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PARAMETERS AFFECTING EMERGENCE AND MANAGEMENT STRATEGIES OF THE APPLE MAGGOT FLY, *Rhagoletis pomonella* (Walsh) DIPTERA: TEPHRITIDAE

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Larry Gene Olsen

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By

Larry Gene Olsen

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ABSTRACT

PARAMETERS AFFECTING EMERGENCE AND MANAGEMENT STRATEGIES OF THE APPLE MAGGOT FLY, *Rhagoletis pomonella* (Walsh). DIPTERA: TEPHRITIDAE

By

Larry Gene Olsen

Emergence of apple maggot flies, *Rhagoletis pomonella*, was determined at the Kalamazoo State Hospital (K.S.H.) orchard in 1977-1980 and in the Upjohn orchard in 1977, 1979-80 by four methods. The yellow Zoecon AM trap was determined to be the preferred tool to estimate first emergence. Biotic and abiotic parameters were examined for their influence on timing of first and season long emergence. Air temperature degree days was discovered to be the best predictor of first emergence. The biotic parameters of variety of apple reared in, orchard floor culture and location of larval pupation all affect first emergence. The phenological predictive model of emergence developed using the K.S.H. data predicted emergence to within ±2.5 days at the K.S.H. orchard and ±.5 days at the Upjohn orchard. Season long emergence expressed as accumulative percent catch can be predicted extremely well by accumulative air or soil temperature degree days or percent soil moisture.

Thirty-one commercial orchards were monitored in 1979 and 1980 for the presence of apple maggot flies and percent fruit damage to study parameters associated with different

management schemes. The yellow Zoecon AM trap was preferred over the red sticky sphere trap because it caught flies sooner, caught gravid females sooner, and provided more consistent prediction of fruit damage. Yellow Zoecon AM traps should be placed in the perimeter row of the orchard and located near two potential outside sources of apple maggot. Flies were caught in the orchard an average of 8 days after they were caught in abandoned trees outside the orchard but ranged from -17 to 35 days indicating flies should be monitored in the orchard and not in abandoned trees. It was shown that fly catch and fruit damage greatly decreases from the perimeter row into the orchard, indicating that a feasible alternative management scheme would be to spray perimeter rows when no other pests are present.

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Numerous other people have assisted in this study, without their help this could not have been completed. Dr. Jay F. Brunner helped formulate the objectives and design some of the experiments. Mr. Leonard Larson spent considerable hours assisting in data collection and analysis. Pest Management Field Assistants Phil Schwallier, Scott Ruffe and Pam Cater assisted by monitoring orchards. Many commercial growers let me use a portion of their orchards to carry out studies involving different management strategies. Lastly Mobay Chemical Corporation provided the impetus for the completion and generously gave me time off to finish.

Thank you especially to my wife and two sons who have endured my absence with great patience and provided the necessary encouragement and support without which this could not have been completed.

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INTRODUCTION

The apple maggot fly, <u>Rhagoletis</u> <u>pomonella</u> (Walsh), is a native insect species to northeastern U.S. Its original host was hawthorn. When the cultivated apple was introduced to the U.S., the insect quickly switched hosts and became a serious economic pest. In many states it is the number one insect pest of apples. Currently, control strategies require 3-5 sprays of broad spectrum insecticides which amount to 1/3 to 1/2 of the total insecticides applied to the orchard to prevent this damage. The damage results from internal larval burrowing. Larvae in processed food results in insect fragments which by law cannot be tolerated (Neilson and Sanford, 1974). If damaged fruit is detected in the processing line by inspectors, the entire load can be re- jected and the grower would suffer great financial loss.

The basis of control for the apple maggot fly is to determine when first emergence of the adult occurs, and then make a pesticide application in 7-10 days. Repeated applications are then made at 14 day intervals until harvest. With no controls, 100% damage can occur. Biological monitoring to determine first emergence has evolved the past several years. Current methods involve considerable effort, and it would be better to predict when emergence occurs. To make this prediction, several biotic and abiotic parameters have to be quantified and combined into a predictive model. Then environmental monitoring networks will have to be established and connected in an on-line manner. With abiotic inputs driving the model and certain biotic parameters updating it, outputs would predict emergence at any site. This would provide information for more efficient and less costly chemical control.

Management strategies of this pest are in the process of evolving. Currently sprays are recommended 7-10 days after first emergence of the flies in abandoned trees. One strategy to improve this is to place traps in commercial orchards and delay initiating controls until flies are caught on them. Preliminary evidence suggested that this method could prevent two needless sprays, because it takes flies 3-6 weeks to disperse out of the abandoned trees and into the commercial orchard. Parameters important in trapping in this manner need to be studied further and understood thoroughly before this management strategy can be confidently recommended.

This dissertation investigates two distinct aspects of the apple maggot fly. The first part quantifies parameters associated with emergence of the apple maggot fly in high population situations, and incorporates them into a predictive model. The second part investigates parameters important to monitoring and managing the apple maggot in commercial orchards. These results are summarized and suggestions are made for grower or consultant use when managing the apple maggot fly.

LIFE CYCLE OF THE APPLE MAGGOT FLY

A knowledge of the biology is an essential prerequisite to understanding the problems associated with predicting emergence and timing controls for the apple maggot fly. Figure 1 is a generalized model of the apple maggot fly life cycle which gives a conceptual framework from which specific features can be more fully described. The insect overwinters as a pupae in the soil underneath infested trees. When environmental factors are correct, emergence of adult flies occurs, normally during the last week of June in southwest Michigan, the first week of July in west central Michigan, and middle July in northwest Michigan (Brunner and Johnson, 1976). Emergence then continues for about three months. After emergence, the adult fly goes through a 7-10 day preoviposition period. This is the period after emergence and before egg laying can occur because the female reproductive system is not fully developed. During this period adults disperse inside and outside the orchard feeding on foliar exudates and insect honeydew. These substances supply the nutrients required for the physical maturation. Multiple mating can occur during this period. After maturing, the fertilized females search for susceptible fruits to lay their eggs. Eggs are deposited just under the surface of apples. The adults are exposed to a diversity of biological and environmental induced mortalities throughout the remainder of their lives. The eggs hatch in 3-7 days. For the next three to four weeks the larvae tunnel and feed internally on the fruit. They pass through three instars during this time. Their feeding weakens the apple and it falls prematurely allowing the third instar larva to leave the apple and burrow into the soil. A short duration fourth instar occurs, and then the pupa is formed. The insect diapauses and stays in this stage over winter.

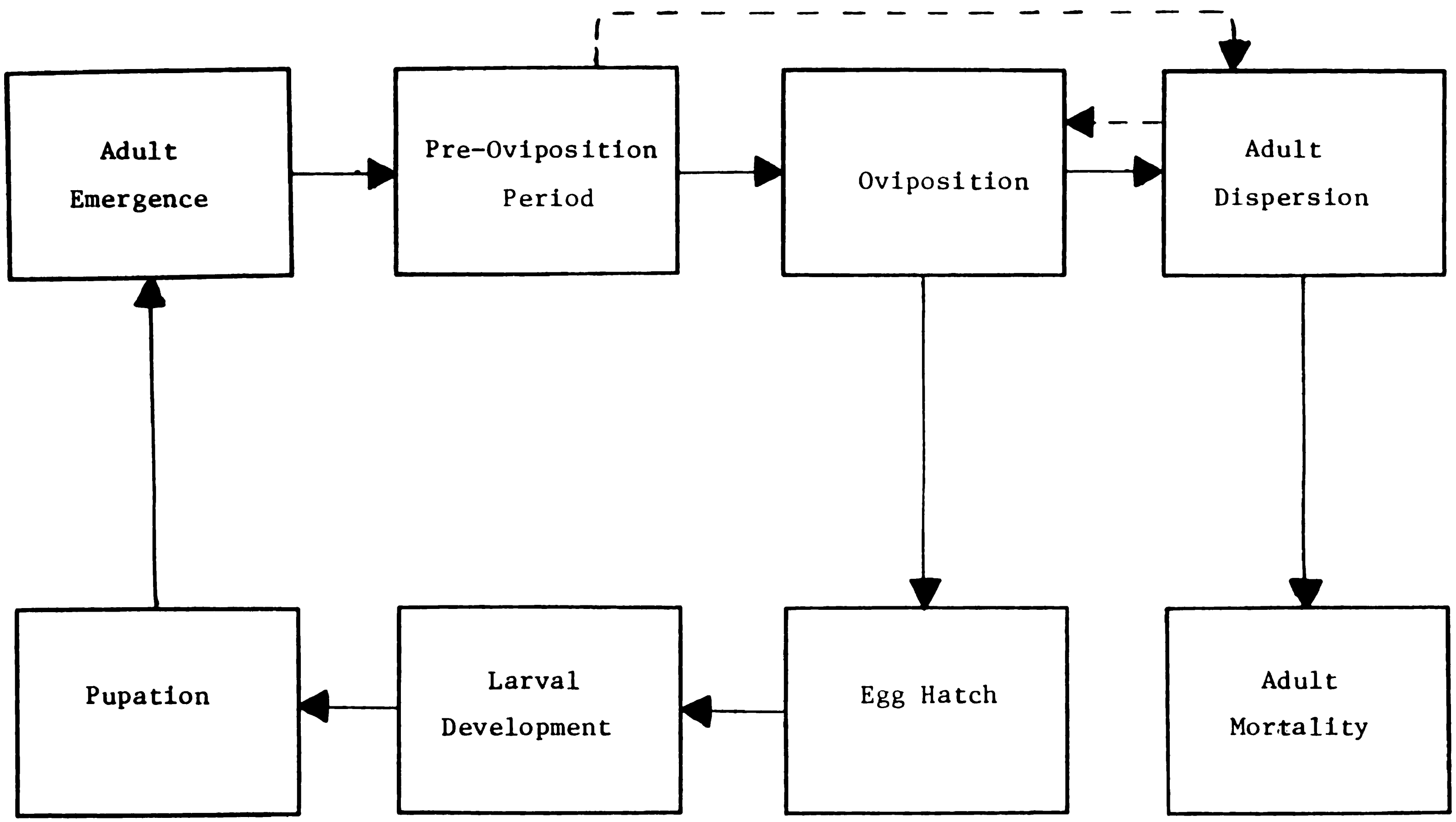


Figure 1. Conceptual model of the life cycle of apple maggot, Rhagoletis pomonella (Walsh).

PART 1 - PARAMETERS

AFFECTING EMERGENCE

EMERGENCE PATTERNS IN MICHIGAN

Prior to identifying and quantifying variables associated with emergence, emergence patterns have to be established and data gathered. This should be completed at several locations over several years so that differences that might exist can be shown to be real and consistent. Causes of the variances associated with real differences can then be studied.

Literature and Materials and Methods

Monitoring Techniques - Throughout this study, four techniques of measuring emergence or flight activity were utilized. The first involved placing an emergence cage over ground that was naturally infested by apple maggot pupae the proceeding fall. One meter square pyramids shaped cages that had a collection devise on the top filled with ethylene glycol were utilized in these studies . This preserved the flies so they could be counted and sexed at each visit. As reported in the literature (Caesar and Ross, 1919; Mundinger, 1930), this method provides a very accurate indication of emergence. However, it does not determine the length of the flight activity period during which female flies can infest the fruit. This may continue forty to sixty days after emergence.

In another set of experiments, these same emergence cages were utilized, but they were placed over seeded ground (Herrick, 1912; Allen and Fluke, 1933; Dean, 1942; Lathrop and Dirks, 1945; Glass, 1960; Dean and Chapman, 1973). The previous fall, apples infested with apple maggot larvae were collected, and placed on soil where no pupae were previously present. The location was accurately marked, and the cages were placed over this spot the following summer. As before, soil was mounded up on the outside of the base of the cage so no flies could escape. This type of emergence provides somewhat unrealistic data because of a high population of pupae consolidated into a small space, but is useful for answering certain types of questions.

Within the past twenty years, visual sticky traps that mimic the foliage have been developed to monitor fly activity in the tree (Still, 1960; Oatman, 1964a; Maxwell, 1968b; Prokopy, 1968a; Moore, 1969; Kring, 1970; Prokopy, 1972a; Buriff, 1973; Trottier, Rivard and Neilsen, 1975; Reissig, 1975; Reissig, 1977). The behavior of the fly that allows this technique to work is that during the pre-oviposition period the flies are searching for potential food sources. Leaves exude substances that the fly feeds on, and supports populations of leafhoppers and aphids that excrete honeydew, another fly food source. Therefore, a surface that resembles a leaf becomes attractive to the fly during this pre-oviposition period when feeding has top priority. Several researchers have tested colors, sizes, shapes, and volatile substances to be added to the trap to determine which combination provides the greatest trap catch (Prokopy, 1968a; Reissig, 1975). Prokopy (1968a) showed the best color was Saturn yellow which reflects a supernormal amount of energy in the 580 mm range. This is the wave length range reflected by green leaves, and is detected by flies as a leaf. A trap size and shape experiment lead to the discovery that the best trap has a rectangle of 8 x 12 cm (Prokopy, 1972a). Odoriferous substances added into the stickum enhance catch, and protein hydrolysate plus ammonium sterrate (Howitt and Connor, 1965) apparently give the best result. These features have been combined into a standard yellow trap that is commercially available as the Yellow Zoecon AM trap (Zoecon, 1980). There are two advantages to using this type of trap. First, many hours of labor involved in seeding cages in the fall, building and repairing cages, setting cages in place in summer, and taking them down in the fall are saved. More importantly, the activity period of the fly in the tree can be more accurately estimated.

A fourth monitoring technique utilized was a fruit mimic (Prokopy, 1967b; Prokopy, 1968b; Moore, 1969; Kring, 1970; Prokopy, 1973; Prokopy, 1977). Prokopy (1977) reported that an 8 cm red sphere provided a much more accurate indication of fly activity in the tree. His criteria included sooner first catch, more flies, and better prediction of the amount of fruit damage. An assumed advantage of these traps is that they trap female flies when they are gravid and ready to oviposite. A catch would indicate that controls should be applied immediately.

Research Sites - In 1977, two research orchards were identified for studying the apple maggot. The K.S.H. (K.S.H.) orchard located on the western edge of Kalamazoo, Michigan, was under the supervision of Dr. A. J. Howitt of the Department of Entomology at Michigan State University, and could be used for the duration of this study. The orchard is about 40 years old, and has a mixed planting of approximately 40 acres that includes 15 varieties (Figure 2). It has a minimum level of pesticide applications each year, with usually only a single massive dose of Difolitan(Single Application Technique) applied to control primary apple scab. This maintains foliage for tree growth, but has minimal effect on apple maggot populations. There is a high natural level of apple maggot flies in the orchard, with nearly 100% fruit infestation every year.

The second research orchard is located on the Upjohn Chemical Company farm located northeast of Kalamazoo, Michigan. This orchard was used for the duration of the study under a cooperative agreement between Dr. Howitt and the Upjohn Company. The orchard is about 40 years old, has twelve acres, and is mainly composed of McIntosh, Jonathan, and Northern Spy varieties, but also has a row of Snow apples, and two rows of sweet cherries (Figure 3). This site is used periodically for chemical evaluation of single tree replicated designs. Therefore, the resident population of apple maggot flies is under some chemical pressure and is

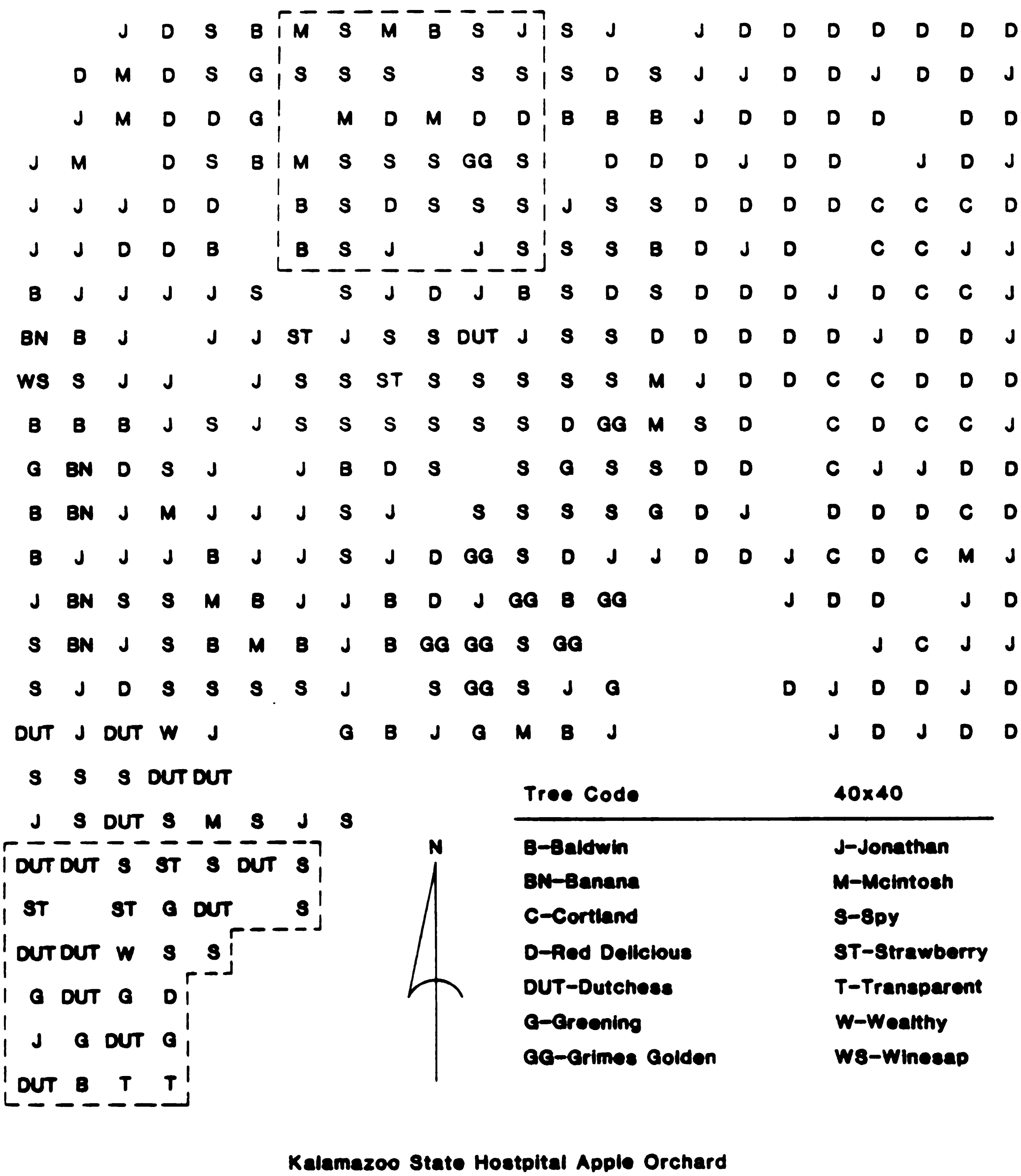
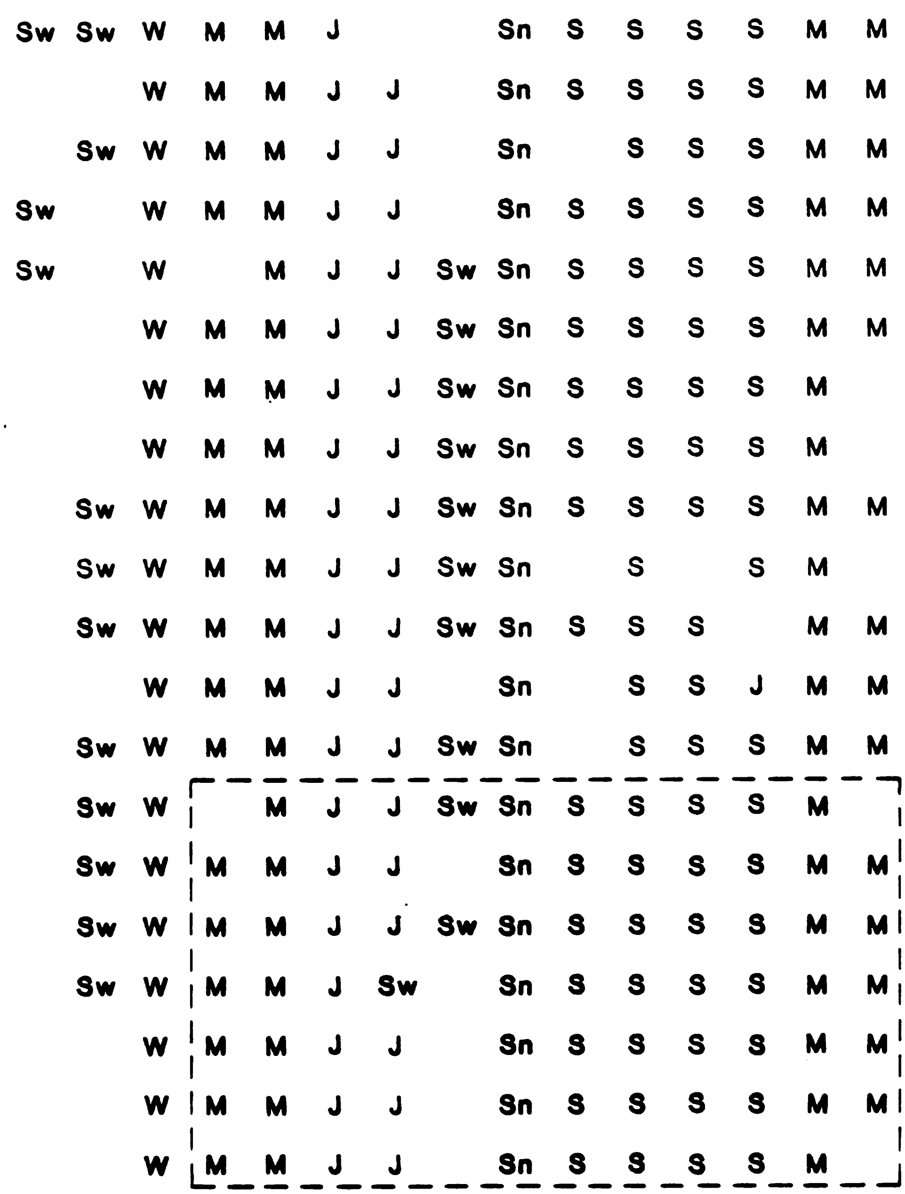


Figure 2. Map of the Kalamazoo State Hospital Orchard Showing Study Areas and Variety Composition.



Tree Code	40x40
J-Jonathan	Sn-Snow
M-Mcintosh	Sw-Sweet Charry
S-Spy	W-Wealthy

Upjohn Apple Orchard

Figure 3. Map of the Upjohn Orchard Showing Study Areas and Variety Composition.

not nearly as high as the K.S.H. orchard. However, flies are present and active in the orchard every year, and are present at much higher levels than that experienced by commercial growers. This medium density population might provide data that serves as an important link between high and extremely low population levels of apple maggot.

In 1979 and 1980 commercial orchards were also monitored. Appendix 2 gives information pertinent about each block studied. Included is the owner's name and location, the varieties and number of traps in the block. Also included is a rating of potential pest pressure to the orchard. After selecting the block to be monitored, a thorough investigation of the surroundings of each orchard was made. Looked for was both the number and distance of abandoned apple trees or other host plants for apple maggot. A rating of pressure to the commercial orchard was made that is found in Table 1. These values for each orchard were determined and are found in the last column of Appendix 2. Flies caught in the commercial orchards were not used in emergence studies, but were used to study factors important to timing for controls.

Table 1. Rating System of Potential Apple Maggot Fly Pressure to Commercial Orchards.

Rating	Criteria
0	No abandoned trees or hawthorns evident
1	One tree in excess of 100 meters
2	One tree adjacent to the orchard
3	Two or more trees in excess of 100 meters
4	Two to ten trees adjacent to the orchard
5	Many host trees adjacent to the orchard

Around each orchard abandoned apple trees were located that were assumed to have high populations of apple maggot flies that could disperse into the commercial orchards. Traps were hung in these trees, and flight activity monitored. Several factors related to timing for controls were studied, one of which was the normal activity in abandoned tree sites. These trees were monitored at each visit to the orchard in 1979 and 1980.

Two additional sites were monitored in 1980 to serve as a validation of predictions based on results obtained from the K.S.H. and Upjohn studies. Site one had early red variety apples located in the Hofacker yard near the Fruit Ridge Avenue and Four Mile Road intersection northwest of Grand Rapids, Michigan. Site two was a transparent variety tree in the Yabs backyard in DeWitt, Michigan. Site one was an extremely early site due to the sandy soil and mowed yard which allowed for rapid development of the pupae. High populations of flies were present and trapped, so data gathered there should be sound and prove adequate for validation purposes. At site two very few flies were caught, so that data gathered there will not be used for validation purposes.

Emergence and Flight Studies - In 1977, 50 yellow Zoecon AM traps were placed in the K.S.H. orchard. Twenty-five of these were in early variety trees on the south side of the orchard, and twenty-five were clustered in later maturing varieties on the north side of the orchard. Traps were hung one per tree, and positioned one-third the distance into the tree canopy on the south side of the tree at eye level according to Prokopy (1972a), Reissig (1975) and Neilson et. al. (1976). Apple maggot flies were counted weekly and the traps cleaned off. At two week intervals the old traps were replaced with new ones as per manufacturers recommendations. Monitoring was initiated on June 17 and terminated September 28.

Also that year, 15 traps were placed in the Upjohn orchard. Five trees each of McIntosh, Jonathon, and Northern Spy were monitored. Traps were positioned, checked and replaced as in the K.S.H. orchard. Monitoring was initiated on June 17 and terminated September 28.

Emergence cages were placed in the K.S.H. orchard in 1977. Ten cages were placed over natural populations in the early variety section and ten in the late variety section. Five trees were selected in each section that had comparable canopies. Under each tree, one cage was positioned on the south side and one on the north side of the tree. This was done to provide a mean emergence value per tree, per variety, per orchard, and to determine if differences existed in emergence times between the south and north sides of the trees. Cages were monitored weekly, and the flies counted and removed.

In 1978, trapping and cage studies were repeated in the K.S.H. orchard. The number and placement of traps and cages was identical to that of the previous year. The only difference in 1978 was that monitoring was initiated on June 23, performed daily for three weeks, twice a week for the next four weeks, and once a week for the last six weeks. Sampling was terminated on September 22.

In 1979 the number of sampling locations were greatly expanded. In the K.S.H. orchard, the total number of traps trees was reduced to 15, seven in the early variety section and eight in the late variety section. Each tree was used in a paired test. On one side of the tree was hung the standard yellow Zoecon AM trap. On the opposite side was hung a red sticky sphere. At weekly intervals their positions were reversed. The yellow traps were replaced at two week intervals. Sixteen cages were placed over natural populations of apple maggot flies, eight in the early section and eight in the late section. A cage was placed under the south and north side of each of four trees in each section. Sampling was initiated on June 20 and performed three times a week for four weeks, twice a week for nine weeks, and once a week for five more weeks. It terminated on October 13.

At the Upjohn orchard in 1979, paired tests were also conducted. Three trees of each of three varieties utilized in 1977 were monitored with the yellow trap and red sphere. Traps were checked, reversed, replaced, and taken down the same as in the K.S.H. orchard in 1979. Trees selected were check trees so the effects of experimental insecticides would be reduced on trap catch.

Twenty commercial orchards were also monitored in 1979 (Appendix 2). Each orchard had a trap density of 1, 2, 4, or 10 traps per 10 acres. In each trap tree paired comparisons were made as in the K.S.H. orchard with trap placement, reversal, replacement and removal identical. These orchards were set up on June 19, and monitored three times each week for three weeks, twice a week for the next four weeks, and once a week for the next five weeks.

Around each of these orchards were located abandoned trees. Thirteen trees in total were monitored on the same schedule as the adjacent commercial orchard. Each trap tree provided data for paired comparisons, with the methodology identical to previously described.

In 1980, monitoring schemes were very similar to 1979. In the K.S.H. orchard, the same trees and methods were used as in 1979 for the trap comparison studies. Cage studies were conducted in 1980, but these were seeded with infested apples in the late summer of 1979 rather than being placed over naturally infested soil. Seven cages in total were seeded on 3-4 day intervals, with the first seeding made on July 16 and the last August 6. They were monitored three times a week for six weeks beginning June 23 and then weekly for eight weeks.

In the Upjohn orchard in 1980, the same trapping scheme was utilized as in 1979. Nine trees, three of the main varieties, had a yellow trap and red sphere on them for comparison purposes. Trees selected were check trees in the chemical tests so as to reduce insecticide influences on flight activity and trap catch. Monitoring intervals were the same as those in the K.S.H. orchard in 1980.

Different commercial orchards were monitored in 1980 than 1979. Those selected (Appendix 2) were closer to Lansing to reduce travel expenses. Five orchards were monitored three times a week beginning June 23 for nine weeks, then once a week for three weeks. Pest Management Field Assistants in other parts of the state monitored another six commercial orchards on the same schedule. Each orchard had a different density of traps, but each trap tree had a comparative test between the yellow and red sphere traps. In the area around each orchard abandoned trees were located, trapped and monitored identically as the commercial trees.

Two new sites were established as validation points in 1980. As previously mentioned, the Yabs site was eliminated because of the limited number of flies caught. At the Hofacker site, one tree of four in the yard was monitored. A yellow trap and red sphere trap were hung on opposite sides of the tree. Positions were reversed weekly, and the yellow trap replaced every two weeks. Flies were counted and removed starting on June 23 three times each week for six weeks, and then weekly for eight weeks.

Results and Discussions

Season long emergence and flight patterns of apple maggot fly have been determined for different locations and years in Michigan. Table 2 was prepared to show when on a calendar basis, different proportions of emergence or trap catch occurred. This compares different years, different locations, and different methods of monitoring. The detailed discussion of the average and range associated with each cell in this Table will be delayed until later in this dissertation when parameters associated with these variances are studied. The general purpose here is to show the large variability associated with each event. This is indicated in the last row.

The one method of monitoring fly activity that remained the same through all locations and years was trap catch on the yellow Zoecon AM trap. Because of this consistency, season long emergence graphs were prepared (Figures 4-13). These graphs show weekly average trap catch and the accumulative percent emergence. Large differences in timing of events become clearly evident between years at the same location, and between locations when these graphs are compared.

TABLE 2. Mean Calendar Dates for Different Proportions of Emergence and Trap Catch of the Apple Maggot Fly at Various Locations in Michigan from 1977 to 1980.

Year	Location	Method	No. of Samples	First Catch	1%	5%	10%	25%
1977	K.S.H.	Yellow Trap	50	6/20	6/20	6/22	6/26	6/06
	Upjohn	Yellow Trap	15	6/20	7/03	7/10	7/18	7/28
	K.S.H.	Natural Cages	20	7/06	7/06	7/06	7/06	7/06
1978	K.S.H.	Yellow Trap	50	6/27	7/03	7/08	7/09	7/14
	K.S.H.	Natural Cages	20	6/27	6/27	6/28	6/29	7/01
1979	K.S.H.	Yellow Trap	15	6/25	7/01	7/07	7/12	7/24
	Upjohn	Yellow Trap	9	7/13	7/13	8/01	8/06	8/12
	Abandoned	Yellow Trap	13	7/12	7/26	7/30	8/03	8/12
	K.S.H.	Red Sphere	15	7/02	7/08	7/14	7/19	7/31
	Upjohn	Red Sphere	9	7/16	7/16	8/05	8/07	8/11
	Abandoned	Red Sphere	13	7/17	7/28	8/02	8/13	8/16
	K.S.H.	Natural Cages	16	6/25	6/25	6/26	6/28	7/01
	Upjohn	Natural Cages	3	7/11	7/11	7/11	7/11	7/11
	K.S.H.	Seeded Cages	8	6/17	6/19	6/22	6/25	7/01
1980	K.S.H.	Yellow Trap	15	6/28	7/03	7/08	7/09	7/17
	Upjohn	Yellow Trap	9	7/05	7/22	7/23	7/24	7/27
	Abandoned	Yellow Trap	11	7/11	7/14	7/22	7/26	8/03
	Hofacker	Yellow Trap	1	6/21	6/21	6/23	6/24	6/26
	K.S.H.	Red Sphere	15	6/28	7/06	7/09	7/13	7/19
	Upjohn	Red Sphere	9	7/14	7/14	7/22	7/24	7/29
	Abandoned	Red Sphere	11	7/28	7/28	7/29	7/31	8/03
	Hofacker	Red Sphere	1	6/23	6/23	7/08	7/08	7/10
	K.S.H.	Seeded Cages	7	6/28	6/28	6/30	7/02	7/04
Ranges in Dates		All	335	6/17 7/28	6/19 7/28	6/22 8/05	6/24 8/13	6/24 8/16
Variation in Days		All	-	41	39	44	50	51

TABLE 2. Con't.

Peak	50%	75%	95%	Last Catch	Total Flies
8/10	7/27	8/17	9/20	9/28	6,736
8/10	8/06	8/16	8/31	9/28	11,345
7/13	7/12	7/18	8/20	8/31	103
7/14	7/24	8/03	8/17	9/25	9,912
7/05	7/05	7/11	7/27	8/11	459
8/06	8/04	8/18	9/02	9/29	4,917
8/30	8/29	9/02	9/09	9/12	262
8/28	8/18	8/25	9/03	8/18	848
8/06	8/05	8/17	8/28	8/29	2,255
9/13	8/29	9/07	9/12	9/13	490
8/28	8/23	8/29	9/02	9/18	7,764
7/04	7/06	7/12	7/27	9/03	791
7/19	7/19	8/06	8/06	8/06	3
7/04	7/10	7/19	8/06	9/22	1,000
8/11	8/03	8/13	8/24	9/17	3,727
7/25	8/07	8/15	8/26	9/12	308
8/06	8/09	8/16	8/22	9/03	183
6/24	7/17	7/15	7/25	8/11	118
8/11	7/31	8/11	8/24	9/17	1,637
8/25	8/10	8/22	9/01	9/12	175
8/11	8/09	8/13	8/22	9/08	109
7/09	7/12	7/17	7/24	8/04	78
7/07	7/07	7/12	7/21	8/25	810
6/24	7/05	7/11	7/21	8/04	48,030
9/13	8/29	9/07	9/20	9/29	030
81	55	58	61	56	

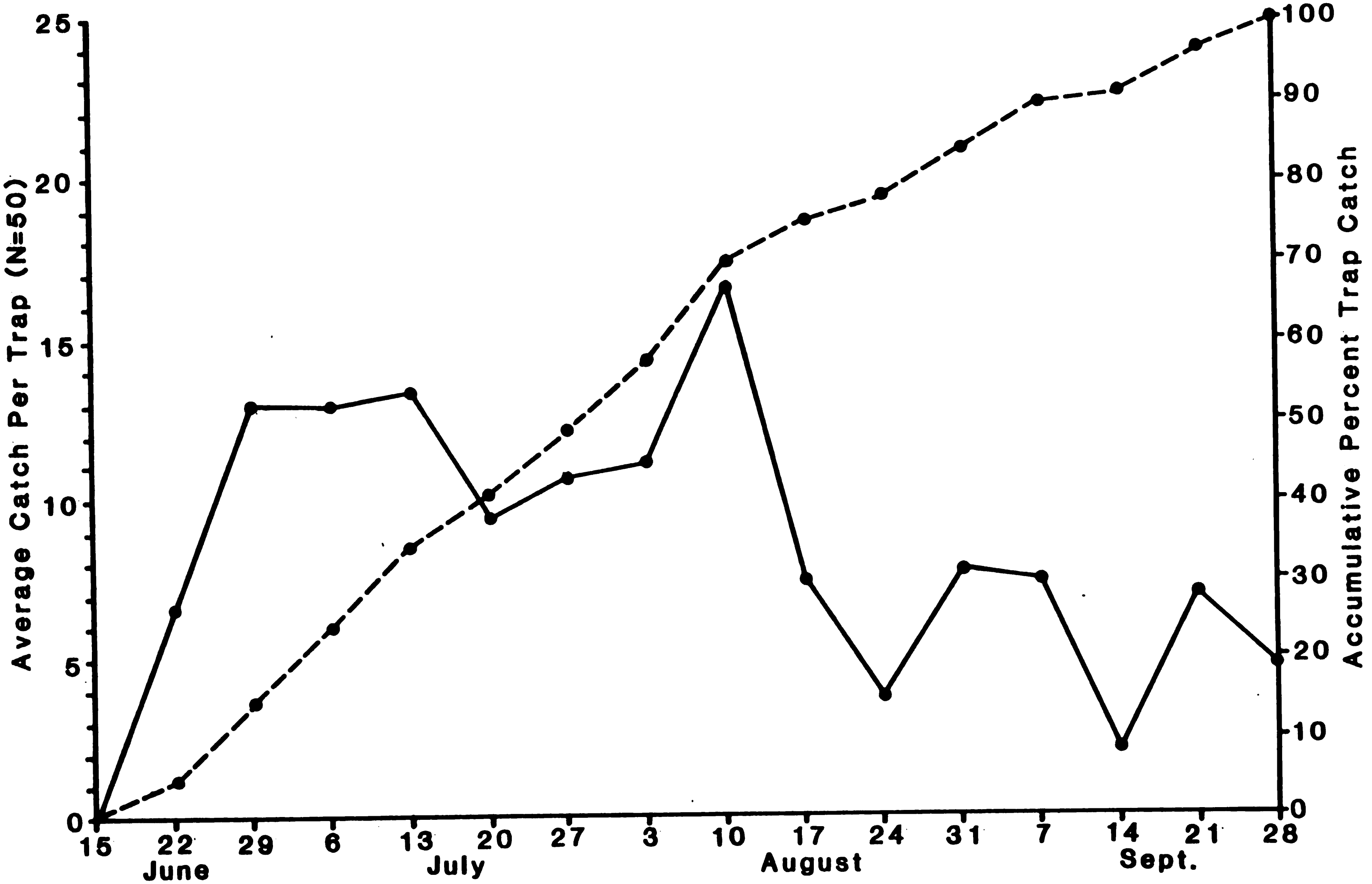


Figure 4. Trap Catch of Apple Maggot Flies at the Kalamazoo State Hospital Orchard in 1977 on Yellow Zoecon AM traps.

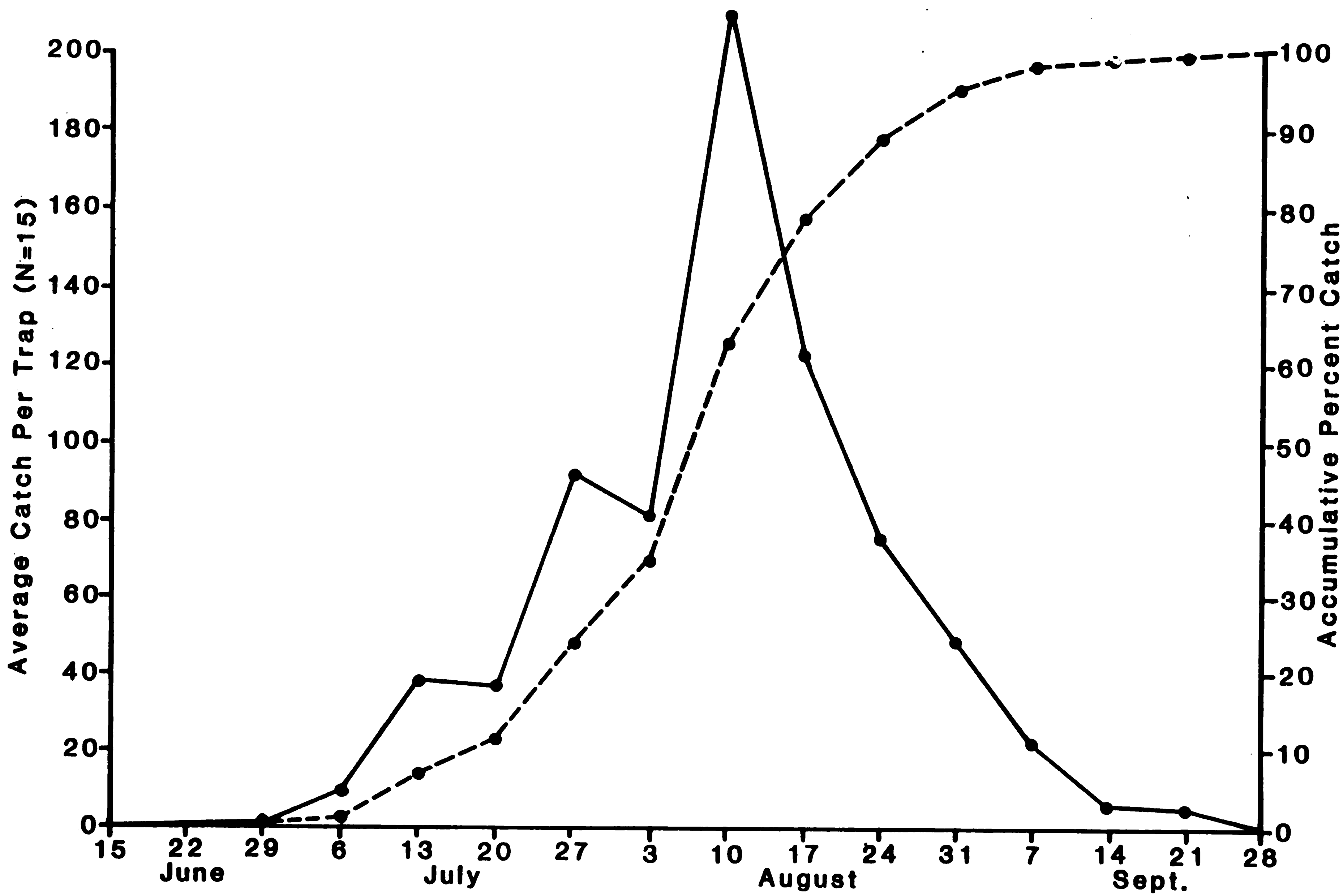


Figure 5. Trap Catch of Apple Maggot Flies at Upjohn Orchard in 1977 on Yellow Zoecon Traps.

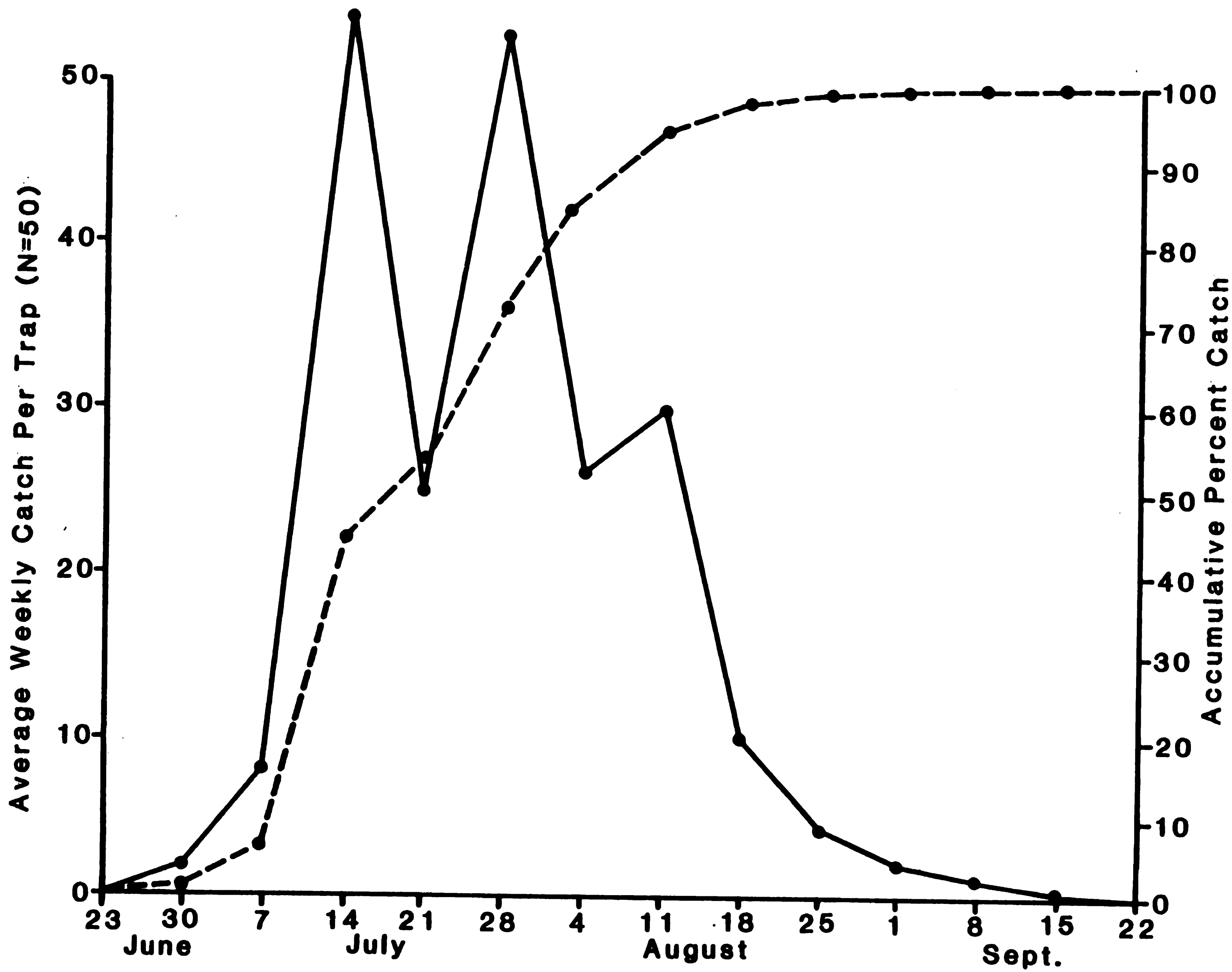


Figure 6. Trap Catch of Apple Maggot Flies at the Kalamazoo State Hospital Orchard in 1978 on Yellow Zoecon AM traps.

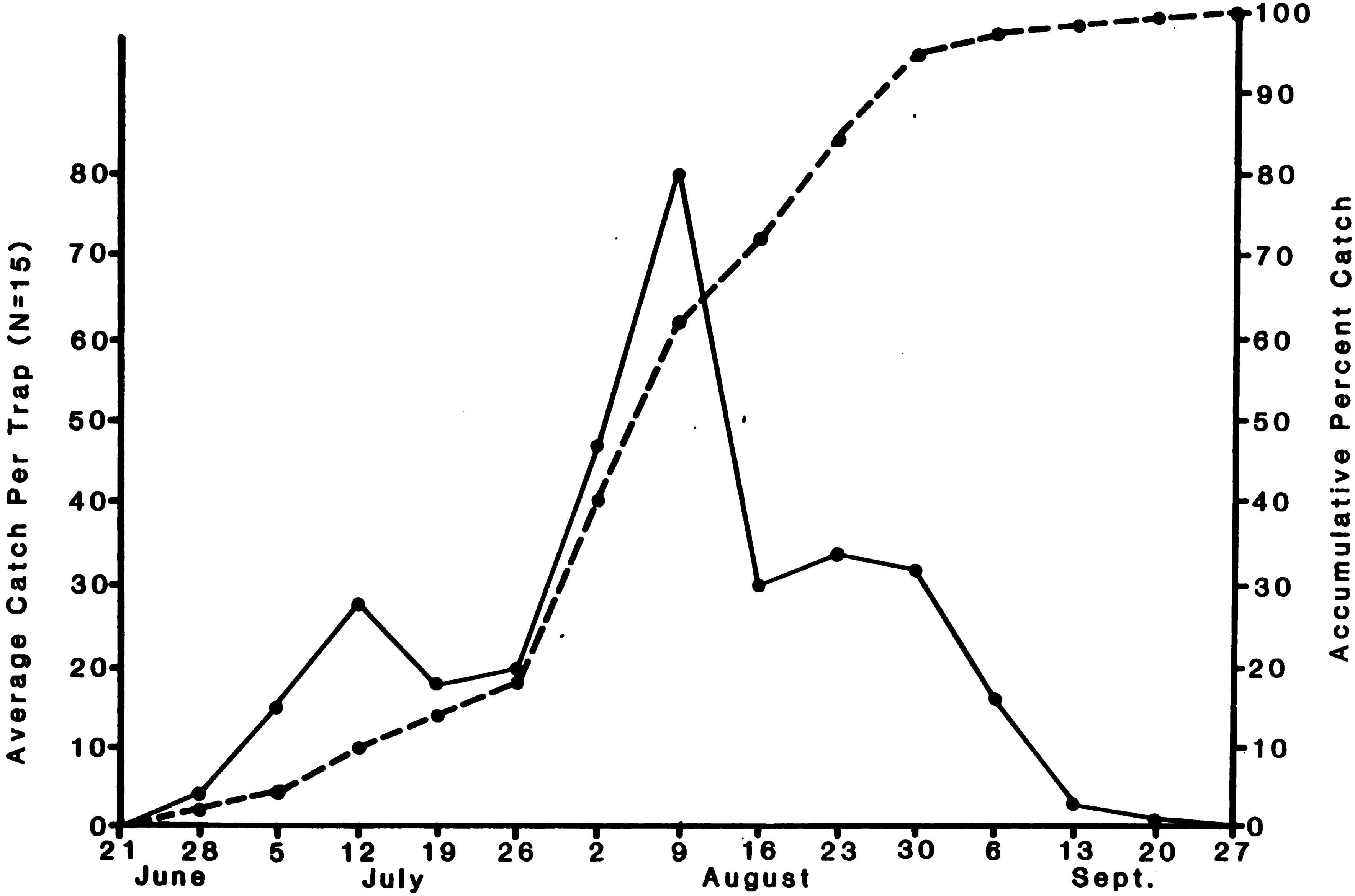


Figure 7. Trap Catch of Apple Maggot Flies at the Kalamazoo State Hospital Orchard in 1979 on Yellow Zoecon AM Traps.

