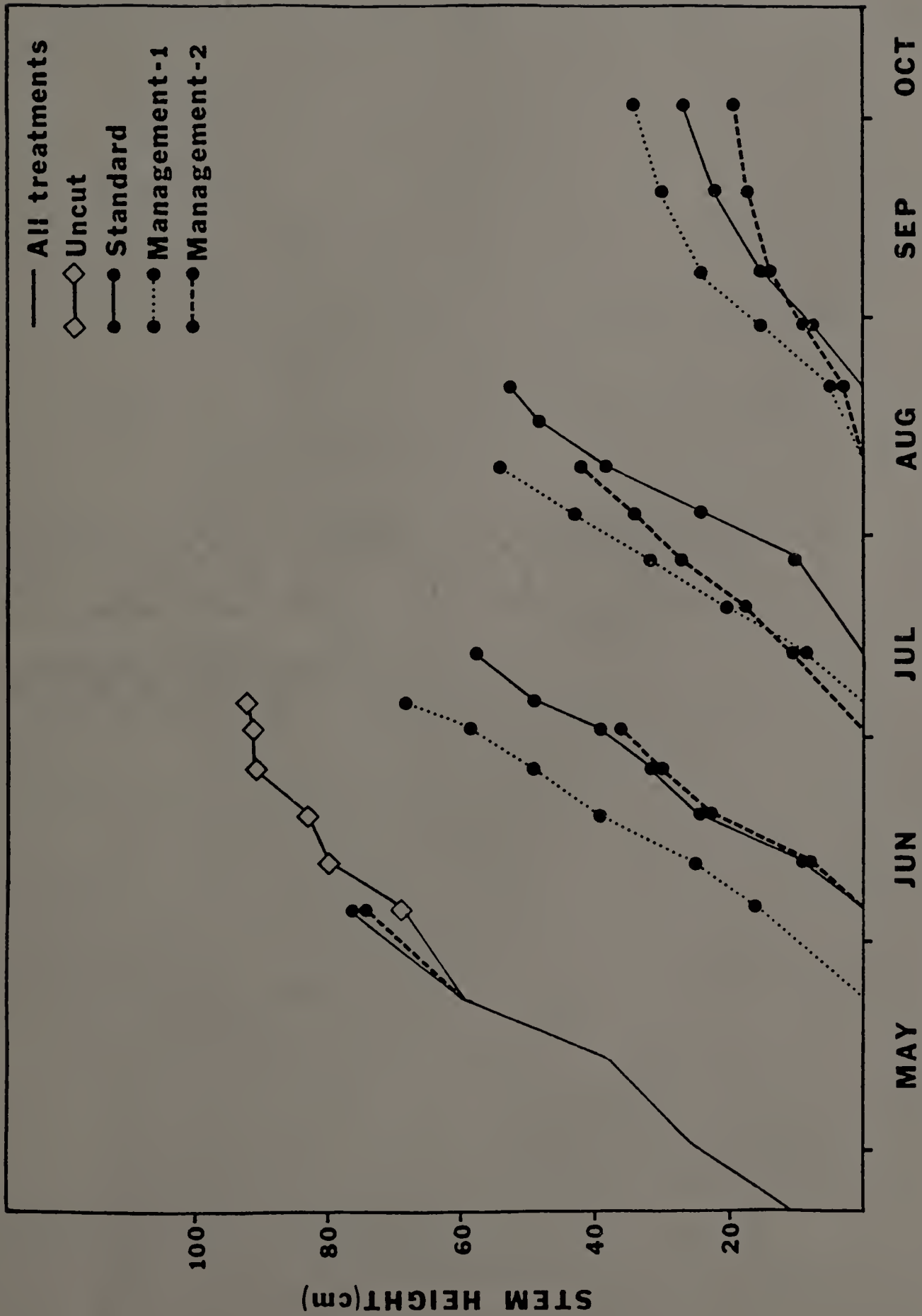


Figure 6. Crop growth patterns under four harvest schedules at Amherst, MA in 1980.

Table 8. Total dry matter (TDM) and crude protein (CP) yields of alfalfa harvested under three schedules at Amherst, MA in 1980.

Harvest	Yield Component	ALFALFA YIELD (10^4 grams/ha) ¹		
		Standard	Management-1	Management-2
first	TDM	451.5a	289.1b	458.1a
	CP	82.5a	59.3b	84.3a
second	TDM	390.2a	420.8a	219.7b
	CP	73.6a	80.3a	49.2b
third	TDM	362.3a	397.3a	238.7b
	CP	67.0a	74.4a	44.7b
Seasonal totals	TDM	1204.0a	1107.2ab	916.5b
	CP	223.1a	214.0ab	178.2b

¹horizontal values followed by the same letter are not significantly different at the 5% level by Duncan's multiple-range test.

full-season total hay and crude protein yields of the management-2 treatment were 23.9% and 20.1%, respectively, below those of the standard treatment. This was primarily due to the depressed growth response of the crop following the early second harvest (Figure 6). In addition, the only serious weed infestation in this study occurred during the third regrowth of the management-2 treatment when redroot pigweed, Amaranthus retroflexus L., became common.

The stage of crop growth attained before killing frost (X-10-81) also differed between treatments (Figure 6); only the management-1 treatment reached the early bloom stage during this final regrowth.

Discussion

Harvest schedule modifications. Alfalfa is grown in long-term rotations in the northeastern United States, lasting 4-6 years or more under ideal conditions. As winterkilling is the most important problem in overall crop production, stand persistence considerations are as important as yield in formulating management decisions. Thus in order to fully interpret the impact of harvest modifications for pest control, a long-term cost benefit analysis is required. However, the results of this one-year study, coupled with the findings of harvest management research (Smith 1978), provide a basis for evaluating the potential of this pest management option.

The standard harvest treatment (i.e. three cuts at 10% crop bloom) represents the optimal stand management practice in the northeast, balancing crop yields and stand maintenance. Earlier harvests produce a

higher quality forage and the possibility of four cuts per season, but reduce the carbohydrate root reserves so critical to winter survival. Conversely, full-bloom harvests produce a lower quality forage, but maximize root reserves. Thus the suitability of modified harvests must be judged in relation to the accepted optimal practice, represented by the standard treatment in the present study.

In this regard, the management-2 treatment was an unacceptable crop management option. Like the standard treatment, the first harvest of management-2 was subjected to severe ABL infestation. Although the early second harvest minimized subsequent leafminer damage, this premature cutting resulted in a reduced second harvest yield and poor growth during the third and fourth regrowths. In addition, the final uncut regrowth was well below that of the standard and management-1 treatments, thereby increasing the potential of stand winterkill (Smith 1978).

The management-1 harvest schedule displayed considerably greater potential as a crop management option. The early first harvest virtually eliminated ABL pest pressure throughout the growing season. Although the truncated first harvest yield was below that of the standard treatment, subsequent crop production in the second, third, and fourth regrowth periods was increased. Overall crop yields and protein differences between the standard and management-1 treatments were insignificant, and the stage of regrowth at killing frost was greater for the latter treatment.

Several other factors would dictate the value of a modified

harvest to control the ABL. Following severe winterkill, delaying harvest of spring regrowth to the full-bloom stage is essential for restoring root reserves. Thus, early first harvests would be impractical. In contrast, spring weather conditions which accelerated the development of alfalfa growth in relation to leafminer phenology would be ideal for maximizing the benefits of first harvest ABL control. Quick-maturing alfalfa varieties would be most useful in this regard.

Adult dispersal potential relates to the use of early first harvests in several ways. First, as witnessed in the present study, flies are able to move between small plots at harvest. This is especially important when harvests are conducted during periods of high adult density. On a commercial scale in Massachusetts, it is common for established stands to be located adjacent to spring- and summer-seeded fields. Thus, the harvest of established stands could facilitate infestation of highly susceptible new growth. Secondly, it is unlikely that modified harvests would be acceptable on an annual basis, as this would probably decrease stand density. Since the adult ABL may disperse ca. 80 kilometers per season (Mellors and Helgesen 1978), the proximity of neighboring stands may be a key factor in evaluating the role of modified harvests at a particular site.

Harvesting practices affect other members of the alfalfa insect community, including the economically important alfalfa weevil, Hypera postica (Gyllenhal) and the potato leafhopper (PLH), Empoasca fabae (Harris) (Simonet and Pienkowski 1979). In the present study, weevil populations were too low to interpret the impact of ABL harvest control

on this early-season defoliator. However, studies in Michigan (Cassagrande and Stehr 1973) report that harvesting first growth between 232 and 288 °C-days (base temperature=8.9°C) minimized weevil damage. The management-1 harvest, timed to control the ABL, occurred at 249 °C-days (base temperature=6.8°C). Thus the integration of harvest control strategies for the two pests may be feasible. The effect of modified harvests on the PLH is less predictable, as the arrival of this annual immigrant in Massachusetts varies considerably between years. However, maintenance of stand vigor is essential in reducing PLH injury; thus harvest schedules which deplete root reserves, such as management-2 in this study, are unacceptable.

ABL pest status. The high ABL populations encountered in this study were in part due to the late harvest at this field in 1978 and 1979 which provided an uninterrupted host population for leafminer increase. The infestation levels present in the standard treatment probably approach a "worst-case analysis" in terms of ABL damage potential. Unfortunately, the experimental design of this study did not permit isolation of the impact of ABL pressure from the impact of harvesting schedule on alfalfa production. Nonetheless, these results contribute to the present understanding of leafminer pest status.

As previously mentioned, yields under the management-2 harvest schedule were apparently decreased by an interruption of the buildup of carbohydrate root reserves during the second crop growth. The first harvest of the management-1 treatment no doubt caused a similar problem,

as the early harvest was made when crop growth was only 79% of 10% bloom values (Figure 6). However, the subsequent second harvest yield of management-1 was greater than that of the standard treatment (Table 8). The ABL was the only serious pest of the study plots at this time, as alfalfa weevil and spittlebug populations were extremely low and the potato leafhopper had not yet arrived. Thus if crop response to first harvest timing and ABL damage are considered the primary variables influencing crop production during the second harvest period, then a minimum decrease in yield of 7.3% is attributable to the ABL. As the second growth of management-1 was assumedly inhibited by suboptimal root reserve levels, the negative impact of the leafminer on second harvest yields was probably greater still. Indeed, a concurrent caging study, in which the differential impact of first harvest timings was removed, revealed a 26.3% second harvest yield loss due to the ABL (Alicandro and Peters 1980). In retrospect, the addition of a treatment in which insecticides were selectively employed to control the ABL under a standard harvest schedule would have facilitated distinguishing ABL damage from harvest timing impact.

