Evaluation of an arthropod pest management system for use in apple orchards under conditions encountered in Iowa

Loras Francis Freiburger

Iowa State University

Follow this and additional works at: https://lib.dr.iastate.edu/rtd

Recommended Citation

Freiburger, Loras Francis, "Evaluation of an arthropod pest management system for use in apple orchards under conditions encountered in Iowa" (1980). Retrospective Theses and Dissertations. 19247. https://lib.dr.iastate.edu/rtd/19247

This Thesis is brought to you for free and open access by the Iowa State University Capstones, Theses and Dissertations at Iowa State University Digital Repository. It has been accepted for inclusion in Retrospective Theses and Dissertations by an authorized administrator of Iowa State University Digital Repository. For more information, please contact digirep@iastate.edu.
Evaluation of an arthropod pest management system for use in apple orchards under conditions encountered in Iowa

by

Loras Francis Freiburger

A Thesis Submitted to the Graduate Faculty in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

Major: Horticulture

Signatures have been redacted for privacy

Iowa State University
Ames, Iowa
1980
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEDICATION</td>
<td>vi</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>LITERATURE REVIEW</td>
<td>3</td>
</tr>
<tr>
<td>MATERIALS AND METHODS</td>
<td>12</td>
</tr>
<tr>
<td>RESULTS</td>
<td>25</td>
</tr>
<tr>
<td>Insect Monitoring</td>
<td>25</td>
</tr>
<tr>
<td>Mite Monitoring</td>
<td>28</td>
</tr>
<tr>
<td>Insect Damage</td>
<td>33</td>
</tr>
<tr>
<td>Economic Analysis</td>
<td>39</td>
</tr>
<tr>
<td>DISCUSSION</td>
<td>40</td>
</tr>
<tr>
<td>Insect Pest Monitoring and Damage</td>
<td>40</td>
</tr>
<tr>
<td>Mite Management</td>
<td>42</td>
</tr>
<tr>
<td>Economic Analysis</td>
<td>44</td>
</tr>
<tr>
<td>SUMMARY AND CONCLUSIONS</td>
<td>46</td>
</tr>
<tr>
<td>LITERATURE CITED</td>
<td>48</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>55</td>
</tr>
</tbody>
</table>
LIST OF TABLES

Table 1. Dates of application of phosmet (1.7 kg a.i./ha) to the prophylactic and the treat-when-necessary pest management areas during 1978 and 1979

Table 2. The influence of pest management system and cultivar on total numbers of Tetranychus urticae Koch and Amblyseius fallacis Garman collected during the season in 1978 and 1979, and during July of 1980

Table 3. The influence of pest management system on seven categories of insect damage to fruit and on total insect damage to fruit during 1978 and 1979

Table 4. Mean comparison of the effects of cultivar on seven categories of insect damage to fruit and on total insect damage to fruit during 1978 and 1979

Table 5. Fruitworm damage as influenced by pest management system and cultivar in 1978

Table 6. Total insect damage as influenced by pest management system and cultivar in 1978

Table 7. Relative component costs for insect pest control by pest management system for 1978 and 1979
LIST OF FIGURES

Figure 1. Application of insecticide treatments
   a) Tractor-drawn shield used to reduce spray drift between treatment units
   b) Close-up of tractor-drawn shield and sprayer
   page 13

Figure 2. Pherocon® ICP trap installed in apple tree
   page 14

Figure 3. Codling moths caught in Pherocon® ICP trap
   page 15

Figure 4. Redbanded leafroller moth caught in Pherocon® ICP trap
   page 15

Figure 5. Pherocon® AM standard trap installed in apple tree
   page 16

Figure 6. Apple maggot adult caught in Pherocon® AM trap (arrow)
   page 16

Figure 7. Codling moth damage to fruit
   a) Typical first generation damage
   b) Typical second generation damage
   page 20

Figure 8. Leafroller damage to fruit
   page 21

Figure 9. Green fruitworm damage to fruit
   page 21

Figure 10. Catfacing (Lygus sp.) damage to fruit
   page 22

Figure 11. Apple curculio late season adult feeding damage to fruit
   page 22

Figure 12. Birdpeck damage to fruit
   page 23

Figure 13. Flight activity of the codling moth [Laspeyresia pomonella (L.)] as determined by weekly moth captures in Pherocon® ICP traps in the old and new orchards during 1978 and 1979
   page 26

Figure 14. Flight activity of the redbanded leafroller [Argyrotaenia velutinana (Walker)] as determined by weekly moth captures in Pherocon® ICP traps in the old and new orchards during 1978 and 1979
   page 27
Figure 15. Flight activity of the apple maggot *Rhagoletis pomonella* (Walsh) as determined by weekly fly captures in Pherocon® AM traps in the old and new orchards during 1978 and 1979.

Figure 16. Development of populations of *Tetranychus urticae* Koch on the cultivars Starkrimson, Chieftain, Jonared, and Goldspur, and on trees under the prophylactic and treat-when-necessary pest management systems during 1978.

Figure 17. Development of populations of *Tetranychus urticae* Koch on the cultivars Starkrimson, Chieftain, Jonared, and Goldspur, and on trees under the prophylactic and treat-when-necessary pest management systems during 1979.
DEDICATION

This work is dedicated to my wife, Lynette, for her unfailing support and assistance.
INTRODUCTION

In recent years, the philosophy of integrated pest management has assumed a position of importance in most research efforts which attempt to improve arthropod pest control capabilities (69). This change from an almost total emphasis on chemical pesticides to a more reasonable approach involving both chemical and non-chemical controls has resulted from the ultimate failure of some chemicals to control pests after relatively short periods of use (31, 40, 45, 68), and the dramatic promotion of secondary pests to primary pest status via chemical destruction of natural enemies (28, 29, 31, 40).

Development of integrated pest management in apples has revolved around biological control of phytophagous mites and timing of sprays for control of major insect pests (8, 18, 72, 75). Promotion of phytophagous mites to primary pest status through chemical destruction of their natural enemies has led to the development of pest control programs in which the need for insecticide applications is determined by monitoring pest activity. Success of such programs has depended on the use of selective pesticides, development of pesticide resistant natural enemies, and reduction of pesticide applications (5, 18, 25, 52, 75). Numerous investigators have designed and improved these programs so that today many of the major apple producing areas in the world are able to benefit from their use.

The objectives of this study were to:

1) Evaluate several pest monitoring techniques developed in other apple growing areas for their ability to facilitate the production of high quality fruit; and
2) Combine these techniques into a cost effective apple arthropod pest management system which could be recommended to Iowa growers.
LITERATURE REVIEW

Chemical control of arthropod pests in an orchard ecosystem is essential for the economic production of quality fruits (6). Several studies have reported increased pest damage where insecticide use had been discontinued (17, 19, 20). Hall (20) found that potential gross income losses of 33 to 91% could be expected by peach producers if insecticide applications were completely omitted. Similar crop destruction of apples was reported by Glass and Lienk (17) in an orchard which had not received an insecticide treatment for ten years. Hagley and Hikichi (19) reported that total fruit damage attributable to the codling moth [Laspeyresia pomonella (L.)] and the apple maggot [Rhagoletis pomonella (Walsh)] ranged from 26.5% to 82.5% in a five year study.