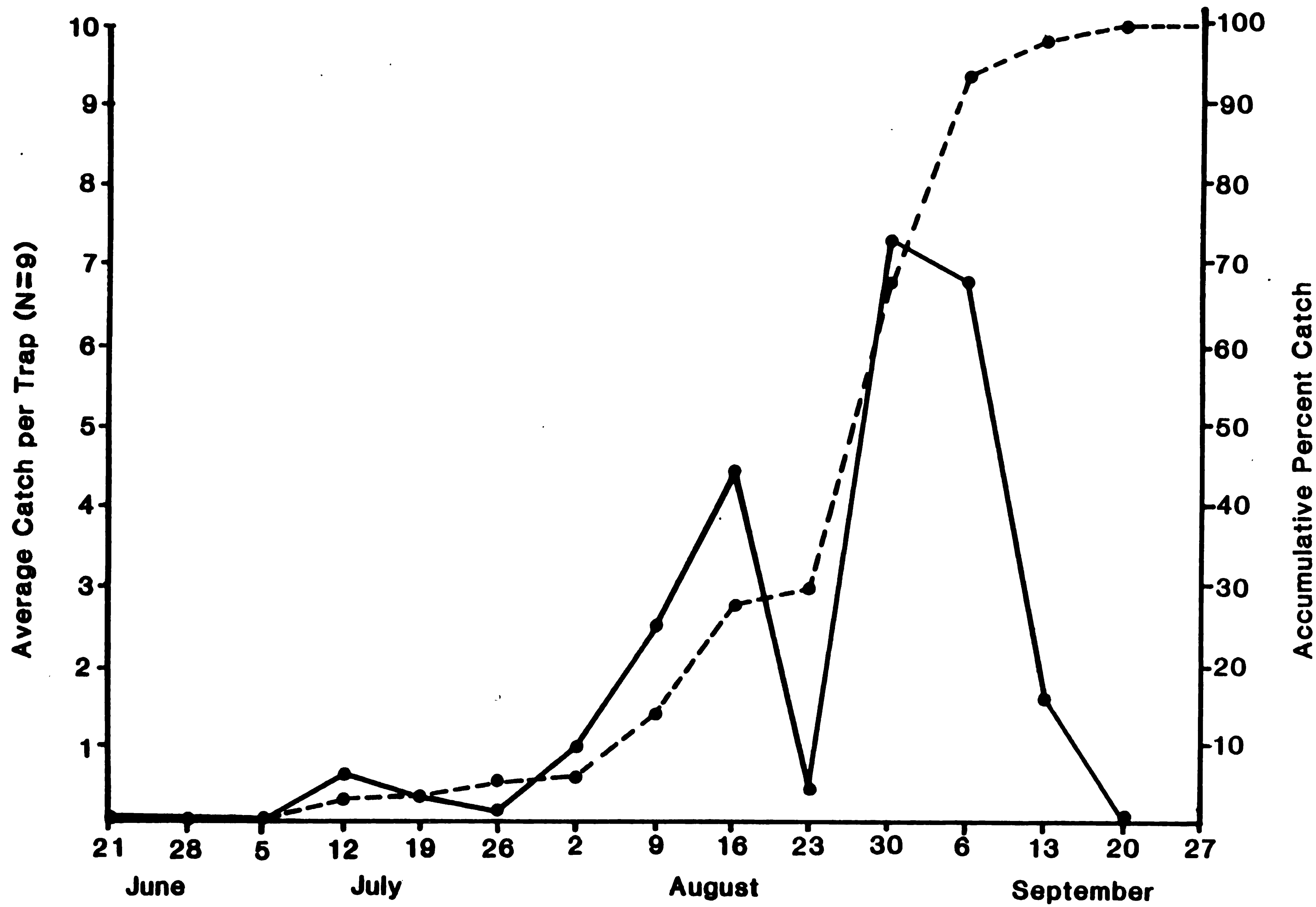


Figure 8. Trap Catch of Apple Maggot Flies at the Upjohn Orchard in 1979 on Yellow Zoecon AM Traps.

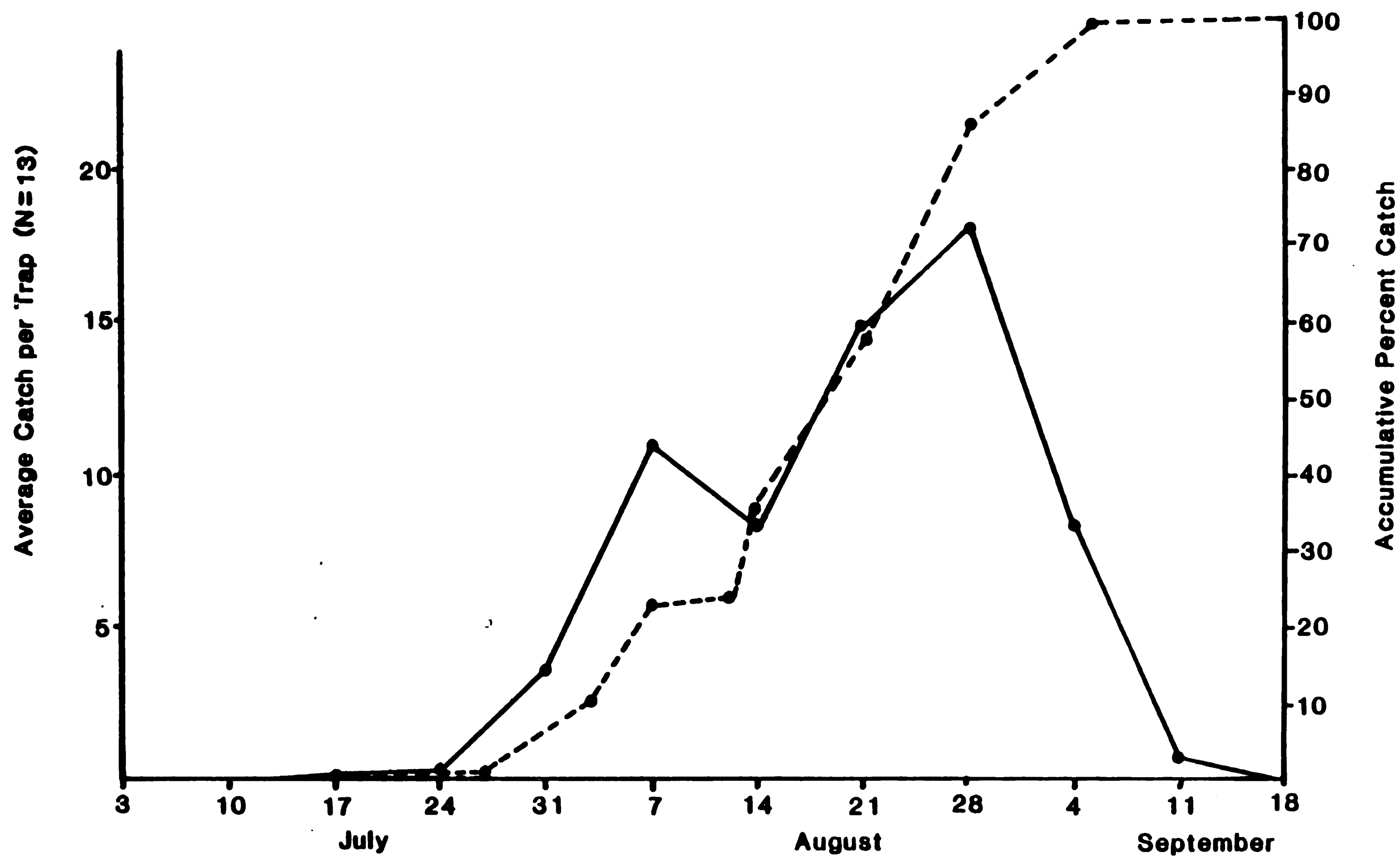


Figure 9. Trap Catch of Apple Maggot Flies in Abandoned Trees Around Commercial Orchards in West Central Michigan in 1979 on Yellow Zoecon AM Traps.

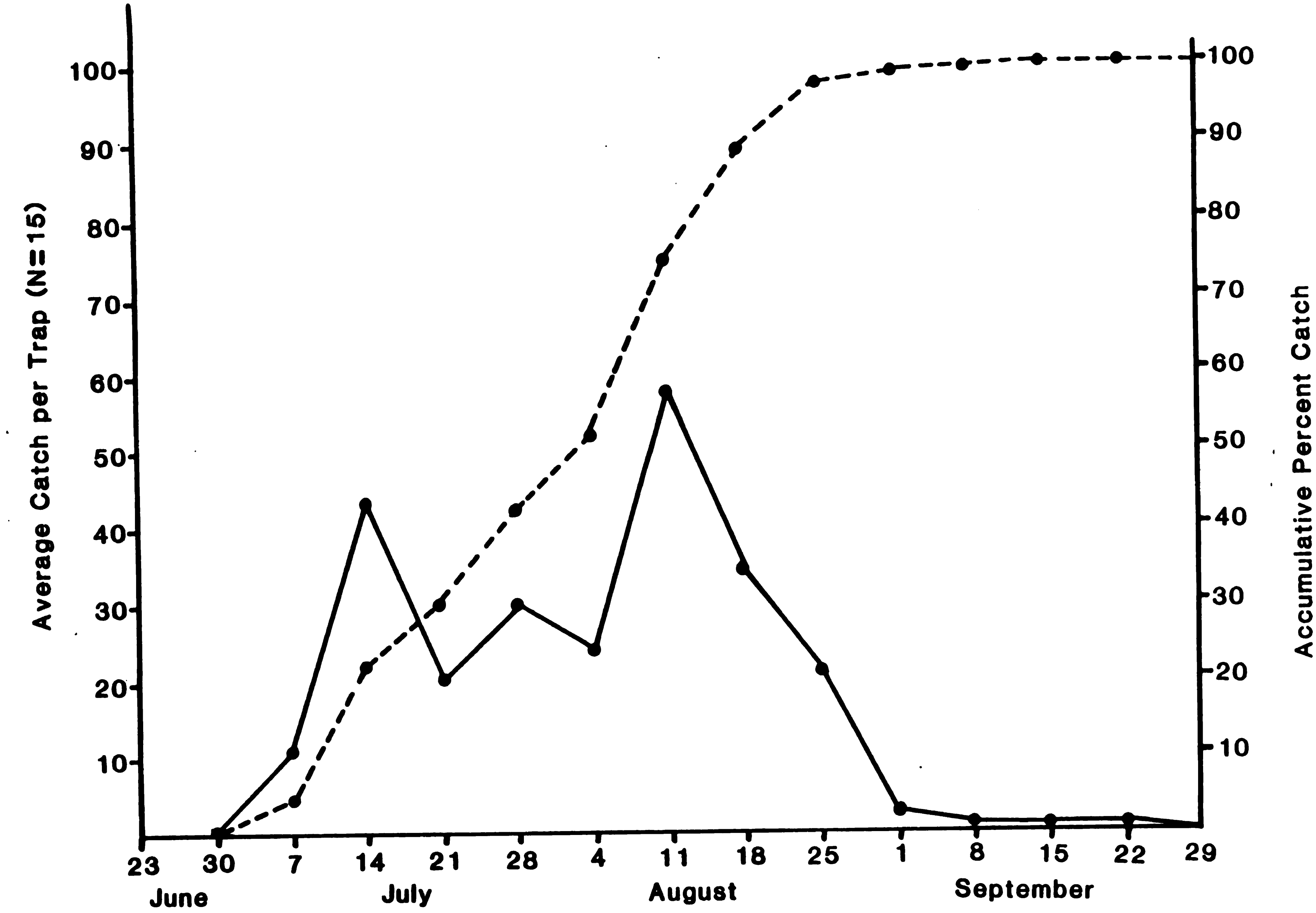


Figure 10. Trap Catch of Apple Maggot Flies at the Kalamazoo State Hospital Orchard in 1980 on Yellow Zoecon AM Traps.

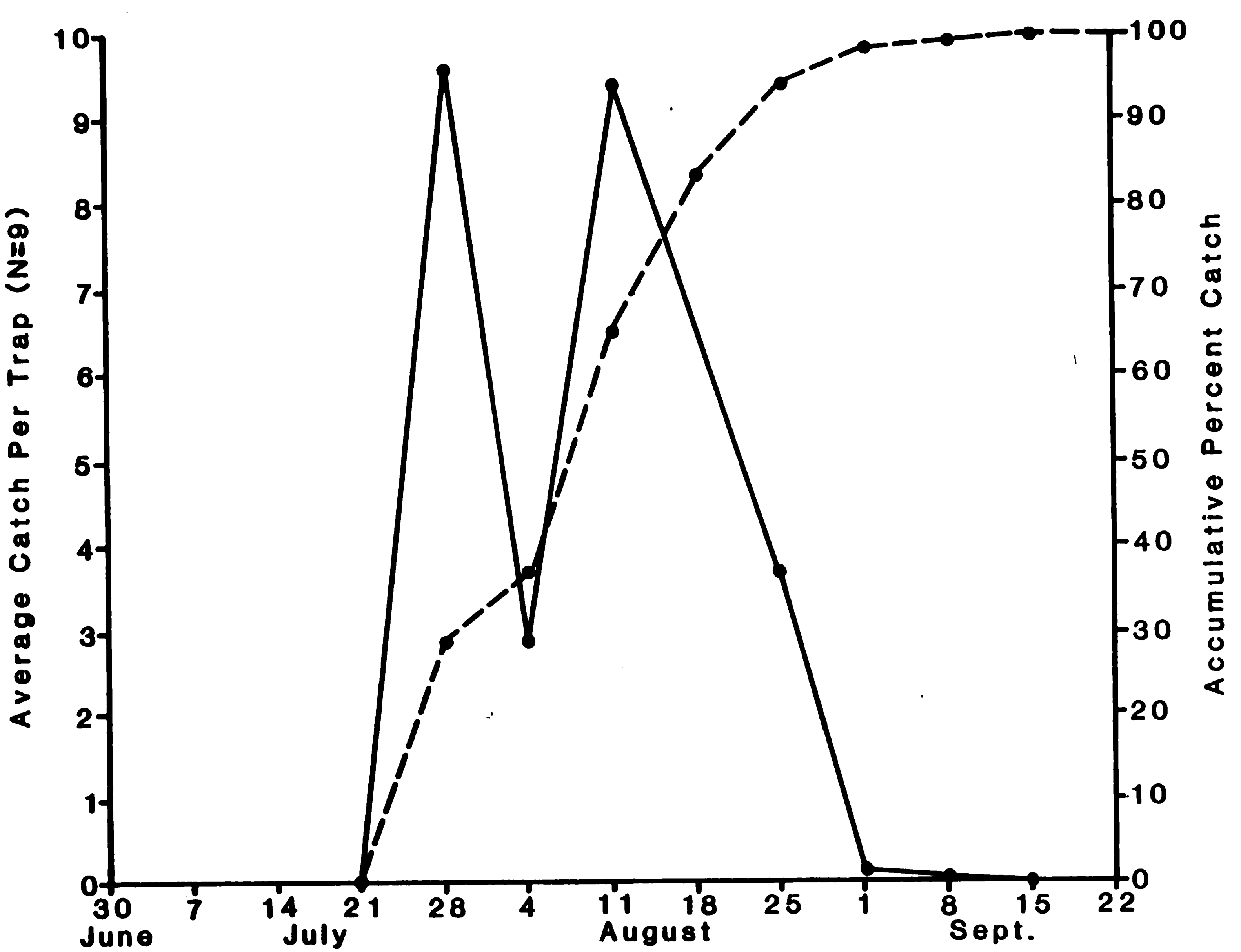


Figure 11. Trap Catch of Apple Maggot Flies at the Upjohn Orchard in 1980 on Yellow Zoecon AM Traps.

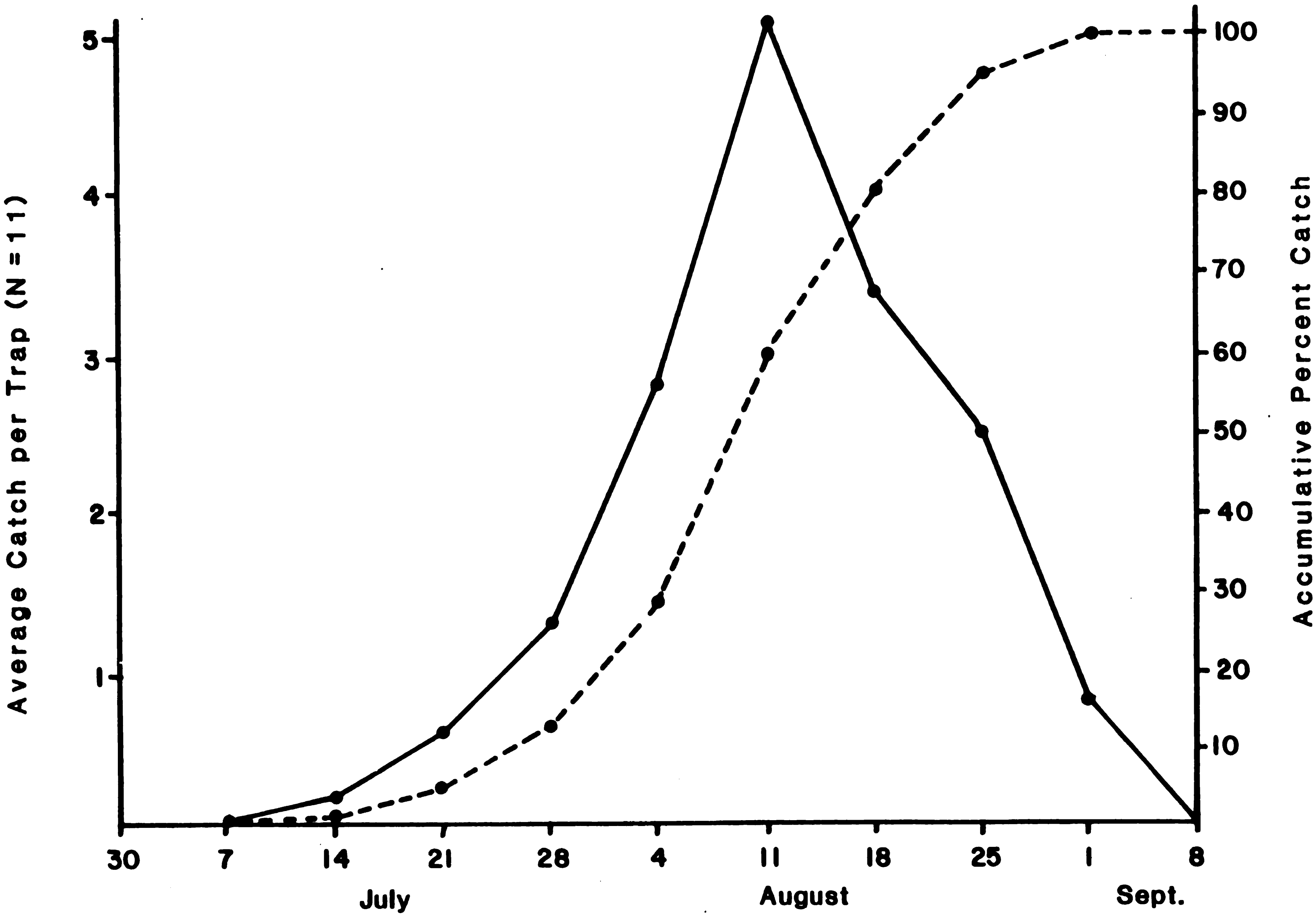


Figure 12. Trap Catch of Apple Maggot Flies in Abandoned Trees Around Commercial Orchards in Central Michigan in 1980 on Yellow Zoecon AM Traps.

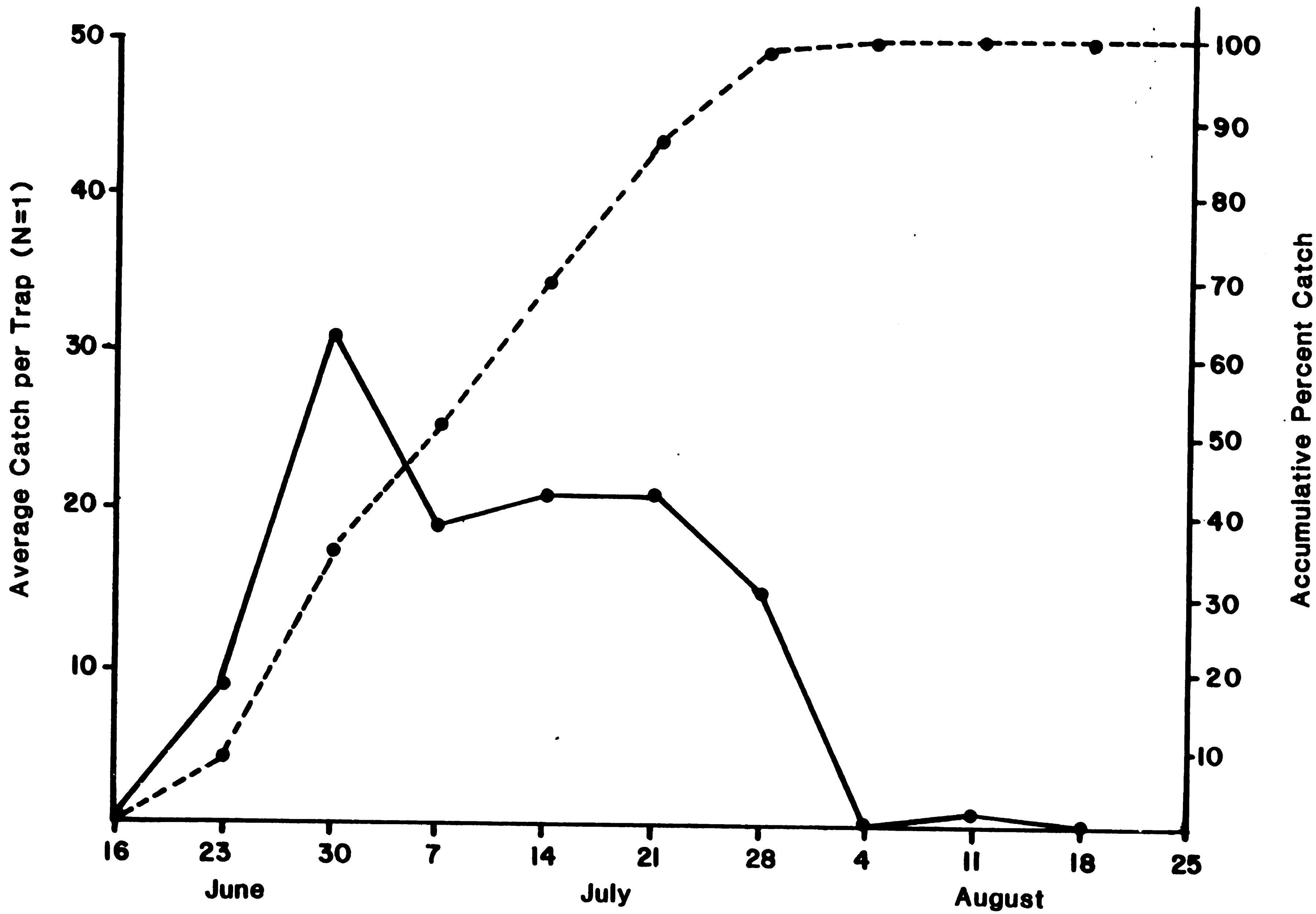


Figure 13. Trap Catch of Apple Maggot Flies at Hofacker in 1980 on Yellow Zoecon AM Traps.

FIRST EMERGENCE BY CALENDAR DATE

First emergence or catch of adults is a very important event in the life cycle of apple maggot under current management practices. When emergence occurs or flies are caught on traps, growers are advised to start pesticide applications in 7-10 days, and continue them at two week intervals until harvest. Because of its importance, studies were conducted in high and medium density situations to better understand the dynamics associated with first emergence. Other studies in low density levels as is experienced in most commercial orchard situations were carried out to determine if those same dynamics are applicable with pesticide pressured populations.

A portion of this study contrasts methods of measuring or estimating emergence. Several methodologies have evolved in the past to measure this event. The first method was to place emergence cages over naturally infested ground and monitor emergence. Another was to seed cages in the fall, and emergence monitored the following summer. Later traps were designed to measure populations that are actually present and active in trees. Yellow traps were designed that mimicked foliage and red spheres were used that mimicked fruit. A study of these methods will measure the variability associated with each method, and the result should be to determine which method is best. Best can be defined as that method which catches flies consistently earlier and has the smallest coefficient of variation (C.V.) of first catch, is the most practial to use, and is a better indicator of fly activity in the tree. The C.V. is calculated by dividing the standard deviation by the mean.

Materials and Methods

Studies were conducted in the K.S.H. and Upjohn orchards during the years 1977-1980. First emergence was determined or estimated by one or more of four different methods. In all of these cases, the frequency of monitoring is the same as that discussed under Adult Emergence.

Results and Discussion

Table 3 presents the data on emergence or first catch by each method for all years at the two locations. Included is the range of dates in first catch, and the mean day of first catch for each method.

The analysis of the data from which Table 3 was formulated proved to be somewhat untidy. These data were taken for a variety of individual small tests, and when combined a posteriori fit no experimental design. Too

TABLE 3. First Emergence or Catch of Apple Maggot Flies in K.S.H. and Upjohn orchards.

Year	Location	Method	No	Range in Date of First Catch	Mean Date of First Catch
1977	K.S.H.	Natural Cages	20	07/06 - 07/20	07/11
	K.S.H.	Yellow Traps	50	06/20 - 07/06	06/21
	Upjohn	Yellow Traps	15	06/20 - 07/06	06/28
1978	K.S.H.	Natural Cages	20	06/27 - 07/11	07/01
	K.S.H.	Yellow Traps	50	06/27 - 07/12	07/03
1979	K.S.H.	Seeded Cages	8	06/17 - 07/04	06/21
	K.S.H.	Natural Cages	16	06/25 - 07/13	07/01
	K.S.H.	Yellow Traps	15	06/25 - 07/06	06/29
	K.S.H.	Red Spheres	15	07/02 - 08/02	07/14
	Upjohn	Natural Cages	3	07/11 - Never	07/11
	Upjohn	Yellow Traps	9	07/13 - 08/13	07/24
	Upjohn	Red Spheres	9	07/16 - 08/13	07/27
1980	K.S.H.	Seeded Cages	7	06/28 - 07/02	06/30
	K.S.H.	Yellow Traps	15	06/28 - 07/09	07/04
	K.S.H.	Red Spheres	15	06/28 - 07/21	07/10
	Upjohn	Yellow Traps	9	07/05 - 07/28	07/21
	Upjohn	Red Spheres	9	07/14 - 08/25	07/25

many treatments were missing to have a nested, factorial, or two way analysis of variance design. Therefore, one way analysis of variance tests were performed with each of the methods at the different locations in different years being considered a treatment. The resultant 17 treatment one way ANOVA with unequal sample sizes was appropriate.

Three sets of these data were removed from the analysis. The 1979 Upjohn natural cage was eliminated because of the extremely small number of flies caught (3), and the few samples units used.

The 1977 yellow trap data from the Upjohn orchard was also eliminated. This orchard had been abandoned for several years, and the mean per trap catch for the year was 756. Starting in 1978, insecticide testing was conducted in this orchard, with alternating trees being treated which resulted in a 95% reduction in the population. In 1979 the mean trap catch was 30 and in 1980 it was 34. This greatly differing population within the orchard would cause an extremely large variation in all the data collected. Therefore the 1977 data was not used, and the 1979-1980 data will be used to represent a medium density orchard.

Lastly, the 1977 natural cage data from the K.S.H. was eliminated. The rationale for this is that in 1977 eight cages were set on June 29. They were not checked again for one week, and six of them had flies in them. On that day the remaining 12 cages were set, and four of them had flies the following week. All the yellow traps in the orchard had caught flies on them before this date which indicates that the first flies emerged and escaped the cages before most of them were in position. Also, it is highly probable that flies emerged throughout the week, and if recorded on the day of actual emergence, the mean date of emergence would have been earlier. This sampling error was corrected in succeeding years by setting all the emergence cages earlier and by sampling them more often the first two weeks of the season.

The one-way ANOVA of the remaining 14 treatments proceeded as follows (BNPGANOVABAL, 1982). The first attempt was to compare all methods of measuring first catch across all years and the two research orchards. Extremely high F ratios resulted from the ANOVA and SNK and LSD multiple range tests separated the 16 different treatments into four and six homogeneous groups at the .05 level. However, the test was invalidated because of the extremely heterogeneous variances, which is one of the basic assumptions for the ANOVA. Thirteen different transformations were made on the data in an effort to meet the assumptions of the ANOVA, none of which were successful. This could be an expected result because of the very different methods of measuring emergence, year-to-year and location differences. The variances should be expected to be very large under these circumstances.

The most reasonable approach to reduce this variability would be to analyse like subsets of the data. This was done and the Bartlett's test found the majority of the variances homogeneous. Those that were not were transformed by the square root and/or log transformations to meet the assumptions. The SNK and LSD mean separation tests were run at the .05 level. In no cases were the means of the transformed data separated any differently than the raw data.

The results are found in Table 4. This compares the influence of the year on the different methods of measuring or estimating first emergence at high population levels at the K.S.H. orchard and reduced population levels at the Upjohn orchard.

Looking at the data from the K.S.H. orchard, emergence from seeded cages were tested in 1979 and 1980. Emergence was significantly later in 1980 than 1979. Two possible reasons for this could be that 1980 was a cooler year and the influence of variety of apple used in seeding. Both will be examined later. The high C.V. of 53 indicates that this is a highly variable data set, and not one from which predictions should be made.

When natural cages were tested, emergence was not significantly different between 1978 and 1979. The influence of temperature is discussed later. Fairly large number of flies were caught (1978 = 459 and 1979 = 791 which helps to stabilize the means. The C.V. of 30 indicates a relatively small variation, so the mean date of July 1 could be used as a good estimator of emergence of flies from natural cages in the K.S.H. orchard.

TABLE 4. Influence of Years on Different Methods of Measuring First Emergence of Apple Maggot Flies at the K.S.H. and Upjohn Orchards (Mean ±S.E. Date of Emergence and Coefficient of Variation for Combined Data for All Years in Each Orchard).

Year	Seeded Cages	Natural Cages	Yellow Traps	Red Spheres
		Kalamazoo State Hospital		
1977	-	-	6/21 ±0.5a	-
1978	-	7/01 ±1.0a	7/03 ±0.7 c	-
1979	6/21 ±1.9a	7/01 ±1.6a	6/29 ±1.1 b	7/14 ±2.6a
1980	6/30 ±0.5b	-	7/04 ±0.8 c	7/10 ±1.7a
All	6/25 ±1.5	7/01 ±0.9	6/28 ±0.6	7/12 ±1.6
C.V.	53	30	48	31
		Upjohn Orchard		
1979	-	-	7/24 ±4.4d	7/27 ±6.8b
1980	-	-	7/21 ±2.3d	7/25 ±4.2b
All	-	-	7/22 ±2.4	7/26 ±3.7
C.V.	-	-	27	35
		Both Orchards		
All	-	-	7/01 ±0.8	7/17 ±1.9
C.V.	-	-	62	40

Dates in each column followed by the same letter are not significantly different at the .05 level by the SNK and LSD tests.

Yellow traps were tested all four years at the K.S.H. and should provide a realistic appraisal of year to year variation. A large number of traps were set each year (1977 = 50, 1978 = 50, 1979 = 15, and 1980 = 15) and each trap caught a relatively large number of flies. The minimum number of flies caught on any single trap was 1977 = 20, 1978 = 32, 1979 = 137, and 1980 = 142. However, the mean number of flies caught per trap during this period was 1977 = 135, 1978 = 216, 1979 = 330, and 1980 = 248. At first glance this appears to be a competition effect, with the more traps used the fewer flies caught. However, each year there was one trap per tree attempting to catch flies that emerged just under that tree. The difference in the total number of traps is the total number of trees with traps in them. A more plausible explanation for this difference is the varying resource. More or less apples were available for oviposition from one year to another, and that can greatly alter the population size the following year. As is shown the mean date of June 21, 1977 is the earliest year for trap catch, and it was significantly earlier than the other years. The mean emergence date of June 29 in 1979 was the second earliest and was significantly different than the other years. The mean dates of emergence in 1978 of July 3 and 1980 of July 4 were statistically not different, but different from other years. This difference, plus a C.V. of 48 shows that there is a variation component due to year in the first trap catch of apple maggot flies in the K.S.H. orchard. A possible explanation for this of warmer or cooler seasons is discussed later.

The red sphere traps were tested in the K.S.H. orchard in 1979 and 1980. Their mean date of first catch were July 14 and July 10, respectively. These dates do not differ significantly. This is different than the other two methods of measuring emergence at the K.S.H. orchard for in both cases 1979 was significantly earlier than 1980. The presumed reason for this must relate to the behavioral response of the flies to the spheres and the number of apples present competing for oviposition and mating sites. The C.V. of 31 is relatively small, indicating that the mean date of

July 12 would be a fairly good estimate of first trap catch on red spheres in the K.S.H. orchard.

The bottom portion of Table 4 presents mean dates of first emergence or trap catch at the Upjohn orchard which has a much reduced population of apple maggot flies. When the yellow trap was used to estimate emergence, differences between years was not found. The mean date of first trap catch of July 24, 1979 and July 21, 1980, were statistically the same. The mean date for both years of July 22 had a small C.V. of 27 associated with it which indicates a fairly small variance and a good estimator.

The red sphere traps had no statistical difference in the mean date of emergence between 1979 and 1980. It is reasoned therefore that when lower populations of apple maggot flies are present, fewer of the extremely early flies are present. When this is the case, the yearly variation is reduced (C.V. = 35), and much more consistent mean date of first trap catch occurs.

A comparison between these two orchards is also presented in Table 4. With yellow traps, the mean date of first catch is statistically later in the Upjohn orchard than the K.S.H. orchard. The delay ranges from 26 days in 1979, to 17 days in 1980. The associated overall C.V. is 62 which also shows this very large variation. Reasons for this delay such as variety component and weather will be discussed later. The major reason of population size explains the majority of this difference. In the K.S.H. orchard the mean per trap catch was: 1979 = 330, 1980 = 248, while in the Upjohn orchard the mean per trap catch was 30 in 1979 and 34 in 1980. The greatly reduced population has fewer early individuals, and results in later mean date of first catch.

Red sphere traps were also significantly later in the Upjohn orchard than in the K.S.H. orchard. The delay in mean first catch was 13 days in 1979 and 15 days in 1980. The C.V. was 40, a fairly large variation. The possible explanations of weather and variety composition will be discussed later. The population size differences mentioned in the previous paragraph can also explain the majority of the difference. The mean per trap catch in the K.S.H. orchard was 150 in 1979 and 109 in 1980, and in the Upjohn orchard 54 in 1979 and 19 in 1980. This smaller population size results in later first catch.

Table 5 was prepared to determine differences between the methods of estimating emergence within each year. The seeded cage method was always the earliest. In 1979 and 1980 at the K.S.H. orchard, the mean dates of June 21 and June 30 were significantly earlier than any of the other methods. This was expected because of the concentration of a large number of flies into a very small area (1 meter square), and every one of the flies being caught (none escaping the cage).

Cages placed over naturally infested ground are later in catching emerging flies than are the seeded cages, are the same as yellow traps, and are earlier than the red spheres. In the one year where both cage methods were compared, the mean date of emergence from the natural cage of July 1 was 10 days later than the seeded cage, a significant delay. The reason for this is the smaller population size sampled, with the mean catch per seeded cage of 125 to that in natural cages of 49. When yellow traps are compared to natural cages, no real differences are evident. In 1978, the mean date of emergence was two days later on the yellow traps, but in 1979 it was two days earlier. Therefore according to this data, these methods are the same. The natural cages are sooner than the red spheres in mean emergence dates. In the K.S.H. orchard in 1979, the difference of 13 days was statistically significant.

Yellow Zoecon AM traps are intermediate in measuring the mean emergence dates. They are significantly later than the seeded cages as has been discussed. They are no dif-

TABLE 5. Influence of Method of Estimating First Emergence of of Apple Maggot Flies at the K.S.H. and Upjohn Orchards Over a Four Year Period (Mean ±S.E. Date of Emergence plus Coefficient of Variation within the Year).

Method	1977	1978	1979	1980
		K.S.H.		
Seeded Cages	-	-	6/21 ±2.0a	6/30 ±0.5a
Natural Cages	-	7/01 ±0.7a	7/01 ±1.6b	-
Yellow Traps	6/21 ±0.5a	7/03 ±1.0a	6/29 ±0.9b	7/04 ±0.8b
Red Spheres	-	-	7/14 ±2.6c	7/10 ±1.7c
		UPJOHN		
Yellow Traps	-	-	7/24 ±4.4d	7/21 ±2.3d
Red Spheres	-	-	7/27 ±6.8d	7/25 ±4.2d
		BOTH ORCHARDS		
All C.V.	45	23	63	41

Dates in each column followed by the same letter are not significantly different at the .05 level by the SNK and LSD tests.

ferent on the average in measuring first emergence than are the natural cages which is very important in orchard monitoring. Their responsiveness in comparison to red spheres varies with the population of the flies but is always earlier. In the higher population levels of the K.S.H. orchard, they caught flies 15 days earlier in 1979 and 6 days earlier in 1980. These differences were significant. In the medium density Upjohn orchard they caught flies 3 days earlier in 1979 and 4 days earlier in 1980 on the average. However, these differences were not significant.

The last row of Table 5 lists the coefficient of variation within each year. This percentage value gives an indication of how variable the data was within all the methods of measuring emergence. Generally a 30 value indicates good biological data. In 1977, the C.V. was 45. This is quite large, especially when only one method was used to determine it. The 23 C.V. in 1978 is very small. This supports the non-significant difference of the two methods used in the K.S.H. that year. The 1979 C.V. of 63 is the largest one in the table. This is to be expected because all four methods are compared for first emergence, and a between orchard component adds variation to this value. Because it is so large, a mean value computed from all the data points would have a large variance and not be useful for predictive purposes. The C.V. in 1980 of 41 is also quite large. Again this should be expected because of the several methods utilized and the between orchard variation.

In paired comparisons with traps hung on opposite sides of the same tree, in 38 of 48 trials in both orchards in both years, the yellow trap caught flies first, 8 times they were later, and twice they were the same. Table 6 shows the results from the paired-t test which compared the difference between date of first catch on each trap in each tree (SPSS, 1975). In

the Upjohn orchard in 1979, two red spheres never caught flies, so they were given values in this test equal to the last date of first catch on the remaining spheres of August 30. The results in the K.S.H. orchard shows that in 1979 and 1980 the yellow traps caught flies highly significantly earlier than the red spheres. However, in the Upjohn orchard where there is a lower density of flies present, the yellow trap caught flies sooner, but not significantly sooner. When all the trapping locations in the K.S.H. orchard from both years are lumped, the yellow traps caught flies 10 days sooner than the red sphere, a highly significant difference. This same trend holds in the Upjohn orchard where the yellow traps caught flies 8 days sooner. If all 48 trials are lumped from both orchards and both years, the yellow trap caught flies 9.4 days sooner, a highly significant difference. The fly generally is attracted to yellow traps first as a feeding stimulus. During the next 7-10 days the female is mating and maturing. After mature, she seeks out dark spherical objects on which to oviposite. Then red sphere traps become attractive as a

TABLE 6. Comparison of Yellow Zoecon AM Traps and Red Sticky Spheres in First Capture of Apple Maggot Flies (Mean ±S.E. Date of First Catch)

Year	Location	No.	Mean Date Yellow Trap	Mean Date Red Sphere	Mean Diff.	Sign. Level
1979	K.S.H.	15	June 29 ±0.9	July 14 ±2.6	15.3	.000
1979	Upjohn	9	July 24 ±4.4	Aug. 4 ±6.8	11.2	.079
1980	K.S.H.	15	July 4 ±0.8	July 10 ±1.7	6.1	.000
1980	Upjohn	9	July 21 ±2.3	July 25 ±4.2	4.4	.151
All	K.S.H.	30	July 1 ±0.6	July 12 ±1.6	10.4	.000
All	Upjohn	18	July 22 ±2.4	July 30 ±3.7	7.8	.36
Total Traps		48	July 9 ±0.8	July 19 ±1.9	9.4	.000

Paired-t statistic with one tailed test where H_0: Mean of Yellow Less Than Mean of Red Sphere.

fruit mimic, and catches females when they are gravid and ready to lay eggs. The 9.4 day mean difference between the two traps supports this behavior difference well.

Conclusions

First emergence of apple maggot flies was measured in two orchards by four different methods over a four year period. Great variability existed between the mean dates of emergence between the two sites. In the K.S.H. orchard a large population of flies existed, and the range of means of first emergence was June 21, 1977 to July 14, 1980, or 23 days. In the Upjohn orchard where a much reduced population was present, the range was from July 21 in 1980 to July 27 in 1979, or 6 days. The small range is because of the limited number of tests conducted in the Upjohn orchard and only over two years rather than four.

Between orchard variation indicated that the Upjohn orchard caught flies from 25 to 13 days later in 1979 on the yellow and red traps respectively, and 17 to 15 days later in 1980 than the K.S.H. orchard. These were significant differences, and again shows that the smaller the population, the later the mean date of emergence.

The four methods also varied in their estimates of timing of emergence. Seeded cages caught flies 8 to 23 days earlier in 1979 and 4 to 10 days earlier in 1980 than any of the other methods. This was significantly earlier, and if earliest emergence is required, this method should be used. Cages placed over naturally infested ground were intermediate in their catch of flies. A lower total population is monitored by this method, which delays mean first emergence by not having a higher number of very early individuals present. The yellow Zoecon AM traps were also intermediate in catching flies. They were no different than the natural cages, but were significantly later than the seeded cages and significantly earlier than the red spheres. If first fly activity in the tree is to be measured, this is the best method to use. The red spheres were significantly later in mean first catch than all the other methods. The 9.4 day mean difference between the yellow trap and red sphere matches very well with the duration of the pre-oviposition reported in the literature.

PARAMETERS AFFECTING FIRST EMERGENCE

The emergence of apple maggot has long been known to vary considerably and was shown to be true earlier in this dissertation. On a population level, there must be some important underlying basic factors that explain this lengthy emergence period. Figure 14 was prepared to conceptualize the parameters associated with adult emergence. Data on each component can be generated or obtained from the literature. Once quantified, they can be incorporated into a phenological model. Factors associated with emergence have been compartmentalized as either abiotic or biotic. The abiotic factors of air temperature, soil temperature, soil type, soil mositure and rainfall should explain the majority of the variance associated with emergence based on calendar days. The biotic factors of variety reared in, carry over pupae to second year, orchard floor culture, second generation within one year, and location of pupation in the soil, should provide minor refinements to the predictive model.

Experiments were initiated to identify and quantify these parameters. Both abiotic and biotic components were investigated. Abiotically, air temperature, soil temperature and soil moisture were the key components investigated Other presumably less important parameters noted were orchard floor culture and soil type. It was assumed the biotic components mentioned in the literature are much more important in the total range in emergence, so they were investigated and their component of the variation of emergence was quantified. The more important parameters measured included: variety the fly was reared in, effect on timing of emergence by pupae that carried over to the second year, orchard floor culture, influence of the proportion of the population that emerged early to complete a second generation in one year, and location of larval pupation in the soil.

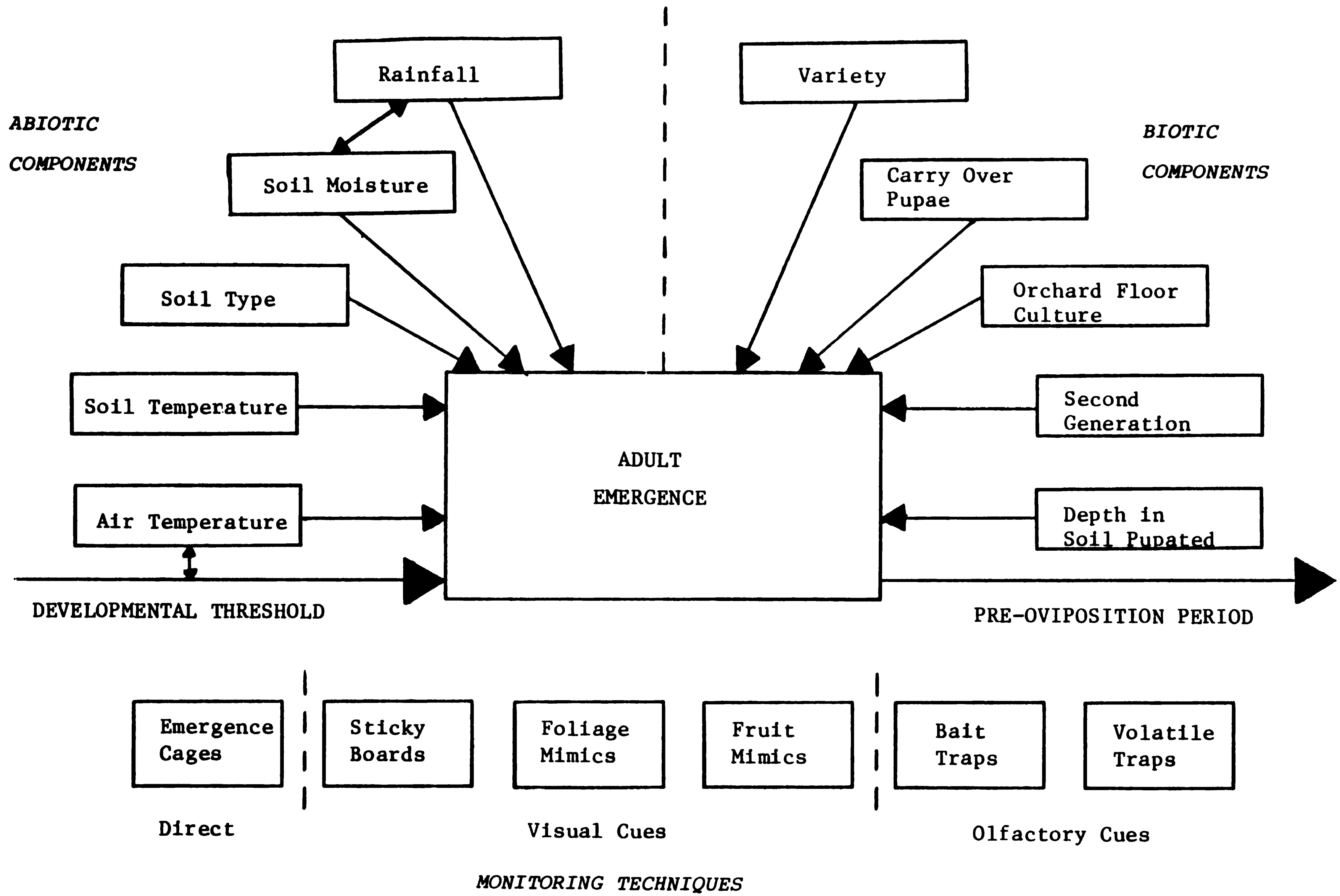


Figure 14. Factors Affecting Emergence of the Apple Maggot Fly and Monitoring Techniques to Measure Emergence.

ABIOTIC COMPONENTS

Air Temperature

Earlier in this dissertation, the emergence of apple maggot over several years and in several locations was presented. On a calendar basis, various points along the emergence curve vary by as much as 81 days (Table 2). The abiotic parameter of air temperature converted to physiological growth can explain some of this variation. This process involves the calculation of degree days. The principle involved states that above some threshold temperature, an organism develops physiologically. As the temperature becomes warmer, it grows more rapidly. Therefore, based on some lower developmental threshold, the apple maggot pupae develop and molt into adults. By knowing the temperature at which development starts, measurements of physiological growth can be estimated by accumulating thermal units. Predictions of future events then can be made by recording maximum and minimum temperatures and calculating thermal units each day, and accumulating them through time.

The common method of calculating degree days is,

$$\frac{\text{daily maximum + daily minimum}}{2} - \text{base temperature.}$$

This method was improved (Baskerville and Emin, 1963) to create a sine wave curve through the maximum and minimum points, and integrating the area under this curve above the threshold.

This refinement gives more precise estimates of the daily physiological growth that occurs.

The lower developmental threshold (LDT) of the apple maggot has been determined by three separate research groups. Reid and Laing (1976) determined the LDT as 8.7°C (47.7°F). Trottier (1975) said the LDT was 9.0°C (48.2°F). Reissig, Barnard, Weires, Glass and Dean (1979) used historical emergence data and air temperatures, and found 6.4°C (43.5°F) gave the best correlation to the first emergence. The differences in these values may be due to genetics of each population studied, errors in calculating thresholds, errors in measuring the temperatures, or the inherent accuracy of each method. The methods reported by Reid and Laing (1976) and Trottier (1975) are the most accurate, and their average value of 8.9°C (48°F) will be used throughout this discussion.

At higher temperatures, insects cease to develop. Physiologically they begin to carry out other body functions such as cooling, and do not continue to provide energy for growth. Reid and Laing (1976) have determined this upper developmental threshold (UDT) for apple maggot to be 31°C (88°F) and this will be used in this discussion.

Using the LDT and UDT values as limits of physiological growth, one can make estimates of insect growth. This is accomplished by placing thermographs in the field to measure the temperatures in the general habitat where the insect is located. From these readings the degree day totals can be calculated and accumulated to predict key events in the life cycle of the insect.