Thompson (1981) reported no differences in alfalfa yield between sprayed and check plots with differing ABL damage levels. However, the adult densities present in his experiment, 34/sweep, are far below the peak of 162/sweep noted in the present study. Such differences in density may partly account for the varying interpretations of these and other studies (Byers and Valley 1978; MacCollum et al. 1980).

Field studies of ABL pest status have emphasized the relationship between crop damage at harvest and alfalfa yield (Thompson 1981; MacCollum et al. 1980). Results of the present study, however, illustrate the dynamic interaction between crop growth and ABL bionomics and damage. Economic injury levels for the ABL must therefore vary with harvest period, stage of growth attacked, and leafminer phenology as well as pest density. It is generally agreed that the pest status of the leafminer bears little resemblance to that of the potato leafhopper, which at low densities may cause considerable damage. Thus efforts at determining ABL pest status should be directed toward identifying conditions under which ABL damage would be optimal. Our results suggest that the potential for ABL damage is greatest under a 10%-full bloom cutting schedule during the second harvest regrowth. By harvesting first crop between 10% and full bloom, the maximum increase in overwintering populations is permitted. Additionally, such timing of first harvest provides a relatively immature second regrowth at the period of peak adult pinholing and oviposition.

Our results underline the necessity of developing dynamic crop-pest models for determining the precise relationship between the alfalfa blotch leafminer and alfalfa. The major components of such a model for the second crop harvest are illustrated in Figure 7. At this time, relationships 1, 2, 3 (Smith 1978) and 6 (Spencer 1974; Bremer 1976; this study) have a firm data base. The methodologies for studying relationship 5 are illustrated by Pinter et al. (1975) and a preliminary insight into relationships 7&8 is provided by our results

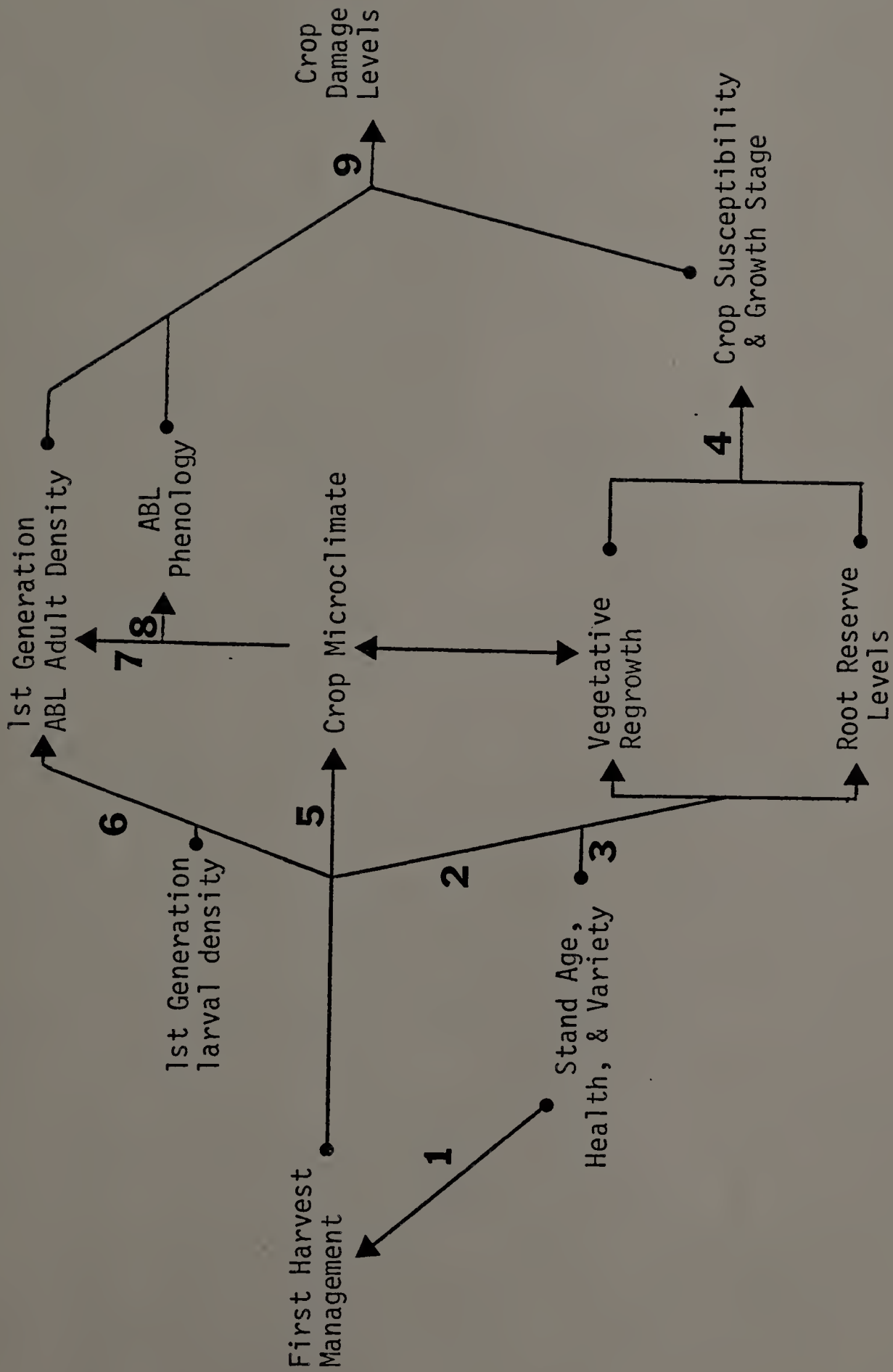


Figure 7. Major factors influencing potential crop damage from the ABL during the second alfalfa growth period.

and those of Mellors and Helgesen (1978). The key to assessing ABL damage lies in developing an understanding of the susceptibility of various crop growth stages (relationship 4) and the effect of various ABL infestations on these growth stages (relationship 9). The design of the present study is of no value in this regard as the key variables, leafminer density and crop growth stage, are dependent. A study similar to that of Thompson (1981) but with higher leafminer densities and variable cutting schedules is a feasible option. Similarly, the caging technique of Alicandro and Peters (1980) allows simultaneous variation of ABL density and crop development and should therefore be useful in determining leafminer economic injury levels.

CHAPTER IV

THE INFLUENCE OF FIELD-CURING HAY ON SURVIVAL OF THE ALFALFA BLOTCH LEAFMINER, AGROMYZA FRONTELLA (RONDANI)

Introduction

Alfalfa is commonly field-cured for several days after harvest in order to decrease moisture content from ca. 70-80% to 20-25%. Otherwise, problems with excessive heat content and molds may cause a loss of feeding value. Pinter et al. (1975) reported that survival of the beet armyworm, Spodoptera exigua (Hübner) is enhanced by the practice of drying cut alfalfa hay in windrows. The windrow microenvironment modified climatic extremes in recently harvested fields, and thus facilitated development of larvae in wilting hay and increased the survival of soil-dwelling pupae. Andaloro (1981) hypothesized that a similar phenomenon may occur in relation to the survival of the alfalfa blotch leafminer (ABL), Agromyza frontella (Rondani), after harvest. Thus, the following investigations were conducted to evaluate the relationship between field-curing alfalfa hay and leafminer survival.

Materials and Methods

Experiment I. The purpose of this study was to compare the ability of immature larvae (first and second instars) and mature larvae (third instar) to complete their development and form puparia in the windrow environment. During the summers of 1979 and 1980, survival in windrows was simulated in the following manner: Stems with only immature larvae

or with only mature larvae were isolated by hand-picking leaflets off stems. The criteria of Hendrickson and Barth (1978) were used to distinguish larval age classes. Stems containing leaflets with only one larval age-class were then placed in white plastic containers (33 cm X 45 cm X 20 cm high), the bottom of which was lined with a 3-ply layer of saturated blotter paper (Hendrickson and Barth 1977). Fifteen 2 cm X 33 cm strips of blotter paper were placed over this 3-ply lining, in order to provide the necessary shading for pupal development. Stems with 200 of each type of mine were placed above this configuration and a 2-cm layer of quackgrass, Agropyron repens (L.) Beauv. was placed over alfalfa stems in order to provide an insulating windrow effect without introducing stray leafminers. Plastic tubs were then placed 2 cm into the soil of a cut stand and left for 72-hour intervals. In the lab, the number of ABL puparia were counted.

Experiment II. The purpose of this study was to evaluate the impact of field-curing hay on ABL larval and pupal survival under the management-1 and standard harvest schedules investigated in Chapter III. A 12 m X 12 m plot of Saranac alfalfa was subdivided into eight 3 m X 6 m units and four replications of the management-1 and standard harvest schedule treatments assigned to these units at random. The first harvest of the management-1 treatment was taken on V-23-80, just as early instar larvae were beginning to form. Standard treatment plots were cut on VI-6-80 at 10% crop bloom, after third instar populations had already peaked (Figure 4). Immediately after harvest, one-half of each plot was hand-

raked to remove all cut hay; the other half was raked into one 0.6 m X 3 m windrow and allowed to field-dry for 72 hours. Before the onset of first generation ABL adult emergence, 10 eclosion traps (Chapter II) were placed in each replicate, 5 in the immediately raked half and 5 in the windrow strip of the field-cured half. Thus, a total of 20 traps were present in each of the four treatments. Traps were left in place until sweep samples indicated that emergence was complete and then returned to the lab for adult counts.

Results and Discussion

Simulated windrow experiments revealed that early instar larvae were virtually unable to complete their development in harvested field-drying hay. Of the 800 first and second instar mines evaluated, only $0.9 \pm 1.5\%$ (95% confidence interval) formed puparia. In contrast, third instar larvae exhibited a significantly greater ability to complete their development in wilted hay ($p < 0.01$, t-test), as $32.0 \pm 8.4\%$ ($n=2000$; 95% confidence interval) formed puparia. These data are probably not indicative of actual third instar survivorship in cut hay under commercial conditions, as this study involved only the lower surface of the windrow micro-environment. Mortality at the upper surfaces of the windrow may be greater due to more stressful temperature and moisture levels. However, these results clearly indicate that the negative impact of field-curing hay relates only to survival of mature ABL larvae.