Although chemical control of pests is essential to modern apple production, such use does not guarantee excellent control. Pimentel (53) reported that even though more than 85% of all apple hectares were treated with insecticides in 1960, losses to apple maggot and codling moth had not decreased relative to 1915. He suggested that this primarily was due to the poor cultural and sanitation practices and higher standards for quality which have resulted from the use of effective pesticides. He further suggested that most commercial growers could reduce their insecticide usage by 35 to 50% and still maintain economic pest control.

Several techniques designed to reduce insecticide use in orchards have been studied. Prokopy et al. (54) compared the effectiveness of alternate row spraying to every row spraying in apples and found the two systems equal even though alternate row spraying applied only half as
much pesticide. They proposed that the potential benefits of reduced sprays would be a savings in material and application costs, a promotion of natural enemies leading to even fewer sprays, the slowing of pesticide resistance buildup in pest species, and a reduction of environmental contamination. Moore (44) found the alternate row technique, a reduced dosage application technique, and an extended interval technique (21 days between sprays) to be equally successful in controlling arthropod pests of apple. Each of the techniques resulted in substantial savings in pesticide costs and the promotion of mite and aphid natural enemies. Trammel (72) evaluated these three methods in addition to a fourth which involved a spray-as-needed approach based on monitoring and reported excellent results with each. Trammel (73) later reported that the alternate row and extended interval approaches gave better control when combined with monitoring.

Extensive research has been conducted to determine effective techniques for monitoring orchard insect pests. Early work on the codling moth by Haseman and Johnson (21) established that control of the first brood was important in reducing subsequent generations. They also found that orchard insecticide applications could be reduced 11 to 33% by timing sprays to moth emergence and egg hatch in breeding cages. Madsen and Davis (34) found cylindrical traps baited with live female moths to be effective in monitoring male codling moth emergence and determining spray needs. They reported that average trap captures of less than 2 moths/week/0.4 hectare were associated with no damage, while an average capture of 5 moths/0.4 hectare during one week resulted in 9.3% damage at harvest.
Roelofs et al. (65) succeeded in isolating trans-8,trans-10-dodecadien-1-ol, the female sex pheromone of the codling moth, in 1970, thus allowing for the monitoring of this pest with synthetic pheromone. Madsen and Vakenti (35) found that cylindrical traps baited with synthetic pheromone were significantly more effective in attracting males than were female baited traps. Codling moth damage was first noticed in the field 7 days after pheromone trap captures exceeded 2 moths/week/0.4 hectare.

Madsen (32) and Madsen and Vakenti (36) reported that when using synthetically baited traps, the number of sprays applied for codling moth could be reduced by two thirds if an economic threshold of 2 moths/trap/week/0.4 hectare was used.

Madsen et al. (38) found that Pherocon®1 ICP traps could be operated at one per hectare with an economic threshold of 2 moths/trap/week and still result in excellent control with 60% fewer sprays. Work done in South Africa by Madsen et al. (37) and Myburgh et al. (46) indicated that sprays for codling moth control need not be applied unless average trap captures exceeded 2 moths/trap/week/hectare for two consecutive weeks during the second and third generations. Cumulative captures of 10 moths/trap/hectare during a particular generation were also damaging. Subsequent work (33, 61, 76) has confirmed these economic thresholds for Pherocon® ICP traps at a density of one for every 0.4 to 1.6 hectares.

Several investigators have not accepted the use of pheromone traps as a monitoring tool for the codling moth unless aided by data on related factors. Riedl and Croft (58) hypothesized that the magnitude of trap

1Manufactured by the Zoecon Corp., Palo Alto, CA 94394.
captures might depend on numerous factors including immigration of male moths from sources outside the orchard, trap density, and climate. Studies conducted by Madsen (32) and Madsen and Vakenti (36) demonstrated the importance of male moth immigration and of identifying outside sources of moths in interpreting trap captures. They concluded that a 200 meter distance was adequate to prevent female moth migration, but would not prevent male moth migration.

Webster and O'Neill (78) reported that the timing of sprays for first generation control could be based on spring moth emergence and mean daily maximum air temperatures. Batiste et al. (1) studied the relationship between first moth capture in Pherocon® ICP traps and first egg hatch relative to daily air temperatures and concluded that cool weather extends the time from first capture to first egg hatch. Riedl and Croft (59) determined three critical points in the seasonal development of the codling moth in Michigan. These points, which they designated biofixpoints 1, 2, and 3, were defined to be first male moth capture in spring, first generation peak capture, and second generation peak capture, respectively. The relationship of egg hatch to biofixpoints 2 and 3 and to degree-day temperature accumulations was determined. The use of these three biofixpoints in conjunction with degree-day accumulations to determine egg hatch was recommended for determining spray needs and timing.

The timing of sprays for control of the apple maggot was originally based on adult fly activity monitored with sticky bait traps (23) and liquid bait traps (24) and on first fly emergence from ground cages (27). Hodson (23) reported that ice cream carton traps coated with tanglefoot and baited with ammonium carbonate provided a simple monitoring tool for
timing apple maggot sprays. Hodson (24) later compared these traps to similarly baited liquid traps and found the sticky traps equally effective and much more convenient to use. Sticky, waxed-paper cards 25.4 cm x 30.5 cm painted red, white, blue, yellow, and green were tested by Maxwell (39) for relative color attractiveness. Green and yellow proved to be the most attractive, with blue and red the least, and white intermediate.

Several researchers have reported that sticky yellow panels baited with Hy-Case® amino and ammonium acetate are highly effective in monitoring apple maggot adult activity (2, 55, 75). Trottier et al. (75) found that yellow panel traps could facilitate a 15% reduction in the number of apple maggot sprays without sacrificing fruit quality. Reissig (56) tested the effects of canopy radius position and height on the attractiveness of baited sticky yellow cards in standard size apple trees. His results indicated that the optimum position for yellow panel traps was in the middle canopy radius at eye level. This study also confirmed the finding of Moore (43) that baited yellow panels are more attractive when hung in the south quadrant of the canopy.

Neilson (47) and Neilson et al. (48) used Pherocon®AM standard traps (a sticky yellow trap) to monitor adult apple maggot activity and determine spray needs. Traps were operated at one per 0.4 hectare, hung in the south quadrant of the canopy, and collected twice each week. The first sprays were applied within seven to ten days of first female capture and subsequent sprays at 12 to 14 day intervals if female captures continued. They reported that this monitoring system resulted in fewer insecticide applications and better control than did calendar sprays based on first adult emergence in ground cages. Reissig and Tette (57) reported a 58% average
spray reduction over a three year period using Pherocon® AM traps at densities ranging from one per hectare to one per 0.4 hectare. They suggested that trap density did not affect the economic threshold since even very slight adult activity (as few as one fly capture) indicated economic damage potential.