One should note that this technique will give an estimate of a certain event. This estimate may be close and within an acceptible confidence interval, but is seldom accurate. Variables that can influence and alter this prediction are both intrinsic and extrinsic to the organism. Within the population is great genetic variation that allows different individuals to respond to its environment differently. A population has spacial heterogenity, and is found in a variety of microhabitats within the environment. These microhabitats have different microclimates over the long run, and different daily variations. Temperature and humidity may be very different in these microhabitats, and this results in a differential growth rate per day. Lastly, the calibration and accuracy of the thermograph can easily vary just 0.5°C which results in estimates that are not accurate. When these variable factors are combined, the resultant prediction based on gross weather records can be significantly different than the real event.

Realizing the possible variables associated with the prediction of a biological event based on weather measurements is important. However, if they are ignored, predictions can still be made within certain realistic bounds that are more accurate than chronological predictions.

Materials and Methods

Air temperature measured at the five foot level in standard weather shelters is the most convenient and universally accepted method of measuring temperature. Predictions based on this method would be most widely applicable because there is a large network of weather stations that take this measurement every day. In order to obtain accurate local temperature measurements, three lead Weather Measure recording thermographs were placed in weather shelters in the K.S.H., Upjohn, Hofacker and Yabs orchards each year these orchards were used. The instruments were activated April 1, and turned off in September or October. Daily maximum and minimum temperatures were transcribed from the chart and entered into the computer where they were converted to degree days (48°F base) using the B.E. technique. Appendix 3 shows the accumulated degree day totals for each of these locations for the years they were utilized.

Results and Discussion

Air temperature degree day accumulations for different proportions of apple maggot fly emergence are found in Table 7. This table includes values over a four year period and at four locations which results in a very large range in degree day accumulations at each stage of emergence. The 1979 air dd values for the abandoned trees were taken from the Peach Ridge Agricultural Weather Station which was centralized for the abandoned traps. In 1980 the M.S.U. Hort. Farm Station weather was used as it was a centralized location for the abandoned traps in 1980. Mean values calculated from these various locations would be of limited predictive value, because they represent very different population levels of flies, populations pressured with pesticides, and different methods of estimating emergence.

To measure the influence of years on the different methods of measuring first emergence, Table 8 was prepared. The values presented are mean degree day values for first emergence. The data was analyzed by a one way analysis of variance, and transformed by the square root or log transformation if needed to meet the assumptions. Student Newman Kuell's mean separation test was then performed at the .05 level. Coefficient of variation values were calculated to determine how variable the data was.

The mean date of emergence in seeded cages was significantly earlier in 1979 than 1980 at the K.S.H. orchard. On a calendar basis this difference was 9 days. The air degree day difference was 181, which corresponds to 8 calendar days at an average accumulation of 25 units per day. Therefore, air degree days was not very useful to explain this variation between the two years. The coefficient of variation however was reduced from 53 to 12 which indicates that the overall variability within the data was greatly reduced, and that the mean value of 943 air dd should be a very reliable predictor of mean first emergence.

The mean date of emergence in natural cages was not significantly different in 1978 and 1979 at the K.S.H. orchard. This was also true in Table 4 which showed the

TABLE 7. Five Foot Level Air Temperature Degree Day (Base = 48°F; B.E. Method) Accumulations for Different Proportion of Emergence and Trap Catch of Apple Maggot Flies at Various Locations in Michigan from 1977 to 1980.

Year	Location	Method	Number of Sample Units	First Catch	1%	5%	10%	25%	Peak
1977	K.S.H.	Yellow Trap	50	1135	1135	1170	1265	1533	2466
	Upjohn	Yellow Trap	15	1108	1397	1627	1864	2112	2433
	K.S.H.	Natural Cages	20	1533	1533	1533	1533	1533	1729
1978	K.S.H.	Yellow Trap	50	981	1108	1220	1240	1317	1317
	K.S.H.	Natural Cages	20	981	981	1008	1033	1074	1150
1979	K.S.H.	Yellow Trap	15	929	1034	1122	1254	1534	1843
	Upjohn	Yellow Trap	9	1102	1102	1512	1621	1748	2014
	Abandoned	Yellow Trap	13	1185	1503	1597	1685	1871	2125
	K.S.H.	Red Sphere	15	1047	1148	1304	1402	1711	1843
	Upjohn	Red Sphere	9	1168	1168	1600	1643	1738	2291
	Abandoned	Red Sphere	13	1307	1550	1733	1776	1917	2125
	K.S.H.	Natural Cages	16	929	929	940	980	1034	1074
	Upjohn	Natural Cages	3	1050	1050	1050	1050	1050	1209
	K.S.H.	Seeded Cages	8	774	814	892	929	1034	1074
1980	K.S.H.	Yellow Trap	15	1016	1096	1216	1241	1467	2101
	Upjohn	Yellow Trap	9	999	1455	1475	1499	1556	1521
	Abandoned	Yellow Trap	11	1124	1196	1429	1490	1660	1730
	Hofacker	Yellow Trap	1	822	822	868	895	947	895
	K.S.H.	Red Sphere	15	1016	1159	1241	1346	1521	2101
	Upjohn	Red Sphere	9	1252	1252	1455	1499	1595	2191
	Abandoned	Red Sphere	11	1531	1531	1550	1590	1660	1852
	Hofacker	Red Sphere	1	868	868	1190	1190	1237	1210
	K.S.H.	Seeded Cages	7	1016	1016	1036	1076	1119	1187
Range in Degree Days		All	332	774-1533	814-1550	868-1733	895-1901	947-2112	895-2466

TABLE 7. (Con't.)

Year	Location	Method	Number of Sample Units	50%	75%	95%	Last Catch
1977	K.S.H.	Yellow Trap	50	2117	2588	3177	3280
	Upjohn	Yellow Trap	15	2334	2536	2767	3143
	K.S.H.	Natural Cages	20	1702	1887	2622	2847
1978	K.S.H.	Yellow Trap	50	1560	1754	2048	2837
	K.S.H.	Natural Cages	20	1150	1263	1636	1898
1979	K.S.H.	Yellow Trap	15	1798	2020	2272	2679
	Upjohn	Yellow Trap	9	1986	1095	2229	2291
	Abandoned	Yellow Trap	13	1948	2077	2267	2492
	K.S.H.	Red Sphere	15	1820	2007	2181	2679
	Upjohn	Red Sphere	9	1986	2201	2274	2291
	Abandoned	Red Sphere	13	2045	2146	2245	2492
	K.S.H.	Natural Cages	16	1101	1254	1606	2298
	Upjohn	Natural Cages	3	1209	1621	1621	1621
	K.S.H.	Seeded Cages	8	1198	1402	1843	2617
1980	K.S.H.	Yellow Trap	15	1881	2101	2369	2902
	Upjohn	Yellow Trap	9	1813	1970	2220	2595
	Abandoned	Yellow trap	11	1811	1938	2065	2328
	Hofacker	Yellow Trap	1	1408	1363	1600	1877
	Upjohn	Red Sphere	9	1887	2123	2380	2595
	Abandoned	Red Sphere	11	1811	1884	2065	2410
	Hofacker	Red Sphere	1	1289	1408	1579	1829
	K.S.H.	Seeded Cages	7	1187	1321	1586	2394
Range in Degree Days		All	332	1101-2334	1254-2588	1579-3177	1621-3280

flies emergence on July 1 both years. Therefore, air degree days did not improve the estimate of mean date of first emergence from natural cages over that provided by calendar date. However, the coefficient of variation was reduced from 30 to 9, which indicates that the air degree day measurements greatly reduced the variation in the data, and the mean of 1050 should be a much better predictor of emergence than the July 1 calendar day estimate.

Emergence as determined by yellow traps provides the best indicator of a possible relationship between the mean air degree day accumulation and mean calendar day of emergence because it was used in all locations in all years. Table 4 showed a 13 day range in mean date of first catch in the K.S.H. orchard from 1977 to 1980, and a 3 day range in the Upjohn orchard from 1979 to 1980. The respective air degree day range (Table 8) is 175 in the K.S.H. orchard and 89 in the Upjohn orchard. These values correspond to 7 and 3 calendar days respectively, so the variation is considerably reduced in the K.S.H. orchard, and the same in the Upjohn orchard. The reduced variation within the K.S.H. orchard is also supported by the C.V. values which were reduced from 48 to 9. The mean air degree day accumulation of 1117 associated with a C.V. of 9 should provide a very good estimator of mean first yellow trap catch in the K.S.H. orchard. In the Upjohn orchard there was a three day mean difference in catch by both the calendar and air degree day estimates. However, the estimate based on the air degree

TABLE 8. Influence of Years on Different Methods of Measuring First Emergence of Apple Maggot Flies at the K.S.H. and Upjohn Orchards. (Mean ± S.E. Air Degree Day Accumulation at Five Foot Level at Base 48°F, B.E. Method, Plus Coefficient of Variation Values).

Location	Year	Seeded Cages	Natural Cages	Yellow Traps	Red Spheres
K.S.H.	1977			1169c	
				±11.4	
K.S.H.	1978		1062a	1099b	
			±21.3	±14.4	
K.S.H.	1979	852a	1037a	994a	1296a
		±35.4	±30.6	±14.7	±62.6
K.S.H.	1980	1033b		1132bc	1277a
		±7.0		±17.7	±45.7
Upjohn	1979			1330d	1392a
				±93.5	±131.9
Upjohn	1980			1419d	1523a
				±58.1	±38.1
K.S.H.	Mean	942.8	1050	1117	1286
		±29.2	±18.1	±8.9	±38.1
	C.V.	12	9	9	16
Upjohn	Mean			1374	1466
				±54.5	±76.9
	C.V.			17	21
Both	Mean			1163	1349
				±12.2	±38.2
	C.V.			13	19

Means in each column followed by the same letter are not significantly different at the .05 level by the SNK test.

day has an associated C.V. of 17, which is better than that of 27 associated with the calendar day estimates. Therefore, the air degree day mean of 1374 is a better predictor than July 22 in the Upjohn orchard.

The twenty-four day average difference between the orchards from Table 4 corresponds to a 257 average air degree day difference, or approximately 11 calendar days. The air degree days therefore reduced the range of values from calendar days between the orchards. The associated C.V. of calendar days between all the data within each orchard was reduced from 62 to only 13 by using air degree days. Again air degree days greatly reduced the variation within all the data.

The red sphere estimate of emergence was not statistically different for any year or location, even though a large range of values occured. The four calendar day difference in the K.S.H. orchard between 1979 and 1980 was only a 21 air degree day difference which converts to one calendar day. This reduction is also seen in the C.V. that was reduced from 31 to 16 indicating that the mean value of 1286 should be a good estimator of mean trap catch in the K.S.H. orchard. However, in the Upjohn orchard the two day difference found in Table 4 was increased to 131 degree days which i. 5 calendar days. This apparent increase in variability of the data is not as large as it appears, as the C.V. is reduced from 35 to 16. Therefore, the air temperature degree day mean of 1466 should be a more reliable estimator of trap catch than the mean calendar date of July 26 in the Upjohn orchard. The difference between the orchards was 13 and 15 days in 1979 and 1980. On a degree day basis, this difference was 96 and 246 units which convert to 4 and 10 days. Therefore, degree days did reduce this between orchard variation substantially. Also, the C.V. was reduced in a similar manner from 40 to 19 when the data from both years in an orchard was compared to both years data in the other orchard. In summary, air degree days is better for determining mean emergence of apple maggot flies on red spheres in both orchards, and greatly reduced the variation between orchards.

Table 9 was prepared to determine if the variation between methods of estimating first emergence could be reduced by using air degree days. In 1977, the C.V. associated with the calendar day estimate was 45. This was greatly reduced to 7 using air degree days. Therefore, the air degree day mean of 1169 provides a better estimator than calendar days for first catch.

The calendar day differences of two days between natural cages and yellow traps was present in the K.S.H. orchard in 1978. This was not a significant difference, nor was the respective air degree mean value difference of 37 which corresponds to two calendar days at average daily accumulations. However, the C.V. was reduced from 23 to 9 when air degree days were used. Therefore, the air degree day method used to estimate first emergence is a better

TABLE 9. Influence of Method of Estimating First Emergence of Apple Maggot Flies at the K.S.H. and Upjohn Orchards Over a Four Year Period (Mean ±S.E. Air Degree Day Accumulation at Five Foot Level at Base 48°F; B.E. Method Plus Coefficient of Variation Within the Year).

Location	Method	1977	1978	1979	1980
K.S.H.	Seeded Cage			852a ±35.4	1033a ±7.0
K.S.H.	Natural Cage		1062a ±21.3	1037b ±30.6	
K.S.H.	Yellow Trap	1169a ±11.4	1099a ±14.4	994b ±14.7	1132a ±17.7
K.S.H.	Red Spheres			1296c ±62.8	1277b ±45.7
Upjohn	Yellow Traps			1330c ±93.5	1419c ±58.1
Upjohn	Red Spheres			1392c ±131.9	1523c ±120.4
Both	All - C.V.	7	9	23	18

Means in each column followed by the same letter are not significantly different at the .05 level by the SNK test.

method than calendar days because of the total reduced variation.

In 1979, the same trends were evident with estimates made by calendar days and air degree day accumulations. The seeded cage mean emergence was 8 days earlier than the yellow trap in the K.S.H. orchard. The degree day difference was 142, which corresponds to 6 calendar days. The yellow trap mean first catch was two days earlier than the natural cages (Table 4). The air degree day difference of 43 which corresponds to 2 days was the same (Table 9). The red sphere was the last tool to catch apple maggot flies in K.S.H. orchard in 1979. The mean date was 13 days later than the natural cage on a calendar basis, and 259 degree days later by air degree days which corresponds to 11 days. Therefore, air temperature degree day values reduced the variability again. In the Upjohn orchard, the red trap caught flies 3 days later than the yellow trap, but this was not a significant difference. The corresponding degree day difference was 62 or 3 calendar days, and was not significantly different. When all the data for 1979 was taken as a whole, the C.V. was 63 for the calendar date data. This is a very large variance, and no estimates based on the overall data should be made. If first emergence is based on air degree days, the C.V. is reduced to 23. Therefore, air degree days greatly reduces the variation within the 1979 data set.

The 1980 year provided the same trends as the other years. The seeded cage had the first mean emergence in the K.S.H. orchard, followed by the yellow trap four days later which was a significant difference. On a degree day basis, this difference was 99, which corresponds to four days, but it was not significantly different by the SNK test. The red sphere mean catch was 6 days after the yellow traps, and 145 degree days later. This corresponds to six calendar days, and was significantly different for both the calendar days and degree days, so the degree day estimate was not any better than the calendar day difference. In the Upjohn orchard, the red sphere mean date of first catch was four days after the yellow trap. The air degree day difference was 104, which is five calendar days. Neither method was significantly different from each other, therefore the degree day estimate was not any better than the calendar day estimate. However, by examining the C.V., the calendar day value is 41 and the air degree day value is only 18. Even though degree days did not alter the significant differences any, they greatly reduced the variability of the data.

Conclusions

The analysis of the air temperatures converted to air degree days showed that, in general, air degree days was a better estimator and had less variability in the data than existed between calendar day estimates. With the seeded cages, air degree days removed 1 calendar day of the 9 day variation present between the two years. When natural emergence cages were used, the air degree days difference was the same as the calendar day difference, but they did reduce the variation in this method of measuring first emergence. Yellow traps were used to estimate first emergence for all years in both orchards. Air degree days did reduce the variance greatly within the orchard and between orchards. In the K.S.H. orchard, the 13 day variation is reduced to 7 days and in the Upjohn orchard the 26 day variation in calendar days was reduced to 5 days. The 17 day average difference between the orchards was reduced to 10 days. Also, the C.V. showed that the data was much less variable. The red sphere mean first trap catch of 4 days was reduced to 1 day in the K.S.H. orchard, but increased from 2 to 5 days when air degree day values were converted to their corresponding calendar day equivalents. Air degree days also reduced by 9 and 5 days the difference between orchards. Therefore, degree days greatly reduced the variability within the data and provides a better base for predictive purposes.

When different methods of estimating emergence were compared within each year, degree day accumulations did reduce the variation present in calendar day differences. In 1977, air degree day values reduced the variation in values associated with each method. In 1978, the two calendar day difference was not improved by air degree accumulations, but did reduce the variability of the data.

In 1979, the range in values was reduced by two days when air degree day values were used. The 8 day difference between seeded cages and yellow traps was reduced to 6 days, and the 13 day difference between yellow traps and red spheres was reduced to 11 days. The total variability in the 1979 data was also reduced by using degree days. In 1980, the air degree day accumulations did not alter the significant differences, but greatly reduced the variation in estimates over those based on calendar days.

SOIL TEMPERATURE

As was shown in the last section, the mean day of first emergence based on air degree days was quite variable even though it improved the estimate of emergence over calendar day estimates. One modification that might reduce this variability further and increase the precision of estimating first emergence would be to measure soil temperatures. This approach is reasonable because the pupae are in the soil and develop at a rate relative to the ambient temperature around them. Maximum and minimum temperatures converted to degree days by the B.E. method would provide a method to measure the amount of physiological development that occurs, and might provide an estimate of emergence with less variability.

Literature

Researchers have used soil parameters to make predictions on events of life stages for other insects, but this has not been extensively done for apple mattot. Maxwell and Parsons (1969) said that "the times of first and mean peak emergence of apple maggot may be closely determined for any one site by summing soil temperatures at pupae depth following a preliminary season's record of soil temperature summations and emergence data. Dean and Chapman (1973) noted that first emergence was very variable and difficult to predict using air temperatures. They felt these predictions could be improved if soil factors were studied and correlated to emergence, because that is where the apple maggot is developing. This has been done with *Rhagoletis cerasi* (Leski, 1963) with great accuracy.

Materials and Methods

Weather measure three-lead recording thermographs were placed in the K.S.H. and Upjohn orchard from 1977 to 1980. One of the leads was placed in the soil at a depth of two inches on the south side of the tree under its canopy. Maximum and minimum temperatures were transcribed from the charts, and entered into the computer where degree day values were calculated at base 48°F (8.9°C) by the B.E. technique. These values were accumulated throughout the season (Appendix 3).

The sampling schemes for monitoring first emergence of apple maggot fly were the same as described earlier. The degree day accumulations on the day of first emergence was recorded for each method at each site. This data was analyzed by the one-way analysis of variance to test for mean differences between methods or years. If the variances were not homogeneous by the Bartletts test, data was transformed by the square root or log transformation and rechecked for homogenity. If significant F statistics were present, Student Newman Kuell's mean separation test was performed.

Results and Discussion

Examination of the soil degree day data reveals some trends, and also some exceptions to them. Table 10 was prepared to illustrate these points. It presents for each month the accumulation of the soil degree days and the

TABLE 10. Relationship of Two Inch Soil Degree Days on the South Side of the Tree to Air Degree Days at the K.S.H. and Upjohn Orchards in 1977-1980. (Base = 48°F; Method = B.E.)

Month	1977 %[1]	1977 dd	1978 %	1978 dd	1979 %	1979 dd	1980 %	1980 dd	Mean % of Air dd
KALAMAZOO STATE HOSPITAL ORCHARD									
April	24	75	29	24	74	102	35	41	40.5
May	49	264	56	220	95	284	53	218	63.2
June	77	380	74	411	83	478	82	418	79.0
July	84	703	100	626	97	656	96	738	94.2
August	102	626	110	690	117	687	105	801	108.5
September	119	512	133	677	125	549	133	638	127.5
Yearly	455	2560	502	2648	591	2656	504	2854	512.9
UPJOHN ORCHARD									
April	14	36	11	9	37	29	12	10	18.5
May	58	345	62	237	65	181	63	188	62.0
June	76	370	79	444	83	429	78	399	79.0
July	79	675	97	624	90	558	79	594	86.2
August	85	495	92	632	102	567	95	669	93.5
September	99	391	96	517	99	410	104	490	99.5
Yearly	411	2312	437	2463	476	2174	431	2350	438.7

[1] % = Percent that soil dd is of accumulated air dd

percent that value is of the air degree days accumulated that month.

In the K.S.H. orchard, each month throughout the season the soil degree days accumulates a higher percentage of the air degree day than the previous month indicating that the soil gradually warms up but at a much slower rate than the air temperatures. Also, each month accumulates about the same percentage during the four year period, except for 1979. In that year, for reasons of instrument calibration, greater percent sunshine, closer mowed grass, better pruned canopy, or some other reason, the months of April and May accumulated a much higher percent than the other three years. This early accumulation caused that year to have the highest percent of the air degree days of the four year test. As will be seen later, it also increased the variability of the estimates of first emergence or trap catch and reduced the reliability of soil degree days for estimators.

The data taken from the Upjohn orchard is more consistent and less variable than that from the K.S.H. orchard. Again, the mean percent accumulation of the air degree day value increases each month throughout the season. However, this appears to be a slightly cooler site because in each year the total percent accumulation is less than it was at the K.S.H. orchard. This may be due to calibration, depth in soil of the sensor which is supposed to be two inches, greater shading due to more canopy and taller grass, soil type, or other differences.

Some trends are also present when data from both orchards are lumped together. Early and late months are variable in their percent accumulation of soil degree days from air degree days. However, mid season months of May, June, July and August are very consistent in their accumulation within each orchard and between the orchards. A least squares linear regression was run on this data, and the following equations resulted (SPOCS, 1977). If soil degree days is to be predicted from air degree days, the Equation 1 could be used at the K.S.H. orchard based on the four years of data.

Eq.1 $y = .664\ x - 35.97$

This equation predicts the soil degree days from air degree days with an $R^2 = .893$. To predict soil dd at the Upjohn orchard, Equation 2 provides an $R^2 = .973$

Eq.2 $y = .807\ x - 88.47$

When both orchards were combined so eight sets of data were used, Equation 3 gave an $R^2 = .964$

Eq.3 $y = .839\ x - 98.9$.

The estimation of emergence based on soil degree day accumulations is the same as estimations based on air degree days (Table 11). When seeded cages were used, the range in dates between years was reduced from 9 calendar days to an equivalent of 8 days, using air degree days to an equivalent of 2 days using soil degree days. This greatly reduced variation between years of 45 degree days indicates the grand mean value is a better estimator of first emergence than the calendar days or accumulated air degree day values.

TABLE 11. Influence of Years on Different Methods of Measuring First Emergence of Apple Maggot Flies at the K.S.H. and Upjohn Orchards (Mean ±S.E. Soil Degree Day Accumulations at the Two Inch Level on the South Side of the Tree at Base=48°F; B.E. Method).

Location	Year	Seeded Cages	Natural Cages	Yellow Traps	Red Spheres
K.S.H.	1977			580a	
				±8.2	
K.S.H.	1978		670a	701b	
			±19.9	±13.4	
K.S.H.	1979	712a	885b	846d	1131b
		±32.7	±28.7	±15.1	±58.4
K.S.H.	1980	667a		765c	893a
		±9.7		±17.1	±40.6
Upjohn	1979			1065e	1132b
				±82.6	±124.2
Upjohn	1980			1010c	1102b
				±43.6	±82.9
K.S.H.	Mean	689.5	771	679	1012
		±17.4	±26.1	±10.2	±41.3
	C.V.	10	19	17	22
Upjohn	Mean			1037	1115
				±45.8	±69.1
	C.V.			19	25
Both	Mean			722	1048
				±13.2	±36.4
	C.V.			23	24

Means in each column followed by the same letter are not significantly different at the .05 level by the SNK test.

Also, the C.V. is reduced from 12 to 10 indicating that soil degree days reduced the variability of the data as was expected.

Examining the data from the natural cage mean emergence reveals some problems. The data in Table 11 says that 1978 was a significantly earlier year for emergence than was 1979. On a calendar basis, the mean emergence was on the same day in 1978 and 1979. Using air degree days as the estimator, the difference between the two years was 25 units which corresponds to one day, which provides a good estimator. However, the soil degree day difference of 215 units which corresponds to 9 calendar days. Also, the C.V. was increased from 9 to 19 units using air and soil degree days. This further supports the belief that one of these years, most likely 1979, was very different. The accumulations for 1979 would have to be reduced by 200 to provide a better estimator of emergence based on soil degree days.

A discussion of the yellow trap data reveals some highly variable results also. In the K.S.H. orchard, the soil degree day mean first catch is more variable than that based on air degree days as based on the C.V. value that was increased from 9 to 17. On a calendar basis, there is a 13 day range in dates of mean catch. Air degree day accumulations reduced this to just 7 days. The soil degree day difference of 266 units corresponds to 11 days. If the K.S.H. 1979 accumulation was reduced by 200 as suggested, then the range would be reduced to 7 days and be just as good an estimator as air degree days, but no better. In the Upjohn orchard the estimate based on soil degree days increased the variability in the estimates slightly. The calendar day differences were 3 days. This was the same using air degree days. The soil degree day range was 55 units which corresponds to 3 calendar days. Using this data, all three methods provide the same relative range in mean first catch. If the C.V. is examined, it is 27 for the calendar days, reduced to 17 using air degree days, and increased slightly to 19 using soil degree days. Based on this the soil degree day estimate is not better than that based on air degree days.

The between orchard comparison reveals that soil degree days increase the variability within the data, but reduces the average daily difference. On a calendar basis, the difference in mean date of emergence was 25 days in 1979 and 17 days in 1980. Using the same years, the air degree day difference converted to days reduced this to just 14 and 11 days. The soil degree day difference was 219 and 245 units or 9 and 10 days respectively. This reduced the difference even further. However, when the C.V. is examined, air degree days reduced it from 62 to 13, and the soil degree days increased it to 23. Therefore, the air degree day values should be used as predictors because of the less inherent variability of the data.

Trap catch on red spheres was quite consistent within orchards between 1979 and 1980. In the K.S.H. orchard, the calendar day difference of mean catch was 4 days. Air degree days reduced this to just 1 day difference. Neither of these values were statistically different. However, because of the greater accumulation of soil degree days in 1979, that year was significantly later than 1980 in mean emergence when using soil degree days as estimators. The 238 units corresponds to 10 calendar days, a much larger value than is present when using calendar day or a degree day estimator. The C.V. of 40 with calendar days is reduced to 19 using air degree days, but is increased to 24 using soil degree days. With the warmer 1979 season data used, the soil degree day estimate becomes a poorer estimator than air degree days for predicting mean trap catch on the red sphere in the K.S.H. orchard.

In the Upjohn orchard, the soil degree day estimate of mean first catch on the red sphere is a better estimator than air degree day values. The calendar day difference of mean dates of first catch varied 2 days between 1979 and 1980. Air degree day differences of 131 increased this to 5 days. The soil degree day difference was 30 units, or slightly more than one day which indicates it is an estimator. The associated C.V. are 35, 21 and 25. Even though that associated with the soil degree days is slightly larger than that of air degree days, it is good enough to serve as a good predictor. The grand mean value of 1115 soil degree days provides an accurate estimate of mean catch of apple maggot flies on red spheres in the Upjohn orchard.

The between orchard variation is improved by using soil degree days. The calendar day difference between the orchards was 13 days in 1979 and 15 days in 1980, with K.S.H. always being earlier. The air degree day differences converted to days was 4 and 10. The soil degree day differences between orchards was 1 in 1979 and 209 which corresponds to 1 and 9 days. This appears to reduce the variability between orchards. However, within the data sets the C.V. is 40 for calendar days, 19 for air degree days, and 24 for soil degree days. Therefore, even though the soil degree day converted to calendar day differences were the smallest, the air degree day data was less variable and their means should be used as predictors.

Table 12 was prepared to determine whether soil degree days could reduce the total variability of the data within a calendar year. Presented are mean ±S.E. values for mean emergence or trap catch. The C.V. was calculated to determine the amount of variability in the data. In 1977, the C.V. was 10. This was much smaller than 45 provided by calendar days, but an increase over that provided by air degree days of 7. In 1978, the same trend existed with the C.V. reduced from 23 to 9 from calendar days to air degree days, and then increased to 13 by soil degree days. In 1979, the same trend was present with the C.V. going from 63 to 23 to 24. Lastly, in 1980 the trend remained the same with the values going from 41 to 18 to 23. Therefore, in no case did the soil degree days reduce the variability of the data less than was provided by air degree days.

TABLE 12. Influence of Method of Estimating First Emergence of Apple Maggot Flies at the K.S.H. and Upjohn Orchards Over a Four Year Period (Mean ±S.E. Soil Degree Day Accumulations at the Two Inch Level on the South Side of the Tree at Base=48°F; B.E. Method).

Location	Method	1977	1978	1979	1980
K.S.H.	Seeded Cage			712 ±32.7a	667 ±9.7a
K.S.H.	Natural Cage		670 ±19.9a	885 ±28.7b	
K.S.H.	Yellow Trap	580 ±8.2a	701 113.4a	846 ±15.1b	756 ±17.0b
K.S.H.	Red Sphere			1131 ±58.4c	893 ±40.6c
Upjohn	Yellow Trap			1065 ±82.6c	1010 ±43.6d
Upjohn	Red Sphere			1132 ±124.2c	1102 ±82.9d
Both	All - C.V.	10	13	24	23

Means in each column followed by the same letter are not significantly different at the .05 level by the SNK test.

Conclusions

Soil degree days did not alter any of the significant differences provided by calendar days or air degree day estimates of mean emergence of apple maggot flies. When C.V. values were calculated, they were smaller than with calendar days, but larger than those calculated from air degree days. The data is more variable between the methods of determing emergence and between the years than that of air degree days, indicating that soil degree days should not be preferred over air degree days for predicting apple maggot emergence. If soil degree day values are desired, they can be calculated by a linear regression equation presented from the accumulated air degree days with an $R^2 = .96$.

SOIL MOISTURE

Many authors have reported that soil moisture has an effect on emergence of apple maggot. Many observe that after a rainstorm there is a flush in emergence (O'Kane, 1914; Mundinger, 1927; Garman and Townsend, 1952; and Oatman, 1964b). Others say that rain has very limited effect on emergence (Porter, 1928 and Glass, 1961). Others report that in dry seasons there seems to be a smaller number of individuals present, emergence is delayed or there is a larger percent of carry over flies to the next year (O'Kane, 1914; Mundinger, 1927; Mundinger, 1930; Phipps and Dirks, 1933b; Oatman, 1964b; and Neilson, 1964; Rivard, 1968).

Data on these observations is quite scarce however with the apple maggot. Hall (1937) had one fly emerge 8 days sooner in ground that had ample water then from ground that was kept dry. The best data found (Dean and Chapman, 1973) showed no clear-cut evidence of such reaction to rainfall. They showed that even though there was a range of available soil moisture from July 5 to August 6 of 11.1 to 62.6%, the fly emergence curve was normal, with no indication of decreased emergence during the dry period or increase when it was alleviated. Glass (1961) did not note a heavy emergence following a rain, presumably because of the liberal amount of humus on the soil which kept it from baking hard and deterring the flies from working their way up to the surface.

In laboratory experiments, high humidity is a requirement for successful rearing of adults from pupae (Neilson, 1962; Boulanger, Stanton and Padula, 1969). Neilson (1964) showed in a laboratory study that percent emergence of apple maggot adults from pupae held at 20, 40, 60, 80 and 100 percent relative humidity was 0, 0, 4, 81 and 70, respectively, presumably the lack of moisture causing mortality during the pupa transformation. Trottier and Neilson (1979) presented a table from laboratory studies that showed a significant relationship between first emergence and relative humidity with lower available moisture delaying emergence.

Biologically, emergence from the soil may be related to soil firmness which is related to soil moisture. Lathrop and Nichels (1932) found that Rhagoletis pomonella (Walsh) adults, depending on soil type and moisture, required 14 to 70 minutes to reach the surface after bursting the puparium. Harris and Ring (1980) reported that clay soil when moisture was low, delayed the emergence of pecan weevil adults from the puparium, presumably due to the passive barrier the dry hard soil formed under such conditions.

Season long emergence can be correlated to rainfall. Jubb and Cox (1974) reported with cherry fruit fly, rain in excess of 1.3 cm. delays 10% emergence from first emergence from 6-11 days. While little or no rain fell, 10% emergence occurs within 5 days. Their partial correlation coefficient (r) of precipitation with emergence date was 0.486. Lathrop and Dirks (1945), Oatman (1964b), and Garman and Townsend (1952) had higher correlations with rainfall during early season emergences than during late season emergence with apple maggot.

The objective of the studies below are to measure soil moisture both in the field and in the laboratory, and correlate it with emergence. Hopefully, soil moisture will explain some of the variations associated with first and season-long emergence.

Materials and Methods

Field Studies - In 1979 and 1980, soil was sampled at the K.S.H. and Upjohn orchards. A sample consisted of sufficient 5/16 inch diameter cores to fill a 2 dram screw cap vial. One to one and a half inch deep cores were taken because the majority of the pupae are located in the upper 1 inch of soil. This has been reported in the literature, and was confirmed by a study I completed in the fall of 1976. In that study 42 cores 4 inches in diameter were extracted at random points under a heavily infested transparent tree in the K.S.H. orchard in mid-October. Each core was cut into one inch slices. The top 1" had 72% of the pupae, the second had 11%, the third had 6%, the fourth at 6%, the fifth had 6%, and the last had none. the soil samples in this study were taken from the north, middle and south sides under the canopy of the tree. This was done to measure the difference in soil moisture due to the sun's exposure and rain penetration, and to find a mean value per date. Samples were taken from under the same tree each time, which also had the soil thermographs in position under them. Sampling was initiated in July 2 in 1979, and June 16 in 1980. Samples were taken at each visit to the orchard. Vials of wet soil were transported to Michigan State University where they were weighed. They were then placed in a drying oven at 30°C for 7 days minimum. This time interval was determined with the first set of samples (Table 13). They were then reweighed, the dry soil dumped out and the vials brushed out and weighed. The percent soil moisture was calculated by subtracting dry weight from wet weight, dividing the results by the weight of the dry soil, and multiplying by 100 (after Harris and Ring, 1980). This determined the amount of water available to the insect.

In 1980, two new sites were selected to serve as a validation of the results obtained from the K.S.H. and Upjohn orchards. Site one was a early red variety located in the Hofacker yard near the Fruit Ridge Aveneue and Four Mile Road intersection north of Grand Rapids. A thermograph was in position under this tree and samples were taken as in Kalamazoo in 1980 and processed in the same manner. Site two was a transparent variety tree in the Yabs backyard in DeWitt, Michigan. Soil samples were taken three times a

TABLE 13. Length of Time Necessary to Completely Dry Soil Samples Contained in a 2 Dram Vial in a Drying Oven Held at 30°C. (Weight Loss from Previous Day in Grams at n=north, m=middle, or s=south side of the Tree).

	K.S.H.			Upjohn			Hofacker			
Day	N	M	S	N	M	S	N	M	S	Mean
1	0.82	0.80	0.81	1.06	0.85	1.03	1.05	0.92	1.15	.954a
2	0.75	0.73	0.73	1.00	1.13	1.03	1.04	0.87	0.89	.908a
3	0.56	0.55	0.54	0.70	0.76	0.71	0.71	0.57	0.62	.636ab
4	0.19	0.30	0.22	0.66	0.67	0.65	0.71	0.56	0.34	.478ab
5	0.00	0.00	0.00	0.23	0.23	0.22	0.39	0.27	0.02	.151c
6	0.00	0.00	0.00	0.03	0.03	0.02	0.36	0.02	0.00	.051c
7	0.00	0.00	0.00	0.02	0.02	0.00	0.09	0.01	0.00	.016d
8	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	.002d

Means followed by the same letter are not significantly different at the .05 level by the Duncan's Multiple Range Test.

week for three weeks, but due to the limited number of flies present, a decent emergence curve could not be prepared nor a meaningful correlation determined, so sampling was terminated.

Laboratory Study - An experiment was completed in growth chambers that measured the influence of relative humidity on emergence from pupae. The chambers were held at constant 29°C (85°F) temperature and 16:8 LD photoperiod regime. Enclosed containers had potassium hydroxide in different concentrations so relative humidities could be held at 10, 15, 20, 25, and 30% (Soloman, 1951). They were monitored with a Weather Measure HM III Relative Humidity Indicator and adjusted if necessary, so ±2% relative humidity was maintained.

Six bushels of infested Jonathan and Northern Spy apples were collected in the fall and placed on hardware cloth over sand. Larvae fell into the sand and pupated. Boulanger, Stanton and Padula (1969) reported that a high moisture level is vital during the time the larvae are leaving the fruit to pupae. This condition was not controlled well, and may be the reason why only 100 healthy appearing pupae remained from over 800 initially collected. Pupae were sifted from the sand one month later and placed in moist sand in a refrigerator at 1°C (34°F) for four months to break diapause (Neilson, 1965). They were then sorted and the apparently healthy ones used in this study. Ten pupae of each variety were placed in 2 oz. plastic rearing cups inside each of the controlled humidity chambers. The chambers were monitored for emergence twice each day after 30 days. Emergence was expected about day 25, or 925 degree days at base 9°C (48°F).

After 76 days, each container received 60 ml of water to raise the relative humidity. This was performed to determine if the pupae were still viable and flies could still emerge. Chambers were monitored daily for another 60 days when it was terminated.

Results and Discussion

Field Studies - Table 14 presents the 1979 data from the K.S.H. and Upjohn orchards. Rainfall data shown is the average from the nearest weather stations. For the K.S.H. orchard the nearest stations are the K.S.H. climate station two miles to the southeast, and the Paw Paw Agricultural Weather station twelve miles directly west of the orchard. For the Upjohn orchard the nearest stations are the Kalamazoo Airport which is six miles south west and the Gull Lake Biological Station which is ten miles east-north-east of the orchard. The percent soil moisture values are presented for the north, middle, and south sides of the tree. Mean values per tree are presented which will later be correlated to emergence and trap catch.

Table 15 presents the same type of data for the 1980 season. Rainfall values for the K.S.H. and Upjohn orchards were determined as in 1979. Those shown for the Hofacker

TABLE 14. Percent Soil Moisture In 1979 at Research Orchards Located in Kalamazoo, Michigan.

	Kalamazoo State Hospital Orchard					Upjohn Orchard				
Date	Rainfall	North	Middle	South	Mean	Rainfall	North	Middle	South	Mean
July 2	.02	36.1	35.0	37.0	36.03	.30	26.3	21.3	28.6	25.40
4	.72	38.8	31.3	38.1	36.07	1.35	30.6	27.6	31.4	29.87
6		35.0	31.9	32.6	33.17		32.6	23.6	30.9	29.03
9		23.9	14.9	22.8	20.53		25.1	21.2	24.4	23.57
11		23.2	16.8	25.2	21.73		25.9	22.5	25.0	24.47
13		17.9	20.2	19.4	19.17		24.6	19.2	27.4	23.73
16		14.3	8.2	14.7	12.40		20.6	14.4	26.0	20.33
19		9.6	10.7	11.9	10.73		20.9	9.4	18.7	16.33
23		14.3	4.2	8.8	9.10		9.0	9.2	13.6	10.60
26	.07	9.9	6.4	12.9	9.73	.05	12.4	8.1	15.4	11.97
30	.76	24.5	22.5	32.4	26.47	.48	23.6	20.8	22.4	22.27
Aug 2	.84	39.4	32.9	40.5	37.60	.43	27.9	23.0	26.1	25.67
6	1.13	46.7	32.1	50.7	43.17	.99	29.5	23.4	32.4	28.43
9	.20	46.2	23.5	28.8	32.83	.19	28.0	18.1	22.1	22.73
13	1.20	34.6	28.4	22.2	28.40	.80	22.7	16.3	23.9	20.97
16	.13	33.1	23.7	21.3	26.03	.04	19.0	13.9	21.6	18.17
20	1.77	61.5	42.2	52.5	52.07	1.56	36.8	36.1	33.6	35.50
23	.11	46.1	37.6	49.0	44.23	.75	39.7	36.0	36.6	37.43
27	.28	44.4	40.5	41.6	42.17	.12	32.2	36.2	32.9	33.77
30	.33	29.6	39.6	39.0	36.07	.21	31.8	32.4	29.2	31.13
Sept 3		34.4	21.7	18.5	36.33		25.8	25.8	19.4	23.67
10		9.2	8.9	5.8	7.97		12.1	16.3	12.1	13.50

TABLE 15. Percent Soil Moisture In 1980 at Research Orchards Located in Western Michigan.

Date	Kalamazoo State Hospital Orchard					Upjohn Orchard				
	Rainfall	North	Middle	South	Mean	Rainfall	North	Middle	South	Mean
June 16		41.5	39.7	46.3	42.5	2.65	44.9	37.7	40.2	40.2
23		55.5	29.3	27.3	37.4	.11	32.4	23.5	31.6	29.2
30		33.4	20.8	17.6	23.9		20.5	24.8	22.2	22.5
July 7	1.46	33.1	34.0	24.9	30.7	1.87	39.1	32.6	38.1	36.6
21	4.34	33.0	36.8	34.3	34.7	2.58	36.2	31.7	26.3	31.4
28	.44	35.3	39.3	41.4	38.7	.73	38.2	29.4	29.2	32.3
Aug 4	2.12	33.8	28.6	36.5	33.0	2.93	36.7	38.0	29.6	34.8
11	.49	32.2	33.7	32.8	32.9	.89	38.1	32.4	27.5	32.7
18	1.52	34.5	29.6	42.4	35.5	.42	29.4	28.3	26.4	28.0
25	1.09	33.2	28.6	29.5	30.4	1.30	32.5	28.5	25.4	28.8
29		25.5	23.3	24.8	24.5		22.6	12.9	15.8	17.1
Sept 5	.60	28.3	26.4	28.1	27.6	1.14	28.1	25.3	21.1	24.8

TABLE 15. Continued

Hofacker Orchard

Date	Rainfall	North	Middle	South	Mean
June 16	.76	25.6	29.7	27.1	27.5
23	.23	11.9	12.5	18.9	14.5
30	.03	10.2	11.9	4.3	8.8
July 7	1.07	24.7	27.5	14.0	22.1
21	2.54	21.8	25.1	22.7	23.2
28	.95	24.6	25.3	25.9	25.3
Aug 4	.15	16.4	6.4	9.0	10.6
11	1.48	22.1	31.2	38.1	30.5
18	.29	16.5	12.0	12.5	13.7
25	2.39	10.5	14.8	14.5	13.3
29	-	14.5	10.5	5.5	10.2
Sept 5	-	-	-	-	-

site were averaged between the Graham Research Station Agricultural Weather Station, 4.5 miles to the south east and the Peach Ridge Agricultural Weather Station, six miles directly north. Values presented for three locations under the tree, and mean values per tree were calculated.

To determine whether there was a significant difference between the locations under the tree, one way analysis of variance tests were completed. In Table 16, each orchard was a separate test with north, middle, and south being the treatments. There were 22 replications or data points in each 1979 test, and 12 points in the 1980 tests. In none of the tests were there any differences between the locations under the tree. Noting that the north side of the tree was consistently wetter, a paired-t test was performed on the differences between the north and south sides of the tree. Four of the five tests showed no differences existed just as was shown in Table 16. However, the 1980 Upjohn data was significantly different at the .05 level by the DMR test.

A more striking observation is that the south side data has larger C.V. values. This indicates that this data is more variable. Explanations for this are that when it rains, the rain penetrates the south side of the tree easier and makes the soil wetter. After rains, the sun hits this soil and dries it out faster. Also the wind aids in the drying process on the south side faster than on the north side. These factors create greater variability than is present on the north side of the tree which is generally more protected.

TABLE 16. Season Long Mean Soil Moistures at Various Locations Under Apple Trees in Three Different Sites (Oneway ANOVA).

	1979				1980					
	K.S.H.		Upjohn		K.S.H.		Upjohn		Hofacker	
	Mean	C.V.	Mean	C.V.	Mean	C.V.	Mean	C.V.	Mean	C.V.
North	30.6a	47	25.3a	30	34.9a	22	33.2a	21	18.1a	33
Middle	24.2a	49	21.1a	37	30.8a	19	28.8a	24	18.8a	48
South	28.4a	49	25.1a	26	32.2a	26	27.8a	25	17.5a	59

Means followed by the same letter are not significantly different at the .05 level by the Duncan's Multiple Range Test.

Because the variances were homogeneous in the last tests all the data from each orchard were lumped to test for orchard differences. Table 17 shows that in 1979 there were no differences between the orchards. However, in 1980 the Hofacker site was significantly dryer than the other sites. This was expected as the trees were on top of a sandy knoll and the grass was mowed under them, both conditions favoring faster drying after a rain storm. The other two orchards have similar soil types and orchard floor conditions, which account for their similar soil moisture contents.

The purpose of this experiment was to determine if soil moisture has an effect on seasonal emergence. An examination of Figure 15 indicates a relationship probably exists. Therefore, accumulative soil moisture values were correlated with accumulative percent emergence (Table 18). When the correlation was made with seeded cage catch, an R^2 value of .70 was found in 1979 and .71 in 1980 in the K.S.H. orchard. This indicates a good relationship for predictive purposes, and would be very good for most biological situations. However, it is not as high as found with other monitoring tools used. A correlation performed with the natural cage catch in the K.S.H. orchard in 1979 resulted in an R^2 value of .55 which indicates a fairly good relationship. This correlation was also performed for the yellow traps. In the K.S.H. orchard, the 1979 value of .97 and the 1980 value of .96 indicates an extremely high relationship. Soil moisture

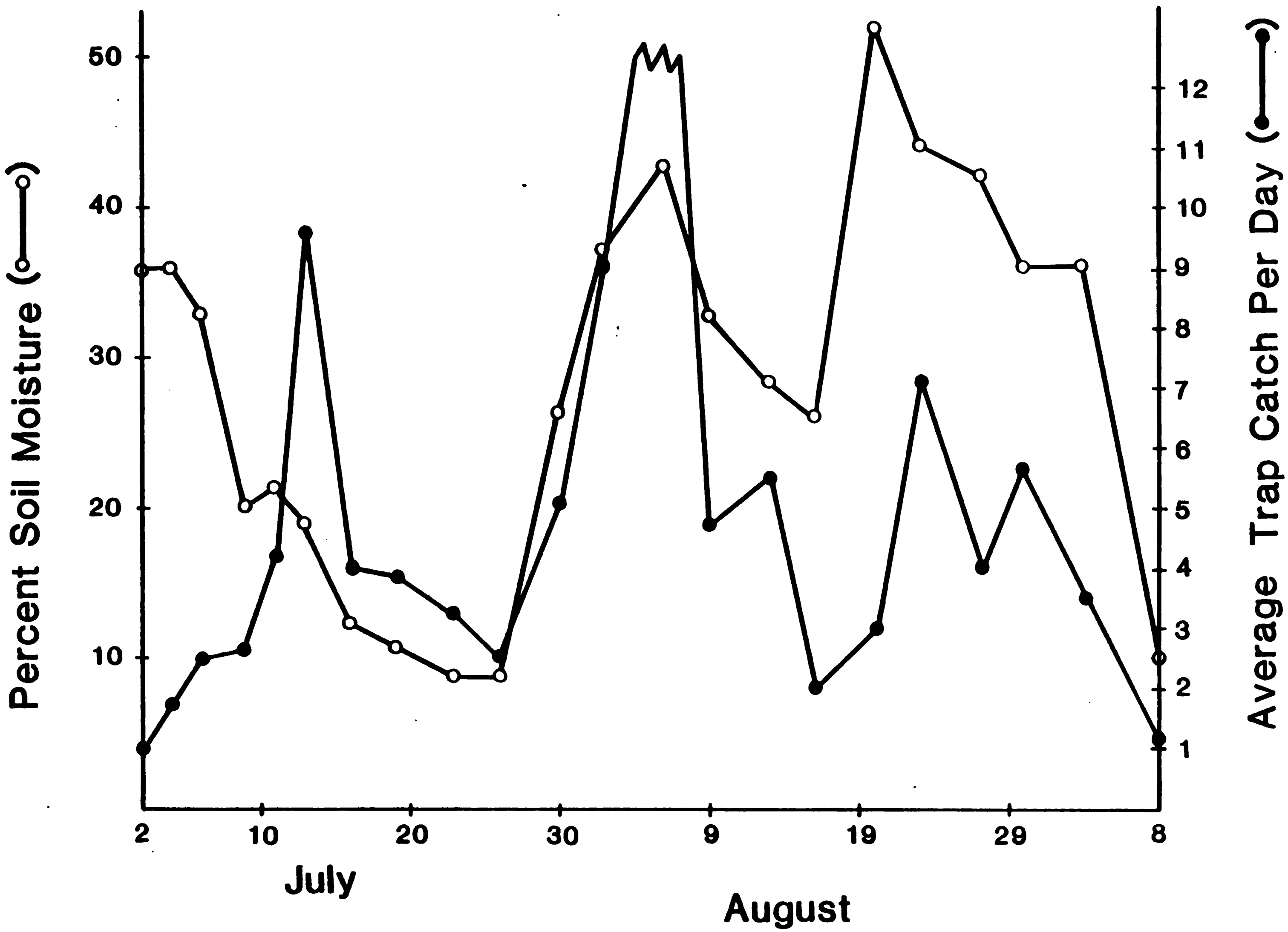


Figure 15. Comparison of Percent Soil Moisture and Average Daily Trap Catch of Apple Maggot Flies on Yellow Zoecon AM Traps in the Kalamazoo State Hospital Orchard in 1979.

in this orchard can predict accumulative trap catch almost exactly. Trap catch on red spheres can be predicted just as well by soil moisture in the K.S.H. orchard as indicated by the very high R^2 values of .96 in 1979 and .96 in 1980.

These same trends were present in the Upjohn orchard where equally high R^2 values were found. The yellow trap values of .79 in 1979 and .90 in 1980 were very high. However, in each case they were smaller than those found in the K.S.H. orchard. This difference can be explained by the significantly lower population level in the Upjohn orchard which creates a less smooth emergence curve. The R^2 values of .84 and .89 for the red spheres were extremely high, but also less than in the K.S.H. orchard.

At the Hofacker site, a very high correlation existed between accumulative soil moisture and accumulation percent trap catch. The yellow trap value was .80, and the red sphere value was .78. These R^2 values are probably less than in the other orchards because of the very fast drying and significantly dryer soils, and the early emergence of the flies.