The results of Experiment II support this observation. Field-drying hay had no significant effect on ABL survival under the management-1 harvest schedule (Table 9), as few mature larvae were present at cutting

Table 9. Cumulative first generation ABL adult densities under four first harvest treatments at Amherst, MA in 1980.

	Harvest Treatment			
	Management-1		Standard	
	removed	windrowed	removed	windrowed
(Adults/m ²) ¹	97.2a	91.7a	1,514.0b	2,194.4c

¹ values followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test.

(Table 7). However, a significant 31.0% reduction in first generation ABL adult density resulted from the immediate removal of harvested hay under a standard harvest schedule. Although this difference was partly attributable to the exiting of wilting leaflets by third instar larvae, the modification of soil temperatures by the windrow may also have increased pupal survival.

The modification of alfalfa field-curing practices for ABL pest management is infeasible, given the importance of proper hay moisture levels during storage. However, the ability of mature larvae to complete their development in windrows underlines the necessity of conducting management harvests before the onset of this stadium. Mellors and Helgesen (1978) report that development from the early instar to the mature instar takes 3.5-4.5 days at 20-25 degrees centigrade. Thus, harvesting at the initial detection of linear, early instar mines should preclude the maturation of larvae during the 2-3 day field-curing period.

C H A P T E R V

FORECASTING AGROMYZA FRONTELLA (RONDANI) SEASONALITY WITH PHYTOPHENOLOGICAL INDICATORS

Introduction

Seasonality forecasts in pest management. Forecasting the seasonal development of key arthropod species is considered an essential component of agricultural pest management programs. The efficacy of pesticide applications, biological and cultural control strategies, and pest monitoring programs may each be enhanced by reliable forecasting systems. However, a study conducted by the Intersociety Consortium for Plant Protection (Anonymous 1979) suggests that the lack of accessible forecasting tools is a limiting factor in extension integrated pest management (IPM) programs. Thus the need for increased research and education efforts in this area is apparent.

The goal of IPM seasonality forecasts is to anticipate the periods, or "windows", when critical events occur in the field (Welch et al. 1978). Such critical events include the onset of a damaging pest life-stage, the buildup of pest density to a critical level, or the development of a susceptible crop growth-stage. The primary role of forecasts lies in crop and pest monitoring programs. By defining a time period in which there exists a high probability of collecting critical data, forecasts aid in scheduling optimal use of IPM scouts.

Three approaches to forecasting arthropod seasonality are currently available for agricultural pest management programs: calendar alerts,

temperature-dependent development models, and plant phenological (phytophenological) indicators. Whereas the first two approaches are quite familiar to most IPM personnel, phytophenological indicator forecasts have received only intermittent use in pest management. The intent of this paper is to familiarize IPM personnel with this viable forecasting option, using the development of a phytophenological forecasting system for the alfalfa blotch leafminer (ABL), Agromyza frontella (Rondani) as an example. First, however, the underlying concepts and previous uses of this technique are discussed.

Conceptual basis for phytophenological forecasts. Phytophenological indicator forecasts have been employed in several facets of natural resource management, including wildlife biology (Leopold and Jones 1947; Hungerford 1953), range management (White 1979) and crop production (Wielgolaski 1974). Although use of the technique in pest management has been limited, phytophenological indicators have been used in forecasting the development of mosquitos (Penfound et al. 1945), forest insects (Kielszewski 1962; Wickman 1976), and agricultural (Przybylski 1970; Matthewman and Harcourt 1971; Straub and Huth 1976) and ornamental pests (Tashiro and Gambrell 1963; Kapler 1967). Although the history and potential applications of phytophenological indicators has been reviewed (Newman and Beard 1962), the underlying concepts of this approach have received little consideration in crop protection literature.

By comparing the theoretical foundation of phytophenological forecasts to that of the more familiar temperature-dependent development

model, a better understanding of the former technique may be obtained. Simulation models of phenological development require a comprehensive analysis of the relationship between climate and species' development. The influence of temperature on both post- and non-diapause development may need to be quantified for multivoltine species; similarly, the determination of diapause termination in the field may be necessary for proper initiation of degree-day accumulations (Tauber and Tauber 1976). In contrast, the development of phytoperiodical forecasts is a highly empirical process. The causal relationships between climatic factors and species' development need not be understood; rather, naturally occurring synchronies in the timing of plant and insect seasonal events are utilized for their predictive value. For example, Tashiro and Gambrell (1963) noted a consistent correlation between full-bloom of horse chestnut, Aesculus hippocastanum L., and peak density of the soil-dwelling prepupae of the European chafer, Amphimallon majalis (Razoumowsky). Thus the easily observed bud-burst of the plant indicator species was useful in forecasting a cryptic life-stage of an insect pest.

The major assumption underlying the use of phytoperiodical indicator forecasts in pest management is that both plant and insect seasonality respond similarly to the many climatic components (e.g., temperature, photoperiod, humidity, etc.). Kapler (1967) suggested that since plant development is influenced by the full range of weather conditions, they provide more accurate indications of insect seasonal development than thermal-unit accumulations alone. Indeed the post-dormancy development of most woody plant (Flint 1974) and insect species

(Tauber and Tauber 1976) is regulated primarily by the same factor, temperature. Similarly, the termination of plant dormancy and insect diapause is generally dictated by photoperiod and temperature. However, the responses of individual plant and insect species to climatic gradients vary considerably. Consequently, the seasonal development of most insects and plants is not consistently synchronized. Just as the modeler must develop an equation to describe a species' temperature-development response, so the phenologist must screen the seasonality patterns of many plant species in selecting reliable indicators of insect phenology.

The ABL as a model system. The alfalfa blotch leafminer (ABL) has elicited considerable concern since it was first detected in North America thirteen years ago (Miller and Jensen 1970). Although several instances of economic damage have been reported (Anonymous 1972; Richard and Gagnon 1976), the pest status of the fly remains uncertain (Thompson 1981). The common practice of harvesting alfalfa between 10% and full bloom may allow ABL population densities to reach injurious levels (Alicandro and Peters 1980). Conversely, properly timed harvests may reduce infestations to insignificant levels (Spencer 1974; Bremer 1976), without decreasing yields (Table 8).

As the ABL completes 3-4 relatively distinct generations annually in Massachusetts (Andaloro 1981), the synchronization of sampling activities to pest phenology was considered a necessary step in the development of a cost-effective management program. Adult population peaks

represent a critical event in leafminer phenology for several reasons. First, peak adult density is the optimal stage for maximizing insecticide efficacy (Thompson 1981). Secondly, peak adult density generally precedes the onset of pupation in the field by 2-5 days (Figure 4). Thus harvest modifications to control the ABL should be instituted shortly after adult density peaks. Finally peak adult density provides an ideal stage for determining economic threshold levels (ETL). Mellors and Helgesen (1978) developed a temperature-dependent model to forecast ABL adult phenology in New York. The information-delivery system needed to implement such an approach is currently lacking in Massachusetts. In addition, the low unit-value of the state crop dictates the development of a forecasting tool suited to implementation at the grower level. Consequently, the efficacy of phytophenological indicator forecasts in scheduling ABL sampling programs was investigated in the present study. As a basis for evaluation, three other forecasting options were also considered.

Materials and Methods

Site Descriptions. Investigations were initiated at Amherst, MA in 1978. Since the commercial stand used in 1978 was replanted to corn the following spring, the study was transferred to a research plot 3.2 kilometers to the west for the final two seasons of the study.

In order to consider topographically-induced variations in ABL and plant phenology, four commercial stands were added in 1980. Figure 8 illustrates the location and altitude of each site. The South Deerfield

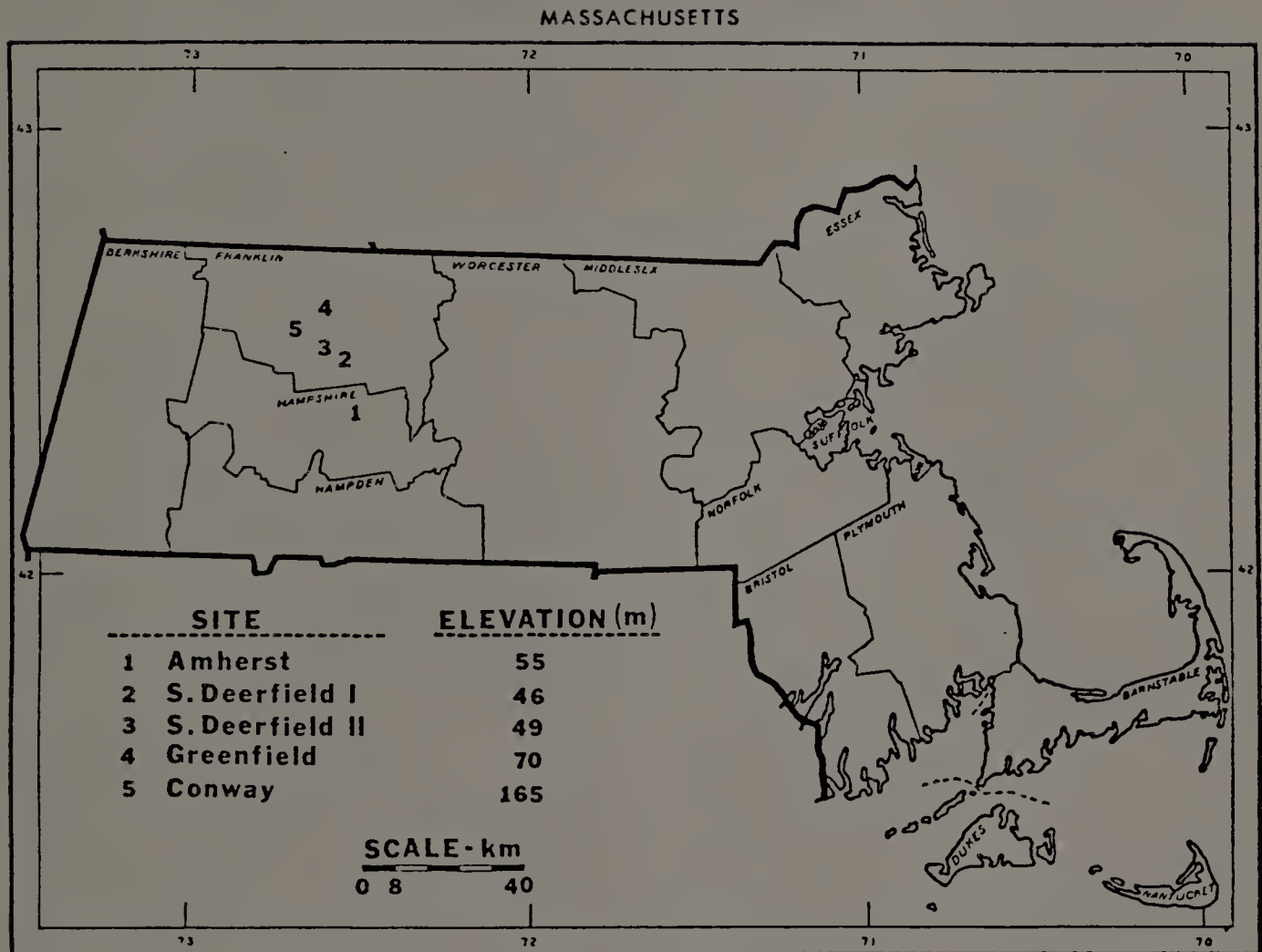


Figure 8. Geography of 1980 study sites.