Isolation and bioassay of the sex pheromone of the redbanded leafroller \( [\text{Argyrotaenia velutinana (Walker)}] \) was reported by Roelofs and Feng (63) in 1967. The pheromone was subsequently identified as cis-11-tetradecenyl acetate by Roelofs and Arn (62).

The flight activity of the redbanded leafroller was first studied with synthetic pheromone traps by Rock and Yeargan (60). Their results suggested that populations of this pest were high in abandoned orchards relative to commercial plantings. They theorized, therefore, that relating synthetic pheromone trap captures to actual population numbers would be difficult due to the insect's polyphagous habit and resultant migrations. Tette\(^2\) successfully used pheromone traps as a monitoring tool where commercial orchards and abandoned orchards or woodlands were monitored concurrently. Pherocon® ICP traps were operated at a density of one per 16.2 hectares and sprays were not applied unless orchard captures exceeded woodland captures by 30 moths per trap and larvae had been detected. After six years of management under this system, no significant redbanded leafroller damage had occurred. Other investigators (64, 74) have reported success in controlling redbanded leafroller through mass trapping with synthetic pheromones.

---

\(^2\) James Tette, Department of Entomology, Entomology-Plant Pathology Laboratory, Geneva, New York 14456, personal communication.
The first successful integrated pest management program on apples involving natural control of plant feeding mites began in 1943 and was reported by Lord et al. (30). The promotion of predaceous mite species was achieved in this program by very selective use of available pesticides. Similar programs designed to facilitate control of the Mcdaniel mite [Tetranychus mcdanieli (McGregor)] and the European red mite [Panonychus ulmi (Koch)] by the predaceous phytoseiid Typhlodromus occidentalis Nesbitt have benefitted growers in British Columbia since the mid 1960s (14).

Natural control of P. ulmi and Tetranychus urticae Koch (the two-spotted spider mite) by the predaceous phytoseiid Amblyseius fallacis Garman was reported in Michigan commercial orchards by Croft and McGroarty (11). They also found that spray drift can have a deleterious effect on ground populations of A. fallacis and ultimately affect the ability of this predator to control within-tree populations of phytophagous mites. According to Croft (9), A. fallacis overwinters as an adult female around the tree base and feeds during the spring and early summer on T. urticae in the ground cover. Both mites move into the trees by early June where control of P. ulmi and T. urticae is achieved by the predator. Tetranychus urticae and A. fallacis then return to the ground in late summer to overwinter. Croft (5) presented a decision making index for determining miticide needs based on predator/prey ratios of A. fallacis and P. ulmi or T. urticae. The maximum population of tetranychids which could be tolerated without serious injury was estimated to be 15-20 per leaf for not more than 14 days.
Survival of predaceous mites in commercial orchards depends on their resistance to various pesticides, prey availability, and the ability of the orchard manager to protect them through pesticide selection. Croft et al. (13) reported a strain of *A. fallacis* in Michigan which was highly resistant to azinphos-methyl and diazinon, and which showed strong to moderate cross-resistance to many other organophosphate pesticides. Laboratory reared populations of this strain were readily established in the field without loss of resistance if regular organophosphate sprays were applied (10). However, an attempt to introduce an organophosphate-resistant strain of *A. fallacis* into British Columbia from Michigan was not successful (15). Croft (7) determined that the survival of *A. fallacis* after release is closely correlated with food availability. He estimated that a prey density of 1 to 5 tetranychids per leaf was necessary for establishment. Field (16) successfully introduced *Typhlodromus occidentallis* Nesbitt into an Australian peach orchard to control tetranychid mites. He reported that benomyl was highly toxic to the predator while captan and phosmet were not.

The protection from toxic chemicals of newly introduced populations of *A. fallacis* has been facilitated by the evaluation of most orchard pesticides for their toxicity toward this phytoseiid. Childers and Enns (4) reported that benomyl had a prolonged suppressive effect on *A. fallacis* and suggested that this was probably due to its systemic nature. The deleterious effects of carbaryl were documented by Oatman (49), Croft and Stewart (12), and Watve and Lienk (77). Azinphos-methyl, captan, phosmet, and dodine were found to be non-toxic toward the predator by Prokopy et al. (54) who reported abundant populations in orchards sprayed
regularly with these materials. The innocuous nature of metiram toward *A. fallacis* was reported by Meyer (42). A listing of twenty-seven commonly used orchard pesticides and their relative toxicities toward *A. fallacis*, *T. urticae*, and *P. ulmi* was presented by Croft (5). He also outlined and urged the use of integrated arthropod pest management through proper pesticide selection to promote natural control of phytophagous mites, reduce pesticide usage, and conserve other predators and parasites.

The purpose of this study was to adapt apple arthropod pest management systems and techniques developed in other areas into an overall system which could be recommended to Iowa growers. The primary criterion for recommendation was to be an analysis of the system's cost effectiveness and ability to prevent pest damage.
MATERIALS AND METHODS

A field study to determine the relative cost effectiveness and feasibility of two apple arthropod pest management systems was conducted at the Iowa State University Horticulture Station. The study was initiated in the Spring of 1978 and terminated in the Summer of 1980.

The experiment was conducted in a 0.5 hectare planting of four cultivars of apple: Delicious, strain Starkrimson; Golden Delicious, strain Goldspur; Jonathon, strain Jonared; and Chieftain. The trees had been planted in 1973 and were dwarfed by one of six interstems: C52, C48, C6, M27, M26, or 'Clark dwarf'.

The experimental design was a randomized complete block with three replications. An experimental unit consisted of 12 trees (consecutive in the row) of one cultivar. Each dwarfing interstem occurred twice in each experimental unit, thus eliminating interstem effects.

All foliar applications of pesticide were made dilute (900 liters per hectare) with an FMC John Bean airblast sprayer. To reduce drift between treatment units, a tractor-drawn shield was towed down the adjacent row while spraying (Figures 1a and 1b).

The two arthropod pest management systems studied represent distinct approaches toward pest control. The first approach, referred to as 'prophylactic', involved applications of the insecticide phosmet at pink and petal-fall followed by weekly applications throughout the remainder of the season. The second approach, referred to as 'treat-when-necessary', also involved pink and petal-fall phosmet applications, but then turned to the use of pest monitoring to determine the need for insecticide
Figure 1. Application of insecticide treatments
  a) Tractor-drawn shield used to reduce spray drift between treatment units
  b) Close-up of tractor-drawn shield and sprayer
treatments. All applications of phosmet were made at a rate of 1.7 kg active ingredient per hectare. Both approaches involved weekly fungicide treatments of metiram and/or captan throughout the season.