<u>Laboratory Studies</u> - The results from this experiment were all negative when the original objective of the relationships of first emergence was desired. After 76 days, zero flies had emerged. This equals 2220 degree days at

TABLE 17. Comparison of Mean Soil Moisture Per Tree at Different Orchards (Oneway ANOVA).

	1979	1980
K.S.H.	28.2a	32.5a
Upjohn	24.0a	29.9a
Hofacker	-	17.8b

Means followed by the same letter are not significantly Different at the .05 level by the Duncan's Multiple Range Test.

TABLE 18. Coefficient of Determination (R^2) of Accumulative Mean Percent Soil Moisture with Accumulative Percent Apple Maggot Fly Emergence or Trap Catch.

	1979		1980		
	K.S.H.	Upjohn	K.S.H.	Upjohn	Hofacker
Seeded Cage	.70		.71		
Natural Cage	.55				
Yellow Trap	.97	.79	.96	.90	.80
Red Sphere	.96	.84	.96	.89	.78

base 48°F, and they should have started emerging at 900 degree days. However, some very important information was learned. In the soil, even though only 10% by weight, water must be in a free state readily available for plant and animal processes. As was shown in the previous section, flies still emerged at these low values. In the laboratory, the relative humidity in the air, even though 30 percent, was still too low for insect utilization. The result is that this experiment agreed with data presented by Neilson (1964) when he said that no emergence occurs below 40% relative humidity in the laboratory, whereas in the field seldom is this high level reached during the normal emergence time. This also agrees with Dean and Chapman (1973) who say the translation of soil moisture to relative humidity is difficult, as under normal orchard conditions the equivalent of 20-40 percent R.H. rarely occurs, while that is the normal range of soil moisture.

Conclusions

There were no significant differences found in the percent soil moisture at three locations under an apple tree canopy. The north side of the tree was the most consistent, so if just one sample were to be taken, it should be taken there. The south side was much more variable due to faster rain penetration allowing for faster wetting, and greater sun exposure allowing for faster drying. There were differences across sites however due to soil types and cover crops.

The effect of soil moisture on first emergence could not be determined, but it was analyzed for season long effects. Correlations found very high relationships between accumulative percent soil moisture and accumulative percent trap catch on yellow traps and red spheres. Laboratory studies confirmed that adequate soil moisture is necessary during pupation to rear adults.

BIOTIC COMPONENTS

Several biotic factors in the orchard are involved in the emergence of apple maggot flies from the soil. Those factors presented in Figure 14 will be examined for their influence on first emergence. The variety influence was studied at the K.S.H. orchard for four years, and the Upjohn orchard for two years. This was done with cages and traps. An estimate of the size of the population that carrys over to the second year was made at the K.S.H. orchard, and how that influenced first emergence. The orchard floor culture was noted as to its influence on emergence. If an orchard has early varieties present, then a small proportion of the population can complete its development in them and emerge as a partial second generation. This was studied to help explain the long duration of emergence by using cages seeded at varying times. Lastly, the location of larval pupation was examined for its influence on emergence. This included location under the tree and depth in the soil.

VARIETY OF APPLE REARED IN

The variety of apple the apple maggot was reared in may have some role in determining the time of emergence the following year. Many authors have reported on variety preferences for oviposition, but only a few on the effect on time of emergence. Those that have came up with varying conclusions. O'Kane (1914) said "various other factors, such as the kind of soil, the location of the pupae with reference to shade and the local conditions of moisture, probably have greater influence on timing of emergence than the variety the larval was reared in." Caesar and Ross (1919) seeded cages with infested summer and fall apples, and had the flies emerge one day sooner in the fall apples. They said "so far as summer and fall varieties go there is no difference between dates of emergence." Porter (1928) said "the emergence data indicate the time of maturity of the fruit in which the maggots develop has a definite influence on the time when the flies emerge in the following season. In all cases emergence of flies which developed as larvae in summer fruit rise at an earlier date than do those for the emergence from material which developed in fall or winter fruit." Phipps and Dirks (1933b) reported that flies from Red Astracan and other early fruits began to emerge about a week sooner than those from McIntosh and all later sorts. Chapman and Hammer (1934) said "flies developing from maggots which came from early-maturing varieties tend to emerge on an earlier schedule than flies originating in later sorts," but they presented no data to back this statement. Garman (1934) said "maggots breeding in early varieties may produce flies that emerge earlier in the year," and he used a figure to illustrate this point. Dirks (1935) said "soil temperatures appear to have influenced time of fly emergence to a greater extent than the time of maturity of the fruit in which the larvae developed." He continued "no consistent differences in time of fly emergence has been apparent during the last three years between apple varieties, whether the larvae developed from summer, fall, or winter fruits." Hall (1937) said "the variety of apple in which the larvae feed affects the time of their maturity - those in the early ripening apples maturing first. Only early maturing larvae transform to adults in the current season." Glass (1960) reported emergence from seedings made with Yellow Transparent apples started and reached the peak and 50 percent points 10 to 16 days ahead of those from other varieties such as Wealthy and McIntosh. Glass (1961) said "individuals from early maturing varieties such as Yellow Transparent tend to emerge in early July whereas those from midseason varieties emerge a little later and those from winter varieties such as Baldwin emerge heavily toward the latter part of the month." Oatman (1964b) said "early or late maturing varieties had considerable effect on emergence. Adults tended to emerge earlier, reach peak emergence sooner, and have a shorter emergence period where the larvae developed in early varieties such as Yellow Transparent than did those which developed in later maturing varieties." Dean and Chapman (1973) performed an analysis of variance on 54 pairs of varieties, and found "there is no strong evidence from this that earliest emergence is associated with an early maturing host variety, although it happened occasionally, and it must be concluded that, in general, the time of maturity of the host variety exerts only a slight effect on the time of fly emergence, but what influence there is usually associates earlier maturity with earlier emergence." Lastly, Reid and Laing (1976) said that the effect of variety reared in had no significant effect on the time of adult emergence.

Materials and Methods

The first method to determine if there was a difference in first emergence date due to the variety the apple maggot fly was reared in was to use seeded cages. In the K.S.H. orchard in the fall of 1978, eight 1 meter square emergence cages were seeded with a bushel of infested apples, with each cage receiving a different variety. The varieties are shown in Table 19, and they were selected because of their varying harvest dates after fall bloom. Cages were monitored three times each week beginning June 14, 1979 to determine first and season long emergence patterns.

The second method of measuring differences in emergence due to variety was to use naturally infested emergence cages. During the summers of 1978 and 1979, meter square emergence cages were placed over naturally infested ground under several varieties of trees in the K.S.H. orchard. In 1978 the sampling initiated June 23 and was performed daily for three weeks, and then cut back to twice weekly for the remainder of the season. In 1979, sampling was initiated on June 18 and performed three times each week. Each variety was replicated at least twice, and some four times to provide mean values.

The third method for measuring variety difference in first emergence at the K.S.H. orchard was to monitor fly flight with yellow Zoecon AM traps. This should provide the most reliable indicator of actual differences because the traps were used each year, and a greater number of replicates were made with each variety. In 1977, 10 different varieties of apples had traps hung in them. A total of 50 trees were sampled weekly beginning June 20. In 1978, the same trees were monitored as in 1977. Sampling initiated on June 23, and continued daily for three weeks. The sampling plan was altered in 1979 by reducing the total number of trees checked to just 15. Eight different varieties were tested. Sampling was initiated on June 18 and repeated three times each week. These same trees were sampled in 1980, with monitoring beginning June 23 and repeated three times each week.

The last technique used to determine variety differences in apple maggot fly first emergence was to monitor flight with red sphere traps. These traps were placed in the K.S.H. orchard in 1979 and 1980 on the opposite sides of the same trees that had yellow traps. They were monitored the same way as was described for the yellow traps.

Variety influence of first catch of apple maggot flies was also monitored in the medium density Upjohn orchard. Yellow traps and red spheres were placed on the opposite side of the trees monitored. In both years, three trees each of three varieties were sampled. In 1979, the sampling was initiated on June 20 and was repeated three times each week. In 1980, sampling started July 2 and was repeated three times each week.

Results and Discussion

Table 19 shows the range in date of first emergence of apple maggot flies due to the variety they were reared in as determined by seeded cage studies. There are obvious differences in these dates and the air degree day accumulations, however, this was non-replicated data, so no statistics can be performed. In general, the later maturing the apple, the later was the first emergence of apple maggot adults.

Table 20 shows the range in first emergence due to variety as determined by natural cages. Because air degree days provided smaller C.V. values than the same data reported as Julian date or soil degree days, they were used

Table 19. Date and Air Degree Day Accumulation (Base 48°F; B. E. Method) of First Emergence of Apple Maggot Fly Due to Variety It Matured In Measured by Seeded Emergence Cages at the K.S.H. Orchard in 1979.

Variety	Days to Harvest From Full Bloom[1]	Season of Apple	First Emergence Date	First Emergence Air dd
Transparent	70-75	Summer	June 20	836
Dutchess	90-95	Summer	June 17	774
Wealthy	120-125	Early Fall	June 17	774
McIntosh	125-130	Early Fall	June 19	814
R. I. Greening	135-145	Fall	July 4	1,074
Jonathan	140-145	Fall	June 19	814
Red Delicious	140-150	Fall	June 22	892
Northern Spy	145-155	Late Fall	June 19	814
Mean			June 21	849

[1] Smock and Neubert, 1950. Table 4, pp 14-15.

Table 20 Effect of Variety on First Emergence of Apple Maggot Flies at the K.S.H. Orchard as Determined by Catch in Cages Placed Over Naturally Infested Ground (Mean Air Degree Days at Base 48°F; B.E. Method)

Variety	1978 No.	1978 Mean	1979 No.	1979 Mean	Both Years No.	Both Years Mean
Wealthy			2	943 a	2	943 a
Transparent	2	994 a	2	943 a	4	969 a
Dutchess	4	1046 a	2	964 a	6	1019 a
Northern Spy	4	1007 a	2	1149 a	6	1078 a
Greenings	4	1094 a	2	1047 a	6	1082 a
McIntosh	2	1080 a	2	1085 a	4	1082 a
Jonathan			2	1117 a	2	1117 a
Red Delicious	4	1120 a	2	1074 a	6	1128 a
Total	20	1061	16	1040	36	1052

Means followed by the same letter are not significantly different at the .05 level by the Duncan's Multiple Range Test.

in this and further analysis. Analysis of variance and Duncan's Multiple Range tests were run on each years' data, and the lumped data for all years. In each run the F value was not significant, so mean separation tests should show no differences. This was the case, as at the .05 level there was no significant differences between the mean date of first emergence for any of the varieties. Even though there are no significant differences, there is a range in the values with the flies emerging sooner in the earlier varieties and later in the late varieties.

Data on the influence of first catch due to variety as determined by catch on yellow traps are more variable (Table 21). In 1977 and 1978 at the K.S.H. orchard, there were no significant differences between the air degree day accumulations at first catch. During 1979, the data provided three different subgroups of varieties that were not statistically different within the subgroups. These groups fit the maturity intervals fairly well, with the exception of Northern Spy catching flies earlier than was expected. Data from 1980 showed four subgroups of varieties that were statistically different. This data fits very nicely the maturity dates of varieties, and was what was expected from these tests in all years. When all years were combined, the DMR test showed no differences between any of the varieties in first catch.

Red sphere traps were also used to determine differences in timing of catch due to variety of apple. Table 22 shows that for both 1979 and 1980 there were differences in timing in the K.S.H. orchard. When these two years were combined, differences were still present. The three subgroups of homogeneous varieties again matched the maturity dates quite closely with the earlier varieties catching flies sooner than the later varieties.

To test whether variety has an influence in first catch of apple maggot flies in an orchard with some sprays applied, tests were set up in the Upjohn orchard. Table 23 presents the data from this medium fly density orchard. When the yellow trap was tested, no statistical variety difference was discovered in either year. Large ranges in mean degree day accumulations were evident between the varieties, and it was assumed that larger sample sizes would have shown statistical differences. When red sphere traps were tested some differences were found. In 1979, flies were caught on Northern Spy significantly later than the other varieties. In 1980, there were no differences. When both years data were combined the variances were still homogeneous, and the F ratio was significant. The variety influence was present, but not exactly as was expected. McIntosh should have been first, followed by Jonathan and Northern Spy if maturity dates were the predominating factor. However, greatly reduced populations and the pesticide applications greatly influence trap catch, and these factors probably overshadow any possible variety effect.

Four different techniques of measuring variety influence on first emergence or catch over a four year time frame were just presented. In order to compare these techniques

Table 21. Effect of Variety on First Catch of Apple Maggot Fly at the K.S.H. Orchard as Determined by Catch on Yellow Zoecon AM Traps. (Mean Air Degree Days at Base 48°F; B.E. Method)

	1977		1978		1979		1980		All Years	
Variety	No.	Mean	No.	Mean	No.	Mean	No.	Mean	No.	Mean
Dutchess	8	1135.0 a	6	1067.5 a	2	978.5 ab	2	1046.0 a	18	1032.3 a
Greening	6	1140.8 a	4	1114.7 a	2	943.0 ab	2	1056.0 ab	14	1093.0 a
Transparent	2	1152.5 a	2	1046.0 a	2	978.5 ab	2	1088.0 abc	8	1066.2 a
Wealthy	2	1135.0 a	2	981.0 a	1	929.0 a	1	1140.0 bcd	6	1046.2 a
Baldwin	4	1143.7 a	4	1172.0 a					8	1157.9 a
Red Delicious	3	1135.0 a	4	1089.2 a	2	1037.0 bc	2	1163.5 cd	11	1105.7 a
McIntosh	3	1146.7 a	5	1058.0 a	2	978.5 ab	2	1163.5 cd	12	1084.5 a
Winesap	3	1203.3 a	2	1044.5 a					5	1099.8 a
Jonathan	2	1237.5 a	2	1066.5 a	2	1087.0 c	2	1187.0 d	8	1144.6 a
Northern Spy	17	1202.8 a	19	1055.3 a	2	988.0 ab	2	1214.0 d	40	1153.8 a
Total	50	1169.0	50	1070.5	15	994.0	15	1131.7	130	1106.6

Means followed by the same letter are not significantly different at the .05 level by the Duncan's Multiple Range test.

Table 22. Effect of Variety on First Catch of Apple Maggot Fly at the K.S.H. Orchard as Determined by Catch on Red Spheres. (Mean Air Degree Days at Base 48°F; B.E. Method)

	1979		1980		Both Years	
Variety	No.	Mean	No.	Mean	No.	Mean
Wealthy	1	1047.0 a	1	1140.0 a	2	1093.5 a
Dutchess	2	1074.0 a	2	1131.5 a	4	1102.7 a
Transparent	2	1135.5 a	2	1128.5 a	4	1132.0 a
McIntosh	2	1223.5 a	2	1290.0 abc	4	1256.7 ab
Greening	2	1277.0 ab	2	1187.0 ab	4	1232.0 ab
Northern Spy	2	1338.5 ab	2	1513.0 c	4	1425.7 bc
Jonathan	2	1460.5 ab	2	1513.0 c	4	1486.7 c
Red Delicious	2	1688.0 b	2	1440.0 bc	4	1564.0 c
Total	15	1296.1	15	1303.1	30	1299.5

Means followed by the same letter are not significantly different at the .05 level by the Duncan's Multiple Range test.

Table 23. Effect of Variety on First Catch of Apple Maggot Fly at the Medium Density Upjohn Orchard in 1979 and 1980. (Mean Air Degree Days at Base 48°F; B.E. Method).

	1979				1980				Both Years			
	Yellow Trap		Red Sphere		Yellow Trap		Red Sphere		Yellow Trap		Red Sphere	
Variety	No.	Mean	No.	Mean	No.	Mean	No.	Mean	No.	Mean	No.	Mean
Jonathan	3	1102.0a	3	1211.0a	3	1316.3a	3	1314.0a	6	1209.2a	6	1262.5a
McIntosh	3	1394.7a	3	1168.0a	3	1490.3a	3	1729.0a	6	1442.5a	6	1448.5ab
Northern Spy	3	1493.7a	3	1886.0b	3	1450.7a	3	1524.3a	6	1472.2a	6	1705.0b
Total	9	1330.1	9	1421.7	9	1419.1	9	1522.4	18	1374.6	18	1472.0

Means followed by the same letter are not significantly different at the .05 level by the Duncan's Multiple Range Test.

and years, and provide some data for a phenology model, Table 24 was prepared. For each year and method, the grand mean of first emergence was calculated. From this grand mean, the mean per variety was subtracted. This deviation provides a uniform method of comparing that removes the method and yearly difference in air degree day accumulation at first emergence. The average difference from mean provided data for unbalanced analysis of variance and mean seperation tests. The data was transformed by adding a constant 250 to remove all negative values. The analysis was performed, the variances were found to be homogeneous and the F ratio was significant. From this table, if an orchard with a high density of apple maggot flies was monitored, no matter what method was employed, flies should be caught first from the Wealthy variety. Sixteen degree days later, they should be caught on the Dutchess variety. This trend continues for all 10 varieties listed, with Red Delicious being the last variety to catch flies. Also, if a mean first emergence value per orchard was determined, 96 degree days could be subtracted from that value if Wealthy was present in that orchard. This new accumulation could then serve as a predictor for first emergence in the orchard on the other end of the scale, if first catch on the Jonathan variety was to be predicted, 68 degree days should be added to the mean value of the orchard. These differences between the varieties were significant, and followed very closely the maturity dates of the individual varieties.

Table 24. Comparison Across Years and Methods of the Influence of Variety on First Emergence or Capture of Apple Maggot Fly at the High Fly Density K.S.H. Orchard (Difference from Mean Air Degree Day Base 48°F; B.E. Method).

Variety	1979 Seeded Cage	1978 Natural Cage	1979 Natural Cage	1977 Yellow Trap	1978 Yellow Trap	1979 Yellow Trap	1980 Yellow Trap	1979 Red Sphere	1980 Red Sphere	Difference From Mean
Transparent	-13	-66	-97	-16	-24	-15	-44	-161	-206	-71 a
Dutchess	-75	-14	-76	-34	-3	-15	-86	-222	-197	-80 a
Wealthy	-75	-	-97	-34	-89	-65	8	-249	-168	-96 a
Baldwin	-	-	-	-25	101	-	-	-	-	38 abc
McIntosh	-35	19	45	-22	-12	-15	32	-73	-43	-12 ab
R.I. Greening	225	33	7	-28	44	-51	-76	-19	-68	8 abc
Winesap	-	-	-	34	-26	-	-	-	-	4 abc
Jonathan	-35	-	77	68	-4	93	55	164	126	68 bc
Red Delicious	43	59	34	-34	19	43	32	392	187	86 c
Northern Spy	-35	-54	109	34	-15	-6	82	42	264	47 b

Means followed by the same letter are not significantly different at the .05 level by the Duncans Multiple Range test. Data transformed by x+250 for analysis with actual means presented.

This same technique of determining grand mean per orchard by method and year, and then calculating deviations from that mean was also performed for the medium fly density Upjohn orchard. Table 25 found significant differences between varieties. Jonathan variety caught flies first, and for predictive purposes, caught them 187 degree days before the orchard mean. McIntosh variety was second, and only 22 degree days after the orchard mean value. Northern Spy variety was last to catch flies, and on the average was 165 degree days later than the orchard mean.

Conclusions

The variety that an apple maggot fly is reared in has an effect on time of adult emergence. In earlier maturing varieties, the adults emerge earlier the following year. This was varified by using seeded emergence cages, natural emergence cages, yellow traps, and red spheres in the high fly density K.S.H. orchard. These differences were significant in several trials. Ranges in air degree days from the grand mean were calculated by variety for predictive purposes.

When tested in medium fly density orchards, the variety still had an effect on first emergence. Both yellow traps and red spheres caught flies first on the Jonathan variety, followed by McIntosh, followed by Northern Spy. The difference between mean first catch per variety were significant, and provided degree day values for predictive purposes.

Table 25. Comparison Across Years and Methods of the Influence of Variety on First Catch of Apple Maggot Fly at the Medium Fly Density Upjohn Orchard (Difference from Mean Air Degree Day Base 48°F; B.E. Method).

	1979 Yellow Trap	1980 Yellow Trap	1979 Red Sphere	1980 Red Sphere	Difference From Mean
Jonathan	-228	-103	-211	-208	-187.5a
McIntoch	65	71	-253	-207	22.4 ab
Northern Spy	164	32	464	2	165.4 b

Means followed by the same letter are not significantly different at the .05 level by the Duncan's Multiple Range Test. Data transformed by x+260 for analysis with actual means represented.

This variety influence on first emergence has an adaptive advantage to the species. When a variety matures early, flies that have been reared in that variety are mature and ready to oviposite in that variety. Flies that emerge later are then mature and ready to oviposite in later maturing varieties. This ensures species survival by having mature flies present over a long time frame to coincide with fruit susceptibility.

TWO YEAR LIFE CYCLE

A certain small proportion of the apple maggot population will not emerge as normal, but will overwinter the second winter and emerge as flies the second summer. For predictive reasons, one needs to know whether these flies emerge earlier than normal first year flies. This was measured at the high fly density K.S.H. orchard by placing emergence cages over the identical spot for two consecutive summers.

Literature

Many authors have reported that a small proportion of the apple maggot population will overwinter the second year, (Table 26). Generally, it was found that these flies emerge during the same period as first year flies. By going farther north in its range, the fly has a tendency to overwinter for more years. Neilson (1976) in Nova Scotia found .14 to 3.67 percent carried over to the third year, and 0 to .11 percent carried over to the fourth year in seven different tests. This may help to insure species survival when suitable oviposition sites are not available every year.

A few authors hypothesized on causes for these carry-over individuals. Oatman (1964 b) noted "a 15 percent carry-over population in 1962 and a 5 percent carry-over in 1963. The difference was probably due to below-average temperatures and rainfall during the 1961 emergence period creating a higher carry-over than that caused by above average conditions during 1962." Also, Trottier (1979)

Table 26 Literature References to the Occurrence of a Two Year Life Cycle of Apple Maggot Fly with Percent of Carry-Over and Time of Emergence in Relation to First Year Flies Recorded.

Source	Percent of Carry-Over	Time of Emergence
O'Kane (1914)	Some	Ordinary time
Caesar & Ross (1919)	6.6 to 18	-
Porter (1928)	0.1 to 37.5	Usual emergence Period
Phipps & Dirks (1933)	5.2 to 8.3	Height of regular Flies
Allen & Fluke (1933)	37	8 days later
Garman (1934)	relatively small	-
Dirks (1935)	.91 to 2.21	Same period
Hall (1937)	1.2	Same Period
Glass (1960)	few individuals	Normal time
Oatman (1964,b)	5 to 15	-
Dean & Chapman (1973)	.97	-
Cameron & Morrison (1974)	Up to 16	Same Period
Neilson (1976)	11.11 to 58.11	-

found that a greater percentage of pupae carry-over to the second season in dryer soils. Probably Porter's (1928) explanation is the best. "The two year cycle operates definitely to the advantage of the species, insuring the survival of at least a few individuals over seasons of complete crop failure."

Material and Methods

All the work related to second year emergence was performed in the K.S.H. orchard. The eight cages seeded with infested apples on uninfested ground in the fall of

1978 were monitored in 1979 to determine first and seasonal emergence patterns. In 1980, cages were placed in the identical spot, and monitored again. The dates and air degree day accumulations at first emergence were recorded to determine timing in relation to first year flies. Also the total number of flies were recorded to determine the percentage involved in carrying over to the second season. These emergence dates were compared with first year emergence from seven cages seeded with apples in the fall of 1979 on other patches of uninfested ground adjacent to the second year cages. Monitoring initiated June 23 and was performed three times a week until after all cages had caught the first fly.

Results and Discussion

The data from this test is presented in Table 27. The average first emergence from first year pupae was June 30 or 1036 air degree days. The second year flies first emerged on average July 3 or 1101 air degree days. Analysis of variance found these two treatments not statistically different, which was confirmed by the Duncan's Multiple Range Test.

On the average, the delay was three days. This may be an actual difference, and if so, then one that was unexpected. One would theorize that flies passing through two seasons would emerge sooner because they have had twice as

Table 27. Effect of Carry-Over Pupae on Timing of Emergence of Apple Maggot Flies at the K.S.H. Orchard in 1980 (Air Degree Days at Base 48°F; B.E. Method)

	First Year Emergence		Second Year Emergence	
Cage	Date	Air dd	Date	Air dd
1	6-30	1036	7-5	1140
2	6-28	1016	7-5	1140
3	6-28	1016	7-2	1076
4	6-30	1036	7-7	1187
5	6-30	1036	6-28	1016
6	6-30	1036	7-2	1076
7	7-2	1076	6-30	1036
8	-	-	7-5	1140
Mean ±S.E.	6-30±.5	1036±7.1	7-3±1.1	1101±21.0

much time to develop physiologically. It is possible that this is the case, and the explanation why the delay was present was that a much smaller population was monitored (Table 28). This shows a range of 2.9 to 11.3 percent of the flies carrying over to the second year, and an average of 6.8 percent. With fewer total flies present, it is reasonable to assume that fewer earlier individuals in the population are present, and therefore first catch would be delayed.

Conclusions

It was found that flies overwintering to the second year emerge an average of three days later than flies emerging the first year. This difference may be real, or may be due to the greatly reduced total population that is sampled the second year. This reduced population sampled may overweigh any real difference that might be present and would be expected. These findings concur with those presented in the literature.

It is important to note that in every case a certain proportion of the flies did overwinter the second year. This phenomenon has adaptive advantages to the species. This allows for individuals to be present the second season and continue the species if all the oviposition sites were absent one year. This is a possibility as: (1) spring frosts tend to remove many apples and could destroy an entire crop; (2) diseases such as apple scab could be severe

TABLE 28. Number and Percent of Apple Maggot Flies Over-Wintering to the Second Season at the K.S.H. Orchard by Variety.

Cage	First Year Emergence	Second Year Emergence	Percent of Total
Transparent	34	2	5.6
Greening	66	2	2.9
Wealthy	87	4	4.4
Dutchess	85	3	3.4
McIntosh	55	7	11.3
Jonathan	113	4	3.4
Red Delicious	324	34	9.5
Northern Spy	137	10	6.8
Total Caught	901	66	6.8

and destroy the fruit or make it unsuitable for oviposition; (3) other insect pests such as plum curculio and codling moth could be extremely successful and cause all the apples to abort before apple maggot emerges; or (4) the natural bienniel bearing of trees could result in no fruit alternating years.

ORCHARD FLOOR CULTURE

The orchard floor culture may effect emergence. With deep grass underneath the trees, the sunlight cannot penetrate to warm the soil as quickly, which can delay emergence. If the grass is mowed or a herbicide is applied, then the soil surrounding the pupae warms faster, and earlier emergence should occur. With a clean cultivated orchard, emergence times may or may not be speeded up. The soil warms faster which would result in earlier emergence, but the pupae that survive discing and desication are deeper in the soil and are not exposed as rapidly to the warmth. Also, on cultivated soil fewer flies are obtained than on uncultivated soil which tends to delay emergence (Mundinger, 1930).

In this study, temperatures were measured under different natural conditions. The environment was not modified by disturbing the soil nor placing artificial objects under the trees. Degree day accumulations were made and compared under these different conditions. It is assumed that degree day accumulations is a good method of integrating all the variables such as depth of grass, amount of shading, and orchard floor culture that effect emergence.

Literature

Observations relating to orchard floor cultures effect on timing of emergence are scarce in the literature. Garman (1934) said " research workers have indicated that maggot flies will emerge earlier from sandy soils than from heavy loams." This could be due to the sandy soils warming up faster to cause earlier development, or the soils being looser so the flies can crawl up and out easier. Glass (1960) states that "variations from seeding to seeding due to such factors as shade density of the tree appear to have had very little influence on the time of maggot emergence." His data shows that "the location of the seeding within the test orchard was not a significant factor in time of emergence."

Materials and Methods

Three lead Weather Measure thermographs were placed in the K.S.H. orchard the second week of July in 1979. One probe was in the standard U.S. Weather Service 5-foot shelter, the second was on the soil surface in tall grass directly exposed to the sun, and the third was on the soil surface in tall grass but shaded by the tree canopy. These three locations were monitored for the remainder of the season to determine if there were differences in the amount of heat penetrating to the soil surface.

In 1980, these same temperature instruments were placed at different sites around the state. Site one was the Upjohn orchard where 5-foot air and shaded soil surface temperatures were recorded. Here there was plenty of canopy to shade the probe, and it was placed in thick tall grass for additional protection. Site two was the Hofacker yard north west of Grand Rapids. Five-foot level air temperatures and shaded grass litter zone temperatures were recorded. This grass litter zone probe had indirect sun exposure caused by the shading, but the grass was mowed frequently which would simulate a well mowed or herbicided commercial orchard. This should provide a medium heating and emergence. Site three was the Yabs yard. The 5-foot air temperature probe was identically placed in the weather shelter as in the other locations. The grass litter zone prob was in mowed grass, but exposed to the direct sunlight. This should provide the quickest heating and earliest emergence. These locations were monitored from April 1 to the end of July to determine differences in these three types of orchard floor cultures. No thermometers were placed in disced soil, as the majority of the apple orchards in Michigan are under one of the above types of sod culture.

Results and Discussion

There are differences in the accumulation of degree days at the three different sites monitored in the K.S.H. orchard in 1979 (Table 29). Because of the extremely high temperatures which could not be entered into the computer program to calculate degree days by the Baskerville-Emin method, the averaging method was employed to calculate degree days. An analysis of variance was performed on the data broken down into half month intervals (Table 30). The

Table 29. Effect of Orchard Floor Culture on Degree Day Accumulations at the K.S.H. Orchard in 1979 (Degree Day Base 48°F; Average method).

	Five Foot Air			Direct Sun Tall Grass			Shaded by Tree Tall Grass		
Date	Max	Min	dd 48°	Max	Min	dd 48°	Max	Min	dd 48°
July 16	89	64	28.5	123	62	44.5	98	63	33
July 17	88	70	31	106	52	31.0	86	57	23.5
July 18	85	66	27.5	121	48	36.5	91	54	24.5
July 19	84	66	27	126	53	41.5	94	57	27.5
July 20	84	59	23.5	115	56	37.5	87	57	24
July 21	88	56	24	128	58	45	100	62	33
July 22	90	59	26.5	114	57	37.5	94	78	38
July 23	93	73	35	124	72	50	97	73	37
July 24	80	70	27	86	71	30.5	81	73	29
July 25	75	63	21	88	66	29	79	67	25
July 26	82	61	23.5	121	62	43.5	92	67	31.5
July 27	90	74	34	118	74	48	96	74	37
July 28	83	66	26.5	100	67	35.5	85	69	29
July 29	88	64	28	122	66	46	95	72	35.5
July 30	84	71	29.5	93	73	35	83	72	29.5
July 31	81	61	23	108	66	39	84	68	28
Accumulation			435.5			630.0			485

TABLE 29. Continued

Date	Five Foot Air			Direct Sun Tall Grass			Shaded by Tree Tall Grass		
	Max	Min	dd 48°	Max	Min	dd 48°	Max	Min	dd 48°
August 1	68	63	17.5	71	65	20	71	68	21.5
2	78	62	22	106	64	37	83	67	27
3	83	65	26	106	65	37.5	86	69	29.5
4	87	66	28.5	106	68	39	87	71	31
5	79	66	24.5	93	67	32	81	69	27
6	82	68	27	110	70	42	86	71	30.5
7	91	75	35	119	76	49.5	89	76	34.5
8	80	51	17.5	98	71	36.5	83	72	29.5
9	84	78	33	113	76	46.5	83	70	28.5
10	78	61	21.5	89	68	30.5	81	62	23.5
11	70	54	14	98	59	30.5	79	58	20.5
12	75	57	18	103	61	34	83	68	27.5
13	70	56	15	77	59	20	72	65	20.5
14	67	44	7.5	83	50	18.5	72	54	15
15	68	41	6.5	96	47	23.5	77	52	16.5
16	72	58	17	100	57	30.5	77	61	21
17	62	55	10.5	61	57	11	62	60	13
18	60	54	9	61	58	11.5	61	60	12.5
19	64	58	13	66	61	15.5	66	64	17
20	68	58	15	71	62	18.5	69	63	18
21	80	60	22	76	60	20	79	64	23.5
22	74	68	23	90	61	27.5	73	69	23
23	85	64	26.5	77	65	23	81	70	27.5
24	71	57	16	88	66	29	74	63	20.5
25	77	59	20	90	61	27.5	75	63	21
26	78	74	28	81	64	24.5	74	67	22.5
27	77	63	22	77	63	22	74	68	23
28	76	64	22	80	65	24.5	73	65	21
29	80	65	24.5	81	65	25	76	66	23
30	87	62	26.5	96	64	32	82	66	26
31	88	66	29	93	67	32	81	69	27
Accumulation			637.5			871			722

TABLE 29. Continued

Date		Five Foot Air			Direct Sun Tall Grass			Shaded by Tree Tall Grass		
		Max	Min	dd 48°	Max	Min	dd 48°	Max	Min	dd 48°
Sept.	1	83	69	28	84	69	28.5	77	70	25.5
	2	83	69	28	89	67	30	78	70	26
	3	80	60	22	78	64	23	78	68	25
	4	74	60	19	74	61	19.5	71	66	20.5
	5	84	62	25	72	63	19.5	78	68	25
	6	80	54	19	88	57	24.5	76	61	20.5
	7	67	41	6	85	47	18	68	53	12.5
	8	64	44	6	91	47	21	65	53	11
	9	74	60	19	85	59	24	70	61	17.5
	10	84	60	24	96	66	33	75	65	22
	11	80	64	24	88	64	28	75	61	20
	12	84	65	26.5	96	64	32	74	66	22
	13	74	59	18.5	79	64	23.5	70	55	14.5
	14	63	53	10	75	46	12.5	63	51	9
	15	65	47	8	85	47	18	63	51	9
	16	76	47	13.5	87	60	25.5	70	53	13.5
	17	80	60	22	90	57	25.5	74	59	18.5
	18	74	57	17.5	88	57	24.5	79	48	15.5
	19	66	45	7.5	81	43	14	63	47	7
	20	76	59	19.5	86	54	22	68	57	14.5
	21	65	53	11	75	46	12.5	63	48	7.5
	22	66	38	4	80	40	12	63	45	6
	23	66	47	8.5	81	41	13	64	47	7.5
	24	74	43	10.5	84	48	18	68	52	12
	25	76	45	12.5	85	43	16	70	49	11.5
	26	83	50	18.5	89	47	20	70	55	14.5
	27	82	50	18	84	47	17.5	72	43	9.5
	28	83	60	23.5	88	57	24.5	75	60	20
	29	86	82	36	90	57	25.5	76	60	19.5
	30	70	51	12.5	73	50	13.5	68	54	13
Accumulation				518			639			470

Table 30. Mean Differences in Degree Day Accumulations Between Different Orchard Floor Cultures for Various Time Periods at the K.S.H. Orchard in 1979 (Degree Days Base 48°F; Averaging Method).

Orchard Floor Culture Monitored	July 16-31	August 1-15	August 16-31	Sept 1-15	Sept 16-30
Five Foot Air Temp	27.5 a	20.9 a	20.2 a	18.9 a	15.7 ab
Shaded-Tall Grass	30.5 a	25.5 a	21.2 a	18.7 a	12.7 a
Direct Sun-Tall Grass	39.4 b	33.1 b	23.4 a	23.7 a	18.9 b

Means followed by the same letter are not significantly different at the .05 level by the Duncan's Multiple Range test.

variances were homogeneous for each set of data. The F test was highly significant for three of the five time periods and the Duncan's Multiple Range test separated the means into two signficantly different subsets. During the last half of July and the first half of August, the soil that has no shade is significantly warmer than the shaded soil and that is the 5-foot weather shelter. This fact would indicate that pupae in this type of environment would warm up faster, and allow the adults to emerge sooner. In the shaded areas, the soil is cooler, and flies can emerge over a longer time period. Later in the season, from mid-August to mid-September, there are no differences in the temperatures in these three sites. It is during this time period that the lavae are leaving the apples to pupate. If the extremely warm surface temperatures were present then as in late July (120+°F, Table 29), it is reasonable to believe that there would be a great mortality of the larvae before they could burrow down into the cooling soil to pupate. During the last of September, the unshaded soil surface was significantly warmer than the shaded soil, but not different than the five foot weather shelter. In all time periods, the mean temperature was warmer on the unshaded soil than in the other two sites. This seems reasonable, and could explain why flies emerge earlier in some locations than others, and why the long emergence period occurs in all sites.

Differences were also present in temperatures between the different types of orchard floor culture in 1980. Before analysis of the data on grass litter zone temperatures were made, air temperature degree day analysis were performed. Table 31 shows that all three sites did not have statistically different air degree day accumulations for the same calendar day time periods. Therefore, with same air degree day accumulations, any differences that might be present in grass litter zone temperatures must be due to the different type of orchard floor culture where the temperature probe was located. Table 32 shows that differences were present for every time period in the grass litter zone temperatures. The tall grass shaded by the tree at the Upjohn orchard was the coolest site from April 1 to May 15. From then until the end of July, it was no different than the shaded grass shaded at the Hofacker site. The mowed grass exposed to the sun at the Yabs site was always significantly warmer than the shaded tall grass culture. From the first of May on, the mowed grass exposed to the sun was warmer than the shaded mowed grass. This seems reasonable as the sun should warm up the soil faster when it directly hits the prob, rather than when it is screened out and only indirectly warms the soil surface.

Table 31. Mean Number of Air Degree Day Units Per Day for Different Time Periods Throughout the Year at Different Sites in Michigan in 1980 (Five Foot Level Degree Days at Base 48°F; B.E. Method).

Location of Sample	April 1-15	April 16-30	May 1-15	May 16-31	June 1-15	June 16-30	July 1-15	July 16-31
Upjohn	1.9 a	3.5 a	5.3 a	13.2 a	13.7 a	20.5 a	25.5 a	23.2 a
Hofacker	10.7 b	4.5 a	7.3 a	14.8 a	12.1 a	17.1 a	23.1 a	23.2 a
Yabs	-	4.6 a	8.9 a	17.2 a	14.4 a	21.5 a	25.5 a	26.2 a
F Value	21.90	0.20	1.39	1.69	0.47	1.63	1.18	1.71

Means followed by the same letter are not significantly different at the .05 level by the Duncan's Multiple Range test. Critical $F_{.05(2,42)} = 3.23$

Table 32. Mean Number of Grass Litter Zone Degree Day Units Per Day for Different Time Periods Throughout the Year at Different Sites in Michigan in 1980 (Degree Days at Base 48°F; B.E. Method).

Location of Sample	April 1-15	April 16-30	May 1-15	May 16-31	June 1-15	June 16-30	July 1-15	July 16-31
Upjohn - Tall Grass-Shaded	0.0 a	1.4 a	3.4 a	8.7 a	11.2 a	16.3 a	21.5 a	22.2 a
Hofacker-Mowed Grass-Shaded	8.3 b	6.5 b	9.0 b	8.9 a	10.0 a	15.2 a	21.6 a	20.4 a
Yabs-Mowed Grass-Exposed	-	7.9 b	13.9 c	21.1 b	18.5 b	25.1 b	29.8 b	29.5 b
F Value	28.19	7.69	15.84	53.51	27.54	20.2	24.99	34.64

Means followed by the same letter are not significantly different at the .05 level by the Duncan's Multiple Range test. Critical $F_{.05(2,42)} = 3.23$

Conclusions

The data presented indicates that apple maggot pupae located in short grass or on herbicided soil that are directly exposed to the sun should emerge first as they are warmed sooner. Those pupae that are located in mowed grass but shaded from direct sunlight should emerge significantly later. The last flies to emerge should be in orchard floor cultures of tall grass and shaded from the sun by the tree canopy.

PARTIAL SECOND GENERATION

The flight pattern of adult apple maggot flies lasts about three months (Figures 4-13). One source of the late season individuals is from a partial second generation. Larvae that developed in early maturing varieties develop soon enough to emerge the same year and infest later developing varieties (Illingworth, 1912; Herrick, 1912; Caesar and Ross, 1919; Porter, 1928; Phipps and Dirks, 1933; Hall, 1937; Neilson, 1962; and Prokopy, 1968c; Boulanger, Stanton and Padula, 1969). Seldom do many of these larvae complete development before fall (Chapman and Hess, 1941) and are therefore suicidal. In the more northern regions of its range, no second generation adults appear (O'Kane, 1914 in New Hampshire; Mundinger, 1930 in Hudson Valley; Neilson, 1976 in Nova Scotia). Dean and Chapman (1973) said "bivoltinism undoubtedly occurs in the Hudson Valley, but it is of no consequence so far as the species control in commercial orchards is concerned." Studies were conducted at the K.S.H. and Upjohn orchards to determine if there is a partial second generation in Michigan, and how large a portion it is of the total population.

Materials and Methods

Emergence cages seeded with infested apples in the summer of 1979 were monitored that fall and the next summer to determine emergence patterns. Seven cages were seeded with the Dutchess variety. Seedings were made on July 16, July 19, July 23, July 30, August 2 and August 6. This sequence of seeding was made to determine how late in the season apples can fall to the ground and still have sufficient time to have a partial second generation, and to see if there was an effect on time of emergence the following year due to the time of pupation the preceeding summer. Hall (1937) said that all second generation adults were derived from larvae which reached maturity before August 20, although all larvae that matured by that date did not transform to adults in that same year. Glass (1960) said that, "In 1953 collections from the same group of Wealthy trees were made on August 18, August 29, and September 9. Emergence data shows that there were no appreciable differences in emergence between cages. This probably means that larval emergence from the fruit was essentially the same regardless of when the fruit was collected. It seems likely the time of collecting infested fruit from any one locality and variety does not influence appreciably the time flies will emerge the following season." Reid and Laing (1976) said that the date the puparia was formed was not significant to the time of emergence of adults the following year.

The second method to determine if a second generation of flies was present was to determine the gravidity of the females. By dissecting females and looking for the presence of eggs in the oviducts, one can distinguish whether the female is mature or not. If no eggs are present, then the female is considered immature and has just emerged. In nature, females very seldom oviposite their full compliment of eggs, so females without eggs are immature and not older individuals with spent ovaries. Also, older individuals appear very ragged and beat up and can readily be distinguished from newly emerged ones. All flies caught in the K.S.H. and Upjohn orchards in 1979 and 1980 on yellow Zoecon AM and red sphere traps were sexed. The females were then dissected to determine if they were gravid. It was assumed there would be a period of no immature flies caught during late summer, followed by a low percent of immature females that are the second generation flies. As the sex ratio of the flies is very close to 50:50, the results from the dissections of the females should be indicative of the total population.

Results and Discussion

Emergence cages seeded with infested apples on uninfested ground showed that there is a partial second generation of apple maggot flies in Michigan (Table 33). Between September 22 and September 29 the first of these flies emerged. On October 13 these cages were removed, as it was assumed no more flies would emerge that year. This second generation ranged from 0 to 2.17 percent of the emerged flies in each cage, but averaged only 0.25 percent of the total flies that emerged from progeny of the 1979 adults. This is similar to Hall's (1937) data that had 5.4%

second generation from Dutchess apples in Ontario. This would have very little effect on a growers control program, and has very little effect on late season emergence. From this table it is evident that larvae that enter the soil as late as July 23 can pupae and complete development yet that fall.

Table 33. Occurrence of Second Generation Apple Maggot Flies from Dutchess Variety in 1979 at the K.S.H. Orchard.

Seeded Date	Sept. 13	Sept. 22	Sept. 29	Oct. 13	Total in 1979	Total in 1980	Percent Second Generation
July 16	0	0	1	0	1	45	2.17
July 19	0	0	0	0	0	105	0.0
July 23	0	0	1	0	1	242	0.41
July 26	0	0	0	0	0	4	0.0
July 30	0	0	0	0	0	247	0.0
Aug 2	0	0	0	0	0	140	0.0
Aug 6	0	0	0	0	0	18	0.0
TOTAL	0	0	0	0	2	811	0.25

By dissecting the females to determine if they are gravid, one can show that there are late season individuals that are immature. Table 34 indicates that from September 13 to the end of the 1979 season at the K.S.H. orchard, about 50 percent of the individuals are newly emerged. These represent the partial second generation. To note, at this high density orchard there is a large preference for the yellow traps over the red sphere by the immature females. At the medium fly density Upjohn orchard, too few flies were caught to make any specific conclusions, but it appears doubtful there are any second generation flies in their orchard.

TABLE 34. Percent Infertile Female Apple Maggot Flies as Determined by Dissections of Trapped Females in 1979.

	K.S.H. (n=15)				Upjohn (n=9)			
	Yellow Trap		Red Sphere		Yellow Trap		Red Sphere	
Date	%	No	%	No	%	No	%	No
July 2	84.4	37	100	1	NC	0	NC	0
July 4	86.1	31	NC	0	NC	0	NC	0
July 6	81.8	45	66.7	2	NC	0	NC	0
July 9	69.1	67	21.4	3	NC	0	NC	0
July 11	68.0	66	10.0	1	NC	0	NC	0
July 13	53.4	126	18.2	6	33.3	1	NC	0
July 16	26.0	38	16.2	6	50.0	2	100	2
July 19	21.1	15	5.0	2	NC	0	0.0	0
July 23	29.1	51	26.5	9	0.0	0	NC	0
July 26	22.4	22	4.1	2	NC	0	NC	0
July 30	14.4	39	12.5	10	0.0	0	NC	0
Aug. 2	17.2	55	82.	4	0.0	0	0.0	0
Aug. 6	0.0	0	0.0	0	0.0	0	0.0	0
Aug. 9	3.7	6	10.8	4	44.4	4	0.0	0
Aug. 13	10.7	29	10.2	5	20.0	7	0.0	0
Aug. 16	.7	1	0.0	0	NC	0	0.0	0
Aug. 20	3.1	4	6.2	2	0.0	0	NC	0
Aug. 23	0.0	0	3.8	1	0.0	0	0.0	0
Aug. 27	0.6	1	0.0	0	7.1	1	0.0	0
Aug. 30	1.6	3	0.0	0	0.0	0	0.0	0
Sept. 3	5.6	9	20.0	2	0.0	0	0.0	0
Sept. 6	2.6	1	0.0	0	0.0	0	0.0	0
Sept.10	0.0	0	0.0	0	0.0	0	33.3	2
Sept.13	40.0	10	50.0	2	11.1	1	0.0	0
Sept.22	57.1	4	NC	0	NC	0	NC	0
Sept.29	50.0	2	NC	0	NC	0	NC	0
Oct. 13	NC	0	NC	0	NC	0	NC	0
Total		650		62		15		

NC Indicates no females were caught on the traps.

The dissections of the 1980 season show the same early season trends that were present in the 1979 data, but were not continued late enough in the fall to provide data on what portion of the whole population the second generation represents (Table 35). Early in the season at the high density K.S.H. orchard, 100 percent of the females caught are immature. This indicates these traps are effective in capturing early emerging individuals, and can be successfully used for monitoring emergence in high population situations. The percent immature flies caught on the yellow traps gradually decreases in number and percent until the end of August. At that time all females caught were gravid. The same trend was present on the red sphere trap. The main difference was that the immature females prefer the yellow traps over the red spheres as indicated by the much larger percents in the yellow trap column.

At the medium density Upjohn orchard, trap catch was greatly delayed. Not until late July was the first immature female caught. Once caught, they were present at about the same percentage as in the higher density K.S.H. orchard. After mid-August, no more infertile females were caught in this orchard. It is reasonable to assume that there is no or a very small second generation in this orchard as the first females caught were in mid-July, and this does not leave sufficient time for the larvae to mature, pupate, and emerge prior to winter. The same preference for the yellow trap by immature females was also present in this orchard.

Table 35. Percent Infertile Female Apple Maggot Flies as Determined by Dissections of Trapped Females Caught in 1980.

	K.S.H. (n=15)				Upjohn (n=9)			
	Yellow Trap		Red Sphere		Yellow Trap		Red Sphere	
Date	%	No	%	No	%	No	%	No
June 28	100.0	1	100.0	1	NC	0	NC	0
June 30	100.0	1	100.0	1	NC	0	NC	0
July 2	66.7	2	0.0	0	NC	0	NC	0
July 5	78.0	32	33.3	3	NC	0	NC	0
July 7	88.7	70	38.6	7	NC	0	NC	0
July 9	82.0	137	15.8	3	NC	0	NC	0
July 11	81.0	111	0.0	0	NC	0	NC	0
July 14	62.5	110	16.2	6	NC	0	0.0	0
July 16	39.7	29	9.4	5	0.0	0	NC	0
July 18	42.1	32	0.0	0	NC	0	NC	0
July 21	40.7	35	5.2	3	NC	0	20.0	0
July 23	25.9	41	7.4	2	7.4	4	0.0	0
July 25	29.8	31	5.9	1	22.6	7	0.0	0
July 28	20.5	26	5.9	3	8.6	3	0.0	0
July 30	14.1	14	4.5	2	11.8	2	0.0	0
Aug 4	13.8	27	1.3	1	26.7	4	0.0	0
Aug 11	.9	10	0.0	0	9.1	6	0.0	0
Aug 18	3.8	16	0.0	0	0.0	0	0.0	0
Aug 25	4.2	15	5.3	1	0.0	0	0.0	0
Aug 29	0.0	0	0.0	0	0.0	0	0.0	0
Sept 5	0.0	0	0.0	0	0.0	0	0.0	0
Sept 12	0.0	0	0.0	0	0.0	0	0.0	0
Sept 19	18.2	2	0.0	0	NC	0	NC	0
Total		742		39		26		1

NC indicates no females were caught on the traps.