I site was within 300 meters of the Connecticut River; all other sites were upland habitats.

Each alfalfa stand was between two and five years old and of Saranac cultivar. No insecticides were applied to any field during the study period and harvest schedules varied between three and four cuts per season.

Seasonal temperature trends. Temperature data of the Amherst College weather station, 3.5 kilometers south of the Amherst study site, were used to characterize meteorological variability between the three years of the study.

The developmental threshold for the ABL, 6.8°C (Hendrickson and Barth 1978), was used as a base temperature for accumulating degree-days. Degree-days were computed by subtracting 6.8°C from the mean daily temperature, which was determined by averaging daily maximum and minimum values. Negative values were considered equal to zero. Degree-days were accumulated from January 1 each season, as the timing of ABL diapause termination in the field has not been determined. As a basis for assessing climatic variability during the study period, seasonal degree-day accumulations were compared to 32-year norms for the Amherst area. These were determined by subtracting 6.8°C from 32-year mean monthly temperatures, and multiplying this value by the number of days in that month.

ABL phenology. The tendency of leafminer adults to aggregate on the upper stem portions of alfalfa (Bremer 1976) facilitates the use of the sweep-net in monitoring adult population dynamics. Furthermore, Plummer

and Byers (1981) report the sweep-net to be as effective as the D-vac in sampling adults, except at very low densities. A standard 38 cm net with a 0.9 m long handle was used to collect adult ABLs by taking 180 degree arc sweeps through the top 20-25 cm of crop growth. At an alternating 3 and 4 day interval, three 5-sweep samples were collected per site; intervals were shortened during periods of rapid population density change. Sampling was restricted to between noon and 5 p.m. to minimize possible effects of diurnal variations in adult activity (Saugstad et al. 1967). Similarly, potential variations due to sweeping technique (Cothran and Summers 1972) were reduced by assigning sweep-net sampling to a single individual per season.

Plant Seasonality. Observations of plant phenology were confined to within a 4.8 kilometer radius and to within fifteen meters elevation of respective alfalfa stands. Observations were made at 2-day intervals during key stages in ABL and plant species' development, and on ABL adult sampling dates during other periods.

During 1978 and 1979, the flowering dates of approximately 150 species were recorded at the Amherst site to establish a list of potential indicators (unpublished data). To facilitate this initial screening process, the initial anthesis or beginning of bloom of only the earliest flowering individual of each species was recorded in 1978. This same individual, for perennials, or a member of the same population, for annuals and biennials, was observed in 1979. All plant specimens observed had unobstructed southern exposure and were not adjacent to artificial heat sources (e.g., buildings).

From this 2-year list, promising indicator species were evaluated in forecasting ABL adult emergences at all five sites during 1980. In order to assess intraspecific phenological variability in indicator populations, an increased number of individuals were observed at each site.

The value of host plant phenology in forecasting adult ABL seasonal activity was also investigated. On a weekly interval, one 20-stem sample was collected randomly along diagonal transects through each alfalfa stand. In the lab, mean stem heights and flowering stage were determined.

Evaluation of forecasting options for ABL management. The efficacy of phytophenological forecasts was compared to that of three other forecasting options: calendar date, cumulative degree-days, and "ABL-days."

Calendar date forecasts were determined by using the 3-year mean date of occurrence for each ABL adult population peak as a forecasting index for each particular season. Forecast length was equal to the number of days between this 3-year mean and the actual date of peak occurrence during each season.

The number of days between overwintering ABL generation peak adult density and subsequent generation peaks was termed "ABL-days". Three-year mean values for "ABL-days" were used as a forecasting index for first and second leafminer generations.

In order to provide a common base unit for comparing forecasting options, a normalizing procedure was used to convert three-year mean

degree-day data back to an appropriate calendar date for each season (White 1975). For the overwintering ABL generation, the mean accumulated degree-day value at peak adult occurrence (Table 10) was reduced by 100 degree-days C to provide a suitable forecasting length. Thus, the dates by which 146.9 degree-days C accumulated each season were used as a forecasting index. The accumulation of thermal-units was much more rapid during the subsequent summer ABL generations. Thus, in order to provide a similar forecast length, the three-year mean accumulated degree-day value at first and second generation peak adult density was reduced by 200 degree-days C. This resulted in forecasting indices of 517.0 and 1096.0 degree-days C for the first and second leafminer generations, respectively.

Inter-site forecasting evaluations during 1980 were made in a similar fashion, except that the variability between sites rather than between years was compared. Degree-day forecasts were excluded from this analysis, as precise temperature data were not available for each site.

Results and Discussion

Seasonal temperature trends. Effective temperatures for development varied considerably during the study period as compared to 32-year norms for the Amherst area. Since critical differences in degree-day accumulations occurred during the spring, the data is presented in \log_{10} form to facilitate comparison of low, early-season accumulations (Figure 9). Since the data is presented in a cumulative manner, the rate of

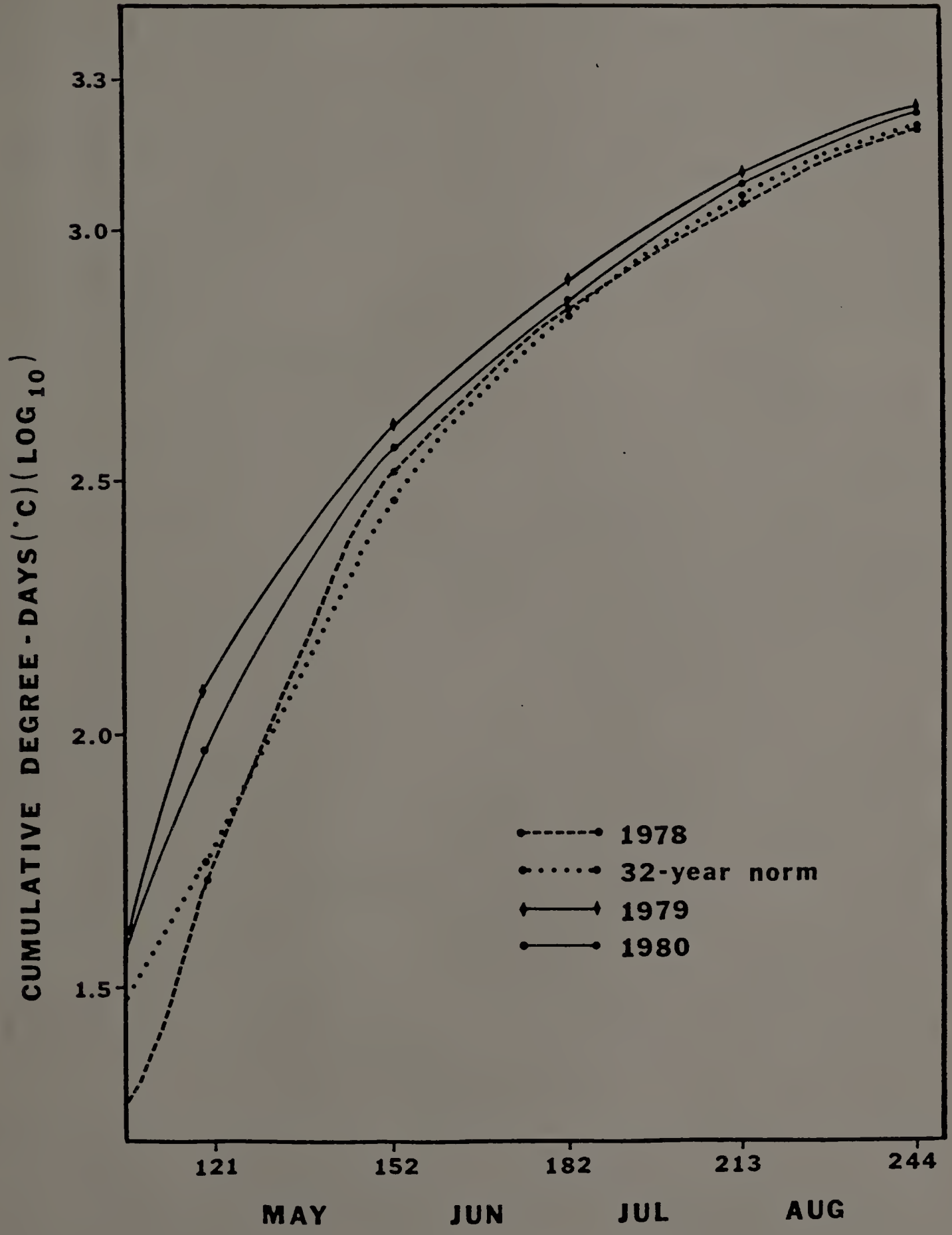


Figure 9. Accumulated degree-days (centigrade) at Amherst, MA during 1978-1979-1980 and 32-year norm values. Threshold temperature is 6.8 degrees centigrade.

accumulation (i.e., the slope of the curve) indicates temperature patterns during particular periods of the year.

Aside from warmer than average springs, temperature trends in 1979 and 1980 were similar to the long-term norm, as indicated by the parallel nature of their accumulation curves. In contrast, the temperature trends of 1978 were quite variable. Early spring was cooler than the norm during this season, May through mid-June was warmer than the norm, and July and August were again cooler than average.