Figure 2. Pherocon® 1CP trap installed in apple tree

Three major insect pests of apple were monitored to facilitate the treat-when-necessary approach. The codling moth [*Laspearia pomonella (L.*)] and the redbanded leafroller [*Argyrotaenia velutinana (Walker)*] were monitored with Pherocon® 1CP traps and the appropriate pheromones (Figures 2, 3, and 4). The apple maggot [*Rhagoletis pomonella (Walsh)*] was monitored using Pherocon® AM standard traps (Figures 5 and 6). All traps were set in the orchard at a density of one per 0.4 hectare and
Figure 3. Codling moths caught in Pherocon® ICP trap

Figure 4. Redbanded leafroller moth caught in Pherocon® ICP trap
Figure 5. Pherocon®AM standard trap installed in apple tree

Figure 6. Apple maggot adult caught in Pherocon®AM trap (arrow)
collected at least once a week. Redbanded leafroller traps were set in the orchard on April 13 in 1978 and April 18 in 1979, codling moth traps on April 24 and May 8, respectively, and apple maggot traps on June 19 and 27, respectively. Apple maggot traps were placed in the south quadrant of a susceptible cultivar where possible.

Appropriate economic thresholds were used to determine spray needs for each monitored insect pest in the treat-when-necessary areas. The capture of any apple maggots during one week was considered damaging for this pest, and an average trap capture of two or more moths per week was used as the economic threshold for the codling moth. No definite economic threshold for the redbanded leafroller could be found in the literature; therefore, no insecticide treatments were made based on the activity of this pest. All other insect pests were monitored weekly by visual inspection of the trees.

The total area monitored to determine spray needs of the treat-when-necessary system was 2.25 hectares. This area was referred to as the new orchard in order to contrast it from the experimental area and from a 0.4 hectare planting of older trees located 0.35 km to the southeast, which were referred to as the old orchard. These older trees were monitored for codling moth, apple maggot, and redbanded leafroller activity during both 1978 and 1979. During 1978, these trees were managed under the prophylactic system, but during 1979, no insecticide applications were made. The new orchard (excluding the experimental area) was managed under the treat-when-necessary system during both years. Pest activity comparisons were made between the new orchard and the old orchard for both years.
Daily minimum and maximum air temperatures were recorded in the orchard during the period January, 1978, through May, 1980. Degree-day accumulations for the codling moth were calculated based on a minimum cardinal temperature of 10°C (59). This minimum temperature was also used to calculate degree-days for the redbanded leafroller, although its validity for this pest could not be ascertained. The relationships between these data and first generation initial capture, first generation peak capture, and second generation peak capture were determined for both the codling moth and the redbanded leafroller. In addition, the relationship of degree-day accumulations to third generation peak capture of the redbanded leafroller was determined.

Phytophagous and predaceous mites were monitored by collecting 24 leaves per treatment unit (12 trees). Counts were made using the modification described by Owens (50) of the leaf-brushing technique employed by Henderson and McBurnie (22). Collections were made every 10 days in 1978, and every 13 days in 1979. A pooled count of all life stages except eggs was made for each mite species. A reduced-rate application of propargite was made to the entire experimental area if phytophagous mite populations exceeded damaging levels (15-20 per leaf) in several treatment units. All pesticides used in the experimental area were selected for their lack of toxicity toward predaceous mites, especially Amblyseius fallacis.

The total absence of predaceous mites during 1978 prompted the introduction of an organophosphate-resistant strain of Amblyseius fallacis in the early summer of 1979. Several hundred healthy mites were received in

---

1 Obtained from Dr. Brian A. Croft, Department of Entomology, Michigan State University.
May. Upon receipt, these mites were reared directly on snap beans (*Phaseolus vulgaris* L.) infested with an organophosphate-susceptible strain of *Tetranychus urticae* Koch\(^2\). This rearing regime was maintained in an isolated, indoor area under fluorescent lights. New seedling bean plants were infested with both mite species by transferring leaves from older infested plants. The older plants were then transferred into the orchard. Four such transfers were made. On June 10 and July 3, the bean plants were placed randomly between the rows in the experimental area. On July 29 and August 11, infested plants were placed in the foliage of the cultivar Starkrimson. Half of the trees thus infested were under the prophylactic management system and the other half under the treat-when-necessary system. Populations of *T. urticae* were allowed to exceed damaging levels during 1979 to promote establishment of *A. fallacis*. During July of 1980, sampling was conducted in 'Starkrimson' trees to determine whether or not *A. fallacis* had survived the winter.

Fruit damage due to insect feeding was determined after harvest. Fruit from each experimental unit were separately harvested, counted, sized and graded to a combination U.S. Fancy and U.S. No. 1. Culled fruit were carefully examined for surface and internal damage. Insect damage was characterized from descriptions by Metcalf et al. (41) and Slingerland and Crosby (67). Seven damage categories were determined: codling moth (Figures 7a and 7b), leafroller (Figure 8), green fruitworm (Figure 9), catfacing as caused by *Lygus* sp. (Figure 10), apple curculio (*Tachypterelus* sp.) late season adult feeding (Figure 11), and birdpeck (Figure 12),

\(^2\) Obtained from Dr. Brian A. Croft, Department of Entomology, Michigan State University.
Figure 7. Codling moth damage to fruit
a) Typical first generation damage
b) Typical second generation damage
Figure 8. Leafroller damage to fruit

Figure 9. Green fruitworm damage to fruit
Figure 10. Catfacing (Lygus sp.) damage to fruit

Figure 11. Apple curculio late season adult feeding damage to fruit
which was considered to represent pecking for small larvae on or just below the fruit surface. Percent damages for each category were calculated on a fruit number basis. A comparison of pest control costs for the two pest management systems studied was made by calculating per hectare costs for insecticide, monitoring material, monitoring labor, and revenue loss due to insect damaged fruit. Relative insecticide costs were determined directly from spray records based on a per kilogram retail cost of $4.26 for phosmet. Monitoring material costs were static during the two years of the study and were based on monitoring of the codling moth and apple maggot. Monitoring labor costs were based on an assumed wage of three dollars per hour and included monitoring of the codling moth, apple
maggot, redbanded leafroller, and minor pests (costs for mite monitoring were not included). Revenue loss due to insect damage was based on a per box (18.9 kg) price of $9.25 which was then adjusted for sale of these fruit at $0.11 per kilogram as cider apples.

No cost reductions in spraying labor, fuel, or machinery depreciation could be realized in the treat-when-necessary system, since scheduled fungicide applications were made regardless of the need for insecticide treatment.

The experiment was conducted as a 2x4 factorial with two treatments (pest management systems) and four cultivars. Analyses of variance (71) were conducted to determine the effects of treatment and cultivar on each insect damage category, seasonal mite populations, and total insect damage. In addition, treatment by cultivar interactions were examined. Duncan's new multiple-range tests (71) were conducted to separate cultivars.