Conclusions

A partial second generation of apple maggot flies is present in the high fly density K.S.H. orchard. These individuals commence emerging about September 25 as determined by cage studies. This date was a little late as determined by dissections of females from a larger population which found immature females present from September 10 to the end of the season. These flies are few in number, and represent only 0.25 percent of the flies that emerged as progeny from the 1979 summer adults. It was found that larvae that entered the soil as late as July 23 could still emerge that fall. This data affirms that of Dean and Chapman (1973) who claim these flies are of no consequence so far as the species control in commercial orchards is concerned.

At the medium fly density Upjohn orchard, it is doubtful that even a partial second generation exists. No females were caught in that orchard after September 13, so this could not be confirmed. However, the first individuals were caught two to three weeks later than in the K.S.H. orchard, and this delay is great enough to prevent sufficient development of larvae and pupae for the second generation to emerge.

In both orchards, there was a definite preference of trap types. The infertile females were caught on the yellow traps 13.5:1 over the red spheres. This supports the belief that infertile females are attracted to yellow traps which serve as a possible site for finding food. After maturation, they search out spherical objects, looking for mating and oviposition sites. Data presented showed that very few infertile females compared to all females were caught on the red sphere which also supports this supposition.

The occurrence of a second brood is suicidal to the species. When adults emerge in mid-September, it must take 10 days minimum for their ovaries to mature due to the cool weather. By the first of October when they are ready to deposit eggs, the susceptible varieties, and the ones in which they were reared, are all gone. The apples remaining are the less preferred, hard winter varieties. If an egg is deposited in these apples, it is doubtful they would hatch or survive due to the firmness of the flesh. If they were to survive and hatch there is not sufficient time remaining for maturation of the larvae before freezing weather sets in. If the eggs do hatch and the larvae survive, the apple is probably picked and removed from the orchard. This also interrupts the life cycle and prevents pupation in the soil. All these factors are against a successful second brood, and may be the reason why it is so small. This may also explain why the species does not become established further south and is scarce in the southern limits of its range.

LOCATION OF LARVAL PUPATION

When an infested apple falls to the ground, the apple maggot larva leaves it and burrows into the soil to pupate. The emergence of the fly the following summer can be influenced by where this pupa is located. If it happens to be on the south side of the tree and close to the surface, emergence is expected to be earlier because the pupa was exposed to the optimum warming and development conditions. If it burrows deeper into the soil, or falls on the north side of the tree where it is shaded, emergenece the following summer should be delayed. Experiments were conducted to determine if emergence is actually delayed on the north side of the tree, and to quantify the differences in the soil temperature in these different microhabitats so their influence on emergence will be known.

Literature

The literature is somewhat contradictory as to the effect of sun exposure on the emergence of flies. Glass (1960) reported that "emergence data showed that the pattern for paired cages was nearly identical under variable shading conditions." He concluded that "the location of a seeding within a test orchard was not a significant factor in time of emergence." Dean and Chapman (1973) said there are no consistent trends to show differences in emergence from exposed or shaded cages. However, Porter (1928) said "the flies emerged earlier from cages in the sun than they did from similar material in cages in the shade." And Dirks (1935) said "emergence cages maintained in full sunshine have yielded flies ten to thirteen days earlier and the height of emergence has occurred ten to thirteen days earlier than cages maintained in full shade. It is evident that under orchard conditions infested apples dropping on the south side of the tree and exposed to sunshine would produce flies much earlier than drops completely shaded on the north side of the tree."

It is also reasonable to assume the depth at which the larvae pupate would have an influence on emergence next year. O'Kane (1914, p82) found pupae among the upper grass roots, but also discovered they are deeper. His data showed the depth distribution of the pupae to be: 1/2" = 5.7%; 1" = 14.3%; 1 1/2" = 28.3%; 2" = 24.8%; 2 1/2 = 9.0%; 3" = 8.2%; 3 1/2" = 4.1%; 4" = 1.6%; 4 1/2" = 3.2%; and 5" = .1%. At these depths the soil is cooler and the pupae should develop slower.

Materials and Methods

Emergence cages were set over naturally infested ground on the south and north side of the tree in the K.S.H. orchard. In 1978, 10 pairs of cages were set on June 23 and in 1979 8 pairs of cages were set on June 18. They were monitored daily in 1978 and three times a week in 1979 until emergence occurred in each cage. After first emergence, monitoring was reduced to twice weekly. This will provide data to show whether a difference in emergence times occurs due to the location of the pupae under the tree.

To determine differences in temperatures where the pupae were located, three lead Weather Measure recording thermographs were used. The influence that depth of pupation might have on emergence was determined by placing one probe of the thermograph on the soil surface in the grass litter zone, and the other one directly below it two inches under the soil. Any differences due to differential shading between north and south sides of the tree were measured by placing temperature probes at the two inch level on both the north and south sides of the tree. Graphs were made of the temperature fluctuations, data was transcribed and entered into the computer where degree days at base 48°F were calculated and accumulated. Appendix 3 contains the daily degree day accumulations calculated. These values should explain some of the difference in emergence between the different microhabitats.

Results and Discussion

In 1978, apple maggot flies emerged first on the mean date of June 29 from cages placed on the south side of the tree (Table 36). Mean first emergence was July 2 from cages o: the north side of the tree. By averaging the difference

Table 36. First Emergence of Apple Maggot Flies From the South and North Side of the Tree at the K.S.H. Orchard in 1978.

	Date of First Emergence			Two Inch Soil dd[1]		
Variety	South	North	Diff	South	North	Diff
Transparent	6-27	6-28	1	662	615	-50
Dutchess	6-27	7-5	8	662	747	85
Greening	Never	7-5	-	-	747	-
Dutchess	6-27	7-1	4	662	676	14
Greening	6-27	7-5	8	662	747	85
Red Delicious	Never	6-28	-	-	615	-
McIntosh	7-4	6-29	-5	802	636	-166
Northern Spy	6-27	6-29	2	662	636	-26
Red Delicious	7-2	7-11	9	764	867	103
Northern Spy	Never	Never	-	-	-	-
Mean	6-29	7-2	3.9	696.6	698.4	-5.7

[1] Degree days at base 48°F; B.E. Method

between the two cages from the seven pairs of cages where flies emerged, a 3.9 day delay was present.

When the soil degree day accumulations on the date of emergence are recorded for the south and north side, the differences disappear. The mean difference between the two locations is only 5.7 degree days, which is much less than one day. Therefore, in this test soil degree days explained 4 calendar day variation in the emergence dates on the opposite side of the tree.

In 1979, the difference in emergence from cages placed on the south and north side of the tree was 7 days (Table 37). In every pair of cages that caught flies, the north side was always later, and the range of the delay was 2 to 16 days.

When soil degree day values were recorded on the dates of first emergence, much of the variation in calendar day differences was explained. The mean difference in soil degree days between the south and north side of the tree was 72.8 units, which is equivalent to four days. Therefore, the 7 days calendar day difference was reduced to just three days difference when soil degree days were used.

As was expected, the two inch soil temperature is cooler on the north side of the tree than the south side on the same calendar date. Table 38 shows the accumulations

Table 37. First Emergence of Apple Maggot Flies from the South and North Side of the Tree at the K.S.H. Orchard in 1979.

Variety	Date of First Emergence South	North	Diff	Two Inch Soil dd[1] South	North	Diff
Transparent	6-25	6-27	2	781	764	-17
Dutchess	6-25	6-29	4	781	799	18
Greening	Never	7-2	-	-	851	-
Wealthy	6-25	6-27	2	781	764	-17
Jonathan	6-27	7-13	16	810	1059	249
McIntosh	6-29	7-9	10	847	970	123
Red Delicious	Never	7-4	-	-	884	-
Northern Spy	7-4	7-11	7	930	1011	81
Mean	6-27	7-4	6.8	821.7	887.7	72.8

[1] Degree days at base 48°F; B.E. Method

Table 38. Soil Temperatures Measured on the South and North Side of the Tree at the Two Inch Depth Recorded as Accumulated Degree Days Since April 1.

Date	South	North	South	North	South	North	South	North
6/20	555	485	542	489	697	647	528	482
6/25	633	567	621	557	781	735	613	571
6/30	719	655	725	656	864	818	751	677
7/04	789	726	802	747	930	884	794	755
7/09	909	844	908	831	1014	970	898	865
7/14	1022	957	1003	919	1128	1083	1012	985
7/19	1143	1086	1103	1017	1238	1190	1131	1109
Mean Diff.	64.3		69.7		46.4		35.3	

Degree Days calculated at base 48°F; B.E. Method during the emergence period of the apple maggot fly. These degree day differences are equivalent to two to three calendar days each of the four years the temperatures were recorded. These results agree with those found in Tables 36 and 37.

Soil temperatures were measured on the soil surface in the grass litter zone and two inches directly below that in the soil. The variation in these two habitats can explain some of the variation in the range in dates of first emergence. The mean difference ranged from 29 to 94 degree day units (Table 39), which corresponds to two to five calendar days. Therefore larvae that pupated near the soil surface can emerge as adults two to five days earlier than larvae that pupated two inches deeper in the soil.

Conclusions

Calendar day differences in first emergence of apple maggot flies between the south and north side of the tree was 3.9 days in 1978 and 6.8 days in 1979. Soil degree day differences at these two sites were 5.7 in 1978 and 72.8 in 1979. In 1978, the soil degrees removed all the calendar day variation. In 1979, the soil degree days removed four calendar days of variation.

An evaluation of degree days under the tree was made. Over a four year period, the mean degree day difference between the soil surface on the south and north side of the

Table 39. Differences in Degree Day Accumulations at the Soil Surface and Two Inch Depth at Base 48°F (B.E. Method) on the South Side of the Tree at the Upjohn Orchard.

	1977		1978		1979		1980	
Date	Surface	Two Inch	Surface	Two Inch	Surface	Two Inch	Surface	Two Inch
6/20	683	586	545	515	556	501	445	402
6/25	759	663	621	588	621	567	727	500
6/30	848	751	719	690	692	639	622	596
7/04	921	823	790	762	748	718	695	672
7/09	1038	945	890	864	815	786	803	781
7/14	1143	1052	979	951	909	886	919	887
7/19	1268	1179	1079	1051	995	971	1045	979
Mean Diff.	94.4		28.9		38.3		34.1	

tree ranged from 35 to 64 units, or an equivalent of two to three calendar days. The soil surface and two inch soil degree day accumulations varied from 29 to 94 units in the same four year period, which is equivalent to two to five calendar days. These differences supported those above which help to explain the calendar day variation in emergence at the different sites.

PHENOLOGICAL PREDICTIVE MODEL OF EMERGENCE

In the past, calendar days have been used to determine when to initiate sprays for apple maggot control. For example, July 4 has been the recommended date in West Central Michigan. (Klackle, 1980). By observing Table 3, the range of first capture on traps within the same orchard and in the same year may be as great as 31 days. Table 2 shows that between years and sites, this range may be as great as 41 days. Therefore a more reliable method than calendar date is essential to provide economic control of this pest in specific orchards.

Within the past few years, phenological models to predict apple maggot fly emergence have been developed. These models are based on measuring weather factors, and then predicting when emergence will occur based on them. Most predictive models use the daily maximum and minimum air temperatures starting on April 1. From these values a certain amount of development is said to occur based on the amount of accumulation of heat over the developmental threshold. This amount is accumulated each day until the critical event to be predicted occurs. Daily accumulations are made by averaging the maximum and minimum temperatures or by integrating the area under the curve of the temperatures for that day (Baskerville and Emin, 1968).

Several researchers have made predictions for certain events in the life cycle of the apple maggot, and those of first emergence are found in Table 40. Trottier (1975) reported that based on degree days alone, first emergence occurred at 425 ±30 degree days at base 9°C using four years of trap data. This predicts emergence to within plus or minus two days at the experimental orchard at Vineland Research Station, Ontario. Reid and Laing (1976) reported that flies would emerge at 550 degree days at base 8.7°C. Lastly, Reissig _et al_ (1979) found trap catch correlated well with 641 degree days at 6.4°C. The generality of all these predictions to local growers is questionable. If emergence occurred early and growers waited to spray, damage would occur. Contrary, if flies were late emerging but sprays were applied early, they would be unnecessary. Reid and Laing (1976) also noted that all the predictions were based on single orchard data. They found that Neilson (1962) emergence data was off 24 days from their prediction leading them to believe that local populations of apple maggot flies respond differently to the environment.

Other researchers have questioned the validity of models to predict the emergence of apple maggot. Dean and Chapman (1973) reported that emergence could not be predicted by use of weather and that average calendar date was not accurate based on more than 40 years of cage emergence data from Hudson Valley, New York, and suggested that cages be set out and monitored to determine first emergence.

Table 40 Predicted Emergence of Apple Maggot Fly Based on Air Degree Day Accumulations.

Location	Developmental Threshold	First Emergence	Variance	Source
Vineland, Ontario	9.0°C	425 B.E.*	± 2 days	Trottier, 1975
Guelph, Ontario	8.7°C	550	-	Reid & Laing,1976
Geneva, New York	6.4°C	641	± 3½ days	Reissig, et al, 1979

* Baskerville Emin (1968) method of determining degree day accumulations was used.

Glass (1969), based on six years of caged emergence data in west New York, said that average temperatures in May, June and July effect peak emergence, but that first emergence can not be predicted by weather but must be monitored using caged apples. Even Reid and Laing (1976) said "emergence data will be of limited predictive value since there is such wide variation in emergence dates."

These predictions might be improved or more widely applicable if other parameters are included in the model besides air temperatures. Soil factors have been incorporated into an emergence model of Rhagoletis cerasi (Leski, 1963) which increased its accuracy greatly. Soil temperature may be the most important soil related factor to utilize to predict emergence, as this could account for the great difference in emergence due to the microhabitat where the pupa is located. Soil moisture could also increase the accuracy. Mundinger (1930) said "it seems reasonable to believe that soil moisture may be a factor of some importance in emergence time since the greatly reduced emergence of 1927 and 1929 paralleled correspondingly dry months."

My speculation is that environmental factors must effect the physiological development of the insect, and that by utilizing different methods of accumulating degree days and precipitation, a discrete threshold should be reached that would be a reliable estimate of emergence at a particular site. Several environmental and biological factors are known to effect time of first emergence somewhat, and eventhough they are not easily quantified, will be included in a predictive matrix.

Season long emergence of apple maggot fly can be correlated to environmental parameters. Lathrop and Dirks (1945) said "the highly significant correlation is interesting, and emphasizes that temperature is a most important factor influencing the seasonal flow of emergence of flies."

Materials and Methods

First Emergence. The majority of the data that provides a basis for this predictive model has already been presented. The approach will be to start at a mean air degree day value, then add or subtract a specific number of units depending on the parameter measured. All the data was generated at the K.S.H. orchard. Therefore, the predictive model will be most representative of that location. At other locations where different conditions such as population size, etc. exists, this prediction may not be accurate.

As was previously discussed, catch on the yellow Zoecon AM traps provides a good estimate of fly emergence. Table 5 showed that flies were caught on traps in the same trees under which natural emergence cages were placed on the same day as they emerged in the cages. Traps are more economical and easier to use. Therefore, trap catch will serve as the indicator of fly emergence in this phenological model.

Season Long Emergence. This was correlated with air degree day accumulations. Percent accumulative emergence values were transformed by the arcsin transformation to straighten out the curve. Least squares liniar regression was then performed, and the corresponding R^2 values calculated. Lastly, a multiple regression of air degree days, soil degree days, and percent soil moisture accumulated after first catch was correlated to the dependent variable of accumulated percent trap catch on the yellow Zoecon AM trap and the red sphere trap.

Results and Discussion

First Emergence - Mean first emergence of apple maggot fly occurs at 1117 air degree days base 48°F (8.9°C) by the B. E. method (Table 8). Using the yellow Zoecon AM trap as the indicator, this estimate was within ±58dd or 2.5 days at the K.S.H. orchard over a four year period.

Two other abiotic components were investigated as to their influence on first emergence. Eventhough considered a very important parameter, soil temperature did not increase the accuracy of this estimate as shown by a larger C.V. value (Table 11). The mean emergence occurred at 679 dd (base 48°F) ±167 or 7 days at the K.S.H. orchard over the same four year period. The last important abiotic parameter measured was soil moisture. This data was not valuable in predicting first emergence, but might be useful in measuring season long emergence.

Several biotic factors were also investigated for their influence on first emergence. The first biotic parameter of importance is variety the fly was reared in (Table 21). When four years' data are combined there is no statistical difference between the first emergence times. However, there is a range of values that can be incorporated into a generalized model (Table 41). By examining these values the deviation from the mean for any variety can be determined.

The second biotic parameter investigated was carry over pupae. It was presumed that since a pupa has been in the ground for two seasons, it would mature physiologically the first year and emerge sooner the second year. This did not occur (Table 27) as the mean emergence for second year flies was delayed three days from first year flies. Therefore this parameter can be ignored in this predictive model.

The orchard floor culture can have a marked influence on time of emergence. When measuring emergence in one

Table 41 Influence of Variety of Apple Reared in on Prediction of First Emergence of Apple Maggot Fly

Variety Reared In	Air Degree Days[1]
Dutchess	-75
Wealthy	-61
Transparent	-41
Winesap	-22
Greening	-14
Jonathan	- 7
Red Delicious	- 1
McIntosh	+38
Northern Spy	+47
Baldwin	+51

[1] 48°F; B.E. Method

orchard, this is not important. However, between orchard differences may be great (Table 32). This is due to the amount of soil shading in the orchard which directly influences the soil temperature degree day accumulations. The varying amount of heat accumulation can greatly alter the time of emergence of the files. For this particular estimation orchard floor cultures will not be included, but for a more generalized model this parameter should be incorporated. Table 42 presents degree day values to subtract from the mean value of emergence based on the orchard floor culture. These values were calculated from differences in the accumulated heat units from April 15 to June 30 found in the different experimental orchards.

Another biotic component studied was the effect a partial second generation could have on time of emergence. This has no effect on first emergence so will not be in-

Table 42 Influence of Orchard Floor Culture on Prediction of First Emergence of Apple Maggot Fly.

Orchard Floor Culture	Air Degree Days[1]
Shaded by tree tall grass	0
Shaded by tree mowed grass	-130
Exposed to sun mowed grass	-417

[1] 48°F; B.E. Method

cluded in this model. However, it does influence the late season portion of the season long model slightly, and therefore will be used later.

The next biotic component investigated the relationship between first emergence and where the pupae were located. If they were on the south side of the tree and in the grass litter zone, then a normal emergence pattern should appear. If no apples fell on the south side of the tree, but all were on the north side, then a 73 dd or 3.9 day (Table 36) delay could be expected in emergence the following year due primarily to the cooler temperatures on the shaded side of the tree and the resultant slower development of the pupa. If all the larvae burrowed down two inches to pupate or the soil was disced or died out to the extent that all pupae in the upper two inches desicated and died, a delay of 49.0 dd or two days could be expected (Table 39). If pupae were only present at the two inch level on the north side of the tree, then another 54dd or 2 days could be expected before first emergence (Table 38). These values are summarized in

Table 43. From this, the relationship of where the larvae pupated can influence emergence of the individual, but in a population sense it would have no effect on first emergence in an orchard.

Table 43 Influence of Location of Pupation on Prediction of First Emergence of Apple Maggot Fly.

Location of Pupation	Air Degree Days[1]
South Side of Tree Surface	----
South Side of Tree Two Inch Depth	- 49
North Side of Tree Surface	- 73
North Side of Tree Two Inch Depth	-103

[1] 48°F; B.E. Method

All of these parameters investigated are incorporated into the 1117 dd value for predicting first trap catch of the apple maggot fly at the K.S.H. orchard. This provided a ±2.5 day estimate over a four year period. However, when these parameters are used to predict emergence at other sites, the accuracy is greatly reduced. Table 44 shows the actual verses predicted first catch at several other sites. All of these sites are either abandoned orchards or abandoned or wild trees around commercial orchards. They all had the yellow Zoecon AM trap placed and changed just as in the K.S.H. orchard. The degree day values presented were

TABLE 44. Predicted First Trap Catch of Apple Maggot Flies with the Yellow Zoecon AM Trap in Abandoned Trees Around Commercial Orchards.

		Actual		Predicted		Error[1]	
Location		Date	dd[2]	Date	dd[2]	Days	dd[2]
Upjohn	1977	06/20	1108	06/20	1110	0	-2
Upjohn	1979	07/13	1102	07/13	1110	0	-8
Upjohn	1980	07/05	999	07/05	1110	0	-11
Hofacker	1980	06/21	705	06/14	625	7	80
1	1979	08/07	1777	07/10	1117	28	660
2	1979	07/12	1185	07/09	1095	3	90
3	1979	08/07	1777	07/10	1117	28	660
4	1979	08/21	2003	07/12	1164	40	839
6	1979	08/07	1777	07/10	1117	28	660
8	1979	07/27	1525	07/12	1164	15	361
9	1979	09/05	2308	07/10	1116	57	1192
10	1979	07/10	1131	07/10	1117	0	14
11	1979	07/31	1623	07/10	1117	21	506
12	1979	07/24	1457	07/10	1117	14	340
15	1979	07/31	1623	07/10	1117	21	506
18	1979	07/31	1623	07/10	1117	21	506
19	1979	08/07	1777	07/10	1117	28	660
21	1980	07/21	1373	07/10	1117	11	256
22	1980	08/11	1837	07/10	1117	32	720
23	1980	08/06	1718	07/10	1117	27	601
24	1980	07/16	1245	07/08	1056	8	189
25	1980	08/18	1825	07/15	1117	34	708
26	1980	07/10	1006	07/12	1056	-2	-50
27	1980	07/23	1429	07/11	1117	12	312
28	1980	08/18	1974	07/13	1164	36	810
29	1980	08/08	1786	07/11	1117	28	669
30	1980	07/25	1469	07/11	1117	14	352
31	1980	07/23	1429	07/11	1117	12	312
Range		77	1603	31	539	59	1242
Mean		7/27.5	1521	7/8.8	1099	18.7	426

[1] Negativer sign indicates number of dd actual event occurred before it was predicted to occur.

[2] dd = Accumulated Degree days base 48°F, B.E. Method

calculated at base 48°F; B.E. method from the nearest official weather reporting station. As can be seen, the range of actual first catch in these sites was 77 days or 1603 dd. With the predicted catch the range was reduced to 31 days or 539 dd. This leaves an error that ranged from -2 to 57 days and -50 to 1192 dd. This proves how inadequate a generalized model is that attempts to predict emergence at any location, as was speculated by Reid and Laing (1976).

There are several reason that might help to explain the large error in this prediction. First there might be some biological differences in the populations between the K.S.H. orchard and the more northern sites as several authors have suggested. The Upjohn prediction was very close for all three years with the predicted and actual being the same date. The Upjohn orchard is within 10 miles of the K.S.H. orchard, and those flies appear to respond to air degree days in the same manner. The rest of the orchards are 30 to 100 miles north and the flies may respond differently to photoperiods, angles of the sun, air degree days, etc.

Another reason could be the proximity of the weather stations to the abandoned trees. The one used for developing the model was located in the K.S.H. orchard, while those at the other sites may have been as far as 20 miles away from the test site.

A possible major reason for this very poor predictability of first catch is population size from year to year. In the K.S.H. orchard a very stable mature population exists year after year. In these other sites the population fluctuation can be very great as pesticide drift, host freeze outs, and many other factors influence it. This was tested by running a regression on the number of flies caught per trap against the dd error of first emergence. A R^2 of 0.15 reveiled a very small relationship between the population size and error of prediction. Therefore some other factors are much more important.

Another factor is the actual population size. With smaller populations, the tails of the population curve are much closer to the mean. This indicates that there are fewer individuals extremely early or extremely late. This fact alone could account for many days delay in first catch. To test this, the K.S.H. orchard data was reworked to determine the mean 1 and 5 percent trap catch air dd accumulations. The mean 1% emergence over the 4 years occurred June 19.7 or 1.1 days later than mean first catch. The air dd accumulations were 1117 for first and 1150 for 1 percent. This did not help reduce the error in the prediction of trap catch in the abandoned trees. Likewise the 5 percent mean trap catch occurred July 4.5 or 1256 air dd. Predicting 5 percent emergence at the abandoned sites also had the same error range. Therefore this did not increase the reliability of the model.

Lastly, experimental error such as thermometer calibration could cause a several day difference in the prediction date (all thermometers were calibrated to try to reduce this error). All these factors help to explain why this predictive model is not very accurate at different sites. The results is that it should not be used to predict emergence at locations other than K.S.H. or Upjohn, and at those other sites traps should be used to measure first emergence.

Season Long Emergence. Accumulative air degree days is a very reliable tool to estimate the cumulative percent trap catch of apple maggot flies at the K.S.H. orchard. Figure 16 shows the typical sigmoid population curve for the accumulated average trap catch on the yellow Zoecon AM trap in 1978. A least square linear regression of this gave an equation which resulted in a coefficient of determination of .9126. This is an exceptionally good fit for any biological data. When this data was transformed by the arcsin transformation which tends to straighten out the ends of accumulative percent data and a least squares linear regression performed on the resultant data, a R^2 value of 0.9643 resulted. This also indicates that accumulative air degree days at base 48°F (8.9°C) by the B.E. method is a very reliable

predictor of percent accumulative trap catch. To test whether this was a fortunate circumstance in 1978 or not, the same procedures were completed for trap catch at another site with another trap and other years (Table 45). This does show that air degree days alone accounts for about 95% of the variability between the actual and predicted relationship. This was not significantly improved by transforming the data, so the raw data can be used for predictive purposes. Because the data fit so well, all four

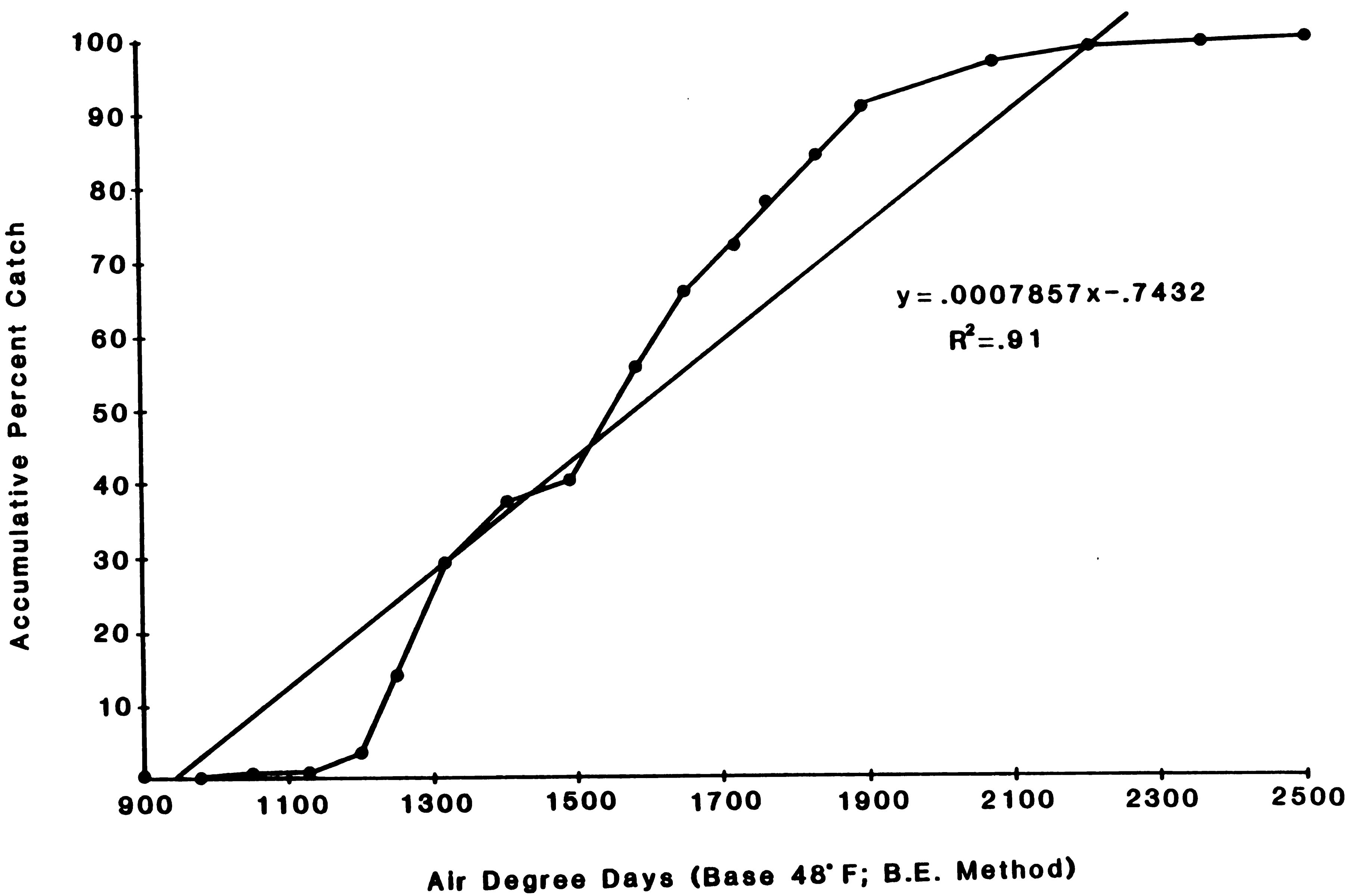


Figure 16. Accumulative Percent Trap Catch of Apple Maggot Flies on the Yellow Zoecon AM Trap at the Kalamazoo State Hospital Orchard in 1978.

TABLE 45. Least Squares Linear Regression of Accumulative Percent Trap Catch to Accumulative Air Degree Days at Base 48°F (8.9°C); B.E. Method

Location	Year	Trap	Data	A	B	R^2
K.S.H.	1977	Yellow	Raw	-.4702	.000456	.995
K.S.H.	1977	Yellow	Arcsin	-.7178	.000619	.971
K.S.H.	1978	Yellow	Raw	-.732	.000786	.913
K.S.H.	1978	Yellow	Arcsin	-1.161	.001128	.964
K.S.H.	1979	Yellow	Raw	-.7091	.000692	.965
K.S.H.	1979	Yellow	Arcsin	-1.071	.000980	.955
K.S.H.	1980	Yellow	Raw	-.6436	.000618	.966
K.S.H.	1980	Yellow	Arcsin	-1.051	.000919	.971
K.S.H.	All	Yellow	Raw	-.505	.000552	.849
K.S.H.	All	Yellow	Arcsin	-.8024	.000790	.838
K.S.H.	1979	Red	Raw	-.8889	.000774	.934
K.S.H.	1979	Red	Arcsin	-1.354	.00112	.938
K.S.H.	1980	Red	Raw	-.6935	.000638	.961
K.S.H.	1980	Red	Arcsin	-1.088	.000929	.976
K.S.H.	All	Red	Raw	-.7859	.000705	.934
K.S.H.	All	Red	Arcsin	-1.213	.00102	.942
Upjohn	1977	Yellow	Raw	-.7557	.000571	.913
Upjohn	1977	Yellow	Arcsin	-1.122	.000814	.889
Upjohn	1979	Yellow	Raw	-1.046	.000819	.834
Upjohn	1979	Yellow	Arcsin	-1.408	.00108	.761
Upjohn	1980	Yellow	Raw	-.9666	.000806	.929
Upjohn	1980	Yellow	Arcsin	-1.428	.00115	.934
Upjohn	All	Yellow	Raw	-.7182	.000610	.809
Upjohn	All	Yellow	Arcsin	-1.077	.000867	.794
Upjohn	1979	Red	Raw	-1.022	.00078	.885
Upjohn	1979	Red	Arcsin	-1.295	.00097	.770
Upjohn	1980	Red	Raw	-1.096	.000845	.969
Upjohn	1980	Red	Arcsin	-1.606	.00119	.961
Upjohn	All	Red	Raw	-1.069	.00818	.928
Upjohn	All	Red	Arcsin	-1.478	.00110	.869

years data at the K.S.H. orchard were lumped to generate a generalized predictive equation for that orchard. The resultant equation (4) gave an R^2 of 0.849 which is an excellent correlation over a four year period.

$$\text{Eq. 4.}\quad y = .0005524\, x - 0.505$$

Multiple regression was performed on the 1979 and 1980 K.S.H. orchard data. The dependent ( ) variable was the accumulative percent catch on the yellow Zoecon AM trap or the red sphere trap. The independent variables started with the first catch and were accumulative air degree days (X_1), accumulative soil degree days (X_2), and accumulative soil moisture (X_3). As previously shown, each of the variables can predict accumulative percent trap catch with a great deal of accuracy. This was confirmed in this analysis. When using the yellow trap as Y, X_1 alone gave an $R^2 = 0.986$, X_2 alone gave a $R^2 = 0.989$, and X_3 alone gave a $R^2 = 0.984$. The multiple regression gave a $R^2 = 0.982$ which is lower than any of the variables alone. In 1980 with the yellow trap as the Y, X_1 alone gave a $R^2 = 0.983$, X_2 gave a $R^2 = 0.985$, and X_3 gave a $R^2 = 0.980$. The multiple regression gave a $R^2 = 0.975$ which is again lower than any one of the variables alone. When combining both years data together and Y being accumulative percent catch on the yellow trap, the X_1 gave a $R^2 = 0.949$, X_2 gave a $R^2 = 0.961$, and X_3 gave an $R^2 = 0.911$. The multiple regression shown in Equation 5 gave a $R^2 = 0.975$.

$$\text{Eq 5}\quad Y = -\,8.91 - 0.06X_1 + 0.12X_2 + 0.67X_3$$

When using the red sphere trap as the dependent variable Y, the same analysis as above gave in 1979; X_1 - R^2 = 0.969, X_2 - R^2 = 0.976 and X_3 - R^2 = 0.978. This multiple regression gave a R^2 = 0.968 which is again lower than any one of the independent variables alone. In 1980 the same analysis gave: X_1 - R^2 = 0.983, X_2 - R^2 = 0.984, and X_3 - R^2 = 0.978. The multiple regression gave a R^2 = 0.975 which is again lower than any variable alone. The regression with both years data lumped together gave the following results: X_1 - R^2 = 0.939, X_2 - R^2 = 0.952, and X_3 - R^2 = 0.903. This multiple regression found in Equation 6 gave a R^2 = 0.966.

$$\text{Eq 6} \quad = -14.35 -0.08X_1, + 0.13X_2 + 0.08X_3$$

These equations, or the single linear regression equations, could be used to very accurately predict the accumulative percent trap catch at the K.S.H. orchard.

Conclusions

When attempting to predict first emergence of the apple maggot fly at the K.S.H. orchard, trap catch on the yellow Zoecon AM trap occurred at 1117 air degree days base 48°F ±2.5 days over a four year period. This prediction even held at the Upjohn orchard where trap catch occurred on the predicted day all three years. The incorporation of soil temperature and soil moisture did not improve the predictability. The influence of variety and orchard floor culture were incorporated into the model and it was used to predict first trap catch at 25 different sites. This did not give good results as the actual event ranged from -2 to 57 days from the predicted event. The calendar day range was 77 days. The land 5 percent trap catch prediction also had this same large error. Therefore in other sites traps should be used to determine flight activity and when to initiate controls rather than relying on this predictive matrix.

Accumulative air degree days provides an exceptionally good means of predicting accumulative percent trap catch on the yellow Zoecon AM trap and red sphere trap at the K.S.H. and Upjohn orchards. A least squares linear regression on the four years data gave an R^2 of .85 for the resultant equations. Multiple regressions performed discovered that it did not improve the predictability by incorporating soil degree days and soil moisture over that achieved by air degree days alone.

PART 2

MANAGEMENT STRATEGIES IN COMMERCIAL ORCHARDS

Under the current management scheme for apple maggot, commercial growers are advised when to time the first application by experience, professional advisors, or the Cooperative Extension Service (CES). The method employed by the CES staff is to place traps in abandoned trees where known infestations exist, and monitor for emergence. Once it has occurred, they alert growers that in 7-10 days the first application should be made. From then on applications should be made at two week intervals. This regional method is suitable for the CES because it's role is to advise all growers when first flies have emerged.

For the great majority of the growers, this strategy would require more sprays than are necessary. Most growers have the pest under control, have limited outside reservoirs of flies, and have a greatly reduced population to manage. A better strategy for them would be to place traps in abandoned trees on their own farm, and monitor emergence there. Based on this approach, control timing would coincide with insect pressure in their own orchard.

The best approach however, is to monitor apple maggot flies within the orchard. With little risk on the growers part, this approach should provide them with the most efficient and reliable method of preventing fruit damage. This approach is being inplemented by most IPM programs and private consultants.

Figure 17 illustrates these approaches in 29 different test orchards. Line A represents the regional approach where after first catch in an area, biweekly sprays are recommended. Using this approach five insecticide applications are needed for apple maggot control. On Lines B and C, the dots indicate first capture of apple maggot flies on the yellow Zoecon AM trap. By trapping in abandoned trees around commercial orchards (Line B), most growers can delay their first maggot spray. The average date of first catch was August 4, indicating that for the average grower two sprays were applied for apple maggot flies that were not necessary. Line C is the preferred method. Growers or consultants can trap flies in grower orchards and wait until flies are caught in the orchard before they spray, assuming other pests are under control. Each dot represents the first catch on a trap optimally placed in the perimeter row of the orchard. If sprays were applied based on this strategy several applications would not be necessary. To note, flies were never caught in seven of the 29 orchards monitored, and in those no applications would have to be made this season for apple maggot.

To most efficiently use the in-orchard monitoring scheme to control the population that could potentially infest their orchards, the grower needs to know and understand several factors involved with monitoring the apple maggot. These include the best method of monitoring such as what trap type should be used, where should it be

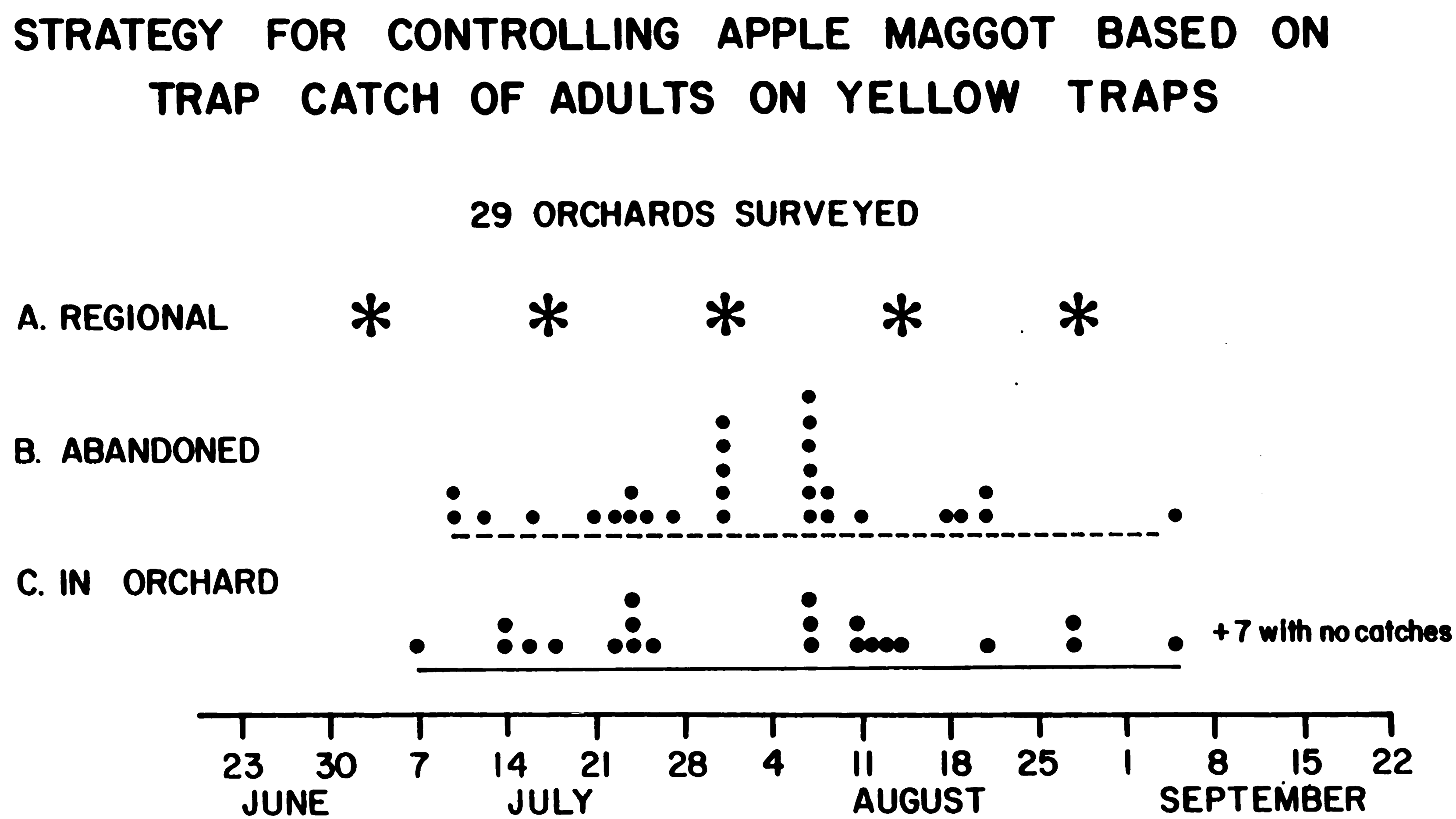


Figure 17. Strategies for Controlling Apple Maggot Flies Based on Trap Catch of Adults on Yellow Zoecon AM Traps (29 Orchards Surveyed).

placed, and at what density in the orchard; how long after flies are detected in abandoned trees will it be before they migrate to the orchard; can he properly identify the apple maggot fly and distinguish it from the other flies on the traps; and is the trap good enough to predict the amount of fruit damage he will experience. If he has information to answer these questions, then he should be able to efficiently manage apple maggot in his orchard.

The last possible management strategy suggested is to spray just the perimeter of the orchard. If flies actually disperse into the orchard, then a reduced trap catch and fruit damage could be measured. If true, then the grower could considerably reduce his costs while maintaining adequate control by spraying just the perimeter rows.

DETERMINATION OF BEST METHOD OF MONITORING

In the past, populations of apple maggot have been monitored by several methods. A study was initiated to determine which of these would be best for the grower or his advisor. Best is defined several ways in order to answer different questions. First, the best type of trap was determined by which one caught the first flies, which one caught the first gravid female, which one caught the most flies, which one caught the last flies and which one gave the highest R^2 to fruit damage. After determining which trap to use, studies were conducted to determine the best positioning and placement of the traps in the orchard. Lastly, the proper density of the traps per orchard was determined by comparing first catch, catch per trap, and relationship to fruit damage.

Literature

Earlier in this dissertation was presented a discussion on the evolution of different types of cages and traps used in research orchards to monitor apple maggot emergence. Some recommendations have been presented on which type of trap should be used and at what density in commercial orchards to monitor apple maggot for management decisions.

Several researchers have encouraged yellow Zoecon AM trap use by growers to time controls. Orchardists attempting pest management in Nova Scotia place traps at a density of 1 trap per hectar and if any flies are caught, controls are advised to be applied on July 21 on varieties maturing later than Gravinstein (Whitman, 1978). These traps are then cleaned off, and if any more flies are caught after 14 days, another spray is recommended. In New York (Leeper, 1978) growers place 5 or 6 traps on the perimeter of 10 acre blocks. After trap catch, sprays are advised in 7-10 days. In high pressure blocks the entire orchard is sprayed, but in lower pressure blocks only the perimeter rows are sprayed. These recommendations have reduced the number of sprays required for apple maggot control in 6 of 13 test orchards in Nova Scotia, Quebec and Ontario (Neilson, et. al; 1976). Neilson et. al (1976), Trottier et. al. (1975) and Neilson (1978) felt sprays based on adult captures on traps are more appropriate than those based on emergence from cages.

An improvement over the standard yellow Zoecon AM trap in capturing flies in commercial orchards is the red sticky sphere (Moore, 1969; Prokopy, 1972a; and Reissig, 1974), especially late in the season. Prokopy (1975 b) reported that he achieved economically acceptable control using the red spheres. As the fly matures, its behavior changes and the female is attracted to apples for oviposition and not to foliage for feeding. They feed less as they get older (Stanton, 1969), yet the oviposition drive remains high. The red spheres mimic apples and attract flies well. In fact, they caught three times as many female flies three weeks earlier than the Zoecon AM traps in commercial orchards (Prokopy, 1979). He also had a correlation of .87 of damage to trap catch on the red spheres in Massachusetts. His recommendation is to control the flies once they have been caught and the fruit is susceptible. Hitichi (personal comm) in Ontario recommends placing 2 red spheres in each of five perimeter trees per 10 acre block and once a fly is caught, controls should begin immediately.

The future component to be incorporated into traps will be volatiles given off by the maturing fruit. It has been shown that odor of apples attracts apple maggot flies (Prokopy, 1968; Prokopy and Bush, 1973; Prokopy et. al., 1973; and Reissig, 1974b). Reissig (personal comm) has isolated four chemical volatile components given off by Red Delicious and Red Astrican varieties that exhibit a positive bioassay response. Identification is currently in progress and preliminary results indicate four components to be short chain esters. Once identified, they may be synthesized and incorporated into traps. Trapping efficiency could be much greater, and control may be achieved by mass trapping or confusion of the females so that no oviposition can occur.

Materials and Methods

Trap Type Comparison. Two visual trap types were compared for their attractiveness of apple maggot flies in commercial orchards. The standard yellow Zoecon AM trap was placed on one side of the tree 1/3 the distance in the canopy. On the opposite side of the tree was placed a red sticky sphere at the same position. Foliage was removed for a distance of 12 inches around the traps. Traps were placed in 20 commercial orchards in 1979 and eleven commercial orchards in 1980. However, three orchards had resident populations of flies and were discarded from the analysis. The yellow traps were replaced every two weeks. Traps were inspected for the presence of apple maggot flies three times each week, and then cleaned off. Trap locations were reversed every two weeks to avoid a bias created by trap location within the tree. The number of flies caught was recorded at each visit. Flies were saved for sexing and determination of maturity.

Trap Placement. Traps were placed in different locations in the orchard to determine best placement. A series of orchards had traps placed equal distance around their perimeter. Another group had traps placed on the perimeter trees, but biased near outside infestations in abandoned apple trees. The last group had traps placed in the perimeter, second, third and fourth rows in the orchard, but biased toward the outside infestations.

Trap Density. The last test involved placing traps in orchards at different densities. Five orchards had 1, 2, 4 and 10 trap trees each in 1979 in the 4 hectare block. In 1980, 1 orchard had 1 trap tree, two had two trap trees, two had four trap trees, and six had 16 trap trees per 4 hectare block. Using these densities as treatments, the best was tested for by using the criteria used to determine the best trap type.

Results and Discussion

Trap Type Comparison.

First Catch. The comparison of trap types gave the expected results. Table 46 presents the dates of first catch of apple maggot flies in the commercial orchards for both years on each trap type. The mean dates for first catch on the yellow traps was August 10 and for the red spheres was August 15. In abandoned situations, one would expect the yellow trap to catch files first, because of their feeding behavior preferences. However, by the time they leave those sites and disperse to the commercial orchard, they are believed to be gravid and searching for oviposition sites. This was the case as in these years there was no statisitcal preference for the yellow traps in the commercial orchards when the 16 orchards are compared which had flies caught on both types of traps. The yellow traps caught flies 5.8 days sooner, which is not significantly different at the .05 level by analysis of variance. This finding is directly opposite that reported by Prokopy (1979). Because of their ease of use, and because they catch flies sooner (but not statistically), growers should use the yellow Zcecon AM trap to monitor apple maggot flies in their orchard.

The most significant result of this study is to note the range of dates of first catch in the commercial orchard.

TABLE 46. Date of First Catch of Apple Maggot Flies in Commercial Orchards and in Abandoned Trees Around Commercial Orchards on Different Types of Traps.

		In Orchard		Abandoned Tree		Delay From Abandoned	
Year	Orchard	Yellow[1]	Red[2]	Yellow[1]	Red[2]	Yellow[1]	Red[2]
1979	3	8-28	8-28	8-7	7-31	21	28
	4	9-5	8-14	8-21	8-21	15	-7
	5	-	-	8-21	8-21	-	-
	6	-	9-5	8-7	8-7	-	29
	7	-	8-21	8-7	8-7	-	14
	8	8-28	8-28	7-27	7-31	32	28
	9	-	-	9-5	9-5	-	-
	10	7-14	7-31	7-10	7-10	4	21
	11	8-7	8-28	7-31	7-31	7	28
	12	7-24	8-3	7-24	7-17	0	17
	13	8-14	-	7-24	7-17	21	-
	15	7-24	8-21	7-31	8-21	-7	0
	16	8-21	8-7	7-31	8-21	21	-14
	17	-	9-5	7-31	8-21	-	15
	18	-	9-18	7-31	-	-	-
	19	8-7	8-14	8-7	8-21	0	-7
	20	-	9-5	-	-	-	-
1980	21	8-13	-	7-21	7-28	23	-
	22	7-25	8-11	8-11	8-11	-17	0
	23	-	-	8-6	8-11	-	-
	24	8-11	-	7-16	8-6	26	-
	25	8-12	8-19	8-18	-	-6	-
	26	7-7	7-22	7-10	7-30	-3	-8
	27	7-23	7-25	7-23	7-28	0	-3
	28	8-11	8-22	8-18	8-27	-7	-5
	30	7-16	8-13	7-25	8-6	-9	7
	31	8-27	8-6	7-23	8-6	35	0
Mean		8-9.6	8-15.4	8-1.4	8-7.5	8.2	7.9

1 Yellow Zoecon AM Trap
2 Red Sphere Trap

A regional control recommendation based on trap catch in abandoned trees would be made by July 4. In actuality, no orchards monitored had files present at that early date. The average grower would not spray for apple maggot flies until August 10. Several blocks did not have any flies in them until late August, and three never had any flies caught all season. This points out the value of firm level monitoring to determine the presence or absence of a pest. If not present, then pesticide applications are not needed.