ABL phenology. In monitoring the population dynamics of ABL adults, rates of eclosion and survivorship were considered to be the primary variables influencing changes in density. Although immigration and emigration no doubt occurred, their impact was assumed to be minimal during most of the sampling period. However, dispersal between adjacent plots at harvest has been documented (Chapter II) and was observed during 1979 in this study at the Amherst site (Chapter III). Changes in adult density due principally to immigration from adjacent harvested plots are illustrated in Figure 10.

Although as many as four complete leafminer generations are feasible in Massachusetts, only the initial three reach densities of agronomic concern (Andaloro 1981). Third generation adult emergences are generally small, as many third generation pupae enter diapause (Mellors and Helgesen 1980). In the present study, adult densities were consistently greatest during the first generation (i.e., the second emergence), exceeding 150 adults/sweep at the Amherst site in both 1978

and 1980 (Figure 10). The 10% crop bloom harvests of the Amherst site allowed almost complete pupation by the first generation ABL cohort, and interfered only minimally with development of the second generation. The variable densities of the overwintering and second generations probably reflect inter-season differences in winter mortality and summer parasitism rates (Hendrickson and Barth 1979a), respectively.

The developmental progress of the soil-dwelling pupal stage is particularly critical to the timing of adult emergences. Between 10°C and 25°C, the temperature-development curve for the pupal stage is exponential (Mellors and Helgesen 1978), resulting in considerable differences in developmental period over small temperature ranges. Also, as the overwintering stage, the post-diapause development of pupae dictates the timing of subsequent seasonal events.

The effect of the cool spring of 1978 on the maturation of overwintering pupae is reflected in a delayed adult emergence profile (Figure 10). Initial detection of adults at the Amherst site in 1978 was delayed by 10 and 9 days as compared to 1979 and 1980, respectively. Similarly, peak adult density of the overwintering generation occurred 9 days later in 1978 than in 1980. Although the period of peak adult density was not observed in the spring of 1979, a comparison of temperature trends and ABL phenology in 1979 and 1980 suggests that adult density peaked on V-16-79.

A similar time-lag was noted between the "late" 1978 season and the "early" 1979 and 1980 seasons for the peak density of first generation leafminer adults. Inter-plot dispersal of flies at harvest during

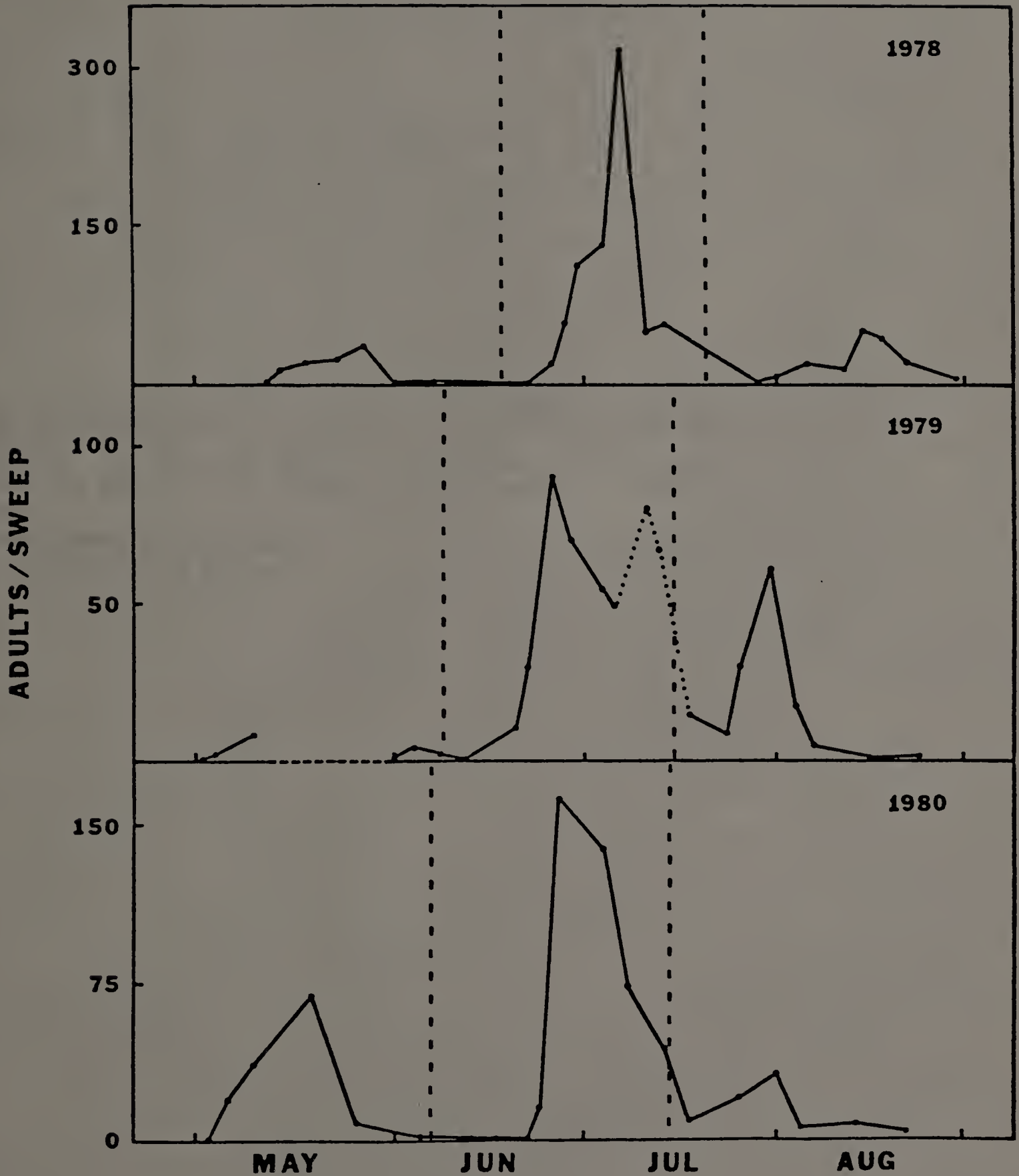


Figure 10. ABL adult population dynamics at Amherst, MA during 1978-1979-1980. Dotted portion of 1979 curve indicates population change due primarily to immigration from an adjacent harvested plot. Vertical hatched lines indicate crop harvesting dates.

1979 resulted in a bimodal peak during the second harvest growth. However, supplementary dispersal trap data document the initial peak as the true indicator of leafminer phenology within the plot (Table 6). As the proximity of the subsequent harvest precluded development of immigrant flies' progeny, second generation sweep samples reflected only "in-field" population dynamics.

The subnormal temperatures of July and August, 1978 further delayed the emergence of second generation adults in relation to 1979 and 1980 occurrence. Peak adult density during the third crop regrowth was delayed in 1978 by 13 and 15 days as compared to 1979 and 1980, respectively. In contrast to the distinct gaps between overwintering and first generation adult populations, a partial overlap between the first and second generations was observed. This was probably due to the rapid development of second generation pupae under high summer temperatures.

The number of degree-days between successive ABL adult population peaks was calculated to provide an estimate of thermal-unit requirements of each generation. As weather station data was used, we were unable to consider the microclimates occupied by larval leafminers or soil-dwelling pupae (Ferro et al. 1979). Nevertheless, three-year mean degree-day values for each generation are similar to those reported under laboratory conditions. Guppy (1981) estimated a degree-day requirement of 285 for overwintering pupae using a developmental threshold of 4°C. Considering the slightly higher base temperature used in our accumulations,

6.8°C (Hendrickson and Barth 1978), the mean degree-day value for overwintering generation peak adult emergence in this study is very similar (Table 10). The developmental requirements for completion of the egg to the adult stage for non-diapause ABL generations have been estimated at 502 (Hendrickson and Barth 1978) to 511 degree-days C (Guppy 1981) in the lab. While the degree-day values observed for completion of first generations in this study were quite close to this value (Table 10), those of the second generation were probably over-estimated as temperatures in this period exceeded optimal temperature for development.

Plant seasonality. Although the 6.8 °C developmental threshold used in computing degree-days is specific to the ABL, similar thresholds have been estimated for numerous plant species (Lindsey and Newman 1956; Taylor 1967). Thus the effective temperature data of Figure 9 is also useful in analyzing the seasonal development of indicator plants.

The initial antheses of all but three of the thirty plant species listed in Table 11 were delayed in 1978 as compared to the warmer 1979 and 1980 seasons. The mean standard deviation in flowering date for the thirty species over the three seasons was 5.1 days. On an individual species basis, however, there was a wide range of responses to the differing climatic conditions of the three study seasons. The flowering of Morrow honeysuckle, Lonicera morrowi Gray and of bull thistle, Cirsium vulgare (Savi) Tenore displayed the greatest, 10.7 days, and the least, 1.2 days, inter-season variability, respectively. Spring flowers exhibited greater inter-season variability than did late-season blooming species. The mean standard deviations in flowering date for the first,

Table 10. Degree-days (centigrade) between peak adult densities of the first three ABL generations at Amherst, MA during 1978-1979-1980.