Data transformations were required for the individual categories of insect damage and total seasonal mite populations due to large proportions of zeros in these data (71). Data on categories of insect damage and seasonal populations of *A. fallacis* were transformed by adding 0.5 to each observation and then taking the square root. Data on seasonal populations of *T. urticae* were transformed by adding 1.0 to each observation and then finding the base 10 log. No transformation was necessary for total insect damage.
RESULTS

Monitoring of pest activity was begun in April during both 1978 and 1979. Following the petal fall insecticide applications, phosmet was applied to the treat-when-necessary trees only if a monitored pest exceeded its economic threshold or if appreciable non-monitored pest activity was detected.

Insect Monitoring

Substantial codling moth activity was detected during 1978 and 1979 in the old orchard, while moderate to light populations were present in the new orchard (Figure 13). The codling moth completed two full generations each year with population peaks in the old orchard occurring on June 13 and August 15 in 1978, and June 6 and August 8 in 1979. First generation peaks in the new orchard coincided with those in the old orchard; however, second generation peaks in the new orchard were delayed. Mean degree-day accumulations to first generation initial capture and first and second generation peak captures were 196 ± 24, 148 ± 73, and 1057 ± 119, respectively for the period January, 1978, through May, 1980. The codling moth exceeded its economic threshold of two moths per trap in the new orchard on eight occasions in 1978, and four occasions in 1979.

Redbanded leafroller activity was also much heavier in the old orchard than in the new orchard during both years of the study (Figure 14). This pest completed three full generations during each year with populations peaking in the old orchard on May 9, July 4, and August 29 in 1978, and May 9, July 18, and September 5 in 1979. Peak captures in the new orchard
Figure 13. Flight activity of the codling moth \([Laspeyresia pomonella (L.)]\) as determined by weekly moth captures in Pherocon®ICP traps in the old and new orchards during 1978 and 1979.
Figure 14. Flight activity of the redbanded leafroller [Argyrotaenia velutinana (Walker)] as determined by weekly moth captures in Pherocon®ICP traps in the old and new orchards during 1978 and 1979.
coincided with those in the old orchard except for the 1978 first generation, which peaked earlier. Mean degree-day accumulations to first generation initial capture and first, second, and third generation peak captures were $54 \pm 34$, $96 \pm 9$, $721 \pm 77$ and $1382 \pm 130$, respectively, for the period of the study. No definite economic threshold for the red banded leafroller could be found in the literature.

Apple maggot adult activity was light in the old orchard during 1978, and heavy during 1979 (Figure 15). Activity in the old orchard extended from July 4 to September 5 in 1978, and July 11 to September 12 in 1979. Peak activity occurred from August 15 to September 5 during both years. The apple maggot exceeded its economic threshold once in the new orchard when one fly was captured on August 15, 1979.

The activity of the apple maggot and the codling moth resulted in eight applications of phosmet in the treat-when-necessary areas in 1978, and five applications in 1979, while 13 and 12 applications were made under the prophylactic system in 1978 and 1979, respectively (Table 1). Non-monitored insect pests did not appear to exceed acceptable levels after petal fall during either year.

Mite Monitoring

The two-spotted mite *Tetranychus urticae* Koch, which reportedly overwinters as an adult at the base of the trees (9), was the only phytophagous mite encountered in the experimental area throughout the study.

*Tetranychus urticae* did not begin to move into the trees in 1978 until the middle of August, after which time populations built gradually to low levels under both pest management systems, and then declined without
Figure 15. Flight activity of the apple maggot [*Rhagoletis pomonella* (Walsh)] as determined by weekly fly captures in Pherocon® AM traps in the old and new orchards during 1978 and 1979.
Table 1. Dates of application of phosmet (1.7 kg a.i./ha) to the prophylactic and the treat-when-necessary pest management areas during 1978 and 1979

<table>
<thead>
<tr>
<th></th>
<th>1978</th>
<th>1979</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prophylactic</td>
<td>Treat-when-necessary</td>
<td>Prophylactic</td>
</tr>
<tr>
<td>5-10 (pink)</td>
<td>5-10 (pink)</td>
<td>5-10 (pink)</td>
</tr>
<tr>
<td>5-30 (petal fall)</td>
<td>5-30 (petal fall)</td>
<td>6-01 (petal fall)</td>
</tr>
<tr>
<td>6-09</td>
<td>6-09</td>
<td>6-11</td>
</tr>
<tr>
<td>6-15</td>
<td>6-15</td>
<td>6-21</td>
</tr>
<tr>
<td>6-21</td>
<td>6-21</td>
<td>6-28</td>
</tr>
<tr>
<td>6-28</td>
<td>--</td>
<td>7-05</td>
</tr>
<tr>
<td>7-06</td>
<td>--</td>
<td>7-11</td>
</tr>
<tr>
<td>7-14</td>
<td>--</td>
<td>7-18</td>
</tr>
<tr>
<td>7-24</td>
<td>--</td>
<td>7-25</td>
</tr>
<tr>
<td>8-02</td>
<td>8-02</td>
<td>8-06</td>
</tr>
<tr>
<td>8-10</td>
<td>8-10</td>
<td>8-15</td>
</tr>
<tr>
<td>8-18</td>
<td>8-18</td>
<td>8-22</td>
</tr>
<tr>
<td>8-25</td>
<td>8-25</td>
<td>8-29</td>
</tr>
<tr>
<td>8-31</td>
<td>8-31</td>
<td>9-06</td>
</tr>
<tr>
<td>9-08</td>
<td>--</td>
<td></td>
</tr>
</tbody>
</table>

 exceeding the economic threshold (Figure 16). Trees under the prophylactic pest management system and trees of the cultivar Starkrimson were the first to be attacked by *T. urticae* in 1978. Movement into the trees occurred much earlier in 1979 relative to 1978 (Figure 17). In addition,
Figure 16. Development of populations of Tetranychus urticae Koch on the cultivars Starkrimson, Chieftain, Jonared, and Goldspur, and on trees under the prophylactic and treat-when-necessary pest management systems during 1978.
Figure 17. Development of populations of Tetranychus urticae Koch on the cultivars Starkrimson, Chieftain, Jonared, and Goldspur, and on trees under the prophylactic and treat-when-necessary pest management systems during 1979
much higher population levels were reached, especially under the prophylactic system and in the cultivar Starkrimson.

Population levels of *T. urticae* exceeded the economic injury level of 15-20 mites per leaf in several treatment units under both pest management systems during the week of August 17, 1979, and a reduced rate of propargite (0.84 kg a.i. per hectare) was applied to the entire experimental area on August 29.

Greater total numbers of *T. urticae* occurred under the prophylactic pest management system than under the treat-when-necessary system during 1979 (Table 2). This trend was also evident in 1978, but not in 1980. More tetranychids were found on 'Starkrimson' than on 'Goldspur' or 'Jonared' during 1979, with a similar trend in 1978.