First Gravid Female. The results for the first capture of gravid females was not different than that for first capture of flies. In 20 of 23 orchards (87%), the day that the first flies were caught there were fertile females on the yellow Zoecon AM traps. The other three orchards had gravid females on the traps at the next visit. On 81 yellow traps that caught flies in commercial orchards over the two year period, 69 or 85% had fertile female flies on them the day of the first capture. Nine of the remainder averaged 8.8 days after initial catch before they had fertile females on them. Three traps that caught male flies never caught female flies. The result from this study indicates that 85% of the time, the first day that flies are caught on the yellow trap in commercial orchards there will be gravid females on them. Therefore, it is not necessary to save flies, sex them and disect the females to determine if they are gravid, because they almost always will be.

When red sphere traps are used, the presence of gravid females on the day of first catch of flies cannot be assured. In 16 of 25 (64%) of the orchards, gravid female flies were present on the sphere the first day flies were caught. In six orchards where females were caught later, the mean delay was 10.0 days. In three orchards females were never caught on the traps. On the 84 traps placed in the orchard that caught flies, 48 or 57% had fertile females on them the first day flies were caught. On eleven traps that caught fertile females later, the mean delay was 11.0 days. Twenty-five red sphere traps caught males but never caught female flies. All these factors indicate that this trap is not as effective nor reliable in catching fertile females as the yellow trap, and should not be used if gravid females are to be indicator for spray applications.

Most Flies Caught. The trap types differed in the number of female and total number of flies caught (Table 47). The yellow Zoecon AM trap caught an average per trap in commercial orchards of 3.04 females. This was not significantly more at the .05 level by the DMR test than was caught by the red sphere traps which was 1.61, but it was 88% more females. Seventy-six percent of all the flies caught on the yellow traps were females, while only 30% were females on the red spheres. Therefore, the yellow trap appears to be a better indicator of the potential damage

TABLE 47. Average Number of Apple Maggot Flies Caught Per Trap on Each Trap Type in Commercial Orchards.

		Yellow Zoecon AM		Red Sphere	
Year	Orchard	Females	Total	Females	Total
1979	1	6.9	8.7	4.3	12.6
	2	3.2	4.2	13.0	17.7
	3	2.0	3.0	1.0	2.0
	4	0.2	0.7	0.2	1.0
	5	0.0	0.0	0.0	0.0
	6	0.0	0.0	0.0	0.1
	7	0.0	0.0	1.0	1.0
	8	0.5	0.7	0.2	0.5
	9	0.0	0.0	0.0	0.0
	10	2.5	2.5	0.7	4.2
	11	2.5	2.5	2.5	5.5
	12	29.4	35.8	6.1	12.0
	13	5.0	6.0	0.0	0.0
	14	9.6	18.5	1.8	26.9
	15	3.5	4.0	0.5	1.5
	16	0.1	0.3	0.6	1.8
	17	0.0	0.0	0.0	1.0
	18	0.0	0.0	0.2	0.2
	19	1.5	1.5	1.5	4.0
	20	0.0	0.0	1.0	1.0
1980	21	0.1	0.1	0.0	0.0
	22	5.0	5.0	3.0	33.0
	23	0.0	0.0	0.0	0.0
	24	1.5	2.0	0.0	0.0
	25	0.5	0.5	0.3	1.0
	26	18.0	25.1	10.5	37.5
	27	0.2	0.4	0.0	0.1
	28	0.2	0.2	0.1	0.2
	29	1.2	1.4	0.5	0.9
	30	0.5	1.5	0.2	0.5
	31	0.1	0.1	0.7	1.1
Mean		3.04	4.02	1.61	5.40

that could occur in the orchard. If total numbers of flies caught were meaningful, then the red sphere would be a better trap to use. On the average, it caught 5.4 flies per trap compared to 4.02 flies per trap on the yellow traps. This is not a significantly larger number, but is a 34% increase in catch. As is indicated by the above values, the red trap caught considerable more male flies.

Last Fly Caught. Another important parameter in apple maggot management is to know when to apply the last spray. Currently most growers apply their last spray in mid to late August. Table 48 shows that this is too soon. The first column indicates trap catch of flies in abandoned trees around commercial orchards. These are the flies that can invade the orchard and infest the fruit especially in late August when the fruit in the abandoned trees is heavily infested and apples in the commercial orchard are susceptible for egg laying and are unprotected. These flies are caught until late September providing late season pressure. More importantly, the peak catch in these abandoned sites occurs the first week of September, which means the peak pressure is in early September. The second column is the trap catch of flies in the commercial orchards. As can be seen, the catch occurs over the same time frame, even though there are fewer flies caught in the orchard. Important to note is that the peak catch again occurs in early September, after most sprayers are put away. This confirms that growers stop spraying too soon in the fall, and any damage from apple maggot probably occurs during the four week period after the last spray and the last catch.

Table 48 Weekly Average Trap Catch of Apple Maggot Fly Adults on Yellow Zoecon AM Traps In and Around Commercial Orchards.

Date	Abandoned Trees (24)[1]		In Orchard (111)[2]	
	Yellow	Red	Yellow	Red
June 23	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00
July 7	0.00	0.00	0.02	0.00
14	0.13	0.00	0.04	0.01
21	0.17	0.21	0.10	0.00
28	1.21	0.58	0.16	0.05
Aug. 4	4.33	4.67	0.26	0.07
11	6.96	4.50	0.55	0.34
18	5.25	9.08	0.34	0.59
25	9.21	17.00	0.64	1.65
Sept. 1	11.62	21.21	1.12	1.17
8	6.05	19.46	1.09	1.79
15	1.00	0.43	0.21	1.46

[1] Number of Traps Monitored

A comparison of the last catch of flies by each trap type again indicates the yellow Zoecon AM trap is preferable. In 98 trap trees in commercial orchards which caught female apple maggot flies, 59 percent of the time the yellow Zoecon AM trap caught the females last, twenty-nine percent of the time the red sphere caught females last, and 12% of the time both traps caught females on the last day of catch. If females are the preferred indicator for the last spray, then the yellow trap is twice as effective in monitoring last flight than the red sphere traps. If a grower was not concerned with which sex of fly was present in his orchard, the yellow trap would still be preferred for monitoring last activity, but not to the extent as it was for the last female. Forty-four percent of the time the yellow trap caught the last fly, 40% of the time the red sphere caught the last fly, and 16% of the time both trap types caught the last fly on the same day. So whether last female or last fly activity is required, the yellow trap is a better indicator.

Trap Placement.

During the analysis of best trap placement, three blocks were deleted. These orchards were suspected in 1979 and proved in 1980 to have a resident population of apple maggot flies. Because of these residents, the time delay of migrating from abandoned trees into the orchard as is the typical case with apple maggot experienced by most growers could not be measured. Also, very few blocks have resident flies, and the basic premise on which management decisions are based is that all flies are immigrants, therefore these blocks were deleted to provide a consistent set of data for valid analysis.

Table 49 presents data on determining which method of trap placement is best. If one wanted to place traps to ensure they would catch the first flies migrating into the orchard, one would not place traps uniformly or equidistant around the perimeter of the orchard. In eight orchards tested, this placement caught first flies an average of 11 days later than other methods of trap placement tested when using the yellow traps, and 7 days later when using the red

TABLE 49. Location of Trap Placement in Commercial Orchards in Relation to Different Mean Trap Catch Parameters.

Location	No.	First Catch		Catch/Trap		Delay From Abandoned		Trap Catch to FD (R^2)	
		Yellow	Red	Yellow	Red	Yellow	Red	Yellow	Red
Perimeter Row Uniform	8	08/16	08/20	5.01	2.61	7.7a	14.75a	.67	.87
Perimeter Row Biased	16	08/11	08/19	2.88	5.37	8.2a	7.1a	.33	.31
Second Row Biased	4	08/05	08/13	0.40	1.50	6.5a	7.0a	.34	.21
Third Row Biased	3	08/12	08/18	0.30	0.87	19.3a	12.5a	.75	.56
Fourth Row Biased	4	08/20	08/21	0.17	0.37	21.5a	12.0a	.95	.89

Means followed by the same letter are not statistically different at the .05 level by the DMR test.

spheres. Therefore, this placement scheme is not recommended.

Equidistant perimeter trap placement was greatly improved by placing traps in perimeter trees, but biasing those trap trees selected so they are near potential infestation sources. This was tested in 16 orchards, and the overall results are very good. The mean date of first catch was August 11 using the yellow trap and August 19 using the red sphere, the second earliest of the methods tested. The mean catch per trap was the highest of all the trapping schemes tested using the red sphere trap and second highest using the yellow traps. Therefore biasing the traps toward infestation sources can be recommended to determine when controls should be initiated for apple maggot.

The last approach is to place the traps at different distances into the orchard. This might be desirable to determine how far in the orchards the flies travel. It has been suggested that a grower could spray just the perimeter rows of his orchard late in the season when apple maggot is the only pest present. Table 47 indicates that second row trapping is the best scheme. It caught flies first and had the shortest delay from abandoned trees. However, the sample size is too small to make valid assumptions and recommendations. This practice by all growers will not be recommended .

The relationship of trap catch and percent fruit damage is a very important parameter to use when determining which trap type and placement is best. This will be more fully discussed later. To note here is that the scheme that catches the least flies provides the best coefficient of determination. If these small sample sizes actually express the real situation, then one would want to place traps on the fourth row into the orchard and biased toward the infestation sources. However, this probably would not be suitable because that placement caught the first flies last, caught the fewest flies, and had the longest delay from the abandoned trees. This placement should not be considered because control measures were based on trap catch on the perimeter trees in these orchards, and if they were delayed for catches on the fourth row traps, a different set of damage values would have been used to calculate the R^2 values.

Table 50 indicates that perimeter spraying is feasible if no resident flies are present. The sampling scheme of biasing traps toward the four most likely infestation sources and placing traps in each of the four perimeter rows at each site was replicated in five orchards. A two-way analysis of variance showed no statistical difference between the trap catch from row to row. However, a steady decline in catch occurs, and by the fourth row in the orchard only .05 flies per trap were caught in these five orchards. This indicates that a grower could, with minimal risk to his crop, spray just the perimeter four rows of his orchard for apple maggot when no resident flies are present. This is therefore a feasible alternative to reduce costs for apple maggot control.

Table 50. Migration of Apple Maggot Flies into Commercial Orchards as Determined by Yellow Zoecon AM Trap Catch (5 orchard sample - 4 reps/orchard).

Row into Orchard	Mean Accumulated Catch
1	.45a
2	.30a
3	.25a
4	.05a

Means followed by the same letter are not statistically different at the .05 level by the DMR Test.

Trap Density.

Traps were placed in four hectare blocks in an attempt to determine the density or how many trapping locations are adequate. Fewer traps are desired to reduce material and labor costs, but sufficient traps are needed to reduce the risk of missing flies and occurring fruit damage. Table 51 shows that the mean first catch date is sooner on the yellow traps than the red spheres for each density. Also the trend is present that if first fly catch is most important, 16 traps should be placed in the orchard. However, whether by random chance or experimental error, two trap locations gave the very earliest trap catch. Therefore, by proper placing traps near outside infestation sources, two trap locations should be sufficient.

The fluctuation in the mean catch per trap is not dependent upon density because these traps are generally located at least 100 yards apart, and their effective range is probably limited to a few feet. What this does indicate however, is the relative population of apple maggot in each orchard. As can be seen, these orchards do vary in the average number of flies per trap. In most cases, the red sphere caught more flies than the yellow trap, but this is due to them catching more males. Two traps per 4 hectares appears to be the property density for catching the most flies per orchard. The 10 trap orchards can be ignored because all of them were discovered to have resident populations of flies. This does show however that the trap catches are indicative of the natural population of flies in these orchards.

The two trap per block density is also preferred when minimizing the delay in trap catch from abandoned trees. For each trap type, the time difference in catch between abandoned trees adjacent to the orchard and in traps on the perimeter row nearest the source was the shortest.

Table 51. Relationship of Trap Density to Catch of Apple Maggot Flies.

Density	No. Orchards	Mean First Catch		Mean Catch/Trap		Mean Delay from Abandoned	
		Yellow	Red	Yellow	Red	Yellow	Red
1	6	8-12	8-27	2.33	6.17	10.7a	22.0b
2	7	7-30	8-14	5.09	6.92	4.8a	- 3.0a
4	6	8-15	8-22	0.75	1.83	11.0a	24.5b
10	3	8-7	8-15	12.87	4.63	12.5a	5.0a
16	5	8-6	8-9	0.26	0.32	8.4a	- .25a

Means followed by the same letter are not statistically different at the .05 level by the DMR Test.

Conclusions

Trap Type Comparison. Based on the data gathered from the 31 commercial orchards, the yellow Zoecon AM trap is the preferred trap to use for monitoring apple maggot flies in commercial orchards. They catch flies sooner, catch gravid female flies sooner, and catch females later in the season than the red sphere trap.

Trap Placement. Yellow Zoecon AM traps should be placed in the perimeter row of the orchard, and biased toward the outside orchard sources of infestation. With this placement, flies will be caught sooner than most other placement schemes, more flies will be caught, and the delay in catch from abandoned trees will be reduced over other placement schemes. By placing traps in consecutive rows into the orchard, it was found that flies do not disperse widely throughout the orchard, but generally stay in the outside rows. This can greatly aid management and reduce costs by spraying just the perimeter rows late in the season.

Trap Density. Two yellow traps are sufficient to monitor a 4 hectare block if the traps are located near outside orchard infestation sites. This density provided the earliest mean date of first catch, the largest mean catch per trap, and the shortest delay in catch from abandoned trees. To reduce the risk associated with missing earlier flies, more traps could be set, but this risk avoidance is accompanied with larger material and labor costs.

DELAY IN CATCH OF AM FLIES IN COMMERCIAL ORCHARDS FROM OUTSIDE SOURCES

As has been discussed previously in this dissertation, the arrival of apple maggot flies in the commercial orchard is a very important parameter to measure for efficient control. Few orchards have resident flies, and the flies that invade the orchard must come from outside sources. These sources are generally abandoned and neglected trees in backyards, fencerows, or orchards. Most often there is sufficient food sources and ovipositional sites in these abandoned sites for fly development. However, as over crowding and competition for available resources increases, the flies expend energy, disperse and risk the chance of finding other unexploited resources. Once they reach the commercial orchards, then some control measures need to be taken by the grower to prevent crop loss.

Literature

The dispersal and ovipositional drives in apple maggot can be very strong. Prokopy (1978) found that flies in Dorr County, Wisconsin, left a fruitless orchard, found a green tomato he had hung in a birch tree one-half mile away and oviposited in it. This fruitless condition or lack of oviposition sites is one of the factors involved with dispersion. It should be noted that flies reared on wild and abandoned apple as well as several species of hawthorn can infest apples in commercial orchards (Reissig and Smith, 1978). Therefore all these sources should be trapped.

Disperson is an evolutionarily stable strategy achieved by the apple maggot. Frequently apple and hawthorn flowers or young fruits are destroyed by early summer frosts. Also, many varieties of apple are naturally biennial and diseases can be severe and leave no fruit for oviposition when the females emerge. These factors tremendously reduce the potential oviposition sites, therefore, making it beneficial for a portion of the population to expend energy and disperse to find untapped ovipositional sites. This is apparently what happens when flies enter the commercial orchard. Once there, they can oviposite and maintain the gene pool.

An important criteria growers should know is the lag time between first emergence in abandoned trees and first arrival in commercial orchards. Reissig and Tette (1979) noted first trap catch in mid-July in abandoned trees and in early August in commercial orchards. Prokopy (1979) found in 6 orchards that this delay was 3-6 weeks. Practically this meant that growers who were advised to spray 7-10 days after first trap catch in abandoned trees and then every 14 days thereafter would have applied 1 or 2 sprays for a pest that was not even in the orchard. This delay in arrival in commercial orchards was estimated by trapping flies in outside sources near the commercial orchard and in the perimeter row of the orchard nearest to that outside source.

Materia] and Methods

In each orchard monitored, both the yellow Zoecon AM and red sticky sphere traps were placed in abanonded trees and on the perimeter row adjacent to the abandoned trees in the commerical block. These were monitored and cleaned off, and the flies counted and saved for sexing. The females were dissected to see if they were gravid on their arrival in the orchard. Thirty-one commercial orchards with potential or known apple maggot damage were monitored. Data from three of these orchards was discarded after it was discovered there was a resident population of flies in them, hence the delay in movement into the orchard could not be measured in them.

Results

Table 46 shows that the mean date of first fly catch in abandoned trees around commerical orchards was August 1 on the yellow traps. When red sphere traps were used, this was delayed by six days to August 7. In the commercial orchard, the mean date of first catch on the yellow trap was August 10 and on the red sphere was August 15. The mean delay from outside sources to the orchard was 8.2 for the yellow trap and 7.9 for the red sphere. This was not significantly different. This indicates that on average, a grower or consultant could place a trap in an abandoned tree, and expect flies to be in his orchard 8 days later. However, the range in delay of catch on the yellow trap was from 17 days in the orchard before catch on the abandoned tree to 35 days later on the traps in the orchard than in the abandoned trees, and with red sphere the respective range was from 14 days before to 29 days after. These extremely large ranges of about 7 weeks presents too large of a risk, and indicates the grower should monitor for apple maggot in his orchard, and not assume a mean of 8 days delay in being trapped in the orchard.

Different trap placements were evaluated for their effect on the delay between fly catch in abandoned trees and commercial orchards. Table 49 clearly shows that traps should be placed either in the first or second row of the orchard, even though the differences in mean delay are not significant. When using either trap type, the second row is preferred by this data, but the small sample size precludes its general recommendation. The first row with traps uniformly distributed around the orchard was the best method when using yellow traps, and the first row with traps biased toward the outside sources was best when using the red spheres. When all the criteria are considered for best placement, the first row biased scheme is preferred.

Traps were also placed in orchards at different densities to determine density effect on delay of catch. Table 51 showed some unexpected results. One assumes with greater densities, earlier catch would occur, and with smaller densities later catch would occur. This was the general trend, with the 2 trap density being the only outlayer. With both trap types, the 2 trap density provided the smallest delay in catch from that in the abandoned trees. This may be due to randomness, but because of the other criteria used and the favorable results with this density, it is recommended for apple maggot monitoring in commerical orchards.

Conclusions

On the average, adult apple maggot flies were caught 8 days later in commerical orchards than in abandoned trees outside the orchard. However, the range in dates was -17 to 35 days using the yellow trap, and -14 to 29 days using the red sphere. Therefore, trapping in abandoned trees is not recommended for timing sprays in commerical orchards. Instead, traps should be placed in the perimeter row of the orchard biased toward the outside infestation sites. Two traps per 10 acres when biased toward the two likeliest sources provide the greatest chance of trapping flies as soon as they arrive in the orchard.

IDENTIFICATION OF FLIES ON TRAPS

An important criteria to any control program is to be sure of the identification of the insect under investigation. Using a visual trap with very low specificity like the yellow Zoecon AM trap or the red sticky sphere, very many different species of insects can be attracted to them or accidentally caught. An attempt was made in this study to collect representative specimens that might be confused with apple maggot. These specimens were then identifed and photographed. The final goal is to have these published in an Extension Bulletin so fieldmen and growers will have a identification tool at their disposal to correctly distinguish the apple maggot from other picture winged flies that are caught in apple orchards.

Literature

Several researchers have attempted to identify insects caught on bait traps placed in orchards. Howitt and Connor (1965) studied different baits attractive to the AMF. The baits were used in conjunction with the yellow panel. They broke down the trap catch to orders, and discovered that the most abundant insects trapped by all baits were Diptera. However, seven other orders of insects were caught. Moore (1969) placed sticky-coated baited and unbaited red wooden spheres and yellow panels in apple trees to determine their effectiveness in catching AMF and beneficial flies. He identified the Diptera to family and discovered the great majority of the flies caught on all trap types were

Table 52. List of Picture-Winged Flies Caught on Yellow Zoecon AM Traps Placed in Apple Orchards.

Genera	Species	Common Name	Host
	ANISOPODIDAE		
Sylvicola	*alternata* (Say)		
	BOMBYLIIDAE		
Ogcodocera	*leucoprocta* (Wiedeman)		
	CLUSIIDAE		
Clusia	*czernyi* (Johnson)		
	OTITIDAE		
Delphinia	*picta* (Fabricius)		
Pseudotephritis	*vau* (Say)		
Pseudotephritina	*cribellum* (Loew)		
Seioptera	*vibrans* (Linnaeus)		
	PLATYSTOMATIDAE		
Rivellia	*viridulans* (Desvoidy)		
	TEPHRITIDAE		
Euaresta	*bella* (Loew)		
Euleia	*fratria* (Loew)		
Eutreta	*sparsa* (Wiedeman)		
Icterica	*seriata* (Loew)		
Paroxyna	*albiceps* (Loew)		
Rhagoletis	*basiola* (Osten Sacken)		
Rhagoletis	*cingulata* (Loew)	Eastern Cherry Fruit Fly	Wild Cherry, Pin Cherry
Rhagoletis	*fausta* (Osten Sacken)	Black Cherry Fruit Fly	Wild Cherry, Pin Cherry
Rhagoletis	*pomonella* (Walsh)	Apple Maggot	Apple, Hawthorne
Rhagoletis	*suavis* (Loew)		
Rhagoletis	*tabellaria* (Fitch)	Dogwood Maggot	Dogwood
	TETANOCERIDAE		
Euthycera	*arcuata* (Loew)		
Tetanocera	*valida* (Loew)		

Tachinidae. Leeper (1978) went further and included photographs of six different *Rhagolitis* flies that can be caught in orchards that could possibly be confused with the apple maggot.

Methods

Specimens were removed from traps throughout the four year study and mounted or preserved in alcohol. At the conclusion of the field study, these flies were mounted, labeled, identified, and left in the Michigan State University Entomology collection as voucher specimens.

Results

Table 52 presents a list of species of picture winged flies that were caught on the traps placed in commercial orchards. To the novice, many of these could be confused with the apple maggot. Three of the *Rhagolitis* should be mentioned, because they emerge before apple maggot, are very similar in appearance, and can be found in the commercial apple orchards.

The eastern cherry fruit fly, *Rhagolitis cingulata*, is a principle direct pest of tart cherries. It also has been recorded from wild black cherry and pin cherry, both of which are common species. Quite frequently they will appear on yellow AM traps in early July when their adult population is peaking. In some orchards, due to the presence of a large number of wild cherries, they will be much more numerous than apple maggot flies. Generally they do not feed on apple, so no controls need to be initiated for them.

The black cherry fruit fly, Rhagolitis fausta, is also a direct pest of commercial cherries, but of less importance than the eastern cherry fruit flies. Its hosts are the wild black cherry and the pin cherry. It generally appears on the yellow traps 10 days before the eastern cherry fruit fly, and 3 to 6 weeks before apple maggot. One should recognize this species and be sure not to initiate sprays for it because it has not been reported to feed in apples.

A third Rhagolitis that appears on yellow traps in apple orchards and is very similar in appearance to the apple maggot, it is the dogwood maggot or R tubellaria. As is indicated by its common name, its hosts are the dogwoods. It is not as common as the other Rhagolitis, but can easily be confused with apple maggot. It does not infest apples, so no sprays should be initiated when it is found on the traps.

Conclusions

There are many picture winged flies that are trapped in commerical apples. One needs to be careful when identifying flies on the traps, as many are very similar in appearance to the apple maggot, but do not infest apples.

SAMPLING FOR AND PREDICTION OF FRUIT DAMAGE

The goal for any monitoring system should be to more efficiently and effectively detect the pest being monitored. With apple maggot, two trap types were evaluated for thier use in detecting the pest. Once detected, then control programs were initiated. The detection in this case provided the biofix for determining when oviposition occurs,and when controls should be initiated. One method of evaluating the success of this detection is to determine the amount of damaged fruit in the orchard. Experiments were carried out to determine how large of a sample size was required and where to sample to efficiently estimate the percent fruit damage. This involved both within and between tree measurements. Once sampling procedures were known, then estimates of fruit damage were made. Lastly, correlations of the trap catch to fruit damage were made. With these parameter measured, one could determine the usefulness of the trapping scheme to measure fruit damage and in managing apple maggot.

DETERMINATION OF FIRST OVIPOSITION BASED ON A BIOFIX OF FIRST CATCH

There is a need to know when first oviposition will occur after a certain biofix such as first trap catch, so that growers can efficiently control the AMF. The timing of this event was studied, and a prediction was determined based on air temperature degree day accumulation. Factors that influence this such as fruit availability and fruit susceptibility will be ignored, as once the threshold is reached, the female will likely find a susceptible site and initiate oviposition. With this predictor available, pest managers can then recommend controls based on trap catch within an orchard. This firm level monitoring should reduce the risk to each grower from apple maggot damage.

Literature

Oviposition is the key event in the life cycle of apple maggot that growers attempt to prevent. Once eggs are deposited in the fruit, damage has occurred and the apple is unmarketable. Neilson (1978) reported that the first oviposition occurred 21 days after first catch. This time frame is much longer than is the general understanding. Hall (1937) reports that after emergence, the adults pass through a pre-oviposition period of 4-14 days during which time they feed, mature, and mate. At the end of this time period they are capable of laying eggs. The critical event to measure in the past was first catch, and then sprays were advised in 7-10 days. If the 21 day period is correct, then further delays in spraying could occur and the pest could be more economically managed.

Methods

Experiments were initiated in 1977 to obtain an estimate of the length of the pre-oviposition period. Flies were captured on yellow Zoecon AM traps on 10 trees at weekly intervals at the K.S.H. orchard. This catch served as a biofix for initiating the pre-oviposition period. These same trees had 25 apples tagged each. The apples were examined weekly for the presence of oviposition punctures. Once found, they signaled the end of the pre-oviposition period.

From the results obtained in 1977, it was realized that the weekly monitoring was too long of an interval, and the experiment was modified in 1978. Assistance was available to help monitor, so checks were made twice weekly. Again 10 trees had yellow Zoecon AM traps to serve as a biofix, and 25 apples were tagged and checked for oviposition stings on each of those trees.

During 1978, females were observed probing apples with their ovipositor. These exact spots were marked, and the apples picked and examined under magnification. The new stings were not easily distinguishable. This indicated that most of the stings counted previously were several days old. This time period allowed for apple growth and a slight depression to be formed which was more evident. Therefore, the experiment was modified in 1979 to determine a better estimate of the time interval between first catch and oviposition. The method chosen was to examine ovarian development. Fifteen trees in the K.S.H. orchard, nine in the Upjohn orchard, and twelve abandoned trees around commercial orchards were used as experimental units. Biofix of adult activity was determined by placing yellow Zoecon AM and sticky red sphere traps in each tree. The traps were monitored three times each week. They were cleaned at each visit, and their positions reversed every two weeks when the yellow traps were replaced. All flies were saved, sexed, and the females were dissected to examine for ovarian development (Neilson et. al., 1976). If eggs were found in the oviduct, then they were considered mature and capable of oviposition.

In 1980 these same two trap types were used to serve as a biofix for determining first flight activity. Fifteen trap trees were set in the K.S.H. orchard, 9 in the Upjohn orchard, and 15 in abandoned trees around commercial orchards. Traps were checked daily for the first two weeks of flight. Female maturity was checked by dissecting all the females caught on all the traps until eggs were evident in the oviducts.

During each year, data was separated by the variety of apple in which the traps were located. This enabled analysis of any significant differences in the duration of this interval due to variety.

Results

Weekly sampling in 1977 proved to be too long of an interval to determine the length of time between first catch and first oviposition. Table 53 shows the mean delay was 15.6 days or 388.8 degree days at base 48°F. This value is much larger than what is normally considered the true length. The weekly fruit sampling by Neilson (1978) probably explains why his value was 21 days. However, valuable information was gained on the number of new stings per apple (Figure 18) per week. A nice curve was present that matched quite closely the mean weekly trap catch, which indicates that when more flies are present more oviposition will occur.

Table 53. Duration of Pre-Oviposition Period as Determined by the Interval Between a Biofix of First Catch on the Yellow Zoecon AM Trap and the First Stung Apple at the KSH Orchard in 1977.

Tree	Variety	Biofix Date	First Sting	Length of Period Days	Length of Period DD 48° F
1	Transparent	6-22	6-29	7	170
2	Red Delicious	6-20	7- 6	16	395
3	Dutchess	6-20	7- 6	16	395
4	Dutchess	6-20	7- 6	16	395
5	Greening	6-20	7-13	23	581
6	Jonathan	6-29	7-13	14	380
7	Red Delicious	6-20	7- 6	16	395
8	Red Delicious	6-20	7- 6	16	395
9	Northern Spy	6-20	7-13	23	581
10	McIntosh	6-20	6-29	9	201
			Mean	15.6	388.8

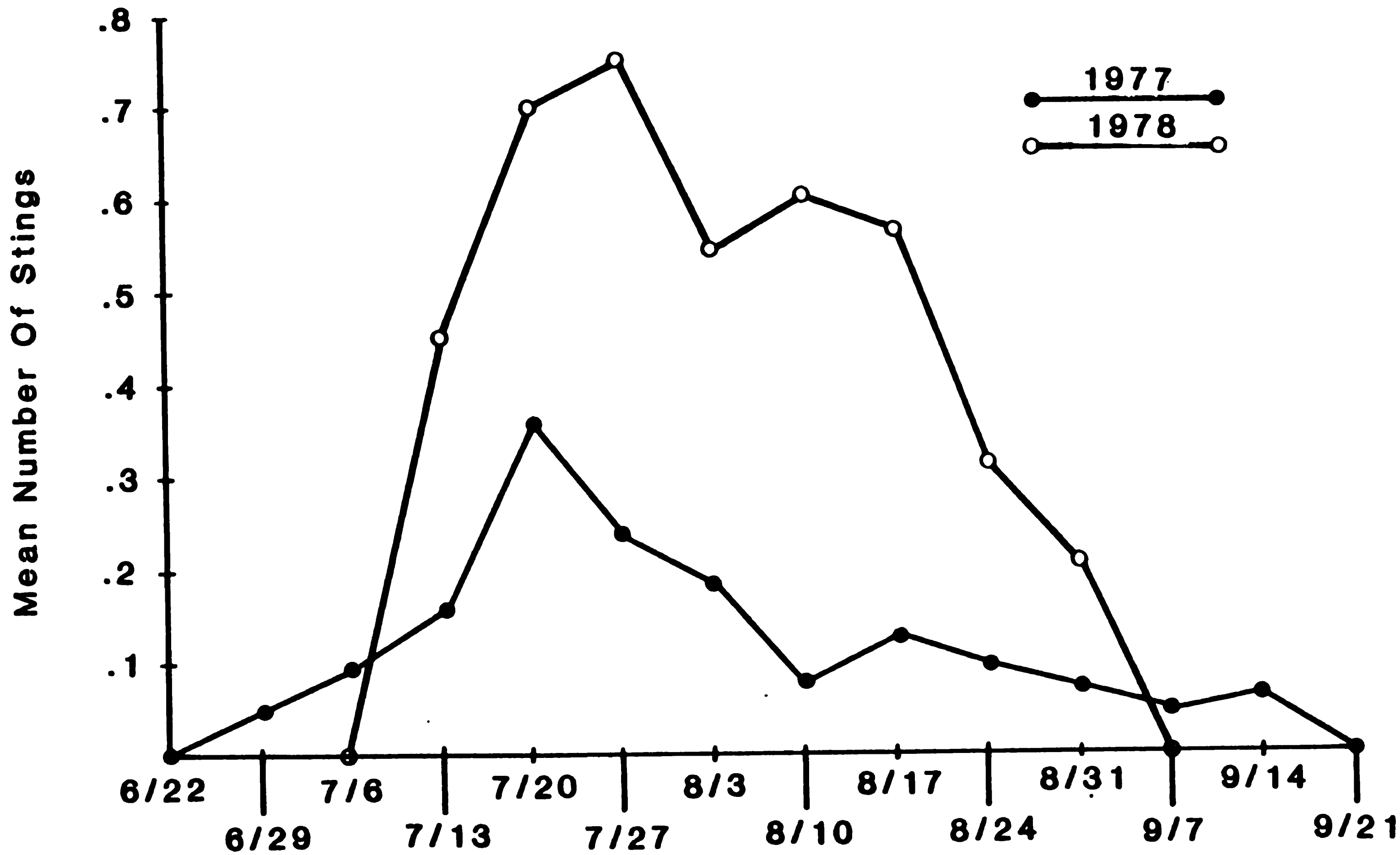


Figure 18. Mean Number of New Oviposition Stings per Apple per Week Due to Apple Maggot at the Kalamazoo State Hospital Orchard (25 Apples per Tree for 10 Trees).

In 1978 the sampling interval was shortened to twice each week. This shortened the mean length of the pre-oviposition period to 10.9 days or 217.2 air degree days at base 48°F at the 5 foot level (Table 54). This value is much closer to that reported in the literature.

Table 54. Determination of the Length of the Pre-Oviposition Period Initiated by a Biofix of Catch on the Yellow Zoecon AM Trap and Terminating with the Finding of Stung Fruit at the KSH Orchard in 1978.

Tree	Variety	Biofix Date	First Sting	Length of Period Days	Length of Period DD 48°F
1	Dutchess	7- 5	7-11	6	113
2	Transparent	6-30	7-11	11	204
3	Greening	7- 5	7-11	6	113
4	Dutchess	7- 6	7-11	5	88
5	Northern Spy	7- 4	7-11	7	136
6	Red Delicious	6-27	7-18	21	421
7	McIntosh	6-27	7-18	21	421
8	Northern Spy	7-14	7-18	4	85
9	Red Delicious	7- 8	7-21	13	273
10	Northern Spy	7- 6	7-21	15	318
			Mean	10.9	217.2

The number of new stings per fruit per week is found in Figure 18. The mean number of stings per fruit was 1.47 in 1977 and 3.76 in 1978. Corresponding to this there were 223 flies caught per trap in 1977 and 235 per trap in 1978 in the same trees where the fruit damage ratings were made. One possible explanation for there being twice as many stings per fruit in 1978 than 1977 would be fruit availability. If more apples were present on the trees in 1977, then more oviposition sites would be available which would reduce the number per fruit. However, no data was taken on the number of fruit per tree, so this is only speculation. Both these values are quite low when compared to the 20 punctures found on many apples and 46 found on one apple reported by O'Kane (1914). However, his mean stings per apple on the 22 trees rated was 3.41 which corresponds well with my data.

In 1979, all flies caught on these traps were sexed (n=6963 in K.S.H. orchard and n=662 in the Upjohn orchard, n=2622 in abandoned trees) and the females were dissected to determine ovarian development. The first gravid fly caught on each trap served as a termination of the pre-oviposition period, as those flies were capable of laying eggs and causing fruit damage. Table 55 shows that at the K.S.H. orchard the average length after first catch on the yellow Zoecon AM trap to mature females was 3.5 days or 64.8 air degree days at base 48°F. On the red sphere trap this interval was 2.5 days or 55.7 air degree days at base 48°F. These were not significantly different. In the Upjohn orchard (Table 56), the mean values were 2.9 days or 61.4 dd base 48°F for the yellow trap and 7.3 days or 154.5 dd base 48°F for the red sphere trap. Again these means were not significantly different even though the interval was longer. The data from the abandoned trees around commercial orchards found in Table 57 is very similar. Using the yellow AM traps as indicators for the initiating of the pre-oviposition period, its length was found to be 1.0 days or 22.7 dd base 48°F. The length using the red sphere trap was 4.9

Table 55. Determination of the Length of the Pre-Oviposition Period in 1979 Beginning with a Biofix of Trap Catch and Terminating with a Catch of Gravid Females at the KSH Orchard.

Method	Variety	Biofix Date	Gravid Date	Length of Period Days	DD 48°
Yellow Trap	Transparent 1	7-2	7-9	7	123
Red Sphere	Transparent 1	7-9	7-9	0	0
Yellow Trap	Transparent 2	7-2	7-2	0	0
Red Sphere	Transparent 2	7-6	7-9	3	69
Yellow Trap	Greening	7-2	7-2	0	0
Red Sphere	Greening	7-13	7-13	0	0
Yellow Trap	Dutchess	7-2	7-4	2	27
Red Sphere	Dutchess	7-6	7-6	0	0
Yellow Trap	Greening	7-4	7-6	2	27
Red Sphere	Greening	7-13	7-13	0	0
Yellow Trap	Wealthy	7-2	7-9	7	123
Red Sphere	Wealthy	7-2	7-11	9	178
Yellow Trap	Dutchess	7-2	7-2	0	0
Red Sphere	Dutchess	7-2	7-9	7	123
Yellow Trap	Jonathan	7-6	7-9	3	69
Red Sphere	Jonathan	8-2	8-2	0	0
Yellow Trap	McIntosh 1	7-2	7-6	4	54
Red Sphere	McIntosh 1	7-13	7-16	3	73
Yellow Trap	McIntosh 2	7-2	7-4	2	27
Red Sphere	McIntosh 2	7-9	7-23	14	337
Yellow Trap	Red Delicious 1	7-4	7-4	0	0
Red Sphere	Red Delicious 1	7-30	7-30	0	0
Yellow Trap	Red Delicious 2	7-2	7-2	0	0
Red Sphere	Red Delicious 2	7-30	7-30	0	0
Yellow Trap	Northern Spy 1	7-2	7-9	7	123
Red Sphere	Northern Spy 1	7-23	7-23	0	0
Yellow Trap	Northern Spy 2	7-2	7-9	7	123
Red Sphere	Northern Spy 2	7-9	7-11	2	55
Yellow Trap	Jonathan 2	7-4	7-16	12	276
Red Sphere	Jonathan 2	7-9	7-9	0	0
Yellow Trap Mean		7-3	7-6	3.5a	64.8a
Red Sphere Mean		7-14	7-16	2.5a	55.7a

Means followed by the same letter are not significantly different at the .05 level by the DMR test.

Table 56. Determination of the Length of the Pre-Oviposition Period in 1979 Beginning with a Biofix of Trap Catch and Terminating with a Catch of Gravid Females at the Upjohn Orchard.

Method	Variety	Biofix Date	Gravid Date	Length of Period Days	DD 48°
Yellow Trap	McIntosh 1	7-30	8-2	3	66
Red Sphere	McIntosh 1	7-16	-	-	-
Yellow Trap	McIntosh 2	8-6	8-6	0	0
Red Sphere	McIntosh 2	7-16	7-19	3	42
Yellow Trap	McIntosh 3	8-13	8-13	0	0
Red Sphere	McIntosh 3	-	-	-	-
Yellow Trap	Jonathan 1	7-13	7-13	0	0
Red Sphere	Jonathan 1	7-16	7-19	3	42
Yellow Trap	Jonathan 2	7-13	8-2	20	421
Red Sphere	Jonathan 2	7-23	8-6	14	318
Yellow Trap	Jonathan 3	7-13	7-13	0	0
Red Sphere	Jonathan 3	7-16	8-9	24	525
Yellow Trap	Spy 1	8-13	8-13	0	0
Red Sphere	Spy 1	8-30	8-30	0	0
Yellow Trap	Spy 2	7-13	7-16	3	66
Red Sphere	Spy 2	8-13	8-13	0	0
Yellow Trap	Spy 3	8-6	8-6	0	0
Red Sphere	Spy 3	-	-	-	-
Yellow Trap Mean		7-27	7-30	2.9a	61.4a
Red Sphere Mean		7-27	8-3	7.3a	154.5a

Means followed by the same letter are not significantly different at the .05 level by the DMR test.

TABLE 57. Determination of the Length of the Pre-Oviposition Period in 1979 Beginning With a Biofix of First Trap Catch and Terminating With a Catch of a Gravid Female in Abanonded Trees Around Commercial Orchards.

Orchard	Method	Biofix Date	Gravid Date	Length of Period Days	DD 48°
1	Yellow Trap	8-7	8-7	0	0
	Red Sphere	8-7	8-12	5	94
2	Yellow Trap	8-7	8-7	0	0
	Red Sphere	7-31	8-12	12	248
3	Yellow Trap	7-12	7-24	12	272
	Red Sphere	7-24	7-31	7	166
4	Yellow Trap	8-7	8-7	0	0
	Red Sphere	-	-	-	-
5	Yellow Trap	8-21	8-21	0	0
	Red Sphere	-	-	-	-
6	Yellow Trap	7-27	7-27	0	0
	Red Sphere	7-31	8-3	3	62
7	Yellow Trap	9-18	9-18	0	0
	Red Sphere	9-18	9-18	0	0
8	Yellow Trap	7-27	7-27	0	0
	Red Sphere	7-31	7-31	0	0
9	Yellow Trap	7-24	7-24	0	0
	Red Sphere	7-17	7-20	3	53
10	Yellow Trap	7-31	7-31	0	0
	Red Sphere	8-14	8-21	7	107
11	Yellow Trap	7-31	7-31	0	0
	Red Sphere	-	-	-	-
12	Yellow Trap	8-7	8-7	0	0
	Red Sphere	8-21	8-28	7	122
Mean	Yellow Trap	8-5	8-6	1.00a	22.7a
Mean	Red Sphere	8-8	8-13	4.89a	94.7a

Means followed by the same letter are not significantly different at the .05 level by the DMR test.

days or 94.7 dd base 48°F. These values were not significantly different. To summarize this, after first catch on the yellow trap, females have eggs in their oviducts 2.5 days or 49.9 dd base 48°F later. Using the red sphere as the indicator, 4.2 days or 87.1 dd base 48°F after first catch, the females have eggs in their oviducts. This indicates the red sphere would give a slightly longer period to prepare for initiating controls. However, in these three sites the red sphere caught the first fly a mean of 4.7 days later than did the yellow trap. Therefore, flies caught on the yellow traps would have eggs in the oviducts before flies are even caught on the red sphere. This suggests the yellow trap would be a better indicator for establishing a biofix and predicting when oviposition could occur.

In 1980, all the flies caught were again sexed and the females dissected to determine ovarian development. The number of flies checked was: n=5386 in the K.S.H. orchard, n=483 in the Upjohn orchard and n=536 in the abandoned trees around commercial orchards. At the K.S.H. orchard, the yellow traps caught flies first as its biofix date was July 4, six days sooner than with the red sphere trap (Table 58). The length of the pre-oviposition period was 5.3 days or 133 dd base 48°F for the yellow trap and 2.1 days or 51 dd base 48°F for the red sphere. These are significantly different values. This shows that this year in this orchard the length of the pre-oviposition period was

TABLE 58. Determination of the Length of the Pre-Oviposition Period in 1980 Beginning With a Biofix of Trap Catch and Terminating With a Catch of Gravid Females at the K.S.H. Orchard.

Method	Variety	Biofix Date	Gravid Date	Length of Period Days	DD 48°
Yellow Trap	Transparent	6-30	7-5	5	104
Red Sphere	Transparent	6-28	7-5	7	124
Yellow Trap	Transparent	7-5	7-7	2	47
Red Sphere	Transparent	7-9	7-9	0	0
Yellow Trap	Greening	7-2	7-2	0	0
Red Sphere	Greening	7-7	7-9	2	54
Yellow Trap	Dutchess	6-28	7-5	7	124
Red Sphere	Dutchess	7-2	7-2	0	0
Yellow Trap	Greening	6-30	7-5	5	104
Red Sphere	Greening	7-7	7-14	7	188
Yellow Trap	Wealthy	7-5	7-7	2	47
Red Sphere	Wealthy	7-5	7-7	2	47
Yellow Trap	Dutchess	7-2	7-5	3	64
Red Sphere	Dutchess	7-7	7-7	0	0
Yellow Trap	Jonathan	7-7	7-9	2	54
Red Sphere	Jonathan	7-16	7-16	0	0
Yellow Trap	McIntosh	7-7	7-18	11	304
Red Sphere	McIntosh	7-16	7-18	2	51
Yellow Trap	McIntosh	7-5	7-18	13	351
Red Sphere	McIntosh	7-5	7-11	6	155
Yellow Trap	Red Delicious	7-5	7-14	9	235
Red Sphere	Red Delicious	7-16	7-16	0	0
Yellow Trap	Red Delicious	7-7	7-14	7	188
Red Sphere	Red Delicious	7-16	7-21	5	146
Yellow Trap	Northern Spy	7-7	7-14	7	188
Red Sphere	Northern Spy	7-16	7-16	0	0
Yellow Trap	Northern Spy	7-9	7-9	0	0
Red Sphere	Northern Spy	7-21	7-21	0	0
Yellow Trap	Jonathan	7-7	7-14	7	188
Red Sphere	Jonathan	7-5	7-5	0	0
Yellow Trap Mean		7-4	7-10	5.33a	133.2a
Red Sphere Mean		7-10	7-12	2.07b	51.0b

Means followed by the same letter are not significantly different at the .05 level by the DMR test.

determined to be shorter when using the red sphere trap. This has the disadvantage of allowing for a shorter time period to initiate sprays after the first fly is caught.

In the Upjohn orchard the biofix date for the yellow trap was July 21, 4 days sooner than that of the red sphere trap (Table 59). Because of this date being later in the season, the females caught on it were already gravid. With the red sphere trap, gravid flies were caught 2.6 days or 56 dd base 48°F later than its biofix. Therefore, the red sphere caught gravid females 7 days later than the yellow trap which was hung in the same tree. This indicates that if one wanted to estimate when damage occurs, the yellow trap was far superior in this orchard.

In the 15 abandoned trees around commerical orchards checked in 1980, the yellow trap was better (Table 60). The mean biofix dates were July 24 for the yellow trap and July 30 for the red sphere. The lengths of the pre-oviposition period were 4.2 days for the yellow trap and 4.5 days for the red sphere. These correspond to 113 and 116 degree days base 48°F, respectively. These differences are not significant, but the yellow trap has a seven day lead period over the red sphere traps for catching gravid females.

To summarize the 1980 data for these three locations, the yellow trap had a mean biofix date 5.3 or 116 dd base 48°F days sooner than did the red sphere trap. The

TABLE 59. Determination of the Length of the Pre-Oviposition Period in 1980 Beginning With a Biofix of Trap Catch and Terminating With a Catch of Gravid Females at the Upjohn Orchard.

Method	Variety	Biofix Date	Gravid Date	Length of Period Days	Length of Period DD 48°
Yellow Trap	McIntosh 1	7-25	7-25	0	0
Red Sphere	McIntosh 1	7-23	7-23	0	0
Yellow Trap	McIntosh 2	7-23	7-23	0	0
Red Sphere	McIntosh 2	8-25	8-25	0	0
Yellow Trap	McIntosh 3	7-23	7-23	0	0
Red Sphere	McIntosh 3	7-25	8-11	17	384
Yellow Trap	Jonathan 1	7-23	7-23	0	0
Red Sphere	Jonathan 1	7-21	7-23	2	37
Yellow Trap	Jonathan 2	7-23	7-23	0	0
Red Sphere	Jonathan 2	7-14	7-14	0	0
Yellow Trap	Jonathan 3	7-5	7-5	0	0
Red Sphere	Jonathan 3	7-14	7-14	0	0
Yellow Trap	Northern Spy 1	7-23	7-23	0	0
Red Sphere	Northern Spy 1	7-21	7-25	4	83
Yellow Trap	Northern Spy 2	7-28	7-28	0	0
Red Sphere	Northern Spy 2	7-30	7-30	0	0
Yellow Trap	Northern Spy 3	7-16	7-16	0	0
Red Sphere	Northern Spy 3	7-25	7-25	0	0
Yellow Trap Mean		7-21	7-21	0.0a	0.0a
Red Sphere Mean		7-25	7-28	2.6a	56.0a

Means followed by the same letter are not significantly different at the .05 level by the DMR test.

TABLE 60. Determination of the Length of the Pre-Oviposition Period in 1980 Beginning With a Biofix of First Trap Catch and Terminating With a Catch of a Gravid Female in Abanonded Trees Around Commercial Orchards.

Orchard	Method	Biofix Date	Gravid Date	Length of Period Days	Length of Period DD 48°
1	Yellow Trap	7-23	7-25	2	49
	Red Sphere	7-28	7-28	0	0
2	Yellow Trap	8-18	9-3	16	435
	Red Sphere	8-27	9-3	7	194
3	Yellow Trap	8-8	8-8	0	0
	Red Sphere	8-8	-	-	-
4	Yellow Trap	7-25	7-25	0	0
	Red Sphere	8-6	-	-	-
5	Yellow Trap	7-23	7-23	0	0
	Red Sphere	8-6	8-6	0	0
6	Yellow Trap	7-21	7-21	0	0
	Red Sphere	7-28	7-30	2	43
7	Yellow Trap	8-11	8-11	0	0
	Red Sphere	-	-	-	-
8	Yellow Trap	8-6	8-6	0	0
	Red Sphere	8-11	8-11	0	0
9	Yellow Trap	7-16	7-16	0	0
	Red Sphere	8-6	8-6	0	0
10	Yellow Trap	8-19	8-19	0	0
	Red Sphere	-	-	-	-
11	Yellow Trap	7-10	7-15	5	140
	Red Sphere	7-31	7-31	0	0
12	Yellow Trap	6-21	6-24	3	80
	Red Sphere	6-23	7-9	16	397
13	Yellow Trap	7-25	-	-	-
	Red Sphere	8-22	8-22	0	0
14	Yellow Trap	7-5	7-18	13	347
	Red Sphere	7-5	7-5	0	0
15	Yellow Trap	7-5	7-25	20	531
	Red Sphere	7-5	7-30	25	638
Mean	Yellow Trap	7-24	7-28	4.21a	113.0a
Mean	Red Sphere	7-30	8-4	4.54a	115.6a

Means followed by the same letter are not significantly different at the .05 level by the DMR test.

mean length of the pre-oviposition period was 3.7 days for the yellow trap and 3.0 for the red sphere or 94 and 73 degree days base 48°F, respectively. Therefore, the yellow trap should be used as a monitoring tool to determine a biofix for apple maggot flight.