ABL Generation	Degree-days (centigrade) ¹			
	1978	1979	1980	3-year mean
overwintering	236.0	279.7 ²	224.9	246.9
first	522.1	454.2	433.9	470.1
second	610.4	558.6	568.1	579.0

¹6.8 degree centigrade threshold temperature

²based upon estimated date of peak adult density (see text)

Table 11. Flowering dates of 30 plant species in Amherst, MA during
1978-1979-1980

Species	Anthesis Dates ¹				
	1978	1979	1980	MEAN	SD ² (Days)
<i>Pyrus communis</i> L.	133	120	120	124	7.5
<i>Berberis thunbergii</i> DC	132	121	122	125	6.1
<i>Prunus pensylvanica</i> L.f.	132	120	122	125	6.4
<i>Sambucus pubens</i> Michx.	132	122	123	126	5.5
<i>Malus pumila</i> Mill.	133	123	125	127	5.3
<i>Syringa vulgaris</i> L.	139	125	127	130	7.6
<i>Aesculus hippocastanum</i> L.	137	130	132	133	3.6
<i>Lonicera morrowi</i> Gray	146	127	128	134	10.7
<i>Sorbus aucuparia</i> L.	146	130	133	136	8.5
<i>Robinia pseudoacacia</i> L.	157	141	144	147	8.5
<i>Rubus allegheniensis</i> Porter	157	146	146	150	6.4
<i>Rosa multiflora</i> Thunb.	164	153	157	158	5.6
<i>Sambucus canadensis</i> L.	174	163	170	169	5.6
<i>Catalpa speciosa</i> Warder	173	167	171	170	3.1
<i>Asclepias syriaca</i> L.	176	169	175	173	3.8
<i>Spiraea latifolia</i> (Aiton) Borkhausen	177	170	171	173	3.8
<i>Phytolacca americana</i> L.	181	178	182	180	2.1
<i>Cichorium intybus</i> L.	185	178	178	180	4.0
<i>Daucus carota</i> L.	187	178	178	181	5.2
<i>Castanea mollissima</i> Bl.	187	178	181	182	4.6
<i>Verbena hastata</i> L.	196	182	183	187	7.8
<i>Solidago juncea</i> Ait.	200	193	195	196	3.6
<i>Spiraea tomentosa</i> L.	205	196	194	198	5.9

Table 11. Continued

Species	Anthesis Dates ¹				SD ² (Days)
	1978	1979	1980	MEAN	
<i>Impatiens capensis</i> Meerb.	212	197	204	204	7.5
<i>Arctium minus</i> (Hill) Bernh.	204	203	206	204	1.5
<i>Cirsium vulgare</i> (Savi) Tenore	205	203	205	204	1.2
<i>Eupatorium perfoliatum</i> L.	207	204	205	205	1.5
<i>Echinocystis lobata</i> (Michx. .)	210	204	205	206	3.2
<i>Tanacetum vulgare</i> L.	211	205	204	207	3.8
<i>Polygonum cuspidatum</i> Sieb. & Zucc.	237	234	237	236	1.7

¹Julian calendar

²standard deviation

second, and last 10 plants to bloom were 7.0, 4.4, and 3.8 days, respectively.

Selection and evaluation of indicator plants. In addition to synchrony with leafminer phenology, several other criteria were used in evaluating the potential of indicator plant species. As recommended by Newman and Beard (1962), indicator plants utilized in this study were common, easily identified species with conspicuous flowering events. Woody perennials were assigned top priority, as their location is fixed and their development easily observed. By restricting plant observations to within 4.8 kilometers of the alfalfa study sites, the availability of indicator species was also assessed. Given the habitats associated with New England dairy farms, all indicator plants selected were located in disturbed areas such as roadsides and field borders or were ornamental plantings.

Selection of potential indicators-1978 & 1979. Although the flowering of species 1 through 6 (Table 11) were synchronous with overwintering ABL adult emergence in 1978 and 1979 at the Amherst site, only pin cherry, Prunus pensylvanica L.f., and Japanese barberry, Berberis thunbergii DC, satisfied all criteria of optimal indicator species. Both species flowered within one day of initial ABL detection in 1979 and 1980. More importantly, the flowering of both species forecast the peak density of overwintering adults 14-16 days in advance.

The selection of potential indicators became increasingly difficult for each subsequent leafminer generation. The vernal flowering habits

of most woody plants limited the use of these preferred indicators as the season progressed. Of the thirty species listed in Table 11 the first fourteen to bloom were woody perennials as compared to only three of the final sixteen. Hardy catalpa, Catalpa speciosa Warder, and common milkweed, Asclepias syriaca L., were selected as the only suitable indicators of first generation adult emergence. C. speciosa bloom forecast peak adult density by 9-14 days during 1978 and 1979 at Amherst, while that of A. syriaca provided a 7-11 day forecast. The similarity between C. speciosa and the later-blooming C. bignonioides limits the former's value as an indicator species. Similarly, the extended blooming period of A. syriaca populations reduces the practical use of this annual species in a pest management forecasting system geared to the grower level. Only wild cucumber, Echinocystis lobata (Michx.), was considered a potentially effective indicator of second generation ABL adult emergence. However, the relationship between the flowering of this annual species and peak adult occurrence was also quite variable (7-16 day forecast) during 1978 and 1979 at Amherst.

Evaluation of potential indicators - 1980. The relationships between the flowering of P. pensylvanica, B. thunbergii, C. speciosa, A. syriaca, and E. lobata populations and ABL phenology were observed at all five sites in western Massachusetts during 1980. As many individuals of each species as were available were included, thereby providing assessments of species abundance and within-species phenological variability.

The only significant topographical variable between sites was

elevation. According to Hopkin's "bioclimatic laws" (Hopkins 1918), a one-day delay in the timing of spring events accompanies every 30.5 meter rise in elevation. Thus, in the present study little observable variation in ABL and plant seasonality would be predicted between the Amherst (55 m), South Deerfield I (46 m), and S. Deerfield II (49 m) sites. Delays of approximately one and four days would be anticipated at the Greenfield (70 m) and Conway (165 m) sites, respectively.

Sweep samples indicated that only at Conway did the timing of overwintering ABL adult emergence differ from the other sites. Peak adult density at Conway was delayed seven days in relation to each of the other four sites (Figure 11). The flowering of populations of both P. pensylvanica (P.p.) and B. thunbergii (B.t.) maintained a consistent synchrony with overwintering ABL emergences at all five sites. Although the progression of flowering events did not conform precisely to elevational differences, the flowering of both species was latest at the highest site, Conway. The 50 percentile bloom of P.p. populations provided a 12-17 day forecast of peak adult density at the five sites, while the 50 percentile bloom of B.t. populations provided a 12-15 day forecast. The use of the latter species, however, was limited by its absence at two sites and its infrequency at two others (Figure 11).

Both P.p. and B.t. populations exhibited considerable variations in flowering date within a site. At Amherst, where both species were common, the initial anthesis of P.p. (n=34) and B.t. (n=20) plants showed a range of 6 and 5 days, respectively. However, the flowering of all members of each species preceded peak ABL adult density by a

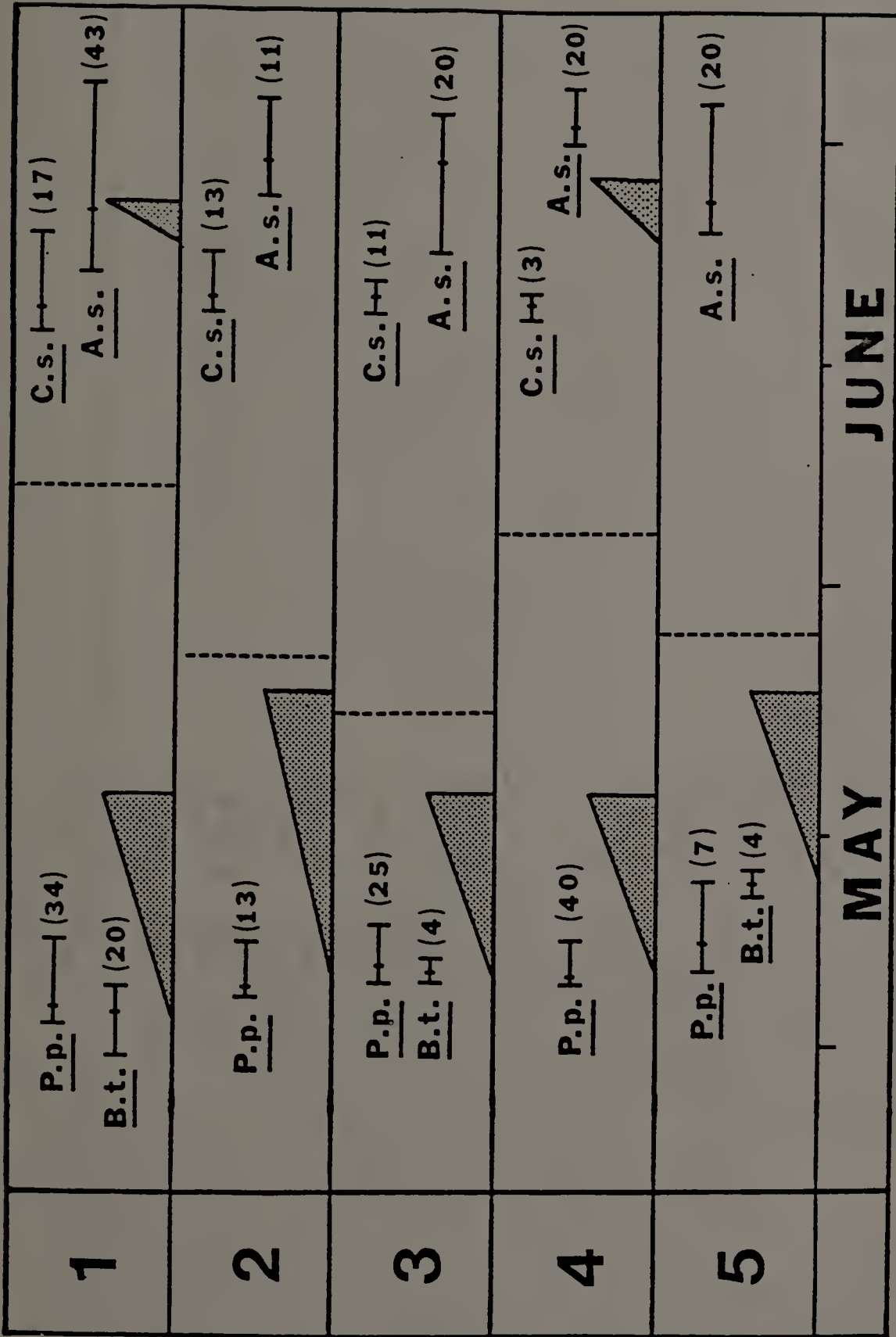


Figure 11. Phenology of ABL adults and indicator plants at five sites in western MA during 1980. (See Figure 8 for geography of sites and names corresponding to the site numbers in this figure). Stippled pyramids indicate relative ABL adult activity for the overwintering and first generations. Horizontal bars describe the range and mean of population flowering dates for *P. pennsylvanica* (P. p.), *B. thunbergii* (B. t.), *C. speciosa* (C. s.), and *A. syriaca* (A. s.). Numbers in parentheses indicate population size observed for each indicator species. Vertical hatched lines indicate crop harvest date.

minimum of nine days. Thus, the consistent use of any individual of either species' population may prove useful in ABL forecasting.