Although four separate attempts were made to introduce *Amblyseius fallacis* Garman into the experimental area during 1979, only small numbers of this predator were recovered in sampling. Populations of *A. fallacis* were not affected by pest management system during either 1979 or 1980 (Table 2). Cultivar differences were found in 1979; however, with more predators recovered from 'Starkrimson' than from 'Goldspur', 'Jonared' or 'Chieftain'.

Insect Damage

Percent damage was calculated by fruit number for each category of insect pest to determine the effects of pest management system and cultivar on insect damage. Differences in total damage were also analyzed.

Pest management system had no effect on any category of insect damage or total insect damage during either year (Table 3). However,
Table 2. The influence of pest management system and cultivar on total numbers of *Tetranychus urticae* Koch and *Amblyseius fallacis* Garman collected during the season in 1978 and 1979, and during July of 1980

<table>
<thead>
<tr>
<th>Comparison</th>
<th>T. urticae</th>
<th></th>
<th>A. fallacis</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Prophylactic</td>
<td>23.4</td>
<td>164.6</td>
<td>120.7</td>
<td>0.0</td>
</tr>
<tr>
<td>Treat-when-necessary</td>
<td>5.7</td>
<td>109.4</td>
<td>135.3</td>
<td>0.0</td>
</tr>
<tr>
<td>Starkrimson</td>
<td>45.5</td>
<td>232.2</td>
<td>N.A.</td>
<td>0.0</td>
</tr>
<tr>
<td>Chieftain</td>
<td>1.5</td>
<td>131.0</td>
<td>N.A.</td>
<td>0.0</td>
</tr>
<tr>
<td>Jonared</td>
<td>4.8</td>
<td>96.7</td>
<td>N.A.</td>
<td>0.0</td>
</tr>
<tr>
<td>Goldspur</td>
<td>5.2</td>
<td>88.2</td>
<td>N.A.</td>
<td>0.0</td>
</tr>
</tbody>
</table>

1 Mean separation within columns by Duncan's New Multiple-range test, 5% level.
2 Not applicable.
*Significance based on F test at 5% level.
Table 3. The influence of pest management system on seven categories of insect damage to fruit and on total insect damage to fruit during 1978 and 1979

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Codling moth</th>
<th>Apple maggot</th>
<th>Leafroller</th>
<th>Fruitworm</th>
<th>Catfacing</th>
<th>Curculio</th>
<th>Birdpeck</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prophylactic</td>
<td>0.04</td>
<td>0.00</td>
<td>0.47</td>
<td>0.26</td>
<td>2.24</td>
<td>2.16</td>
<td>0.70</td>
<td>5.88</td>
</tr>
<tr>
<td>Treat-w-nec.</td>
<td>0.06</td>
<td>0.00</td>
<td>0.48</td>
<td>0.15</td>
<td>2.66</td>
<td>2.40</td>
<td>0.25</td>
<td>6.01</td>
</tr>
<tr>
<td>Insect damage (%) 1978</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prophylactic</td>
<td>0.00</td>
<td>0.06</td>
<td>0.18</td>
<td>0.23</td>
<td>1.41</td>
<td>0.03</td>
<td>0.00</td>
<td>1.91</td>
</tr>
<tr>
<td>Treat-w-nec.</td>
<td>0.00</td>
<td>0.05</td>
<td>0.11</td>
<td>0.18</td>
<td>1.34</td>
<td>0.10</td>
<td>0.00</td>
<td>1.78</td>
</tr>
</tbody>
</table>
feeding by apple curculio adults in July and August of 1979, did approach significance at the 10% level with greater damage occurring under the treat-when-necessary system. Very slight damage was caused by the monitored pests (codling moth, apple maggot, and redbanded leafroller) during the study, while non-monitored spring pests (catfacing insects and fruitworms) caused substantial damage in both years. Late season apple curculio feeding was relatively heavy in 1978, but light in 1979.

There were no differences among cultivars for codling moth, apple maggot, apple curculio, or bird peck damage in either year (Table 4). In 1978, there was greater leafroller damage in 'Goldspur' than 'Jonared', but not in 1979. In 1979, catfacing damage was greater in 'Chieftain' than 'Jonared', while in 1978, 'Goldspur' appeared to be associated with more damage. Total damage was greater in 'Chieftain' than 'Jonared' or 'Goldspur' in 1979.

An interaction was found between pest management system and cultivar for fruitworm damage in 1978 (Table 5). 'Starkrimson' suffered greater damage under the prophylactic system than under the treat-when-necessary system, whereas the reverse was true for 'Chieftain'. No differences were found among cultivars for fruitworm damage under the treat-when-necessary system, while under the prophylactic system, 'Starkrimson' suffered the greatest damage. No differences in fruitworm damage were found in 1979 (Table 4).

Total insect damage was also inconsistent with regard to pest management system and cultivar in 1978 (Table 6). No differences were found between the two systems in 'Starkrimson', 'Chieftain' or 'Jonared'. 'Goldspur', however, suffered greater damage under the treat-when-necessary
Table 4. Mean comparison of the effects of cultivar on seven categories of insect damage to fruit and on total insect damage to fruit during 1978 and 1979

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Codling moth</th>
<th>Apple maggot</th>
<th>Leafroller</th>
<th>Fruitworm</th>
<th>Catfacing</th>
<th>Curculio</th>
<th>Birdpeck</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starkrimson</td>
<td>0.09</td>
<td>0.00</td>
<td>0.29&lt;sup&gt;1&lt;/sup&gt; ab</td>
<td>0.52</td>
<td>1.36</td>
<td>1.75</td>
<td>0.51</td>
<td>4.53</td>
</tr>
<tr>
<td>Chieftain</td>
<td>0.00</td>
<td>0.00</td>
<td>0.29 ab</td>
<td>0.23</td>
<td>1.57</td>
<td>1.12</td>
<td>0.84</td>
<td>4.05</td>
</tr>
<tr>
<td>Jonared</td>
<td>0.00</td>
<td>0.00</td>
<td>0.06 b</td>
<td>0.08</td>
<td>1.10</td>
<td>2.87</td>
<td>0.00</td>
<td>4.10</td>
</tr>
<tr>
<td>Goldspur</td>
<td>0.13</td>
<td>0.00</td>
<td>1.27 a</td>
<td>0.00</td>
<td>5.77</td>
<td>3.38</td>
<td>0.56</td>
<td>11.11</td>
</tr>
</tbody>
</table>