Because the 1979 and 1980 tests were performed identically, so both years data were lumped to provide a greater number of replicates for general recommendations (Table 61). At the K.S.H. orchard, a total of 30 replicates showed that the mean first catch or biofix was 8.5 days sooner using the yellow traps. The length of the period lasted 4.4 days for the yellow trap and 2.3 days for the red sphere trap, or 99 and 53 degree days base 48°F. At the Upjohn orchard where there were 18 replicates, the biofix was 2.0 days sooner on the yellow trap. The length of the period was 1.4 days on the yellow trap and 4.5 days on the red sphere, or 31 and 105 degree days base 48°F respectively. In the abandoned trees around commercial orchards there were 27 replicates. The mean biofix date was 4.5 days sooner using the yellow trap. The length of the period was 2.7 days with the yellow trap and 4.7 days with the red sphere, or 71 and 106 degree days base 48°F, respectively. When all these locations are lumped, the yellow trap caught flies 5.0 days sooner than the red sphere trap. The length of the periods were 3.1 days with the yellow trap and 3.5 days with the red sphere, or 73 and 77 degree days base 48°F, respectively. This indicates that

TABLE 61. Determination of the Length of the Pre-Oviposition Period Beginning With a Biofix of First Trap Catch and Terminating with a Catch of a Gravid Female.

Location	Year	Method	Length in Period Days	dd 48°F
K.S.H.	1979	Yellow Trap	3.5	65
		Red Sphere	2.5	56
	1980	Yellow Trap	5.3	133
		Red Sphere	2.1	51
Upjohn	1979	Yellow Trap	2.9	61
		Red Sphere	7.3	155
	1980	Yellow Trap	0	0
		Red Sphere	2.6	56
Abandoned	1979	Yellow Trap	1.0	23
		Red Sphere	4.9	95
	1980	Yellow Trap	4.2	113
		Red Sphere	4.5	116
All	All	Yellow Trap	3.1a	73a
		Red Sphere	3.5a	77a

Means followed by the same letter are not statistically different at the .05 level by the DMR test.

the yellow trap should be used to monitor for the biofix, and that controls should be initiated within 3 days after first catch.

The data generated was recorded by variety to determine if there were any differences related to variety of apple the traps were hanging in. Data from 1977 and 1978 at the K.S.H. orchard are presented in Table 62. Only the yellow trap was used these two years. In each case the unbalanced design of the analysis of variance and the DMR test were performed. In all cases the variances were homogeneous by the Bartlett's test at the .05 level. On the 19 trees examined in detail, there was no statistical difference due to variety in the biofix or first trap catch date. The same is true for the length of the pre-oviposition period. However, the number of stings per apple does vary. The earlier varieties have less stings due to their maturing sooner and falling off the tree. This indicates that they are suitable for larval development for a much shorter time frame. The later varieties are susceptible and hang on the tree longer thereby being exposed longer which results in their having significantly more stings. The flies caught per tree are statistically different for the different varieties. One possible explanation might be that the trees had varying number of apples the preceeding year which would result in there being more or less flies under each tree to be caught on the traps.

TABLE 62. Mean Differences in the First Trap Catch Date, Length of Pre-Oviposition Period, Number of Stings Per Apple and Number of Flies/Trap Due to Variety at the K.S.H. Orchard in 1977 and 1978.

Variety	No. Trees	Biofix Date	Length in Days	Stings/[1] Apple	Flies/ Trap
Dutchess	4	6-28a	10.75a	0.42a	208ab
Transparent	2	6-26a	9.00a	1.50ab	293ab
McIntosh	2	6-24a	15.00a	1.52ab	161ab
Greening	2	6-28a	14.50a	1.66ab	94a
Red Delicious	5	6-25a	16.40a	3.11 b	311 b
Northern Spy	4	7-3 a	12.25a	6.63 b	186ab

[1] Mean of 25 apples/tree

Means followed by the same letter are not significantly different at the .05 level by the DMR test.

In 1979 and 1980, the two trap types were compared for these same parameters at the K.S.H orchard (Table 63). Using the yellow trap there was no statistical difference in the biofix or first trap catch date due to variety, but there was a range of five days present. Using the red sphere trap, the early varieties Transparent, Dutchess and Greening had flies caught significantly earlier than did the later varieties, Jonathan, McIntosh, Red Delicious and Northern Spy. The length of the pre-oviposition period was essentially the same for both trap types among the varieties. The number of flies caught per trap on the yellow trap did not differ statistically, but had a range in the means from 224 to 389. The catch on the red spheres was likewise nonsignificant between the varieties, but the means were lower and ranged from 37 to 253.

Comparisons between the four years at the K.S.H orchard were not made. This is due to the different sampling intervals with 1977 being weekly, 1978 twice a week, and 1979 and 1980 three times each week through the termination of the pre-oviposition period. The means generated on the biofix date and length of the pre-oviposition would have a considerable amount of sampling variance associated with them.

In the Upjohn orchard in 1979 and 1980, traps were placed in three trees of three different varieties each year. They were monitored three times per week to quantify the parameters found in Table 64. When measuring the biofix

TABLE 63. Mean Differences in the Biofix Date, Length of the Pre-Oviposition Period, and Number of Flies Per Trap Due to Variety During 1979 and 1980 at the K.S.H. Orchard (4 Replicates).

Variety	Method	Biofix Date	Length in Days	Flies/ Trap
Transparent	Yellow Trap	7-2 ab	3.50abc	257.7abc
	Red Sphere	7-5 abc	2.50abc	69.2ab
Greening	Yellow Trap	7-2 ab	1.75abc	235.5abc
	Red Sphere	7-10 bcd	2.25abc	102.7ab
Dutchess	Yellow Trap	7-1 a	3.00abc	329.2 bc
	Red Sphere	7-4 abc	1.75abc	168.7abc
Jonathan	Yellow Trap	7-6 abc	6.00abc	271.0abc
	Red Sphere	7-16 de	0.00a	45.2a
McIntosh	Yellow Trap	7-4 abc	7.50 c	313.7 bc
	Red Sphere	7-11 cd	6.25 bc	145.2abc
Red Delicious	Yellow Trap	7-5 abc	4.00abc	224.0abc
	Red Sphere	7-23 e	1.25ab	37.2a
Northern Spy	Yellow Trap	7-5 abc	5.25abc	389.2 c
	Red Sphere	7-17 de	0.50ab	253.2abc
Mean	Yellow Trap	7-3	4.4	289
Mean	Red Sphere	7-12	2.3	117

Means followed by the same letter are not significantly different at the .05 level by the DMR test.

TABLE 64. Variety Effect on the Biofix Date, Length of Pre-Oviposition Period, and Flies Per Trap at the Upjohn Orchard in 1979 and 1980.

Variety	Method	Biofix Date	Length in Days	Flies/ Trap
McIntosh	Yellow Trap	7-25ab	7.5a	17.8a
	Red Sphere	7-27ab	5.0a	11.2a
Jonathan	Yellow Trap	7-15a	3.3a	58.3 b
	Red Sphere	7-17a	7.2a	93.3 b
Northern Spy	Yellow Trap	7-27ab	.5a	20.7a
	Red Sphere	8-5 b	.8a	6.5a
Mean	Yellow Trap	7-22	3.8	32.3ns
Mean	Red Sphere	7-27	4.3	37.0ns

Means followed by the same letter are not significantly different at the .05 level by the DMR test.

or first trap catch with the yellow trap, there were no statistical differences between the varieties even though the range in mean dates was 12 days. With the red sphere traps, flies were caught significantly earlier on Jonathans and significantly later on Northern Spy, with McIntosh intermediate. This indicates that the yellow trap gives a less variable first catch, and in all cases the mean first catch was sooner on the yellow trap, with the overall mean being five days sooner. Statistically there was no difference in the length of the pre-oviposition period between the varieties for either trap type. The grand mean indicated that the difference was only half of a day between the trap types. Therefore, either trap could be used with equal reliability to predict the length of the pre-oviposition period in this orchard. There was a difference in the mean number of flies caught per trap due to variety. For both trap types, the traps placed in the Jonathan trees caught significantly more flies than traps placed in McIntosh or Northern Spy trees. When these data are summarized, although not statistically significant, the Jonathan variety would be the best one in which to place the traps in this orchard. This is because the biofix date was first in this variety and the most flies were caught in it. Also, the yellow trap would be preferred because its biofix date was five days sooner than the red sphere trap.

Conclusions

In 1977, weekly monitoring determined the pre-oviposition interval to be 15.6 days or 388.8 air dd base 48°F. This length was much longer than reported in the literature, and the sampling interval had to be shortened. When the interval was shortened to every three days in 1978, the length of the pre-oviposition period was reduced to 10.9 days or 217.2 dd base 48°F. It was discovered in 1978 that the method of determining the end of the period (looking for stings) was not the best as many early stings could be missed. Therefore, these data will not be used as predictors. Useful information was generated from these experiments however. There were found 1.47 stings per apple in 1977 and 3.76 in 1978. These mean values compare well to that reported in the literature. Also, the curve of new stings per fruit followed very closely the trap catch numbers of adults, which indicates as more adults are present more damage is being done.

During 1979, the yellow trap was found to be a better indicator of the biofix than was the red sphere trap by catching flies 4.7 days sooner in three separate tests. Using the yellow trap, the pre-oviposition period was found to last 1.0 days or 23 dd at base 48°F. The red sphere had a length of 4.9 days or 95 dd at base 48°F. In 1980, the yellow trap again caught flies sooner in all three tests, with the mean value being 5.3 days sooner. The mean length of the pre-oviposition was found to be 3.7 days with the yellow trap and 3.0 days with the red sphere trap or 94 and 73 dd base 48°F respectively. When both years data were lumped over all locations, the yellow trap caught flies 5.0 days sooner, and had gravid flies on them two days before the red sphere caught any flies. This indicates it is the preferred monitoring tool, and controls should be initiated with 3 days after first catch.

In tests conducted from 1977 to 1980 at the K.S.H orchard, there was no statistical difference due to variety in the biofix date nor length of pre-oviposition period when the yellow trap was the monitoring tool. However, there was a difference in the number of stings per apple, with the earlier maturing varieties having fewer as they fall off the tree sooner and are not exposed as long as the later maturing varieties. There were also some differences in the mean number of flies caught per trap. These differences are probably due to the size of the apple crop the preceeding year which would regulate the population size available for trap catch the following year. When the red sphere trap was used in 1979 and 1980, the early maturing varieties caught flies significantly sooner than did the later maturing varieties. However, there were no differences between varieties in the length of the pre-oviposition period nor the mean number of flies caught per trap. In the Upjohn orchard in 1979 and 1980, there were no differences between varieties in the biofix date nor the length of the pre-oviposition period when using the yellow trap. There were some differences when the red sphere trap was used, but in each case the red sphere trap was inferior due to the later first catches. Even though not statistically significant, the yellow trap should be placed in the Jonathan variety in this orchard to measure the biofix date.

SAME SIZE TO ESTIMATE FRUIT DAMAGE

An important consideration in any experiment is to know how large of a sample size is required to measure the variables investigated. The optimal sample sizes can seldom be taken because of time and cost constraints. However, several different experiments were conducted to determine what sample size should optimally be taken to obtain a reliable estimate of fruit damage in research and commercial orchards. In one test, every apple was picked off trees that had a moderate infestation and rated for damage. With the absolute mean damage known, probability equations could determine how large of a sample is needed to be within reasonable ranges of the true value. This test also revealed the spacial distribution of the damage within the tree, and determined where apples should be picked to obtain more reliable estimates. To determine how many trees per orchard to sample, intensive sampling was conducted to find estimates of percent fruit damage on many trees. This data can be used to determine the fewest number of trees that needed to be sampled in the orchard. Finally, the edge effect was studied to determine if it is a reality with apple maggot. If so, then biases in the estimation of damage in the entire block can be controlled by understanding where the damage is most likely to occur.

Literature

In attempting to estimate fruit damage within a tree Cameron and Morrison (1974) examined 20 apples per tree. Neilson (1978) picked 25 apples from trees that had traps in them. He felt this was a suitable sample size to obtain an estimate of the mean damage in the tree. The fruit damage rating sample size for estimating apple maggot damage utilized by the Michigan Apple Pest Management project was to randomly select 20 apples per tree and 15 trees of each major variety in the orchard (Olsen, Unpublished). Reissig and Tette (1979) sampled 100 apples from the top and middle of the tree, and all drops from 5 trees per block. To calculate optimum the sample sizes, equations from Southwood (1978) were used.

Methods

Whole Tree Sampling. In 1979, every apple was examined for damage on four trees. Three of these trees were at the Upjohn orchard, and the fourth was a backyard tree that was routinely sprayed. After recording all other damages, thin slices were removed to look for apple maggot larval tunneling to confirm its presence. The number of apples with damage and the number of stings per apple were recorded. Each apple was given a coordinate to the nearest inch off the ground and north or south and east or west directions from the center of the tree. The sampling was performed in late September and early October to assure no further damage would occur.

Orchard Sampling. In five orchards in 1980, fifty trees at random were rated for apple maggot damage. Trees were assigned rows and numbers in that row, and then a random number table was consulted for determining sample trees. This large sample assured all varieties and all areas of the orchard would be checked. Fifty apples were examined per tree. This was performed in mid-September so apples would be present on all varieties, and no new damage would occur.

Edge Effect. In five orchards in 1980, a sampling scheme was devised to detect an edge effect. Five trees each in the four perimeter rows were evaluated for apple maggot damage. Again, 50 apples per tree were carefully examined. The fruit damage rating was performed in mid-September for reasons already discussed.

Results

Whole Tree Sampling. Table 65 shows the data from the whole tree sampling for apple maggot damage. The first three trees are in the Upjohn orchard where every other tree was sprayed. As shown elsewhere, this spraying scheme reduced the apple maggot population by 95% as determined by trap catch. The percent infested level is high, but the mean stings per fruit is quite low. The last tree is in a backyard situation with many sources of apple maggot

TABLE 65. Whole Tree Sample for Apple Maggot Damage.

Variety	No. Apples Sampled	Percent Infested	Std Dev	Mean Stings Per Fruit	Sample Size ± 10%	± 5%
McIntosh	348	37.1	.484	.95	46.7	187
McIntosh	290	24.8	.433	.46	37.3	149
Jonathan	335	54.9	.498	1.55	49.5	198
Red Delicious	377	14.8	.356	.15	25.2	101

surrounding it. The tree was sprayed weekly to hold the damage down to a satisfactory level.

These data show differences between trees in the frequency of damage. In the Upjohn orchard this probably is due to the variety preference as the insect is established in the orchard and equally distributed throughout. By observation, and with this data, Jonathan seems to be preferred over McIntosh for oviposition. The Red Delicious tree is in another locality where the population is very low (1 female/trap for the entire season), resulting in the lower frequency.

Also shown in this data is the relationship between frequency of occurrence or percent fruit damage and the mean number of stings per apple. A least squares linear regression analysis found a coefficient of determination (R^2) of 0.998. Therefore, using these four trees as the data base and having the percent fruit damage in the range of 15 to 55%, a very reliable estimate of the number of stings/fruit (y) can be found by plugging x (the percent fruit damage) into equation 7:

$$\text{Eq 7} \quad Y = 0.035\ X - 0.386$$

To calculate the optimum sample size from each of these four trees to estimate the percent fruit damage, the equation $N = \frac{t^2pq}{d^2}$ from Southwood (1978) was used. This assumes a frequency of occurance estimate is to be made. The p is the probability of occurence found in a preliminary survey, here the true value. The q equals 1-p, the t is the Student t of standard statistical tables and approximates 2 for samples of greater than 10 at the 5% level, and D is the predetermined half-width of the confidence limits of the mean. To be 95% (alpha = .05) sure that the sample estimate is within confidence limits of ±10% of the true frequency, sample sizes of 25 to 50 need to be taken on these trees. If one wanted to be more precise and be within ±5% of the true mean, larger sample sizes in the 100 to 200 range would need to be taken for each tree.

This data can also give an indication of the spacial distribution of the damage within the tree. A priori it was assumed that at the very low frequency of occurrence in the commercial orchards the damage would be clumped or aggregated. As there are very few flies that successfully enter the orchard and sting fruit, those fruit that were damaged would be clumped. The female would not have much time to search out oviposition sites and lay eggs before she would be killed by the insecticides routinely applied. This distribution would likely approximate the negative binomial where the variance is greater than the mean. As will be shown, this distribution fit very closely the negative binomial distribution. In these medium density orchards the flies have very limited insecticide pressure to kill them and they have much more time to search out new unexploited oviposition sites. This would suggest a random or uniform spacial distribution. There are two aspects of their behavior would encourage a uniform distribution. After laying an egg in an apple, the female deposits a deterrent pheromone to prevent other eggs from being laid in this same fruit (Prokopy, 1972b; Prokopy et. al., 1976). This behavior tends to even out spacially the damage. Also, females show aggressive behavior toward each other in a territorial defense. These aspects have been noted and a uniform distribution shown to occur by Levoux and Mukerji (1963), Cameron and Morrison (1974) and Boller and Prokopy (1976). Reissig and Smith (1978) however found a random spacial distribution of eggs in the tree which was described by the Poisson distribution. They reasoned that under heavy fly pressure the females did not respond adequately to the marking pheromone, and they laid their eggs anywhere they found a host.

To test the hypothesis that there is no significant difference in the frequency of damage in any part of the tree at the medium density Uphohn orchard the trees were artifically layered at 1 meter levels and quartered in the north-south and east-west plains. Analysis of variance was performed with each of the thin gradrants of the tree representing a different treatment. If significance was found, the DMR test at P = .05 separated the means. On the two McIntosh trees there was no statistical difference between the treatments in the frequency of damaged apples (Table 66). These trees were believed to have a random or

TABLE 66. Analysis of Spacial Distribution of the Apple Maggot Damaged Apples Within the Tree.

		Mac 1		Mac II		Red Del	
Height	Quadrant	N	$\bar{x}$	N	$\bar{x}$	N	$\bar{x}$
1-2 Meters	NE	0	-	10	.30	43	.09b
	NW	32	.25	3	.33	24	.04b
	SW	6	0	10	.60	10	0a
	SE	6	.50	6	.17	73	.03b
2-3 Meters	NE	5	.40	35	.14	65	.23b
	NW	90	.44	29	.10	43	.31b
	SW	17	.47	16	.25	22	.23b
	SE	37	.47	53	.18	85	.16b
3-4 Meters	NE	10	.30	49	.27	4	.50b
	NW	61	.25	4	0	0	-
	SW	44	.39	13	.54	2	.50b
	SE	25	.36	39	.18	1	0a
4-5 Meters	NE	0	-	4	.25	0	-
	NW	0	-	1	0	0	-
	SW	7	.57	2	1.0	0	-
	SE	3	.33	13	.31	0	-
F Value		1.27 NS		1.95 NS		3.66 **	

Means followed by the same letter are not statistically different at P=.05 by the DMR test.

uniform distribution. and this cannot be refuted because there were no statistical differences in the spacial distribution of their damaged apples, even when the two trees were lumped and analysed as one (F = 1.17 NS: critical value $F_{.25(11,587)} = 1.32$ and $F_{.5(11,587)} = .96$). However, the Red Delicious tree did have significant differences. The bottom SW and top SE quadrants had zero damage which was significantly less than the other quadrants in the tree. To determine if the clumping effect is real, the variance (.1268) was divided by the mean (.1485) to give 0.85 which is not indicative of a clumped population. This more closely fits the random distribution approximated by the Poisson distribution. Therefore these significant differences were probably due to the very small sample sizes in some of the quadrants. Lumping these three trees for analysis is not valid because of the different locations and very different pest density.

To summarize this is difficult because of the few trees that were sampled. It appears that there are no differences in the spacial distribution of the damage, which would again support the hypothesis of a deterrent pheromone. If this is the case, then in future sampling schemes apples can be randomly picked from any location on the tree to obtain an unbiased estimate of the mean ercent fruit damage on that tree. This supports the same statement made by Cameron and Morrison (1974) in their intensive sampling for the spacial distribution of larvae in the tree.

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Orchard Sampling.

Number of Trees and Apples - In the five commercial apple orchards intensively rated for apple maggot damage, the range in fruit damage was 0 to 1.28 percent. It was hypothesized that this damage frequency fit the negative binomial distribution. This was tested, and the parameters calculated by the goodness of fit test were found to be x = 0.272 and K = 0.1488. The Chi-square test calculated a value of 2.601 with 3 degrees of freedom. The tabular value of $x^2_{.1\ (3)} = 6.251$ and $x^2_{.5\ (3)} = 2.366$. Therefore we have no reason to reject the null hypothesis, and can assume that the data does fit the negative binomial distribution.

With ample proof that the damage distribution is defined by the negative binomial, the equation $N = (1/x + 1/K) \div E^2$ (Southwood, 1978) will give the desired number of samples to take to determine the mean damage. Here x and K are the parameters of the negative binomial distribution (found above) and E is the predetermined standard error as a decimal of the mean (.1 and .05). Solving this equation, one finds that to be within 5 percent of the true mean, 4159 apples need to be sampled, and if less precision is required only 1040 apples need to be sampled to be within 10 percent of the tree mean. When 50 apples are examined per tree, then 82 and 21 trees per orchard should be randomly examined for apple maggot damage to be within 5 and 10 percent of the true mean.

The data from the Upjohn orchard can also be used to determine the number of trees that should be examined in the entire orchard to estimate the orchard frequency of occurrence or percent fruit damage in moderately infested orchards. Using the equation $n = (S_s^2/N_s + S^2p) \div (\bar{x} \times E)^2$ (Southwood, 1978) one can calculate the sample size necessary when taken from two levels, i.e. apples per tree and number of trees. In this equation n_s = the number of samples within the tree ($\sim$50 from Table 62), S_s^2 = variance within the tree, S^2p = variance between the trees, $\bar{x}$ = mean per tree, and E is the standard error of the mean wanted (.05 and .1). Solving the equation using the within tree variance of .248 from the Jonathan tree where the largest sample size is required, the between tree variance of .2391, and the three tree mean of .3957, the number of apples required is 626 to be within 5% of the true orchard mean, and if 50 apples per tree are examined, 12.5 trees should be checked per orchard. If less precision is wanted, only 156 apples and 3.1 trees need to be sampled to be within 10 percent of the true orchard mean.

Figure 19 was prepared to show the relationships of sample size. In commercial orchards (A) or in medium damage density orchards (B), one can pick a number of apples per tree to sample, and then determine how many trees per orchard need to be examined by using the isoquant as the indicator. This can be done for greater (5%) or less (10%) precision. For example, in commercial orchards, to be

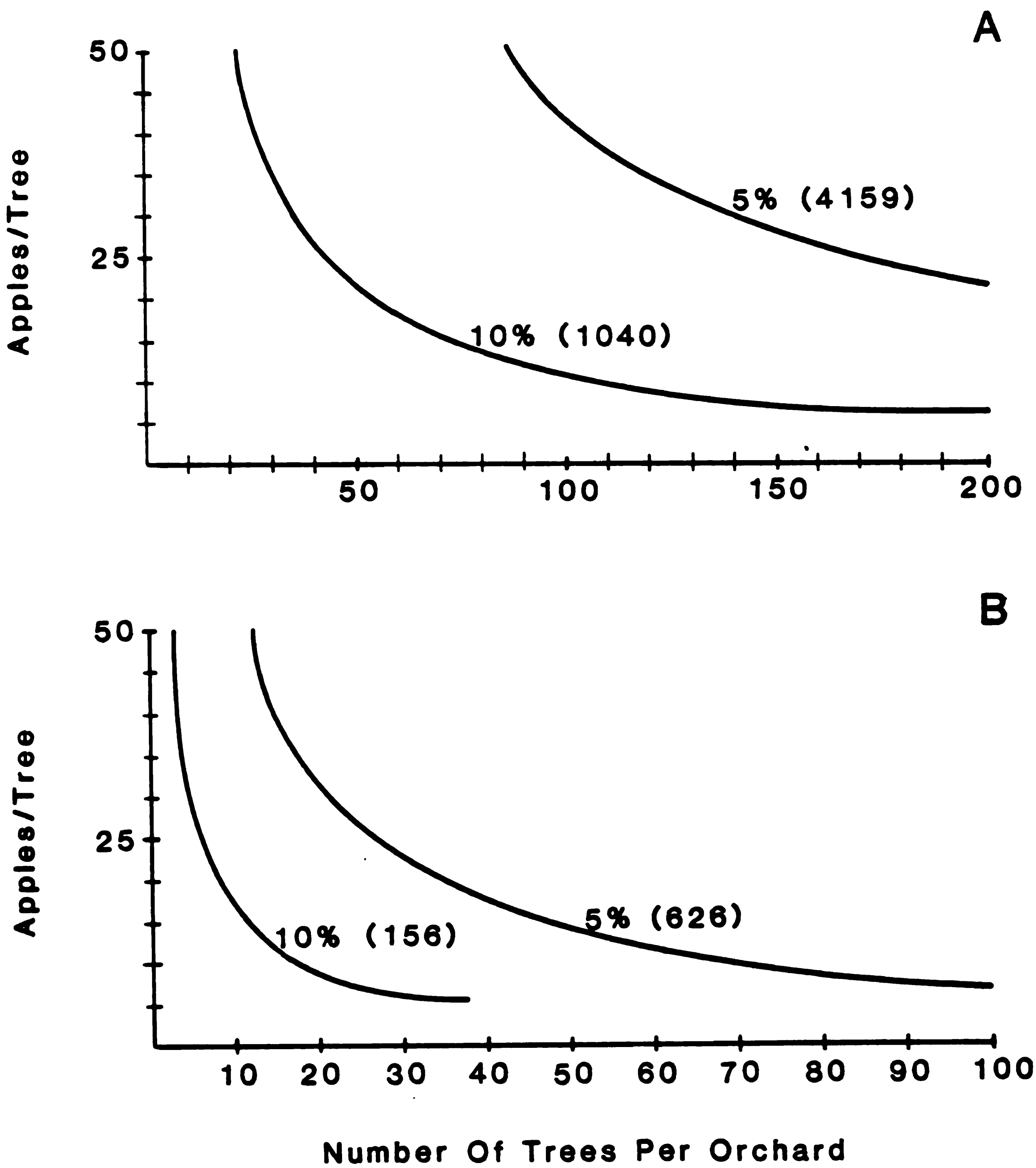

Figure 19. Isoquants of the Number of Apples to Examine for Apple Maggot Damage at Low (A) and Medium (B) Density Damage Levels for Precision of 5 and 10 Percent of the Mean.

within 10% of the true orchard mean, one could examine 50 apples/tree and 21 trees per orchard, or 25 apples/tree and 42 trees per orchard. To determine which sample to take depends on the cost of monitoring one tree verses the cost of moving to different trees. Considering the time spent moving from tree to tree, one would prefer to examine more than 10 apples/tree because at that level 104 trees need to be examined to have the same degree of precision.

Edge Effect of Damage. Table 67 shows the results from the fruit damage survey taken from the perimeter rows of the orchard nearest the outside infestation sources. Two-way analysis of variance found no statistical difference between the rows nor between orchards, but a very strong trend exists. This shows that the further into the orchard one goes, the less the damage caused by apple maggot. This data supports a principle suggested by Reissig and Tette (1979) and others that perimeter spraying of the orchard is a feasible alternative to whole orchard spraying for apple maggot if the orchard does not already have a resident pest population. It also shows that biased sampling can result in higher or lower than true mean levels of damage, so sampled trees must be randomly selected to reduce this slight edge effect bias.

TABLE 67. Percent of Apples Infested with Apple Maggot in the Perimeter Rows of Commercial orchards.

Row Into Orchard	Mean Percent Infestation
1	1.92
2	.67
3	.75
4	.17

F = 1.80 N.S.

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Conclusions

The whole tree sampling revealed differences between trees in the frequency of damage, partially due to variety and partly due to fly pressure. It also revealed an excellent correlation between the mean frequency of damage and mean number of stings per fruit. For sampling purposes, to be within 10% of the true mean, 50 apples per tree should be examined. Those apples can be randomly taken from anywhere on the tree as there was no significant difference in the frequency of damage within the tree in these medium damage level trees.

The orchard sampling showed that the damage was clumped and its distribution was approximated well by the negative binomial distribution. Using sample size equations, isoquants were created to determine the number of apples per tree and trees per orchard to sample to estimate the mean frequency of occurrence of apple maggot damage. Sample sizes in medium damage density orchards were determined in the same manner.

The clumping of damage in orchards by apple maggot was discovered to be an edge effect. Although not significant, damage was greatly reduced the farther into the orchard one sampled. This indicates biasing can be a problem, and one needs to randomly select trees to sample if unbiased estimates of the orchard mean density of apple maggot damage is to be determined.

CORRELATION OF TRAP CATCH TO FRUIT DAMAGE

A very critical consideration in monitoring an insect is the reliability of the monitoring tool. In these experiments both the yellow Zoecon AM and sticky red sphere traps were used to trap apple maggot flies. Their true value can be measured by their ability to estimate fruit damage. With a reliable trap, the more flies caught the greater the amount of damage expected. To test this, traps were positioned in commercial orchards two years to catch flies, and apples were examined for fruit damage. This experiment should give a relative estimate of the usefulness of these trap types, but is not the ideal situation. A large confounding factor in this experiment is the differential insecticide pressure applied to the pest population. An ideal situation would be one where the test orchard was very recently abandoned so there would be no insecticides to kill the flies, and one in which flies are not yet resident in the orchard but are still migrating in as in the commercial situation. These orchards are difficult to locate if existent and are very far apart, and therefore not viable as efficient experimental units. However, in each orchard monitored, the insecticides were applied based on trap catch on traps in the perimeter row. This fact should help to reduce some of the between orchard variability.

In any experiment there remains some unexplained variability. The following list contains parameters that may affect the relationship between trap catch and percent fruit damage:

a.	Trap Components	Placement of traps in the tree Location of trap trees Trap efficiency over time
b.	Fruit Damage Rating	Number of apples sampled per tree Number of trees sampled Location of apples sampled in the tree Location of sample trees
c.	Biology of the Fly	Pest numbers from outside the orchard Distance of alternate hosts to orchard Physiological state of the fly
d.	Cultural	Variety susceptibility Number and efficiency of sprays
e.	Experimental	Lack of conducting the experiment the same way every time
f.	Random	Weather

Most of these variables have been minimized, optimized or kept as identical as possible to reduce the total variability.

Literature

Early workers had poor success showing a relationship between trap catch and damage with apple maggot (Hodson, 1948). Reissig and Tette (1979) said "Infestation levels were not directly related to the number of captured flies, and infested fruit was found even in blocks in which only a few flies were trapped. This indicated that it would be necessary to apply a control spray in monitored blocks in commercial orchards whenever even one fly was captured to completely prevent subsequent fruit damage." Prokopy (1979) found no correlation (r = .26) of capture of apple maggot on the yellow Zoecon AM trap to fruit damage in commercial orchards, but a high correlation (r = .86) with red sticky spheres. This provides strong evidence that the pest management programs and growers should be using red sticky spheres to determine population levels within commercial orchards.

Materials and Methods

Adult apple maggot flies were trapped in 20 commercial orchards in 1979. Trap trees in each orchard had a red sphere and yellow Zoecon AM trap on opposite sides of the tree. Trap locations were reversed every 2 weeks when the yellow trap was replaced. Each trap was examined 3 times per week. The number of traps varied in the orchard so that a randomized block design experiment was carried out. Five orchards had 1 trap tree per 4 hectares, 5 had 2 trap trees, 5 had 4 trap trees, and 5 had 10 trap trees. The trap trees were biased toward the perimeter of the orchard nearest outside sources in an attempt to catch immigrating flies.

In 1980 eleven commercial orchards were monitored. The same procedures were used as in 1979, however, the number of trap locations was different. One orchard had one trap tree, two had two trap trees, and eight had 4 trap trees, all of which were positioned on perimeter rows near possible outside infestation sources.

Fruit damage estimates were made by examining 50 apples per tree for at least 15 trees per orchard. A mean orchard damage value was then determined. The mean trap catch number per orchard was then correlated to percent fruit damage in each orchard in an attempt to determine the degree of predictability in future trapping programs.

Results

Trap Type Comparison. Correlations of accumulative mean trap catch per orchard to percent fruit damage resulted in a determination of the degree of predictability between the parameters measured. A least squares linear regression analysis yielded the results shown in Table 68. This data suggests that of these six parameters, the best predictor of fruit damage in 1979 was the average number of flies caught on the red sphere traps (R^2=.53). This included all 20 orchards monitored, even the ones that were found to have resident populations of flies. When those orchards with resident populations were removed from the analysis, the R^2 value fell to .04 for the number of flies caught on the red sphere, but increased to .39 for the number of flies caught on the yellow trap. This indicates that the yellow trap is a more consistent indicator in a variety of orchard conditions. In 1980, the red trap was again a slightly better predictor for fruit damage than was the yellow trap.

TABLE 68. Coefficient of Determination (R^2) of Apple Maggot Trap Catch in Commercial Orchards to Percent Fruit Damage.

Parameter Measured	1979	1980	Combined
Males on Yellow Zoecon AM Trap	.33	.56	.26
Females on Yellow Zoecon AM Trap	.34	.76	.30
Both Sexes on Yellow AM Trap	.37	.71	.31
Males on Red Sphere Trap	.39	.75	.13
Females on Red Sphere Trap	.29	.77	.23
Both Sexes on Red Sphere Trap	.53	.80	.19

However, both of these values are quite high and either trap would be a reliable tool for predicting fruit damage based on fly catch on them. When both years of data were combined into the analysis, 31 orchards were used. The best trap type over the varying conditions of different orchards and different years was the yellow trap. Its reliability as a predictor of fruit damage was not good (R^2=.31), but it was better than the red sphere trap. Overall, eventhough the red sphere is a slightly better indicator, the yellow trap is preferred because it gives more consistent reliable estimates of fruit damage. Also, not to be ignored is that it is a very much easier trap to use, to set out, and to clean up after use.

Of interest in these two years is the marked improvement of these traps in predicting fruit damage in 1980. The major reason for this is the experience gained by the author in trap placement. In 1980, great care was taken to place traps in the perimeter row of the orchard near the most likely sources of outside infestation. Each orchard was walked around and the outside habitat studied for wild apple trees or native hawthornes. There were mapped, and then the most likely or severe sources had a trap placed next to them. In 1979, some traps were intentionally placed uniformly around the orchard which was discovered not to be a desirable placement scheme.

Another feature discovered from this Table was that sexing of the flies is not necessary. It was assumed that the number of female flies would be a much better indicator of fruit damage, as they sting the fruit and cause the damage. However, this was not the case, as the average accumulative number of flies per trap gave the highest R^2 value. This simplifies future trapping programs by not requiring a sexing of the flies, but merely counting the total number of flies on the trap.

Outside Fly Pressure. A study of a few of the other parameters that might help explain some of the remaining variability was performed. The size of the outside population that could migrate into the orchard to cause fruit damage should have a large R^2 value. This was not the case, as the average catch of flies on the yellow trap in abandoned trees gave an R^2 of .01 to fruit damage in the adjacent orchard, and that on the red sphere was only .13. When combining the potential size of the population and its distance away from the orchard by the rating scheme found in Table 1, a regression analysis gave similarly bad results (R^2=.11). This indicates that this rating system is not a very reliable predictor of the amount of fruit damage in the orchard. However, some of the variability in the differing amount of fruit damage between orchards can be explained by the outside pest pressure, therefore good sanitation around the orchard is critical to reduce the amount of damage from apple maggot.

Another variable that is difficult to quantify is weather. If, as happened in 1981, an outside source has a large number of flies due to a favorable climate the preceeding year, and their oviposition and feeding sites are removed by winter kill of the buds, spring frosts, or heavy scab pressure this year, then they will actively disperse into adjacent commercial orchards. This added pressure can then cause an unexpectedly high amount of damage. This is difficult to quantify, but should be kept in mind when managing apple maggot.

Conclusions

Apple maggot fly catch on the red sphere trap was a slightly better predictor of fruit damage in both years of the study when all orchards were considered, but when orchards with resident populations of flies were deleted from the analysis, it was an inferior predictor. When both years data were lumped to present greater variable conditions, it was slightly inferior to the yellow Zoecon AM trap. Because the yellow trap is much easier to use, and it being a more consistent predictor, its use is recommended. Flies caught on the trap do not need to be sexed, but can be averaged as accumulative per trap catch to make predictions concerning fruit damage. Also learned from this test was that perimeter placing of traps biased toward the outside infestation sources is a key to improving the reliability of either trap type in predicting fruit damage.

RECOMMENDATIONS FOR MONITORING AND MANAGING APPLE MAGGOT IN COMMERCIAL ORCHARDS

The following recommendations are the results of experiments carried out for two summers in commercial orchards in Michigan. These experiments were initiated to evaluate different management strategies and possibly to improve and reduce the cost of control of apple maggot. These experiments are important because: 1) the high control costs growers experience, 2) possible excessive use of pesticides by some growers that may have deliterious effects on the environment and beneficial species, and 3) the availability of monitoring tools that aid in the precise timing of sprays to reduce these negative factors. Once these tools are combined into a reliable program, they can be implemented to provide more efficient control of apple maggot.

1. Timing of the first apple maggot spray

The apple maggot overwinters as pupae in the soil underneath apple trees. In mid-summer the adults emerge, feed, mate, and lay eggs in suitable apples. The eggs hatch, and the larvae tunnel throughout the apple, making it unmarketable. To prevent this damage, sprays are applied at emergence and repeated throughout the season until harvest. The toxic residues, if they are effective, kill the adults before any egg laying occurs.

A. Regional Recommendations - During the past decade the Cooperative Extension Service (CES) has trapped apple maggot adults in abandoned orchards, and advised growers to make the first application 7-10 days after the initial catch. This is the pre-oviposition or maturation period of the adult flies. Thereafter sprays should be applied at 10 or 14 day intervals. This strategy is acceptable to the CES because they are responsible for all growers and all pest pressure situations. Some growers in the region do have a serious problem with apple maggot and need the five sprays that are shown in Figure 17, line A to control apple maggot adequately. Other growers may have purchased a new orchard and do not know its pests pressures and may need a complete schedule. The CES recommendation if followed will ensure them clean fruit. However, the CES also recognizes the fact that the majority of the orchards have a very minor problem with apple maggot, and this strategy is not proper for them. If growers followed strategy A in these clean orchards their costs would be much greater than necessary, and possible negate any profit.

B. Trapping outside each orchard - A much better approach to apple maggot control would be to trap the pest in abandoned trees around each orchard. These trees provide the source of infestation for commercial orchards. Based on first catch there, a grower would have a much better indication of when the apple maggot could invade and infest his orchard. As seen on Line B in Figure 17, most growers could delay their first spray for a considerable interval.

Each point represents the first catch using yellow Zoecon AM trap in abandoned trees, and no spray would be required before this date. The average first catch in the Kent county area was August 1, a full month or two sprays after the CES spray recommendation was initially made. To note also was that some orchards had no apple maggot pressure until late August, by which time the grower has already sprayed 3 or 4 times for apple maggot and put his sprayer away for the season.

C. In orchard trapping - To date the best strategy for managing apple maggot would be to trap it in the orchard and apply sprays only when the pest is present. This approach was tried and the results are found on line C in Figure 17. Each dot represents the first catch on a trap placed optimally in the perimeter row of the orchard, and in the tree nearest to the outside infestation source. If sprays were applied based on this method of monitoring several applications would not be necessary for apple maggot, and if other pests were not present then savings in spray applications could be achieved. To note, flies were never caught in seven of the 29 orchards monitored, and in those no applications would have to be made this season for apple maggot.

2. Number of sprays necessary for apple maggot control

The current recommended approach to control apple maggot is to apply a spray 7-10 days after first emergence, and then repeat applications every 14 days until harvest.

This approach will maintain a toxic residue on the foliage and control adults before they infest the fruit.

An alternative strategy was carried out for two summers in 31 commercial orchards. This involved trapping flies in orchards, and basing spray on trap catch. The first spray was applied at first catch, and additional sprays were made only when flies were caught thereafter, and only after the residual period of the last spray had passed.

The proof of whether this approach is feasible depends on the quality of fruit at harvest. A fruit damage rating survey was performed in each orchard to determine the amount of damage inflicted by apple maggot. As expected as the trap catch increased the amount of fruit damaged was larger. Therefore, traps can be used as a tool to determine when sprays should be applied.

3. Last spray for apple maggot control

Currently most growers apply their last insecticide spray in mid-August. This is too soon as is shown in Figure 17 and Table 48 which increases their risk of infestation. Figure 17 shows that in some orchards the first flies are not caught until after this time. The first column of Table 48 indicates trap catch of adults in abandoned trees around commercial orchards. These are the flies that can invade the orchard and infest fruit, especially after mid-August when the fruit in the abandoned trees are severely infested and apples in the commercial orchard are susceptible for egg laying. The second column is the trap catch of flies in the commercial orchards. As can be seen, the catch occurs over the same time frame, even though they are much less in the orchard. Important to note is that the peak catch in both cases occurs in early September, after most sprayers are put away. This confirms that growers stop spraying too soon in the fall, and any damage from apple maggot probably occurs during the 4 week period after the last spray and the last catch.

4. Perimeter spraying

It has been suggested that a grower could spray the perimeter rows of his apple orchard late in the season for apple maggot control. This strategy was tested by two different methods.

Yellow Zoecon AM traps were placed in 4 selected trees in each of the perimeter four rows nearest to the infestation source. This 16 traps per orchard design was replicated in 5 orchards. It was hoped flies would be caught as they moved into the orchard to determine how far they migrated in. Table 50 shows that the majority of the flies caught were in the perimeter row, and that by the fourth row very few flies were caught. This indicates that based on trap catch, perimeter spraying of the outside 4 rows is a feasible alternative to reduce costs for apple maggot control.

Another test of this approach was to determine fruit damage in each of the perimeter four rows. Five trees were chosen at random in each of the 4 perimeter rows on the side of the orchard nearest the infestation of apple maggot adults. The data presented in Table 67 was taken from five orchards in 1980. It shows that the farther into the orchard, the less the damage caused by apple maggot. This further supports the perimeter spraying approach for managing apple maggot.

Conclusions

Data taken for two summers supports the strategy of spraying to control apple maggot based on yellow Zoecon AM trap catches on the perimeter row of commercial orchards. This will usually delay the first application, but will require sprays later in the season. The amount of damage can be fairly accurately predicted from these trap catches. Perimeter sprays can be applied to prevent damage as confirmed by trap count and fruit damage rating experiments.

As in any agricultural system, one pest cannot be considered alone. These recommendations indicate how this one pest can be more effectively managed to reduce costs and damage. However, one should monitor the orchard weekly to check on other pest populations, and make management decisions based on the complex of pests and beneficial organisms present.

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APPENDIX

APPENDIX 1

Record of Deposition of Voucher Specimens*

The specimens listed on the following sheet(s) have been deposited in the named museum(s) as samples of those species or other taxa which were used in this research. Voucher recognition labels bearing the Voucher No. have been attached or included in fluid-preserved specimens.

Voucher No.: 1982-3

Title of thesis or dissertation (or other research projects):

PARAMETERS AFFECTING EMERGENCE AND MANAGEMENT STRATEGIES OF THE APPLE MAGGOT (DIPTERA: TEPHRITIDAE *Rhagoletis pomonella*)

Museum(s) where deposited and abbreviations for table on following sheets:

Entomology Museum, Michigan State University (MSU)

Other Museums:

Investigator's Name (s) (typed)

Larry Gene Olsen

Date May 21, 1982

*Reference: Yoshimoto, C. M. 1978. Voucher Specimens for Entomology in North America. Bull. Entomol. Soc. Amer. 24:141-42.

Deposit as follows:

Original: Include as Appendix 1 in ribbon copy of thesis or dissertation.

Copies: Included as Appendix 1 in copies of thesis or dissertation.
Museum(s) files.
Research project files.

This form is available from and the Voucher No. is assigned by the Curator, Michigan State University Entomology Museum.

APPENDIX 1.1

Voucher Specimen Data

Page 1 of 2 Pages

All flies were caught in apple orchards on yellow Zoecon AM traps.

Species or other taxon	Label data for specimens collected or used and deposited	Number of: Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
DIPTERA: ANISOPODIDAE									
Sylvicola alternata	Kalamazoo Co., MI. 6 July 1979					1			M.S.U.
DIPTERA: BOMBYLIIDAE									
Ogcodocera leucoprocta	Allegan Co., MI. 11July 1979					1			M.S.U.
DIPTERA: CLUSIIDAE									
Clusia czernyi	various MI locations & dates					2	1		M.S.U.
DIPTERA:OTITIDAE									
Delphinia picta	Several MI locations & dates					12	11		M.S.U.
Pseudotephritina cribellum	Kent Co MI 28 Aug 1979					1			M.S.U.
Pseudotephritis vau	Clinton Co., MI 16 July 1980						1		M.S.U.
Seioptera vibrans	Kalamazoo Co., MI 9 July 1979					1	1		M.S.U.
DIPTERA: PLATYSTOMATIDAE									
Rivellia viridulans	Various MI locations & dates					3	2		M.S.U.
DIPTERA: TETANOCERIDAE									
Euthycera arcuata	Kalamazoo Co., MI					1	1		M.S.U.

(Use additional sheets if necessary)

Investigator's Name(s) (typed)

Larry Gene Olsen

Date May 21, 1982

Voucher No. 1982-3

Received the above listed specimens for deposit in the Michigan State University Entomology Museum.

Curator Date 5/21/1982

All flies were caught in apple orchards on yellow Zoecon AM traps.

Number of:

APPENDIX 1.1

Voucher Specimen Data

Page 2 of 2 Pages

All flies were caught in apple orchards on yellow Zoecon AM traps.

Species or other taxon	Label data for specimens collected or used and deposited	Number of: Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
DIPTERA: TEPHRITIDAE									
Euaresta bella	Various MI locations & dates					3	1		M.S.U.
Euleia fratria	Ionia Co., MI. 6 Sept 1979						1		M.S.U.
Eutreta sparsa	Ottawa Co., MI. 7 Aug 1979					3			M.S.U.
Icterica seriata	Ionia Co., MI. 7 Aug 1979					1			M.S.U.
Paroxyna albiceps	Kent Co., MI. 28 Aug 1979					1			M.S.U.
Rhagoletis basiola	Various MI locations & dates					2	2		M.S.U.
Rhagoletis cingulata	Various MI locations & dates					6	1		M.S.U.
Rhagoletis fausta	Clinton Co., MI. 3 July 1979					1			M.S.U.
Rhagoletis pomonella	Various MI. locations & dates					31	5		M.S.U.
Rhagoletis suavis	Various MI. locations & dates					25	10		M.S.U.
Rhagoletis tabellaria	Various MI. locations & dates					11	1		M.S.U.
Rhagoletis sp (hybrid?)	Kent Co., MI. 7 Aug 1979					1			M.S.U.

(Use additional sheets if necessary)

Investigator's Name(s) (typed)

Larry Gene Olsen

Date May 21, 1982

Voucher No. 1982-3

Received the above listed specimens for deposit in the Michigan State University Entomology Museum.

Curator Date 5/21/1982

Appendix 2. List of Cooperating Growers and a Description of their Orchards Monitored.

Year	Owners Name	Location	Block Name	Age	Main Varieties	No. of Traps	Rating of Pressure
1979	Blythe, Ed	Muir	Dump	52	McIntosh Northern Spy Red Delicious	10	0
	Blythe, Ed	Muir	Hill	52	McIntosh Northern Spy Red Delicious	1	0
	Gee, Francis	Muir	Front	60	McIntosh Northern Spy Red Delicious	10	2
	Gee, Francis	Muir	Back	60	McIntosh Northern Spy Red Delicious	2	2
	Jones, Clyde	Laingsburg	7 acre	30	Early McIntosh Jonathan	1	0
	Jones, Larry	Laingsburg	Golden	15	Red Delicious Spur Gold	4	2
	Jones, Larry	Laingsburg	Stark Crimson	12	Golden Delicious Red Delicious	2	2

ppendix 2. *List* of Cooperating *Growers* and a Description of their Orchards Monit

Appendix 2. List of Cooperating Growers and a Description of their Orchards Monitored (cont.)

Year	Owners Name	Location	Block Name	Age	Main Varieties	No. of Traps	Rating of Pressure
1979	Klein, Joe	Sparta	Home	30	Jonathan McIntosh Northern Spy Winesap Winter Banana	2	3
	Klein, Royal	Sparta	Corner	12	Northern Spy Red Delicious Rome	4	4
	Perkins, Glenn	Grand Rapids	Home	15-85	Northern Spy	4	3
	Perkins, Glenn	Grand Rapids	Farm	30	Golden Delicious Jonathan McIntosh Red Delicious	2	2
	Reister, Robert	Conklin	Golden	18	Golden Delicious	4	1
	Reister, Robert	Conklin	Rome	18	Jonathan Rome	2	0
	Schwallier, Fred		Coopersville	Zahm	30 Jonathan Northern Spy Red Delicious	Fentons	10 3

Appendix 2. List of Cooperating Growers and a Description of their Orchards Monitored (cont.)

Year	Owners Name	Location	Block Name	Age	Main Varieties	No. of Traps	Rating of Pressure
1979	Schwallier, Fred	Coopersville	24th Ave.	12	Ida Red Jonathan Red Delicious	1	1
	Schwallier, Fred	Coopersville	Home	45	Jonathan McIntosh	4	3
	Schwartz, Orville	Sparta	Back	25	Jonathan Red Delicious	10	3
	Schwartz, Orville	Sparta	Front	25	Jonathan McIntosh Red Delicious	1	3
	Seitsma, Jerry	Grand Rapids	Leased	40	Jonathan Northern Spy Red Delicious	10	5
	Seitsma, Jerry	Grand Rapids	Diagonal	25	Cortland Jonathan McIntosh Northern Spy Red Delicious	1	1

Appendix 2. List of Cooperating Growers and a Description of their Orchards Monitored (cont.)