The early timing of first harvests at the South Deerfield I and II and Conway sites reduced first generation leafminer densities to such low levels that peak densities could not be determined (Table 5). Although sweep samples indicated a substantial first generation at Conway, eclosion trap data suggest that this was due primarily to immigration from adjacent stands. Consequently, the efficacy of C. speciosa (C.s.) and A. syriaca (A.s.) forecasts of first generation adult emergence were evaluated at the Amherst and Greenfield sites only. At both sites, the 50 percentile bloom of C.s. populations preceded adult ABL peak occurrence by eight days. Although a seven day range in flowering was noted within the Amherst C.s. population (n=17), all individuals bloomed a minimum of two days before the adult population peak. As C.s. was absent at one site and uncommon at another, availability may limit its use. The 50 percentile bloom of A. syriaca forecast peak adult density by only one day at Amherst and was four days late at Greenfield; the lack of synchrony in population blooming limits the use of A.s. as a practical indicator species.

All members of the Amherst E. lobata population (n=15) bloomed three-eight days prior to second generation peak adult density. However, E.l. was absent at the remaining four study sites.

Forecasting options for ABL management. As Waggoner (1974) has noted, the essential components of practical seasonality forecasts are accuracy

and forecast length; the requirements of each component are determined by the goals of individual forecasting systems. In terms of ABL pest management, highly accurate seasonal forecasts are essential for scheduling adult sampling programs and implementing both chemical and cultural control strategies. Determining the precise timing of peak adult occurrence is essential for the optimal application of insecticides (Thompson 1981). Furthermore, as adult peaks precede the development of early instar larvae by one-three days, the adult ABL presents an optimal stage for economic threshold level considerations. However, long-term less accurate forecasts would also be of use in cultural control efforts, as these would facilitate the advanced planning of machinery and personnel requirements required for harvest schedule modification.

Of the four forecasting indices considered, calendar date provided the longest but least accurate forecast for each ABL generation at Amherst during 1978-79-80 (Table 12). Although calendar forecasts were too variable to be of aid in scheduling IPM strategies, their long-term nature would make them useful in advanced planning of harvest modifications to control the fly.

Cumulative degree-day, "ABL-day", and phytophenological indicator forecasts each accounted for the variability in leafminer phenology better than calendar date. Degree-day forecasts were sufficiently precise to time sampling programs during the overwintering adult emergence period. However, first and second generation forecasts lacked the two-three day accuracy needed to estimate peak adult densities on an inter-season basis. An inter-site analysis of this technique was not conducted

Table 12. Comparison of indices for forecasting ABL adult population peaks at Amherst, MA during 1978-1979-1980

ABL Adult Peak	Component	Forecasting Index				
		Calendar ¹ Date	Cumulative Degree-days	ABL-days	Indicator Species	
					<u>P. p.</u> ²	<u>B. t.</u> ³
overwintering	length	140.0	9.7 ⁴	-----	15.3	15.0
	accuracy ⁷	5.3	2.3	-----	1.2	1.0
first	length	180.3	14.7 ⁵	40.3	55.7	55.3
	accuracy	5.9	4.0	0.6	0.6	0.6
second	length	216.7	11.7 ⁶	76.7	92.0	91.7
	accuracy	8.1	5.7	2.9	1.7	2.1

¹Days since January 1 ²P. pensylvanica ³B. thunbergii

^{4,5,6}based upon the dates by which 146.9, 517.0, and 1096.0 degree-days (C) had accumulated each season, respectively.

⁷standard deviation in days

as precise temperature data were not available at each commercial study site. Due to the instrumentation and computations involved in determining degree-days, the adoption of this method at the grower level is unlikely.

The interval between overwintering ABL adult peaks and the peaks of subsequent generations, termed "ABL-days", provided a long, accurate forecast during the first and second leafminer generations. Previous researchers have noted considerably greater inter-season variations in the intervals between adult peaks (Spencer 1974; Bremer 1976). Thus the low variability noted in "ABL-day" forecasts during this study may be an artifact of similar inter-season climatic conditions during the summer months. By its very nature, this index is of no value in forecasting overwintering adult emergences.

Ideally, host plant phenological development provides the most attractive phytophenological forecasting option. Ecklund and Simpson (1977) noted a consistent correlation between alfalfa height and spring activity of the alfalfa weevil, Hypera postica (Gyllenhal). However, in the present study crop height at overwintering ABL adult peak density ranged from 35.2 to 63.8 centimeters (mean=47.5 cm; SD=10.3) at the five sites during the three-year study period. As harvesting schedules varied between sites, crop growth stage provided no basis for forecasting adult occurrence during subsequent generations. Since the rate of spring regrowth in alfalfa is influenced by fertilization practices and previous fall cutting dates (Smith 1978), this approach offers little potential in ABL forecasting.

Compared to eight other seasonality forecasting indices, White (1979) considered the flowering of index species to be the simplest and most practical method for scheduling range management activities. Our results agree, as the flowering dates of P. pensylvanica and B. thunbergii accounted for the seasonal variation in ABL phenology better than any other forecasting technique. This was true on both an inter-season (Table 12) and an inter-site (Table 13) basis. The precision of these indicator forecasts presents the grower with a cost-effective means of scheduling ABL sampling programs.

The forecasts provided by P. p. and B. t. in Massachusetts should be useful in other areas of the northeastern United States where the leafminer and indicator species coexist. However, geographical adaptations of phenological characteristics have been documented for both insect (Sternburg and Walbauer 1978) and plant (Vance and Kucera 1960; Pearcy and Ward 1972) species. Thus the implementation of this forecasting technique in other regions should be preceded by an investigation of the phenological relationships between local leafminer and plant indicator populations.

Protocols for developing phytophenological forecasts. As the calendar timing of phenological events exhibits considerable variation between seasons (Lindsey and Newman 1956), it is essential to evaluate practical seasonality forecasts under varying sets of climatic conditions. The development of temperature-dependent models may be expedited by studying species responses under variable environmental conditions in the lab. In contrast, the evaluation of phytophenological forecasts is limited to

Table 13. Comparison of indices for forecasting overwintering generation ABL adult peaks at five sites in western MA in 1980

		Forecasting Index						
ABL Adult Peak	Forecast Component	Calendar ¹ Date	Percentile Bloom of Indicator Population					
			P. Pensylvanica ³ onset ³ 50%	100%	B. thunbergii ² onset ³ 50%	100%		
overwintering	length	139.4	15.0	14.0	10.4	15.0	13.3	12.0
	accuracy ⁴	3.1	2.6	2.0	1.5	2.7	1.5	1.0

¹Days since January 1

²absent at South Deerfield I and Greenfield sites

³first individual in population to flower

⁴standard deviation in days

inter-season analyses. Thus previous researchers have either conducted long-term investigations, such as nine years by Tashiro and Gambrell (1963), or supplemented their data base with existing plant and insect phenological records (Matthewman and Harcourt 1972). The former approach is too time-consuming for developing IPM programs, while the data base for the latter is seldom available. Jackson (1966) demonstrated that plant phenological research may be expedited by making observations in diverse microclimates for a few seasons rather than by compiling long-term records at one site. Indeed, such an approach was found useful in the present study. By integrating inter-season observations at one site, Amherst, with inter-site observations during one season, 1980, seven replications were provided within a three-year period. The widespread adoption of such an approach should minimize the investment required in evaluating IPM forecasting systems.

Ferro et al. (1979) illustrate the potential problems of using standard meteorological data in studies of arthropod population dynamics. The efficacy of phytphenological indicator forecasts is limited by this same factor, as the climatic conditions experienced by indicator species may differ substantially from those of the insect micro-habitat. The alfalfa crop produces variable microclimatic modifications as it matures (Pinter et al. 1975); thus varying crop harvest schedules may influence microclimates of ABL larvae and pupae and thereby alter the timing of adult emergences. However, in comparing ABL adult eclosion profiles between an unharvested and a standard harvest schedule plot, only a two day delay was noted in the former treatment (Figure 5). Such

a variation represents the extreme under commercial operations and thus would have minimal impact on the use of the forecasts evaluated in this study.

Intraspecific flowering variability may influence phenological forecasts. In the present study, the wide range in flowering dates within many species was the primary factor preventing their use as indicators. Kapler (1967) utilized the date by which all members of indicator plant populations had bloomed as a forecasting index, in order to minimize flowering variations due to microclimate (Jackson 1966) and genetic variability (McMillan 1967). The results of our study agree, as 100% population bloom provided the most accurate forecasts of ABL emergence (Table 13). As an alternative to the use of endemic plant populations, the development of phenological gardens (Blair et al. 1974) may be feasible in dense agricultural regions. This would virtually eliminate the problems of genetically and environmentally induced variations in the seasonal development of indicator plants.

Our results and those of Straub and Huth (1976) suggest that the value of phytophenological forecasts declines with each successive generation of multivoltine insect species. Two factors may help to explain this observation. First, as the timing of generations of multivoltine insects are dependent events, variations in post-diapause development during the spring are reflected throughout later generations. In contrast, late-blooming plant species may be insensitive to this critical set of post-diapause climatic conditions. Secondly, while spring and early-summer flowering events are regulated primarily by temperature patterns, the flowering of late-summer and fall species may

be influenced more by photoperiod (Jackson 1966). This may account for the decreased variability in inter-season flowering date for late-blooming species in this study (Table 11) and the lack of reliable indicator plants for second and third leafminer adult population peaks.