Insect damage ( % ) 1979

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Codling moth</th>
<th>Apple maggot</th>
<th>Leafroller</th>
<th>Fruitworm</th>
<th>Catfacing</th>
<th>Curculio</th>
<th>Birdpeck</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starkrimson</td>
<td>0.00</td>
<td>0.07</td>
<td>0.17</td>
<td>0.24</td>
<td>1.28 ab</td>
<td>0.07</td>
<td>0.00</td>
<td>1.82 ab</td>
</tr>
<tr>
<td>Chieftain</td>
<td>0.00</td>
<td>0.07</td>
<td>0.13</td>
<td>0.28</td>
<td>1.87 a</td>
<td>0.07</td>
<td>0.00</td>
<td>2.42 a</td>
</tr>
<tr>
<td>Jonared</td>
<td>0.00</td>
<td>0.07</td>
<td>0.10</td>
<td>0.22</td>
<td>1.06 b</td>
<td>0.11</td>
<td>0.00</td>
<td>1.56 b</td>
</tr>
<tr>
<td>Goldspur</td>
<td>0.00</td>
<td>0.00</td>
<td>0.19</td>
<td>0.09</td>
<td>1.29 ab</td>
<td>0.03</td>
<td>0.00</td>
<td>1.60 b</td>
</tr>
</tbody>
</table>

<sup>1</sup>Mean separation within columns by Duncan's Multiple-range test, 5% level.
Table 5. Fruitworm damage as influenced by pest management system and cultivar in 1978

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Pest management system</th>
<th>Fruitworm damage (%)</th>
<th>F&lt;sup&gt;1&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Prophylactic</td>
<td>Treat-when-necessary</td>
<td></td>
</tr>
<tr>
<td>Starkrimson</td>
<td>1.05&lt;sup&gt;2&lt;/sup&gt;a</td>
<td>0.00</td>
<td>23.69**</td>
</tr>
<tr>
<td>Chieftain</td>
<td>0.00 b</td>
<td>0.46</td>
<td>7.84*</td>
</tr>
<tr>
<td>Jonared</td>
<td>0.00 b</td>
<td>0.16</td>
<td>0.96</td>
</tr>
<tr>
<td>Goldspur</td>
<td>0.00 b</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

<sup>1</sup>F test between pest management systems within cultivar, significance at 5% (*) level.

<sup>2</sup>Mean separation within columns by Duncan's New Multiple-range test, 5% level.

Table 6. Total insect damage as influenced by pest management system and cultivar in 1978

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Pest management system</th>
<th>Total insect damage (%)</th>
<th>F&lt;sup&gt;1&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Prophylactic</td>
<td>Treat-when-necessary</td>
<td></td>
</tr>
<tr>
<td>Starkrimson</td>
<td>6.65</td>
<td>2.40&lt;sup&gt;2&lt;/sup&gt;b</td>
<td>3.31</td>
</tr>
<tr>
<td>Chieftain</td>
<td>4.14</td>
<td>3.95 b</td>
<td>0.01</td>
</tr>
<tr>
<td>Jonared</td>
<td>4.37</td>
<td>3.83 b</td>
<td>0.05</td>
</tr>
<tr>
<td>Goldspur</td>
<td>8.36</td>
<td>13.84 a</td>
<td>5.51*</td>
</tr>
</tbody>
</table>

<sup>1</sup>F test between pest management systems within cultivar, significance at 5% (*) level.

<sup>2</sup>Mean separation within columns by Duncan's New Multiple-range test, 5% level.
system than under the prophylactic system. No differences in total damage were found among cultivars under the prophylactic system, while under the treat-when-necessary system, 'Goldspur' suffered the greatest damage.

Economic Analysis

A comparison of relative costs for insect pest control for 1978 and 1979 is presented in Table 7. Substantial savings (38% in 1978 and 50% in 1979) were realized in insecticide costs under the treat-when-necessary system relative to the prophylactic system. However, when costs for monitoring the codling moth and apple maggot and for revenue losses due to insect damaged fruit were included, these savings were reduced considerably. Despite these additional expenditures, the treat-when-necessary system resulted in a 3.2% reduction in total costs in 1978, and a 12.9% reduction in 1979.

Table 7. Relative component costs for insect pest control by pest management system for 1978 and 1979

<table>
<thead>
<tr>
<th>Cost</th>
<th>1978</th>
<th>1979</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prophylactic</td>
<td>Treat-w-nec.</td>
<td>Prophylactic</td>
</tr>
<tr>
<td>Dollars per hectare</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insecticide</td>
<td>214</td>
<td>132</td>
</tr>
<tr>
<td>Monitor material*</td>
<td>N.A.</td>
<td>19</td>
</tr>
<tr>
<td>Monitor labor</td>
<td>N.A.</td>
<td>59</td>
</tr>
<tr>
<td>Revenue loss</td>
<td>39</td>
<td>35</td>
</tr>
<tr>
<td>Total cost</td>
<td>253</td>
<td>245</td>
</tr>
</tbody>
</table>

*Based on cost for monitoring the codling moth and apple maggot.

bNot applicable.
DISCUSSION

Insect Pest Monitoring and Damage

The ultimate success of any pest management program depends upon the soundness of the sampling techniques and economic thresholds used in making pest control decisions (66). In this study, sampling techniques and economic thresholds developed in other regions for the codling moth, apple maggot, and redbanded leafroller were tested under Iowa conditions to determine their practicality and economic feasibility.

Flight activity of the codling moth was relatively light in the new orchard throughout the study, exceeding the economic threshold of two moths per trap per week only 13 times. Fruit damage due to this pest was held to less than 0.1% in both years under both the prophylactic and treat-when-necessary pest management systems. This apparent effectiveness of the Pherocon® IC trap in monitoring the codling moth and determining spray needs supports the findings of numerous investigators (32, 37, 38, 46, 61, 76), and the recommendations of the Zoecon Corporation (79).

Codling moth activity in the old orchard was much heavier than in the new orchard. This greater activity was probably due to the fact that some of these trees received no insecticide treatments in 1978 and none of them received treatment in 1979. In addition, the old orchard contained more pupation sites (loose bark), received less rigorous pruning, which resulted in poor spray coverage, and was situated within 150 m of native woodland. Although no attempt was made to determine the occurrence or extent of male moth migration from the old orchard to the new orchard, trap captures in the new orchard did not indicate that migration was occurring.
Redbanded leafroller activity during both years was moderate in the new orchard and heavy in the old orchard. Leafroller damage was maintained below 0.5% under both pest management systems, even though no insecticide applications were ever made specifically to control this pest. In addition, no redbanded leafroller larvae were found in old orchard trees which had not received insecticide applications. The inability of this pest to cause economic damage at average trap captures exceeding 20 moths per week agrees with the finding of Tette\textsuperscript{1} that such densities do not necessarily indicate damage potential.

Apple maggot activity was heavy in the old orchard, especially in 1979, while only one fly capture occurred in the new orchard. The ability of the apple maggot to cause damage under both pest management systems in 1979, when only one fly was captured, confirms the finding of Reissig and Tette (57) that even very slight adult activity indicates economic damage potential. The Pherocon\textsuperscript{R} AM trap appeared to be an effective monitoring tool for determining spray needs. However, since apple maggot activity tended to coincide with insecticide applications for control of second generation codling moth, no definite evaluation of the trap or its economic threshold could be made.