Appendix 2. List of Cooperating Growers and a Description of their Orchards Monitored (cont.)

Year	Owners Name	Location	Block Name	Age	Main Varieties	No. of Traps	Rating of Pressure
1980	Acker, Bill	Onekema	Erdman Rd.	12	Crab Golden Delicious McIntosh Northern Spy Red Delicious R.I. Greening Transparent	2	1
	Beck, Dan	St. Johns	North Woods	25	Golden Delicious McIntosh Northern Spy Red Delicious	16	4
	Beck, John	St. Johns	Old Trees	55	Cortland Golden Delicious Jonathan Northern Spy Red Delicious Wagner	16	1
	Binz, John	Freeland	Apple Mountain	50	Golden Delicious Jonathan McIntosh Northern Spy Red Delicious Snow	16	2

Appendix 2. List of Cooperating Growers and a Description of their Orchards Monitored (cont.)

Year	Owners Name	Location	Block Name	Age	Main Varieties	No. of Traps	Rating of Pressure
1980	Gee, Francis	Muir	Front	60	McIntosh Northern Spy Red Delicious	16	2
	Leaman, Jack	Freeland	Back	15	Golden Delicious Jonathan McIntosh Northern Spy Red Delicious	1	1
	Short, George	Onekama	Maidens Road	40	Northern Spy Red Delicious	4	3
	Tennes, Bernie	Charlotte	Old Orchard	45	Jonathan McIntosh Northern Spy	16	3

Appendix 2. List of Cooperating Growers and a Description of their Orchards Monitored (cont.)

Year	Owners Name	Location	Block Name	Age	Main Varieties	No. of Traps	Rating of Pressure
1980	Tennes, Bernie	Charlotte	Centennial	4	Golden Delicious Ida Red Jonathan McIntosh Paula Red Red Delicious	16	3
	Thorsen, James	Freeland	Mixed Block	15	Ida Red McIntosh Red Delicious	2	1
	Turner, Ken	Freeland	Apples	25	McIntosh Northern Spy Red Delicious	4	2

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APPENDIX 3-1

Accumulation of Air Degree Days At Base 48°F (8.9°C) at the Kalamazoo State Hospital Orchard in 1977 (B.E. Method).

DAY	APR	MAY	JUN	JUL	AUG	SEP	OCT
1	1	324	865	1377	2236	2873	3314
2	8	333	871	1394	2258	2893	3318
3	11	342	880	1417	2286	2914	3320
4	12	349	897	1454	2312	2941	3325
5	12	370	918	1492	2338	2959	3331
6	12	389	925	1533	2364	2984	3337
7	13	397	930	1563	2391	2994	3361
8	14	402	937	1592	2417	3016	3361
9	15	404	945	1621	2440	3036	3368
10	28	409	956	1651	2466	3046	3372
11	47	417	967	1674	2480	3056	3376
12	70	429	976	1702	2497	3067	3376
13	87	450	986	1729	2518	3075	3376
14	100	470	1003	1756	2535	3087	3378
15	116	488	1021	1792	2552	3098	3382
16	134	509	1046	1823	2577	3117	3383
17	159	534	1076	1855	2588	3138	3383
18	185	560	1098	1887	2598	3161	3386
19	210	586	1120	1927	2608	3171	3386
20	230	611	1135	1965	2622	3177	3388
21	252	636	1151	1990	2637	3186	3391
22	263	661	1170	2012	2656	3201	3399
23	268	685	1190	2038	2671	3213	3404
24	270	711	1220	2063	2682	3230	3404
25	270	737	1242	2080	2696	3246	3412
26	273	756	1265	2096	2917	3258	3412
27	284	775	1292	2117	2752	3267	3412
28	293	798	1320	2143	2783	3280	3412
29	300	816	1340	2164	2801	3294	3412
30	312	835	1359	2192	2820	3302	3412
31	312	857	1359	2216	2847	3302	3412

APPENDIX 3-2

Accumulation of Two Inch Soil Degree Days on the South Side of the Tree at Base 48°F (8.9°C) at the Kalamazoo State Hospital Orchard in 1977. (B.E. Method).

DAY	APR	MAY	JUN	JUL	AUG	SEPT	OCT
1	0	77	349	734	1447	2072	2573
2	0	81	357	751	1471	2097	2583
3	0	85	365	767	1493	2120	2593
4	0	87	373	789	1515	2143	2601
5	0	94	385	813	1537	2166	2609
6	0	102	395	837	1558	2187	2618
7	0	109	403	862	1581	2209	2626
8	0	112	411	886	1602	2229	2631
9	0	114	419	909	1622	2249	2637
10	1	117	426	932	1644	2267	2641
11	3	120	434	952	1666	2284	2645
12	5	124	442	975	1685	2299	2648
13	8	133	451	999	1704	2313	2649
14	13	140	461	1022	1723	2328	2651
15	17	149	472	1045	1744	2340	2653
16	23	157	486	1072	1763	2354	2655
17	29	169	503	1096	1784	2370	2656
18	35	181	521	1122	1802	2388	2656
19	42	193	538	1148	1820	2405	2657
20	48	205	555	1177	1836	2419	2658
21	53	217	568	1206	1852	2432	2659
22	58	229	582	1231	1868	2446	2662
23	61	241	597	1255	1886	2460	2664
24	64	254	614	1273	1903	2475	2665
25	66	267	633	1295	1920	2491	2667
26	67	279	651	1318	1936	2506	2667
27	69	291	668	1338	1955	2519	2667
28	71	303	687	1358	1978	2534	2667
29	73	315	705	1379	2003	2548	2667
30	75	327	719	1399	2026	2560	2667
31	75	339	719	1422	2048	2560	2667

APPENDIX 3-3

Accumulation of Two Inch Soil Degree Days on the North Side of the Tree at Base 48°F (8.9°C) at the Kalamazoo State Hospital Orchard in 1977. (B.E. Method).

DAY	APR	MAY	JUN	JUL	AUG	SEPT	OCT
1	0	34	258	671	1379	1988	2493
2	0	36	266	687	1400	2011	2505
3	0	38	273	704	1423	2033	2516
4	0	40	282	726	1445	2056	2524
5	0	44	294	750	1467	2077	2532
6	0	51	304	771	1488	2098	2540
7	0	59	314	796	1508	2119	2549
8	0	63	324	820	1529	2139	2556
9	0	67	333	844	1549	2159	2563
10	0	69	342	867	1571	2177	2570
11	0	71	352	890	1591	2194	2576
12	0	74	363	913	1610	2209	2581
13	1	78	375	935	1630	2224	2584
14	3	82	389	957	1650	2239	2587
15	5	86	404	983	1668	2252	2590
16	7	91	422	1008	1688	2266	2594
17	9	95	439	1033	1706	2283	2596
18	12	101	456	1059	1722	2302	2597
19	15	108	471	1086	1738	2319	2599
20	18	116	485	1115	1754	2334	2602
21	19	125	499	1141	1771	2348	2605
22	21	135	514	1165	1788	2363	2608
23	22	146	531	1188	1805	2377	2612
24	24	159	549	1210	1821	2393	2615
25	26	171	567	1232	1837	2409	2618
26	27	184	585	1251	1855	2424	2618
27	29	196	604	1271	1877	2438	2618
28	30	209	623	1292	1901	2452	2618
29	32	221	639	1313	1922	2467	2618
30	33	234	655	1335	1943	2480	2618
31	33	246	655	1357	1965	2480	2618

APPENDIX 3-4

Accumulation of Air Degree Days At Base 48°F (8.9°C) at the Kalamazoo State Hospital Orchard in 1978 (B.E. Method).

DAY	APR	MAY	JUN	JUL	AUG	SEP	OCT
1	0	82	505	1074	1719	2364	2880
2	0	85	520	1088	1736	2385	2886
3	8	90	531	1108	1754	2409	2893
4	11	92	544	1127	1765	2426	2894
5	14	92	558	1150	1778	2448	2898
6	16	96	578	1175	2474	2898	3007
7	20	99	602	1202	1815	2502	2898
8	20	111	607	1220	1838	2535	2898
9	20	114	619	1240	1862	2565	2902
10	29	122	641	1254	1879	2593	2911
11	29	131	666	1263	1898	2624	2915
12	34	149	688	1275	1921	2637	2922
13	34	160	694	1296	1946	2647	2925
14	34	166	700	1317	1973	2667	[illegible]
15	34	176	717	1342	2001	2683	[illegible]
16	35	187	736	1358	2024	2701	2925
17	37	203	764	1376	2048	2722	2925
18	37	223	788	1402	2074	2741	2928
19	38	243	808	1432	2095	2769	2929
20	38	248	831	1464	2108	2799	2934
21	39	257	845	1493	2124	2808	2945
22	42	267	859	1525	2145	2814	2959
23	42	286	877	1542	2170	2821	2959
24	48	304	902	1560	2197	2831	2959
25	52	324	924	1583	2219	2837	2960
26	58	349	951	1614	2242	2845	2960
27	64	375	981	1636	2266	2854	2962
28	71	400	1008	1649	2290	2857	2962
29	80	428	1033	1669	2309	2864	2962
30	82	456	1059	1683	2328	2871	2967
31	82	477	1059	1699	2345	2871	2970

APPENDIX 3-5

Accumulation of Two Inch Soil Degree Days on the South Side of the Tree at Base 48°F (8.9°C) at the Kalamazoo State Hospital Orchard in 1978 (B.E. Method)

DAY	APR	MAY	JUN	JUL	AUG	SEP	OCT
1	0	15	274	745	1396	2048	2633
2	0	17	289	764	1417	2069	2645
3	0	19	302	783	1436	2091	2657
4	0	20	315	802	1454	2111	2669
5	0	20	328	821	1471	2132	2680
6	0	21	341	842	1490	2154	2689
7	0	23	356	865	1509	2177	2696
8	0	26	370	887	1528	2201	2703
9	0	29	382	908	1550	2225	2710
10	0	33	395	929	1569	2249	2719
11	0	38	411	947	1589	2273	2729
12	0	45	426	953	1609	2293	2739
13	0	53	439	964	1630	2209	2747
14	0	59	449	1003	1652	2329	2754
15	0	65	462	1023	1675	2348	2759
16	0	72	475	1042	1698	2369	2763
17	0	81	492	1060	1720	2390	2767
18	0	91	509	1081	1744	2411	2772
19	0	103	525	1103	1766	2435	2776
20	0	116	542	1126	1786	2460	2781
21	0	126	557	1151	1806	2482	2787
22	0	134	572	1176	1826	2501	2795
23	0	144	587	1200	1848	2518	2801
24	1	155	604	1222	1874	2535	2804
25	2	167	621	1245	1896	2552	2807
26	3	180	641	1269	1919	2567	2810
27	6	195	662	1292	1941	2582	2813
28	8	209	683	1313	1964	2595	2816
29	11	225	704	1335	1986	2607	2818
30	14	242	725	1356	2008	2619	2820
31	14	258	725	1376	2028	2619	2823

APPENDIX 3-6

Accumulation of Two-Inch Soil Degree Days on the North Side of the Tree at Base 48°F (8.9°C) at the Kalamazoo State Hospital Orchard in 1978 (B.E. Method)

DAY	APR	MAY	JUN	JUL	AUG	SEP	OCT
1	0	26	261	676	1304	1996	2664
2	0	28	274	693	1324	2023	2677
3	0	30	284	711	1344	2051	2689
4	0	32	295	728	1363	2077	2699
5	0	32	306	747	1380	2104	2708
6	0	34	318	767	1399	2133	2715
7	0	35	330	789	1418	2162	2721
8	0	38	341	810	1439	2194	2727
9	0	41	351	831	1462	2223	2731
10	0	45	362	850	1481	2252	2740
11	0	48	376	867	1501	2282	2748
12	0	55	391	882	1521	2300	2757
13	0	63	401	900	1543	2315	2765
14	0	68	409	919	1566	2334	2771
15	0	73	419	939	1590	2355	2773
16	1	79	430	957	1615	2378	2774
17	1	86	445	975	1639	2400	2776
18	1	95	460	995	1663	2420	2779
19	1	106	474	1017	1687	2445	2782
20	1	117	489	1040	1709	2472	2786
21	2	126	501	1063	1732	2498	2792
22	3	134	512	1088	1755	2519	2799
23	3	143	525	1110	1781	2538	2804
24	5	152	541	1131	1808	2557	2805
25	7	163	557	1153	1830	2577	2807
26	10	175	575	1177	1853	2594	2808
27	13	188	595	1200	1876	2160	2809
28	17	202	615	1220	1900	2624	2811
29	20	216	636	1242	1925	2636	2812
30	24	231	656	1252	1947	2649	2813
31	24	245	656	1282	1972	2649	2816

APPENDIX 3-7

Accumulation of Air Degree Days at Base 48°F (8.9°C) at the Kalamazoo State Hospital Orchard in 1979 (B.E. Method)

DAY	APR	MAY	JUN	JUL	AUG	SEP	OCT
1	0	138	446	1034	1730	2250	2700
2	0	148	458	1047	1751	2272	2723
3	0	150	476	1062	1774	2298	2734
4	0	150	497	1074	1798	2322	2744
5	0	152	516	1087	1820	2346	2760
6	0	164	539	1101	1843	2371	2772
7	0	183	560	1122	1872	2395	2780
8	0	209	587	1148	1896	2412	2788
9	0	236	615	1170	1920	2434	2793
10	0	264	636	1198	1936	2455	2794
11	0	286	649	1225	1945	2465	2798
12	12	286	660	1254	1959	2470	2799
13	16	292	674	1277	1971	2478	2799
14	17	298	695	1304	1976	2498	2799
15	17	303	724	1327	1983	2517	2799
16	18	309	751	1350	1995	2537	2799
17	20	317	774	1366	2007	2562	2799
18	24	338	796	1383	2020	2570	2799
19	30	352	814	1402	2041	2576	2799
20	40	362	836	1425	2052	2586	2799
21	44	366	865	1450	2065	2600	2799
22	51	373	892	1479	2085	2617	2799
23	63	381	909	1507	2108	2622	2799
24	73	383	917	1534	2120	2632	2799
25	87	389	929	1558	2134	2644	2799
26	92	394	940	1584	2149	2650	2799
27	97	400	957	1606	2165	2656	2799
28	103	405	980	1632	2181	2668	2799
29	115	417	1000	1658	2199	2679	2799
30	125	423	1020	1688	2215	2690	2799
31	137	435	1020	1711	2232	2690	2799

APPENDIX 3-8

Accumulation of Two Inch Soil Degree Days on the South Side of the Tree at Base 84°F (8.9°C) at the Kalamazoo State Hospital Orchard in 1979 (.B.E. Method).

DAY	APR	MAY	JUN	JUL	AUG	SEP	OCT
1	0	104	395	880	1541	2125	2673
2	0	109	405	896	1563	2144	2684
3	0	115	417	912	1585	2167	2691
4	0	117	429	930	1608	2190	2697
5	0	121	443	945	1629	2213	2705
6	0	129	456	961	1652	2236	2713
7	0	140	472	977	1672	2256	2724
8	0	156	488	994	1696	2277	2733
9	0	174	508	1014	1719	2299	2740
10	0	194	529	1035	1742	2317	2747
11	0	211	544	1057	1761	2332	2754
12	2	219	558	1080	1778	2351	2759
13	6	227	572	1103	1794	2369	2764
14	8	236	589	1128	1815	2389	2764
15	8	245	609	1153	1829	2408	2764
16	8	254	627	1176	1845	2428	2764
17	10	263	647	1197	1857	2444	2764
18	15	276	664	1218	1872	2464	2764
19	19	288	680	1238	1889	2481	2764
20	25	299	697	1258	1904	2499	2764
21	27	308	714	1280	1922	2518	2764
22	33	317	734	1302	1941	2533	2764
23	42	326	753	1327	1961	2550	2764
24	48	333	768	1351	1980	2567	2764
25	55	340	781	1375	1998	2479	2764
26	62	347	795	1397	2011	2592	2764
27	70	354	810	1421	2029	2606	2764
28	77	361	828	1445	2047	2621	2764
29	85	369	847	1468	2065	2636	2764
30	93	377	864	1495	2087	2656	2764
31	102	386	864	1520	2107	2656	2764

APPENDIX 3-9

Accumulation of Two Inch Soil Degree Days on the North Side of the Tree at Base 48°F (8.9°F) at the Kalamazoo State Hospital Orchard in 1979 (B.E. Method).

DAY	APR	MAY	JUN	JUL	AUG	SEP	OCT
1	0	76	352	835	1486	2082	2620
2	0	79	361	851	1508	2103	2635
3	0	84	372	866	1530	2125	2652
4	0	87	384	884	1553	2148	2666
5	0	89	397	900	1575	2172	2680
6	0	95	410	916	1598	2196	2696
7	0	104	425	933	1622	2219	2707
8	0	116	443	950	1647	2240	2718
9	0	131	462	970	1670	2262	2728
10	0	146	481	990	1693	2284	2738
11	0	162	496	1011	1715	2304	2744
12	0	172	510	1034	1733	2320	2750
13	0	180	524	1059	1751	2335	2755
14	1	189	540	1083	1766	2352	2755
15	1	198	558	1105	1781	2370	2755
16	1	207	577	1128	1796	2388	2755
17	1	215	597	1150	1810	2408	2755
18	1	226	614	1170	1826	2424	2755
19	2	238	630	1190	1844	2439	2755
20	4	249	647	1210	1861	2454	2755
21	6	259	667	1231	1879	2469	2755
22	9	267	686	1253	1898	2486	2755
23	14	277	704	1276	1918	2499	2755
24	19	285	720	1299	1938	2512	2755
25	26	293	735	1322	1957	2527	2755
26	34	301	749	1345	1976	2539	2755
27	41	308	764	1367	1990	2551	2755
28	49	316	781	1391	2005	2564	2755
29	57	324	799	1414	2020	2578	2755
30	65	332	818	1437	2042	2600	2755
31	75	342	818	1463	2062	2600	2755

APPENDIX 3-10

Accumulation of Air Degree Days at Base 48°F (8.9°C) at the Kalamazoo State Hospital Orchard in 1980 (B.E. Method).

DAY	APR	MAY	JUN	JUL	AUG	SEPT
1	0	124	543	1055	1835	2590
2	1	135	560	1076	1858	2616
3	1	150	576	1096	1881	2636
4	1	165	586	1119	1908	2661
5	5	190	599	1140	1936	2684
6	10	207	616	1159	1961	2706
7	18	212	630	1187	1989	2725
8	25	212	637	1216	2021	2747
9	25	215	644	1241	2052	2772
10	25	225	649	1266	2078	2784
11	26	231	662	1295	2101	2797
12	26	241	678	1321	2121	2816
13	26	254	694	1346	2138	2841
14	26	258	708	1375	2163	2863
15	26	264	722	1409	2183	2879
16	26	272	739	1440	2197	2893
17	29	280	755	1467	2213	2902
18	36	288	770	1491	2233	2911
19	47	303	781	1521	2255	2927
20	59	314	789	1557	2283	2948
21	70	330	809	1586	2314	2974
22	92	352	837	1611	2336	2997
23	105	372	870	1630	2351	3009
24	105	396	900	1650	2369	3017
25	105	416	933	1675	2394	3027
26	108	433	964	1700	2419	3030
27	110	448	990	1719	2449	3036
28	111	468	1016	1740	2479	3046
29	115	490	1026	1762	2510	3058
30	118	512	1036	1780	2538	3071
31	118	527	1036	1805	2565	

APPENDIX 3-11

Accumulation of Two Inch Soil Degree Days on the South Side of the Tree at Base 48°F (8.9°C) at the Kalamazoo State Hospital Orchard in 1980. (B.E. Method).

DAY	APR	MAY	JUN	JUL	AUG	SEPT
1	0	30	280	735	1461	2234
2	0	32	293	755	1486	2260
3	0	36	307	775	1511	2286
4	0	39	320	794	1537	2312
5	0	42	334	815	1563	2338
6	0	46	347	835	1589	2363
7	0	49	361	856	1615	2388
8	0	53	374	877	1641	2413
9	0	55	387	898	1667	2437
10	0	58	399	921	1692	2461
11	0	61	411	943	1717	2485
12	0	65	423	966	1742	2508
13	0	69	435	988	1766	2531
14	0	74	448	1012	1789	2553
15	0	79	460	1035	1812	2575
16	0	85	474	1059	1835	2596
17	0	92	487	1083	1858	2616
18	0	99	501	1107	1881	2636
19	1	108	514	1131	1904	2655
20	3	119	528	1155	1929	2674
21	5	129	542	1180	1953	2692
22	8	142	558	1205	1977	2711
23	12	154	575	1230	2001	2729
24	15	168	594	1255	2026	2745
25	17	181	613	1280	2051	2760
26	19	194	634	1305	2077	2774
27	21	208	654	1331	2102	2787
28	23	222	675	1356	2129	2799
29	25	237	695	1382	2155	2810
30	28	251	715	1407	2182	2821
31	28	266	715	1434	2208	

APPENDIX 3-12

Accumulation of Two Inch Soil Degree Days on the North Side of the Tree at Base 48°F (8.9°C) at the Kalamazoo State Hospital Orchard in 1980. (B.E. Method).

DAY	APR	MAY	JUN	JUL	AUG	SEPT
1	0	45	270	696	1441	2245
2	0	49	282	715	1466	2274
3	0	54	294	734	1491	2303
4	0	60	306	755	1516	2331
5	0	66	318	776	1542	2359
6	0	72	331	794	1568	2386
7	0	77	345	818	1597	2413
8	0	80	357	842	1625	2439
9	0	82	368	865	1652	2466
10	0	84	378	889	1677	2491
11	0	88	387	912	1702	2516
12	0	91	397	836	1725	2540
13	0	95	407	960	1748	2564
14	0	99	418	985	1771	2587
15	0	102	429	1010	1795	2609
16	0	105	439	1036	1818	2631
17	0	110	450	1060	1842	2651
18	1	116	461	1085	1865	2670
19	2	126	471	1109	1889	2689
20	5	136	482	1135	1914	2707
21	9	147	493	1161	1940	2726
22	15	159	509	1187	1966	2744
23	20	169	528	1213	1990	2761
24	25	182	549	1238	2015	2777
25	29	194	571	1264	2041	2791
26	31	206	594	1290	2069	2805
27	33	216	616	1315	2098	2818
28	35	226	638	1339	2127	2830
29	38	237	657	1364	2157	2842
30	41	248	677	1389	2186	2854
31	41	259	677	1415	2216	

APPENDIX 3-13

Accumulation of Air Degree Days at Base 48°F (8.9°C) at the Upjohn Orchard in 1977 (B.E. Method).

DAY	APR	MAY	JUN	JUL	AUG	SEP	OCT
1	1	273	859	1357	2205	2790	3167
2	8	282	865	1376	2224	2812	3179
3	14	291	874	1397	2249	2829	3188
4	15	298	882	1433	2279	2847	3193
5	15	321	893	1468	2307	2861	3197
6	15	343	899	1508	2334	2875	3198
7	17	350	904	1542	2361	2894	3198
8	17	357	911	1572	2385	2915	3203
9	18	360	919	1601	2406	2935	3203
10	29	367	929	1627	2433	2943	3207
11	46	376	940	1652	2445	2955	3207
12	61	389	949	1680	2460	2962	3207
13	77	413	959	1706	2480	2970	3208
14	85	431	976	1733	2496	2979	3211
15	98	450	995	1771	2514	2986	3211
16	112	472	1019	1802	2536	3002	3212
17	131	498	1049	1835	2547	3021	3213
18	152	525	1071	1864	2556	3040	3213
19	172	553	1093	1902	2565	3057	3215
20	192	583	1108	1940	2577	3063	3218
21	211	613	1124	1969	2588	3070	3224
22	219	639	1143	1993	2604	3083	3224
23	223	665	1165	2018	2615	3093	3224
24	227	693	1195	2042	2625	3108	3232
25	227	722	1216	2058	2638	3122	3232
26	231	741	1241	2072	2655	3131	3232
27	241	763	1270	2090	2686	3137	3232
28	250	788	1297	2112	2713	3143	3232
29	254	807	1318	2135	2727	3150	3232
30	261	829	1335	2162	2744	3161	3232
31	261	851	1335	2186	2768	3161	3232

APPENDIX 3-14

Accumulation of Two Inch Soil Degree Days on the South Side of the Tree at Base 48°F (8.9°C) at the Upjohn Orchard in 1977. (B.E. Method).

DAY	APR	MAY	JUN	JUL	AUG	SEPT	OCT
1	0	39	390	768	1444	1940	2321
2	0	43	398	784	1461	1959	2327
3	0	44	405	801	1481	1976	2331
4	0	46	414	823	1501	1992	2335
5	0	55	423	848	1521	2008	2340
6	0	63	434	874	1542	2024	2341
7	0	68	442	900	1563	2041	2341
8	0	70	450	922	1585	2059	2344
9	0	72	457	945	1606	2076	2344
10	0	76	464	967	1628	2089	2345
11	0	82	470	986	1647	2101	2345
12	1	91	479	1009	1663	2111	2345
13	2	101	487	1030	1680	2122	2345
14	3	111	498	1052	1697	2132	2345
15	4	122	509	1079	1712	2140	2345
16	6	136	522	1103	1730	2150	2345
17	8	151	538	1128	1745	2164	2345
18	11	168	555	1152	1755	2180	2345
19	15	186	572	1179	1763	2194	2345
20	19	204	586	1207	1772	2205	2345
21	23	221	599	1232	1784	2214	2345
22	27	238	613	1252	1795	2225	2345
23	31	256	628	1272	1806	2236	2345
24	33	274	645	1292	1817	2249	2346
25	35	290	663	1312	1827	2260	2346
26	36	306	680	1330	1836	2270	2346
27	36	321	698	1347	1850	2278	2346
28	36	337	718	1365	1870	2290	2346
29	36	352	735	1384	1887	2301	2346
30	36	367	751	1404	1903	2312	2346
31	36	381	751	1426	1921	2312	2346

APPENDIX 3-15

Accumulation of Ground Litter Degree Days on the South Side of the Tree at Base 48°F (8.9°C) at the Upjohn Orchard in 1977. (B.E. Method).

DAY	APR	MAY	JUN	JUL	AUG	SEPT	OCT
1	0	127	481	865	1555	2123	2560
2	0	131	489	882	1574	2143	2569
3	2	135	496	899	1595	2162	2576
4	3	137	504	921	1617	2181	2583
5	4	147	513	945	1639	2201	2590
6	4	160	525	970	1660	2219	2594
7	5	171	533	994	1682	2238	2596
8	5	179	541	1016	1705	2258	2600
9	6	184	549	1038	1726	2277	2603
10	7	188	556	1059	1749	2293	2605
11	9	193	564	1079	1770	2308	2606
12	11	201	572	1101	1789	2322	2606
13	14	211	581	1122	1808	2334	2606
14	18	222	591	1143	1829	2347	2607
15	23	232	602	1168	1847	2358	2607
16	29	244	616	1193	1866	2370	2607
17	36	257	633	1217	1885	2384	2607
18	44	271	651	1241	1899	2400	2607
19	53	287	668	1268	1911	2416	2607
20	63	303	683	1297	1923	2428	2607
21	74	319	696	1324	1936	2439	2608
22	84	335	710	1347	1949	2452	2608
23	94	351	725	1369	1963	2463	2608
24	104	367	742	1390	1976	2476	2609
25	111	383	759	1413	1989	2489	2609
26	116	399	775	1432	2003	2503	2609
27	120	413	794	1451	2023	2513	2609
28	122	428	813	1470	2045	2525	2609
29	123	443	832	1490	2065	2538	2609
30	125	458	848	1511	2083	2550	2609
31	125	471	848	1535	2102	2550	2609

APPENDIX 3-16

Accumulation of Air Degree Days at Base 48°F (8.9°C) at the Upjohn Orchard in 1978 (B.E. Method)

DAY	APR	MAY	JUN	JUL	AUG	SEP	OCT
1	2	81	485	1036	1683	2365	2892
2	2	84	501	1051	1702	2386	2901
3	8	88	512	1071	1723	2410	2910
4	11	90	524	1090	1735	2426	2912
5	13	90	538	1112	1749	2449	2915
6	14	95	556	1135	1769	2474	2916
7	19	98	579	1161	1788	2503	2916
8	19	110	584	1180	1811	2534	2916
9	19	112	595	1200	1837	2564	2920
10	28	119	613	1214	1854	2592	2931
11	28	128	636	1225	1874	2622	2936
12	33	146	658	1239	1898	2635	2944
13	33	157	664	1260	1925	2644	2948
14	33	163	669	1280	1953	2665	2948
15	33	169	686	1303	1982	2682	2948
16	34	179	705	1319	2006	2701	2948
17	36	191	730	1337	2031	2721	2949
18	36	206	755	1361	2058	2742	2952
19	37	225	775	1391	2081	2769	2954
20	37	245	797	1422	2095	2798	2961
21	38	251	812	1451	2112	2809	2972
22	41	260	825	1482	2135	2816	2985
23	41	270	842	1499	2162	2825	2985
24	46	289	866	1519	2189	2837	2986
25	51	309	888	1542	2212	2844	2988
26	56	333	915	1572	2236	2852	2988
27	63	360	943	1597	2262	2862	2991
28	70	386	968	1610	2288	2866	2991
29	78	413	993	1631	2308	2874	2993
30	80	439	1018	1645	2327	2882	2999
31	80	459	1018	1661	2346	2882	3003

APPENDIX 3-17

Accumulation of Two Inch Soil Degree Days on the South Side of the Tree at Base 48°F (8.9°C) at the Upjohn Orchard in 1978 (B.E. Method).

DAY	APR	MAY	JUN	JUL	AUG	SEP	OCT
1	0	9	264	709	1333	1963	2474
2	0	10	280	726	1353	1982	2484
3	0	11	293	744	1374	2002	2495
4	0	11	305	762	1391	2019	2503
5	0	11	317	781	1406	2038	2510
6	0	12	330	801	1424	2058	2515
7	0	12	345	823	1443	2079	2518
8	0	15	356	845	1463	2102	2524
9	0	16	367	864	1484	2126	2526
10	0	20	379	883	1503	2149	2532
11	0	23	393	898	1522	2173	2539
12	0	30	408	914	1543	2193	2547
13	0	39	418	932	1565	2206	2552
14	0	45	426	951	1588	2223	2553
15	0	50	437	971	1612	2240	2553
16	0	56	449	990	1636	2258	2553
17	0	63	465	1008	1658	2276	2553
18	0	74	482	1028	1681	2296	2555
19	0	86	498	1051	1705	2318	2555
20	0	99	515	1074	1723	2342	2558
21	0	107	528	1099	1741	2359	2563
22	0	114	541	1125	1760	2374	2571
23	0	124	555	1147	1781	2387	2573
24	1	134	571	1168	1803	2400	2573
25	1	146	588	1190	1825	2413	2575
26	2	159	607	1214	1847	2424	2576
27	3	175	628	1237	1868	2435	2576
28	5	192	648	1256	1891	2444	2577
29	8	211	669	1276	1910	2452	2577
30	9	229	690	1295	1928	2463	2577
31	9	246	690	1314	1946	2463	2579

APPENDIX 3-18

Accumulation of Ground Litter Degree Days on the South Side of the Tree at Base 48°F (8.9°C) at the Upjohn Orchard in 1978 (B.E. Method).

DAY	APR	MAY	JUN	JUL	AUG	SEP	OCT
1	0	33	291	738	1367	2056	2684
2	0	36	306	754	1388	2079	2698
3	0	41	318	772	1409	2104	2711
4	0	42	329	790	1427	2127	2720
5	0	42	342	809	1444	2152	2728
6	0	45	354	828	1463	2177	2734
7	1	46	369	850	1483	2205	2739
8	1	49	381	871	1504	2234	2743
9	1	52	391	890	1527	2262	2748
10	1	58	403	910	1547	2290	2758
11	1	61	418	926	1567	2318	2766
12	1	69	435	942	1589	2337	2775
13	1	78	446	960	1612	2351	2784
14	1	84	455	979	1637	2370	2787
15	1	89	466	999	1663	2390	2790
16	1	95	479	1018	1688	2412	2790
17	2	103	495	1036	1713	2433	2793
18	2	114	513	1057	1738	2453	2798
19	2	126	528	1079	1763	2477	2800
20	2	138	545	1103	1784	2504	2806
21	2	147	561	1127	1805	2523	2815
22	3	155	575	1153	1828	2541	2824
23	3	164	589	1176	1853	2560	2830
24	5	174	605	1197	1878	2579	2833
25	8	184	621	1219	1901	2597	2835
26	11	196	640	1243	1923	2615	2837
27	16	210	660	1266	1946	2631	2839
28	21	224	679	1286	1969	2645	2842
29	25	241	699	1308	1991	2658	2844
30	30	258	719	1327	2012	2671	2846
31	30	274	719	1347	2034	2671	2849

APPENDIX 3-19

Accumulation of Air Degree Days at Base 48°F (8.9°C) at the Upjohn Orchard in 1979. (B.E. Method).

DAY	APR	MAY	JUN	JUL	AUG	SEPT	OCT
1	0	80	374	880	1512	2070	2478
2	0	88	385	893	1528	2095	2489
3	0	91	403	912	1547	2120	2491
4	0	91	419	923	1568	2141	2498
5	0	92	431	934	1600	2163	2499
6	0	103	454	947	1621	2180	2501
7	0	119	472	963	1643	2201	2506
8	0	143	499	982	1674	2218	2506
9	0	168	526	1004	1698	2229	2508
10	0	193	553	1026	1721	2243	2510
11	0	214	563	1050	1738	2256	2510
12	7	214	573	1076	1748	2274	2510
13	11	219	586	1102	1758	2291	2510
14	13	224	605	1127	1770	2315	
15	13	229	633	1147	1775	2327	
16	15	236	659	1168	1783	2331	
17	18	244	674	1180	1798	2338	
18	21	263	684	1194	1809	2349	
19	27	277	707	1209	1823	2364	
20	33	287	728	1227	1842	2373	
21	41	291	750	1245	1853	2379	
22	48	298	759	1269	1872	2386	
23	56	303	765	1297	1892	2392	
24	66	313	773	1324	1915	2397	
25	76	319	784	1343	1925	2404	
26	78	324	802	1363	1939	2415	
27	79	327	822	1390	1955	2425	
28	79	332	845	1412	1970	2435	
29	79	343	859	1435	1986	2446	
30	79	346	872	1461	2014	2464	
31	79	357	872	1489	2046	2464	

APPENDIX 3-20

Accumulation of Two Inch Soil Degree Days on the South Side of the Tree at Base 48°F (8.9°C) at the Upjohn Orchard in 1979. (B.E. Method).

DAY	APR	MAY	JUN	JUL	AUG	SEPT	OCT
1	0	29	220	652	1220	1782	2192
2	0	30	229	687	1240	1802	2210
3	0	30	238	703	1258	1822	2228
4	0	30	248	718	1277	1842	2242
5	0	30	262	729	1297	1862	2252
6	0	31	278	741	1317	1880	2259
7	0	34	298	754	1337	1898	2266
8	0	41	318	769	1359	1916	2270
9	0	53	339	786	1380	1927	2275
10	0	66	351	803	1401	1936	2280
11	0	80	363	822	1421	1947	2283
12	0	89	374	843	1437	1962	2284
13	0	96	388	864	1451	1977	2285
14	0	105	406	886	1465	1994	
15	0	113	424	906	1478	2009	
16	1	118	442	924	1489	2019	
17	2	122	456	941	1501	2029	
18	3	133	469	956	1512	2040	
19	5	143	484	971	1526	2052	
20	8	151	501	987	1542	2062	
21	11	156	519	1005	1557	2069	
22	15	162	535	1023	1573	2079	
23	19	168	546	1044	1589	2088	
24	23	171	556	1065	1609	2095	
25	27	174	567	1084	1625	2103	
26	28	177	579	1102	1641	2112	
27	29	182	594	1122	1657	2120	
28	29	186	609	1141	1685	2138	
29	29	193	626	1159	1710	2155	
30	29	201	639	1179	1736	2174	
31	29	210	639	1197	1764	2174	

APPENDIX 3-21

Accumulation of Ground Litter Degree Days on the South Side of the Tree at Base 48°F (8.9°C) at the Upjohn Orchard in 1979. (B.E. Method).

DAY	APR	MAY	JUN	JUL	AUG	SEPT	OCT
1	0	43	273	704	1243	1808	2341
2	0	46	282	718	1262	1828	2362
3	0	50	293	733	1281	1849	2385
4	0	50	306	748	1300	1870	2399
5	0	51	320	760	1320	1891	2410
6	0	56	336	772	1339	1911	2417
7	0	66	354	785	1359	1931	2424
8	0	80	373	799	1381	1951	2429
9	0	96	394	815	1404	1965	2432
10	0	114	406	832	1424	1987	2436
11	0	129	417	850	1442	2009	2438
12	0	135	428	869	1459	2025	2439
13	0	140	442	888	1474	2042	
14	1	146	460	909	1489	2060	
15	2	153	478	929	1503	2078	
16	3	160	495	948	1514	2092	
17	5	167	510	966	1526	2105	
18	8	179	524	981	1537	2119	
19	11	190	539	995	1551	2134	
20	15	200	556	1011	1566	2151	
21	19	207	572	1027	1579	2165	
22	24	214	588	1044	1596	2178	
23	29	222	599	1063	1613	2191	
24	34	227	610	1083	1632	2202	
25	39	230	621	1104	1652	2215	
26	41	235	633	1122	1669	2229	
27	42	240	648	1140	1684	2246	
28	42	245	663	1160	1711	2263	
29	42	250	678	1180	1736	2282	
30	42	256	692	1200	1761	2302	
31	42	263	692	1220	1789	2321	

APPENDIX 3-22

Accumulation of Air Degree Days at Base 48°F (8.9°C) at the Upjohn Orchard in 1980 (B.E. Method).

DAY	APR	MAY	JUN	JUL	AUG	SEP
1	0	84	397	918	1676	2380
2	2	96	415	938	1691	2400
3	2	109	426	959	1711	2427
4	2	126	440	981	1737	2447
5	4	133	461	999	1758	2469
6	10	133	480	1027	1783	2485
7	18	133	485	1060	1813	2506
8	29	133	493	1084	1842	2528
9	29	135	496	1109	1868	2540
10	29	142	504	1137	1887	2552
11	29	145	519	1160	1905	2570
12	29	153	540	1183	1921	2595
13	29	160	563	1214	1939	2615
14	29	166	579	1252	1957	2627
15	29	170	586	1278	1970	2642
16	29	176	595	1299	1983	2649
17	29	180	609	1320	2006	2659
18	31	189	628	1350	2028	2675
19	37	198	639	1386	2056	2698
20	45	210	654	1412	2086	2724
21	54	227	676	1438	2106	2746
22	64	245	701	1455	2123	2754
23	79	263	729	1475	2142	2762
24	80	273	754	1499	2166	2774
25	80	281	783	1521	2191	2780
26	80	295	812	1539	2220	2787
27	80	318	839	1556	2250	2797
28	80	341	860	1578	2281	2812
29	81	356	876	1595	2307	2826
30	81	365	895	1623	2332	2826
31	81	381	895	1650	2356	

APPENDIX 3-23

Accumulation of Two Inch Soil Degree Days on the South Side of the Tree at Base 48°F (8.9°C) at the Upjohn Orchard in 1980. (B.E. Method).

DAY	APR	MAY	JUN	JUL	AUG	SEPT
1	0	11	209	614	1212	1880
2	0	13	218	630	1231	1903
3	0	18	225	652	1251	1927
4	0	24	226	672	1273	1948
5	0	31	226	691	1294	1969
6	0	33	230	711	1317	1988
7	0	36	237	739	1341	2008
8	0	36	248	760	1366	2027
9	0	36	262	781	1391	2045
10	0	40	275	801	1413	2063
11	0	44	284	819	1434	2080
12	0	48	292	840	1453	2098
13	0	51	300	863	1472	2116
14	0	51	309	887	1492	2131
15	0	53	320	907	1509	2147
16	0	55	336	925	1530	2160
17	0	58	353	940	1548	2176
18	0	63	372	959	1568	2195
19	0	69	389	979	1590	2214
20	1	79	402	998	1612	2233
21	2	89	419	1017	1632	2253
22	5	100	435	1036	1652	2265
23	8	109	457	1052	1673	2279
24	9	116	479	1070	1695	2294
25	10	124	500	1085	1719	2303
26	10	135	521	1099	1745	2312
27	10	149	542	1111	1770	2323
28	10	163	562	1126	1794	2334
29	10	173	580	1146	1817	2349
30	10	187	596	1168	1838	2459
31	10	197	596	1190	1859	

APPENDIX 3-24

Accumulation of Ground Litter Degree Days on the South Side of the Tree at Base 48°F (8.9°C) at the Upjohn Orchard in 1980. (B.E. Method).

DAY	APR	MAY	JUN	JUL	AUG	SEPT
1	0	23	222	639	1322	2011
2	0	24	234	658	1341	2035
3	0	29	245	676	1361	2059
4	0	36	257	695	1383	2081
5	0	38	267	714	1404	2104
6	0	42	279	734	1427	2124
7	0	51	292	754	1451	2146
9	0	51	302	778	1475	2166
8	0	53	313	803	1499	2183
10	0	56	322	826	1521	2200
11	0	59	331	849	1542	2216
12	0	63	340	871	1562	2237
13	0	67	351	894	1582	2256
14	0	69	364	919	1603	2272
15	0	72	379	945	1623	2290
16	0	75	392	971	1642	2303
17	0	78	404	996	1661	2321
18	0	84	417	1020	1683	2338
19	1	91	431	1045	1707	2358
20	3	99	445	1070	1730	2380
21	7	107	458	1094	1751	2401
22	12	116	474	1115	1772	2415
23	19	127	491	1137	1794	2429
24	21	136	509	1158	1817	2446
25	21	144	527	1179	1841	2454
26	21	152	546	1200	1867	2462
27	21	163	565	1221	1894	2474
28	21	176	583	1241	1920	2487
29	21	188	603	1260	1945	2503
30	21	199	622	1279	1967	2503
31	21	211	622	1300	1989	

APPENDIX 3-25

Accumulation of Air Degree Days at Base 48°F (8.9°C) at the Hofacker Site in 1980 (B.E. Method).

DAY	APR	MAY	JUN	JUL	AUG
1	0	234	591	1037	1757
2	2	243	605	1053	1779
3	3	264	616	1075	1801
4	14	282	630	1098	1829
5	28	295	645	1116	1851
6	43	302	659	1135	1877
7	57	302	678	1166	
8	77	302	688	1190	
9	87	302	691	1210	
10	90	311	695	1237	
11	94	315	703	1265	
12	102	324	716	1289	
13	120	326	735	1315	
14	141	328	755	1341	
15	160	339	759	1363	
16	164	342	765	1383	
17	165	347	777	1408	
18	172	356	794	1435	
19	180	366	804	1465	
20	191	380	807	1502	
21	206	394	822	1522	
22	221	410	843	1538	
23	222	429	868	1555	
24	222	452	895	1579	
25	222	471	923	1600	
26	223	483	947	1619	
27	224	497	965	1640	
28	225	518	988	1661	
29	226	539	1002	1681	
30	228	561	1016	1707	
31	228	578	1016	1734	

APPENDIX 3-26

Accumulation of Two Inch Soil Degree Days on the South Side of the Tree at Base 48°F (8.9°C) at the Hofacker Site in 1980 (B.E. Method).

DAY	APR	MAY	JUN	JUL	AUG
1	0	146	360	689	1301
2	2	150	371	704	1321
3	9	158	383	719	1343
4	20	166	395	736	1365
5	32	175	406	754	1386
6	43	181	421	771	1408
7	58	183	431	790	
8	68	183	435	811	
9	73	183	439	830	
10	77	183	439	852	
11	78	187	443	874	
12	82	192	450	895	
13	91	194	460	917	
14	103	196	471	942	
15	117	200	480	967	
16	127	203	487	989	
17	127	206	494	1009	
18	127	212	505	1027	
19	128	218	510	1049	
20	131	225	518	1072	
21	136	231	528	1093	
22	142	238	542	1111	
23	143	248	557	1127	
24	143	262	575	1144	
25	143	275	594	1163	
26	143	286	614	1181	
27	143	296	631	1200	
28	143	308	648	1220	
29	143	321	662	1239	
30	144	335	675	1259	
31	144	349	675	1279	

APPENDIX 3-27

Accumulation of Ground Litter Degree Days on the South Side of the Tree at Base 48°F (8.9°C) at the Hofacker Site in 1980 (B.E. Method).

DAY	APR	MAY	JUN	JUL	AUG
1	0	231	516	899	1556
2	0	245	528	915	1576
3	0	262	539	935	1598
4	11	280	551	954	1622
5	23	298	562	973	1644
6	34	311	580	990	1667
7	52	314	591	1013	
8	63	314	595	1036	
9	67	319	600	1056	
10	72	327	607	1080	
11	76	334	612	1103	
12	82	346	622	1126	
13	93	349	630	1151	
14	108	352	647	1180	
15	125	358	654	1206	
16	132	360	661	1229	
17	132	364	670	1250	
18	143	372	682	1270	
19	154	379	687	1295	
20	168	387	698	1322	
21	182	393	712	1343	
22	198	401	730	1365	
23	206	413	748	1382	
24	206	427	768	1400	
25	211	440	791	1417	
26	213	447	812	1435	
27	216	454	830	1454	
28	217	465	850	1474	
29	219	479	867	1492	
30	223	492	882	1513	
31	223	504	882	1535	

APPENDIX 3-28

Accumulation of Air Degree Days at Base 48°F (8.9°C) at the Yabs Site in 1980 (B.E. Method).

DAY	APR	MAY	JUN	JUL	AUG
1	0	129	681	1346	2272
2	0	148	702	1375	2297
3	0	168	722	1408	2327
4	0	192	741	1432	2361
5	0	215	759	1459	2390
6	0	233	784	1486	2419
7	0	238	804	1517	2451
8	0	243	821	1548	2485
9	0	251	833	1578	2516
10	0	262	845	1601	2543
11	0	279	862	1629	2569
12	0	294	883	1658	2596
13	0	307	907	1692	2621
14	0	317	927	1729	2648
15	0	329	944	1767	2672
16	3	344	964	1801	2698
17	8	355	987	1832	2717
18	14	367	1006	1862	2745
19	23	387	1021	1896	2773
20	37	408	1042	1935	2804
21	54	430	1064	1963	2832
22	74	455	1090	1994	2861
23	89	479	1119	2022	2890
24	89	503	1148	2053	2923
25	97	525	1180	2086	2952
26	99	545	1210	2111	2986
27	103	570	1238	2136	3021
28	107	597	1269	2160	3056
29	114	621	1299	2186	3091
30	119	645	1320	2209	3124
31	119	667	1320	2239	3153

APPENDIX 3-29

Accumulation of Two Inch Soil Degree Days on the South Side of the Tree at Base 48°F (8.9°C) at the Yabs Site in 1980 (B.E. Method).

DAY	APR	MAY	JUN	JUL	AUG
1	0	77	487	1043	1831
2	0	90	506	1062	1852
3	0	107	518	1088	1874
4	0	134	530	1113	1904
5	0	152	546	1136	1931
6	0	161	570	1155	1960
7	0	161	584	1189	1991
8	0	161	592	1214	2021
9	0	164	598	1238	2047
10	0	170	601	1261	2070
11	0	179	611	1288	2093
12	0	190	631	1310	2110
13	0	195	656	1332	2133
14	0	198	688	1369	2156
15	0	203	695	1401	2169
16	0	215	704	1431	2189
17	0	226	720	1454	2207
18	0	235	739	1483	2228
19	12	247	753	1516	2256
20	20	260	769	1552	2288
21	35	277	789	1577	2314
22	54	298	814	1600	2334
23	57	324	841	1618	2355
24	57	347	869	1639	2381
25	59	357	900	1667	2407
26	59	366	929	1689	2437
27	61	386	950	1710	2469
28	63	412	979	1731	2501
29	66	441	1003	1751	2535
30	69	466	1018	1774	2562
31	69	479	1018	1803	2588

APPENDIX 3-30

Accumulation of Ground Litter Degree Days on the South Side of the Tree at Base 48°F (8.9°C) at the Yabs Site in 1980 (B.E. Method).

DAY	APR	MAY	JUN	JUL	AUG
1	0	79	512	1067	1876
2	0	92	531	1087	1901
3	0	107	547	1111	1928
4	0	125	563	1135	1958
5	0	142	579	1160	1988
6	0	155	601	1181	2018
7	0	161	619	1207	2049
8	0	165	633	1232	2080
9	0	169	644	1257	2109
10	0	177	653	1282	2136
11	0	189	665	1310	2163
12	0	200	680	1334	2188
13	0	208	698	1361	2213
14	0	216	718	1392	2241
15	0	225	735	1422	2263
16	0	235	750	1451	2287
17	0	246	766	1477	2308
18	0	257	784	1504	2333
19	7	272	799	1534	2360
20	20	288	815	1566	2389
21	33	305	835	1594	2415
22	46	324	855	1621	2441
23	53	344	877	1645	2467
24	53	365	901	1670	2495
25	59	383	928	1697	2523
26	59	398	954	1721	2553
27	63	415	978	1746	2585
28	65	436	1003	1771	2617
29	68	458	1025	1795	2650
30	72	479	1045	1818	2680
31	72	498	1045	1847	2708