BIBLIOGRAPHY

- Alicandro, A. J. and T. M. Peters. 1980. The injury potential of the alfalfa blotch leafminer: a caging study. Proc. 17th Ann. N.E. Inv. Alfalfa Insects Conf., Chateau Frontenac, Quebec, Oct. 9-10, 1980. pp. 37-42.
- Andaloro, J. T. 1981. Studies on the biology and control of the alfalfa blotch leafminer, Agromyza frontella (Rondani) (Diptera: Agromyzidae): a pest of Massachusetts alfalfa. Ph.D. dissertation, University of Massachusetts.
- Anonymous. 1972. Alfalfa blotch leafminer situation in eastern United States. Coop. Econ. Insect Report. 22: 132.
- Anonymous. 1979. Integrated Pest Management. A Program of Research for the State Agricultural Experiment Stations and the Colleges of 1890. Intersociety Consortium for Plant Protection.
- Bereza, K. 1977. Alfalfa blotch leafminer. Ontario (Canada) Fact-sheet No. 77-067. 2 pp.
- Blair, B. O., J. E. Newman, and J. R. Fenwick. 1974. Phenology gardens in Indiana. , pp. 45-54., In H. Lieth (ed.), Phenology and Seasonality Modeling. Springer-Verlag, New York, xv & 443 pp.
- Bremer, C. 1976. Life history and pest management strategies of the alfalfa blotch leafminer, Agromyza frontella (Rondani) (Diptera: Agromyzidae). M.S. thesis. Cornell University.
- Byers, R. A. and K. Valley. 1978. An economic injury level for the alfalfa blotch leafminer. Proc. 15th Ann. N.E. Inv. Alfalfa Insects Conf., Purdue University, W. Lafayette, IN, Oct. 17-18, 1978, pp. 40-43.
- Cassagrande, R. A. and F. W. Stehr. 1973. Evaluating the effects of harvesting alfalfa on alfalfa weevil (Coleoptera: Curculionidae) and parasite populations in Michigan. Can Ent. 105:1119-1128.
- Cothran, W. R. and C. G. Summers. 1972. Sampling for the Egyptian alfalfa weevil: a comment on the sweep net method. J. Econ. Entomol. 65: 689-91.
- Dureseau, L., Jr., and D. Jeandel. 1977. Alfalfa blotch leafminer (Diptera: Agromyzidae) laboratory studies of biology in Europe. Proc. Entomol. Soc. Wash. 79:259-65.

- Ecklund, R. and R. G. Simpson. 1977. Correlation of activities of the alfalfa weevil and Bathyplectes curculionis with alfalfa height and degree-day accumulations in Colorado. *Environ. Entomol.* 6:69-71.
- Ferro, D. N., R. B. Chapman, and D. R. Penman. 1979. Observations on insect microclimate and insect pest management. *Environ. Entomol.* 8:1000-1003.
- Flint, H. L. 1974. Phenology and gynecology of woody plants., pp. 83-97., In H. Lieth (ed.), *Phenology and Seasonality Modeling*. Springer-Verlag, New York. xv & 443 pp.
- Guppy, J. C. 1981. Bionomics of the alfalfa blotch leafminer, Agromyza frontella (Diptera: Agromyzidae), in eastern Ontario. *Can. Ent.* 113:593-600.
- Hendrickson, R. M. Jr., and S. E. Barth. 1977. Techniques for rearing the alfalfa blotch leafminer. *J. N.Y. Entomol. Soc.* 85:153-7.
- Hendrickson, R. M. Jr., and S. E. Barth. 1978. Biology of the alfalfa blotch leafminer. *Ann. Entomol. Soc. Am.* 71:295-8.
- Hendrickson, R. M., Jr., and S. E. Barth. 1979a. Effectiveness of native parasites against Agromyza frontella (Rondani) (Diptera: Agromyzidae), an introduced pest of alfalfa. *J. N. Y. Entomol. Soc.* 87:85-90.
- Hendrickson, R. M., Jr. and S. E. Barth. 1979b. Introduced parasites of Agromyza frontella (Rondani) in the USA. *J. N.Y. Entomol. Soc.* 87:167-74.
- Hopkins, A. D. 1918. Periodic events and natural laws as guides to agricultural research and practice. p. 42 In USDA Mon. Weather Rev. Suppl. No. 9.
- Horwitz, W. (ed.). 1970. *Official Methods of Analysis of the Association of Agricultural Chemists*. 11th ed., p. 16. Washington, D. C. 964 pp.
- Hungerford, K. E. 1953. A ruffed grouse drumming count technique for northern Idaho conditions. Idaho University Forest, Range, and Wildlife Exp. Sta. Res. Notes 10:1-3. 1953.
- Jackson, M. T. 1966. Effects of microclimate on spring flowering phenology. *Ecology.* 47:407-15.
- Kapler, J. E. 1967. Phenological events associated with the spring emergence of the smaller European elm bark beetle in Dubuque, Iowa. *J. Econ. Entomol.* 60: 50-52.

- Kielszewski, B. 1962. (Phenology as an aid in forest protection). *Sylvan* 106:33-38. (Engl. summ.).
- Leopold, A. and S. E. Jones. 1947. A phenological record for Sauk and Dane counties, Wisconsin, 1933-1945. *Ecol. Monogr.* 17:81-122.
- Lindsey, A. A. and J. E. Newman. 1956. Use of official weather data in spring time-temperature analyses of an Indiana phenological record. *Ecology* 37:812-23.
- MacCollom, G. B., G. Baumann, and J. G. Welch. 1980. Effect of Agromyza frontella (Rondani) (Diptera: Agromyzidae) on alfalfa quality and yield. *J. N.Y. Entomol. Soc.* 88:56-7 (Abstract).
- Matthewman, W. G. and D. G. Harcourt. 1971. Phenology of egg-laying of the cabbage maggot, Hylema brassicae (Bouche) on early cabbage in eastern Ontario. *Proc. Entomol. Soc. Ont.* 102:28-35.
- McMillan, C. 1967. Phenological variation within seven transplanted grassland community fractions from Texas and New Mexico. *Ecology* 48:807-13.
- Mellors, W. K. and R. G. Helgesen. 1978. Developmental rates for the alfalfa blotch leafminer, Agromyza frontella, at constant temperatures. *Ann. Entomol. Soc. Am.* 71:886-888.
- Mellors, W. K. and R. G. Helgesen. 1980. Life table analysis for the alfalfa blotch leafminer, Agromyza frontella, in central New York. *Environ. Entomol.* 9:738-42.
- Miller, D. E. and G. L. Jensen. 1970. Agromyzid alfalfa leafminers and their parasites in Massachusetts. *J. Econ. Entomol.* 63:1337-8.
- Newman, J. E. and J. B. Beard. 1962. Phenological observations: the dependent variable in bioclimatic and agrometeorological studies. *Agron. J.* 54:399-403.
- Pearcy, R. W. and R. T. Ward. 1972. Phenology and growth of Rocky Mountain populations of Deschampsia caespitosa at three elevations in Colorado. *Ecology*. 53:1171-78.
- Penfound, W. T., T. F. Hall, and A. D. Hess. 1945. The spring phenology of plants in and around the reservoirs in north Alabama with particular reference to malaria control. *Ecology* 26:332-52.
- Pinter, P. J., Jr., N. F. Hadley, and J. H. Lindsay. 1975. Alfalfa crop micrometeorology and its relation to insect pest biology and control. *Environ. Entomol.* 4:153-62.

- Plummer, J. A. and R. A. Byers. 1981. Seasonal abundance and parasites of the alfalfa blotch leafminer, Agromyza frontella, in central Pennsylvania. *Environ. Entomol.* 10: 105-10.
- Przybylski, Z. 1970. (The development of the potato beetle (Leptotarsa decemlineata Say) in the area of Rzeszow in connection with synchronous phytophenological phenomena in 1963-1966.). *Ekol. Pol. Ser. A* 18:73-88. (Pol. summ.).
- Richard, C. and C. Gagnon. 1976. Pertes dues aux maladies chex la luzerne au Quebec en 1975. *Canadian Plant Disease Survey.* 56:82-4.
- Saugstad, E., R. A. Bram, and W. E. Nyquist. 1967. Factors influencing sweep-net sampling of alfalfa. *J. Econ. Entomol.* 60:421-26.
- Simonet, D. E. and R. L. Pienkowski. 1979. Impact of alfalfa harvest on potato leafhopper populations with emphasis on nymphal survival. *J. Econ. Entomol.* 72:428-31.
- Smith, D. 1978. *Forage Management in the North.* Kendall/Hunt Publishing Co. Dubuque, Iowa. 237 pp.
- Southwood, T. R. E. 1966. *Ecological Methods with Particular Reference to the Study of Insect Populations.* Methuen and Co. London. 391 pp.
- Spencer, K. A. 1973. *Agromyzidae (Diptera) of Economic Importance.* In *Series Entomologica*, vol. 9, E. Schmitschek (ed.), W. Junk, The Hague, 418 pp.
- Spencer, W. T., Jr. 1974. Observations on the control of the alfalfa blotch leafminer (Agromyza frontella) in alfalfa using chemical and cultural techniques. M. S. thesis, University of New Hampshire.
- Sternburg, J. G. and G. P. Waldbauer. 1978. Phenological adaptations in diapause termination by cecropia from different latitudes. *Ent. exp. & appl.* 23:48-54.
- Straub, R. W. and P. C. Huth. 1976. Correlations between phenological events and European corn borer activity. *Environ. Entomol.* 5:1079-82.
- Tashiro, H. and F. L. Gambrell. 1963. Correlation of European chafer development with the flowering period of common plants. *Ann. Entomol. Soc. Am.* 56:239-43.
- Tauber, M. J. and C. A. Tauber. 1976. Insect seasonality: diapause maintenance, termination, and postdiapause development. *Ann. Rev. Entomol.* 21:81-107.

- Taylor, J. A. 1967. Growing season as effected by land aspect and soil texture, pp. 15-36. In Weather and Agriculture, J. A. Taylor (ed.). Pergamon Press, Oxford.
- Thompson, L. S. 1981. Field evaluation of insecticides for control of the alfalfa blotch leafminer and its effect on alfalfa yield in Prince Edward Island. J. Econ. Entomol. 74:363-65.
- Vance, B. D. and C. L. Kucera. 1960. Flowering variations in Eupatorium rugosum. Ecology 41: 340-45.
- van den Bosch, R. and V. M. Stern. 1969. The effect of harvesting practices on insect populations in alfalfa. Proc. Tall Timbers Conf. on Ecol. Animal Control by Habitat Mgt. 1:47-54.
- Waggoner, P. E. 1974. Using models of seasonality, pp. 401-05, In H. Lieth (ed.), Phenology and Seasonality Modeling. Springer-Verlag. New York. XV & 443 pp.
- 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 complexes. Environ. Entomol. 7:482-94.
- White, L. M. 1979. Relationship between meteorological measurements and flowering of index species to flowering of 53 plant species. Agric. Meteorol. 20:189-204.
- Wickman, B. E. 1976. Phenology of white fir and Douglas-fir tussock moth egg hatch and larval development in California. Environ. Entomol. 5:316-22.
- Wielgolaski, F.-E. 1974. Phenology in agriculture, pp. 369-81. In H. Lieth (ed.), Phenology and Seasonality Modeling. Springer-Verlag. New York. xv & 443 pp.