The low densities of the apple maggot, codling moth, and redbanded leafroller in the new orchard and the very slight damage caused by these pests in the treat-when-necessary areas indicate that Pherocon\textsuperscript{R} traps are effective in monitoring these pests and can be used to determine insecticide needs for the codling moth and probably also for the apple

\textsuperscript{1}James Tette, Department of Entomology, Entomology-Plant Pathology Laboratory, Geneva, New York 14456, personal communication.
maggot in Iowa. Furthermore, the treat-when-necessary system did not create a situation where major pest resurgence could occur.

Trammel (73) and Chapman and Lienk (3) emphasized the importance of maintaining a strong spring insecticide program for control of non-monitored pests such as curculios, plant bugs, and green fruitworms. Results of this study lend support to their findings. As a group, these pests caused more fruit damage than did the codling moth, apple maggot, and redbanded leafroller combined. The inadequacy of the spring insecticide spray program (two sprays instead of the recommended four) was more pronounced in 1978 than in 1979, suggesting that some resurgence of these pests may have occurred in 1978, but was checked by natural control or abiotic factors in 1979. Preliminary observation of spring pest damage in 1980 indicated that even less damage was suffered in the third year of reduced spring insecticide applications. These findings imply that a reduced spring insecticide program might be appropriate in well-managed Iowa orchards.

Mite Management

Tetranychid mites, while present during the study, were not a serious problem in the experimental area. The higher populations of *T. urticae*, which developed in 1979, might have been caused in part by the introduction of this mite with *A. fallacis* on transferred bean leaves. These transfers, two of which were made directly into 'Starkrimson' trees, increased the likelihood that both mites would be recovered from that cultivar. Croft (5) and Owens (50) found that the cultivar Delicious was more susceptible to tetranychid attack than were the cultivars Jonathon and
Golden Delicious. Results of the 1978 monitoring for *T. urticae* in the experimental area and in trees from other parts of the new orchard support their finding.

Development of *T. urticae* relative to pest management system was independent of its introduction with *A. fallacis*, since infested bean plants were either placed randomly on the orchard floor or uniformly in the trees under both management systems. The higher populations of *T. urticae* in the prophylactic areas are in agreement with the findings of Parent (51) and Oatman (49) that insecticide application can promote tetranychid buildup. These results are inconsistent, however, with those reported by Meyer (42), who found that phosmet had no effect on population levels of either *T. urticae* or the predator *A. fallacis*.

Specht (70) and Meyer (42) found *A. fallacis* capable of reestablishing itself rapidly as a natural control agent of *T. urticae* in orchards where the use of pesticides toxic to the predator had been discontinued. Kinsely and Swift (26) found this phytoseiid capable of surviving even in heavily sprayed commercial orchards. Toxic spray applications were discontinued in the experimental area in 1977, when carbaryl use was halted and benomyl use was severely curtailed. By 1979, after two years of proper pesticide management, *A. fallacis* had failed to reestablish itself naturally; therefore, introduction of this phytoseiid was attempted.

Results of mite sampling during 1979 indicated that *A. fallacis* at least had become established temporarily in the experimental area. Greater numbers of the predator were recovered from 'Starkrimson' trees in 1979 due to its direct introduction to those trees and to the greater availability of *T. urticae*. Further sampling in 1980 showed *A. fallacis* to have
survived equally well in both pest management areas. The fact that the predator survived its first winter suggests that continued proper management should result in its permanent establishment.

Economic Analysis

Cost comparisons for the two pest management systems showed the treat-when-necessary system to be more cost effective. This advantage resulted from substantial reductions in insecticide usage made possible by monitoring, and from the effectiveness of the monitoring tools in determining spray needs, thereby holding pest damage to a minimum. Although monitoring costs tended to offset savings in insecticide costs, they were also generous in terms of compensation to the grower for time spent monitoring ($3 per hour). An average of 55 minutes per hectare was required each week to collect traps and investigate non-monitored pest activity. In a large orchard, this time requirement could become prohibitive, suggesting that a reduction in the necessary time input might be needed for grower acceptance of the system.

Time requirements and monitoring costs both could be reduced by almost 50% if the monitoring system were operated at one trap per hectare instead of one per 0.4 hectare. Pherocon® traps for the codling moth and apple maggot have been proven effective at this density with no adjustment in economic thresholds (37, 38, 46, 57, 61). A similar solution would be to operate just a few traps in an area of the orchard known to suffer pest damage, using them as indicators for timing sprays.

Rate of application is another factor which can affect the cost effectiveness of the treat-when-necessary system. In general, growers
applying phosmet at rates greater than 1.7 kg a.i. per hectare (the minimum recommendation) could expect insecticide cost savings to rise in direct proportion to any increase in this rate. This could mean up to a three-fold increase in insecticide cost savings, since the maximum recommended rate is 5.1 kg a.i. per hectare.

The treat-when-necessary pest management system proved to be a practical and cost effective method for preventing insect pest damage. The monitoring tools and associated economic thresholds used in the system seemed to be appropriate for use in Iowa apple orchards.
SUMMARY AND CONCLUSIONS

Evaluation of the practicality and economic feasibility under Iowa conditions of an apple arthropod pest management system involving sampling techniques and economic thresholds determined in other geographic areas for the codling moth and apple maggot was undertaken in this study. To achieve this objective, a field experiment was conducted to compare two distinct pest management systems. One system involved weekly prophylactic insecticide applications while the other involved insecticide applications only as necessary. Evaluation of the two systems involved comparison of their ability to prevent pest damage and revenue loss due to insect damaged fruit, and of their relative costs for insecticide and monitoring.

Monitoring of predaceous and phytophagous mites also was conducted and the predaceous phytoseiid, Amblyseius fallacis Garman, was introduced into the experimental area to control the phytophagous mite, Tetranychus urticae Koch.

This study, by demonstrating the over-all effectiveness of commercially available pest monitoring tools, has provided evidence that integrated arthropod pest management is a viable, possibly profitable, and environmentally desirable alternative to prophylactic pest management in Iowa orchards.

From this study it can be concluded that:

1) the treat-when-necessary pest management system was effective both in terms of preventing insect damage and in terms of economic feasibility;

2) the Pherocon® traps used to monitor the codling moth and apple
maggot in the treat-when-necessary pest management system were effective in determining spray needs for control of these pests;

3) pest resurgence was not a problem under the treat-when-necessary system;

4) the potential effectiveness of the treat-when-necessary system can be enhanced by promotion of *A. fallacis* as a natural control agent of tetranychid mites.
LITERATURE CITED


ACKNOWLEDGEMENTS

I would like to thank Dr. Paul A. Domoto and Dr. Elwood R. Hart for their help and guidance in the completion of this work. I would also like to express my appreciation to Dr. Charles V. Hall and Dr. Henry G. Taber for their advice and counsel as members of my committee. Further, the assistance of Dr. Theodore B. Bailey in statistical design and data analysis was appreciated.